National Park Service
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Natural Resource Stewardship and Science

Big Thicket National Preserve

Natural Resource Condition Assessment

Natural Resource Report NPS/BITH/NRR—2016/1355

ON THE COVER
Cyprus stand in Round Lake – Canyonlands Unit of BITH
Photograph courtesy of the NPS

Big Thicket National Preserve

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Natural Resource Report NPS/BITH/NRR—2016/1355

Andy J. Nadeau
Kathy Allen
Anna Davis
Kevin Benck
Lonnie Meinke
Sarah Gardner
Shannon Amberg
Andy Robertson

GeoSpatial Services
Saint Mary's University of Minnesota
890 Prairie Island Road
Winona, Minnesota 55987

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Executive Summary

The Natural Resource Condition Assessment (NRCA) Program aims to provide documentation about the current conditions of important park natural resources through a spatially explicit, multi-disciplinary synthesis of existing scientific data and knowledge. Findings from the NRCA will help Big Thicket National Preserve (BITH) managers to develop near-term management priorities, engage in watershed or landscape scale partnership and education efforts, conduct preserve planning, and report program performance (e.g., Department of the Interior's Strategic Plan "land health" goals, Government Performance and Results Act).

The objectives of this assessment are to evaluate and report on current conditions of key preserve resources, to evaluate critical data and knowledge gaps, and to highlight selected existing stressors and emerging threats to resources or processes. For the purpose of this NRCA, staff from the National Park Service (NPS) and Saint Mary's University of Minnesota – GeoSpatial Services (SMUMN GSS) identified key resources, referred to as "components" in the project. The selected components include natural resources and processes that are currently of the greatest concern to preserve management at BITH. The final project framework contains 15 resource components, each featuring discussions of measures, stressors, and reference conditions.

This study involved reviewing existing literature and, where appropriate, analyzing data for each natural resource component in the framework to provide summaries of current condition and trends in selected resources. When possible, existing data for the established measures of each component were analyzed and compared to designated reference conditions. A weighted scoring system was applied to calculate the current condition of each component. Weighted Condition Scores, ranging from zero to one, were divided into three categories of condition: low concern, moderate concern, and significant concern. These scores help to determine the current overall condition of each resource. The discussions for each component, found in Chapter 4 of this report, represent a comprehensive summary of current available data and information for these resources, including unpublished preserve information and perspectives of preserve resource managers, and present a current condition designation when appropriate. Each component assessment was reviewed by BITH resource managers, NPS Gulf Network staff, and additional subject matter experts when appropriate.

Existing literature, short- and long-term datasets, and input from NPS and other outside agency scientists support condition designations for components in this assessment. However, in some cases, data were unavailable or insufficient for several of the measures of the featured components. In other instances, data establishing reference condition were limited or unavailable for components, making comparisons with current information inappropriate or invalid. In these cases, it was not possible to assign condition for the components. Current condition was not able to be determined for six of the 15 components (40%) due to these data gaps.

For those components with sufficient available data, the overall condition varied. No components were determined to be in good condition. Five components (fire regime, birds, harvested mammals, freshwater mussels, water quality) were of moderate concern. Water quality and harvested mammals did not have an indication of a current trend, while birds and fire regime exhibited stable trends.

Freshwater mussels were the only component in the moderate concern category that exhibited a declining current trend. Four components were determined to be of significant concern (pine uplands, arid sand hills, air quality, and hydrology). While pine uplands and arid sand hills currently have management practices in place to improve their overall condition, the current status of these communities is still of significant concern. Due to the dynamic nature of these communities, and the ongoing management activities, a trend was not assigned to these components. The remaining two components of significant concern (air quality, hydrology) are strongly influenced by factors outside of NPS control. While they are currently exhibiting downward trends, there is little that NPS managers can do to mitigate these trends. Detailed discussion of these designations is presented in Chapters 4 and 5 of this report.

Several preserve-wide threats and stressors influence the condition of priority resources in BITH. Those of primary concern include invasive exotic plant species, an altered fire regime, fragmentation and habitat loss, and adjacent land use practices. Understanding these threats, and how they relate to the condition of preserve resources, can help the NPS prioritize management objectives and better focus their efforts to maintain the health and integrity of the preserve ecosystem.

Acknowledgments

We acknowledge past and present Big Thicket National Preserve staff for the technical expertise provided during scoping, through multiple stages of review, and via phone and email; specifically, Ken Hyde, Herbert Young Jr., Ryan Desliu, Deanna Boensch, Stephanie Burgess, and Doug Neighbor. Gulf Network Staff, including Martha Segura, Joe Meiman, Jeff Bracewell, and Robert Woodman offered logistical insight and critical review of interim documents. Donna Shorrock, Intermountain Region NRCA Coordinator, and Jeff Albright, Natural Resource Condition Assessment Program Coordinator, provided program guidance. Thank you to all others who assisted in the development of this document.

Acronyms and Abbreviations

ABC – American Bird Conservancy

ADO – Atlantic Multidecadal Oscillation

ARD – Air Resources Division

ATV – All-terrain Vehicle

BBS – Breeding Bird Survey

BCU – Beech Creek Unit

BITH – Big Thicket National Preserve

BSCU – Big Sandy Creek Unit

BSCCU – Big Sandy Creek Corridor Unit

BU – Beaumont Unit

CAA – Clean Air Act

CASTNet – Clean Air Status and Trends Network

CBC – Christmas Bird Count

CBI – Composite Burn Index

CL – Condition Level

CPUE – Catch per Unit Effort

CRP – Clean Rivers Program

CU – Canyonlands Unit

DAMS – Water Impoundments Database

DFWHS – Dallas-Fort Worth Historical Society

dNBR – Differenced Normalized Burn Ratio

DO – Dissolved Oxygen

DRINKS – Drinking Water Supplies Database

EA – Environmental Assessment

Acronyms and Abbreviations (continued)

EPA – Environmental Protection Agency

EPT – Ephemeroptera-Plecoptera-Trichoptera Index

GAGES – Water Gages Database

GCC – Global Climate Change

GPRA – Government Performance and Results Act

GULN – Gulf Coast Network

HCSU – Hickory Creek Savannah Unit

I&M – Inventory and Monitoring Program

IBA – Important Bird Area

IFD – Industrial Facilities Discharge Database

IMPROVE – Interagency Monitoring of Protected Visual Environments Program

IRMA – Integrated Resource Management Application

JGBU – Jack Gore Baygall Unit

LBU – Lower Portion of the Beaumont Unit

LDL – Lower Detection Limit

LNRCU – Lower Neches River Corridor Unit

LNVA – Lower Neches Valley Authority

LPI-PIBCU – Little Pine Island – Pine Island Bayou Corridor Unit

LRU – Lance Rosier Unit

LSHP – Lower Slope Hardwood Pine

LU – Loblolly Unit

MCCU – Menard Creek Corridor Unit

MFRI – Mean Fire Return Interval

MPN – Most Probable Number

Acronyms and Abbreviations (continued)

MSOP – Mid Slope Oak Pine

MTBS – Monitoring Trends in Burn Severity

NAAQS – National Ambient Air Quality Standards

NADP – National Atmospheric Deposition Program

NBU – Neches Bottom Unit

NOAA – National Oceanic and Atmospheric Administration

NPS – National Park Service

NRCA – Natural Resource Condition Assessments

NRCU – Neches River Corridor Unit

NTU – Nephelometric Turbidity Units

NWI – National Wetlands Inventory

PCBs – Polychlorinated Biphenyls

PDO – Pacific Decadal Oscillation

PDSI – Palmer Hydrological Severity Index

PIT – Passive Integrated Transponder

PM – Particulate Matter

POP – Persistent Organic Pollutant

ppb – Parts per Billion

ppt – Parts per Thousand

PWC – Personal Watercraft

RF3 – River Reach File version 3

RIFA – Red Imported Fire Ants

SARA – San Antonio River Authority

SL – Significance Level

Acronyms and Abbreviations (continued)

SMUMN GSS – Saint Mary's University of Minnesota Geospatial Services

SPB – Southern Pine Beetle

SpC – Specific Conductance

STORET – Storage and Retrieval System

SWB – Saltwater Barrier

TCEQ – Texas Commission on Environmental Quality

TCU – Turkey Creek Unit

TDS – Total Dissolved Solids

TPWD – Texas Parks and Wildlife Department

TSS – Total Suspended Solids

UNMBP – United Nations Man and the Biosphere Program

UNRCU – Upper Neches River Corridor Unit

USACE – U.S. Army Corps of Engineers

USFWS – U.S. Fish and Wildlife Service

USGS – U.S. Geological Survey

USPO – Upper Slope Pine Oak

UTV – Utility Task Vehicle

VCU – Village Creek Corridor Unit

VDDT – Vegetation Dynamics Development Tool

VES – Visual Encounter Surveys

VOC – Volatile Organic Compounds

WCS – Weighted Condition Score

Chapter 1 NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

> ***NRCAs Strive to Provide…***
>
> - *Credible condition reporting for a subset of important park natural resources and indicators*
> - *Useful condition summaries by broader resource categories or topics, and by park areas*

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement—not replace—traditional issue-and threat-based resource assessments. As distinguishing characteristics, all NRCAs:

- Are multi-disciplinary in scope;[1]
- Employ hierarchical indicator frameworks;[2]
- Identify or develop reference conditions/values for comparison against current conditions;[3]
- Emphasize spatial evaluation of conditions and GIS (map) products; [4]
- Summarize key findings by park areas; and [5]
- Follow national NRCA guidelines and standards for study design and reporting products.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for

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[1] The breadth of natural resources and number/type of indicators evaluated will vary by park.

[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition summaries by broader topics and park areas

[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-up response (e.g., ecological thresholds or management "triggers").

[4] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

[5] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.
Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff will be asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products.

NRCAs can yield new insights about current park resource conditions, but, in many cases, their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is both credible and has practical uses for a variety of park decision making, planning, and partnership activities.

Important NRCA Success Factors

- *Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline*
- *Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ⇨ indicators ⇨ broader resource topics and park areas)*
- *Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings*

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park’s desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

NRCA Reporting Products…

Provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:

- *Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations* ***(near-term operational planning and management)***
- *Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values* ***(longer-term strategic planning)***
- *Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public* ***("resource condition status" reporting)***

Over the next several years, the NPS plans to fund an NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information visit the NRCA Program website.

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[6]An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

[7] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

[8] The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

Chapter 2 Introduction and Resource Setting

2.1 Introduction

2.1.1 Enabling Legislation

Big Thicket National Preserve (BITH) contains a unique convergence of multiple habitats and an incredibly diverse biological community (Cooper et al. 2004). BITH was established and signed into public law by President Gerald Ford on 11 October in 1974 (PL 93-439).

> *Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That in order to assure the preservation, conservation, and protection of the natural, scenic, and recreational values of a significant portion of the Big Thicket area in the State of Texas and to provide for the enhancement and public enjoyment thereof, the Big Thicket National Preserve is hereby established.*

At the time of establishment, BITH was the first national preserve created and consisted of 34,216 ha (84,550 ac). In 1993, legislative action incorporated an additional 5,431 ha (13,420 ac) of creek corridors in BITH. Between 2004 and 2015, additional land acquisitions expanded the total land area in BITH to just over 45,325 ha (112,000 ac). BITH has been designated as an International Biosphere Reserve since 1981 (UNESCO 2000), and in 2001 the American Bird Conservancy (ABC) designated BITH as a Globally Important Bird Area (IBA). There are 15 management units included in the preserve; some are connected by water corridor units, while others are completely detached.

2.1.2 Geographic Setting

BITH is comprised of several disjointed areas, some connected by narrow corridors, within Tyler, Polk, Hardin, Jasper, Newton, and Liberty counties in the state of Texas (Figure 1). The total area of the preserve is 45,325 ha (112,000 ac) with around 973 km (605 mi) of boundary that is adjacent to commercial timber management areas, some rural home-site developments, and residential subdivisions (Cooper et al. 2004). The northwestern Big Sandy Creek Unit (BSCU) is at the maximum elevation of all the preserve units and corridors, starting at 111 m (365 ft) and gently sloping downward, heading south, to just above sea level near Little Pine Island-Pine Island Bayou (LPI-PIBCU), the southern-most corridor unit (Cooper et al. 2004). The Beaumont Unit (BU) is the southern-most unit and is east and north of the city of Beaumont, Texas.

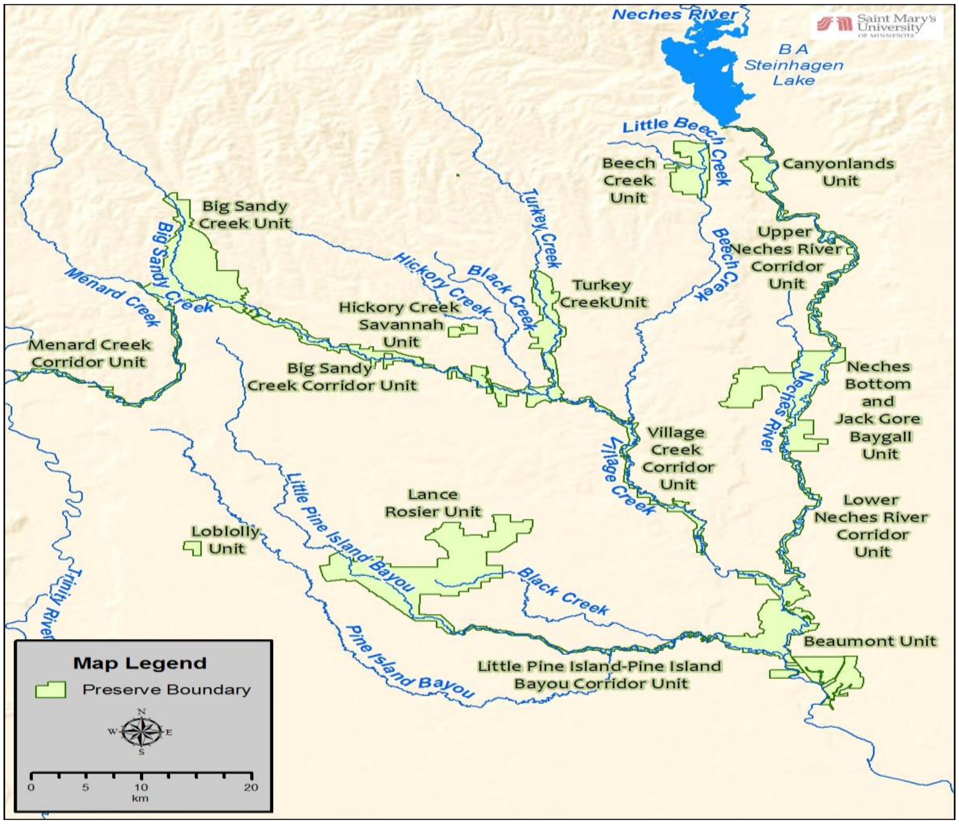

Figure 1. Locations and names of the nine units and six corridors of the preserve.

The BITH area is characterized as humid subtropical and is warm and humid throughout much of the year (Table 1). BITH receives 116.8- 132.1 cm (46-52 in) of precipitation a year on average. Precipitation depends on latitudinal (north-south) location, and is fairly evenly distributed throughout the year. Precipitation often comes as short, intense rains and thunderstorms are common throughout the year (Cooper et al. 2004). The southern latitude and closeness to the Gulf of Mexico tend to regulate the regional climate, with most of the year being warm and humid. Occassional arctic fronts from the north bring freezing temperatures, icy rain, and rarely, snow to the area for short periods.

Table 1. 30-year climate normal (1981-2010) for the Beaumont weather station near the BITH Beaumont Unit (NOAA 2015).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Temperature (°C)													
Max	16.4	18.0	21.8	25.6	29.3	32.2	33.3	33.8	31.2	27.0	22.0	17.2	25.6
Min	5.4	7.1	10.7	14.5	19.6	22.9	23.8	23.4	20.6	15.6	10.5	5.8	15.0
Average Precipitation (cm)													
Total	12.6	9.8	8.9	7.4	13.2	18.3	15.7	12.6	16.1	14.1	12.0	12.7	153.5

2.1.3 Visitation Statistics

The yearly visitation records for 1981 to 2012 show that, on average, BITH receives about 87,000 recreational visitors per year (NPS 2015b). The lowest attendance year between 1981 and 2012 was in 1981 when there were 22,763 visitors; the highest visitor year was in 2010 when 140,489 people visited (NPS 2015b). In 2012, the preserve received the most visitors from April to December and the fewest in January, February, and March with a monthly average of about 11,000. In October of 2012, just over 1,000 of the visitors went back-country camping, though the monthly average number of campers is around 230 (NPS 2015b). BITH provides visitors with opportunities to hike, bike, and camp along the trails or boat along the creeks, rivers, and bayous, with chances to view several species of carnivorous plants and orchids, numerous resident and migratory birds, and other terrestrial and aquatic wildlife.

2.2 Natural Resources

2.2.1 Ecological Units and Watersheds

BITH lies within the South Central Plains Level III Ecoregion (Figure 2). According to Griffith et al. (2007, p. 87), this ecoregion is:

> *Locally termed the "piney woods," this region of mostly irregular plains represents the western edge of the southern coniferous forest belt. Once blanketed by a mix of pine and hardwood forests, much of the region is now in loblolly and shortleaf pine plantations. Soils are mostly acidic sands and sandy loams.*

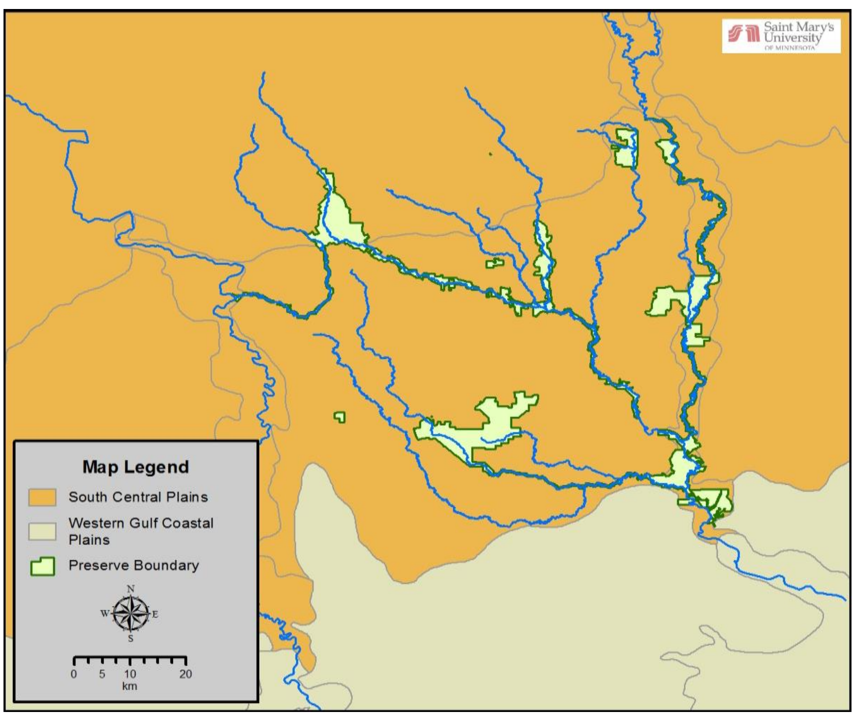

Figure 2. The Level III Ecoregions associated with BITH.

Among the South Central Plains are three distinct Level IV ecoregions that overlap the preserve units. These include the floodplains and low terraces, southern tertiary uplands, and flatwoods (Figure 3; Griffith et al. 2007).The BSCU lies within the Southern Tertiary Uplands of the South Central Plains where historic vegetation was dominated by longleaf pine-bluestem woodlands (*Pinus palustris-Schizachyrium* spp. and *Andropogon* spp.). There were also shortleaf pine-hardwood (*Pinus echinata-Quercus* spp.) forests, and mixed hardwood-loblolly pine (*Pinus taeda*) forests with hardwood-dominated forests along creeks (Griffith et al. 2007). Within more mesic areas of these uplands there were also American beech (*Fagus grandifolia*)/magnolia-beech-loblolly pine forests. Rare species of plants and animals (e.g., species of insectivorous plants and orchids), and the red-cockaded woodpecker (*Picoides borealis*), a Federally Endangered species, are supported by this ecoregion and large portions of the Southern Tertiary Upland consist of public national forest (Bryan et al. 1976).

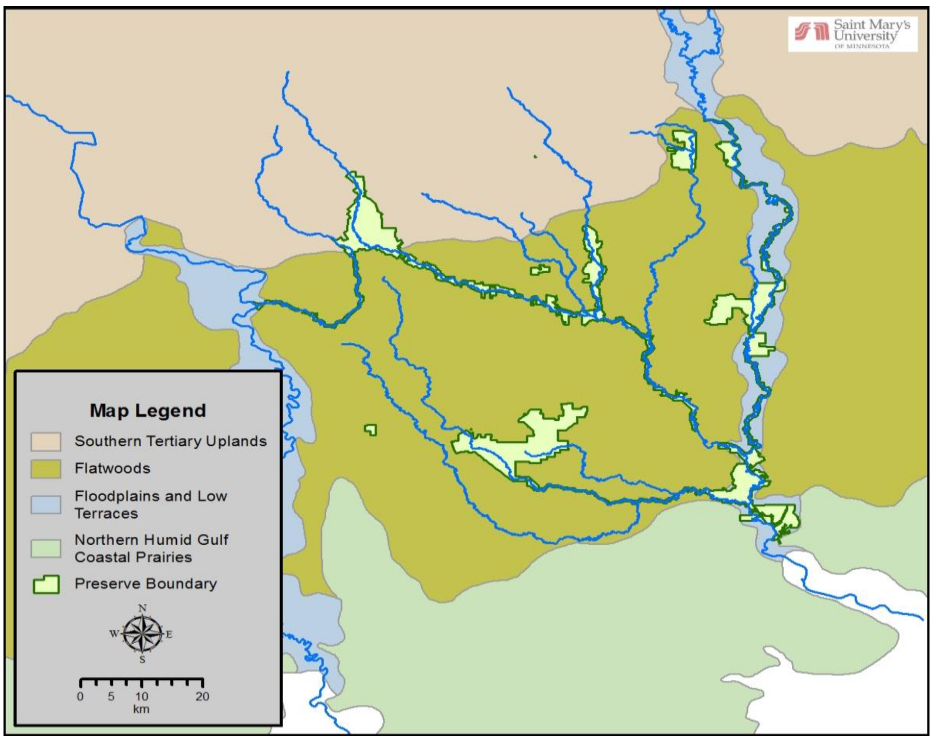

Figure 3. Level IV ecoregions that overlap the units of BITH.

Ten of the 15 BITH units are within the Flatwoods ecoregion. The land in this ecoregion is typically flat to gently sloping, and is at lower elevations than the Southern Tertiary Uplands to the north. The climate is generally warmer, wetter, and less dissected than other ecoregions in the area. (Griffith et al. 2007). According to Griffith et al. (2007), this area has an extensive history of anthropogenic modification, primarily due to the lumber, railroad, and oil and gas industry's development and occupancy. Historically, this area consisted of longleaf pine flatwoods and savannas that were intertwined with diverse mixed pine-hardwood forest types and a mosaic of well-drained and poorly drained communities.

The remaining units lie within the Floodplains and Low Terraces of the Neches River basin. This ecoregion is characterized by active alluvial channels that are dynamic systems. Erosion and deposition actively rework the topography of levees, ridges, and swales while overbank flooding, subsurface groundwater, and local precipitation recharge water levels in the floodplain (e.g., backswamps, pools, sloughs, oxbows, and depressions). This area is a complex continuum of flora created by a combination of topography, hydroperiods (periods of waterlogged soil), and soil composition, all of which have been altered by human impacts to some degree (Griffith et al. 2007). Two state-listed threatened species occur within Floodplains and Low Terraces, confirmed during herpetological surveys between 2008 and 2009.

BITH is situated within four major watersheds: Village Creek, Lower Neches, Pine Island Bayou, and Lower Trinity-Kickapoo River drainage basins. Within these watersheds are several smaller catchments associated with creeks and rivers, many of which run directly through the units of BITH. These include the Big Sandy, Village, Boggy, Black, Cypress, Menard, Tenmile, Theuvenins, Beech, and Turkey Creeks and the Neches and Trinity Rivers, as well as the Pine Island and Little Pine Island Bayous (Figure 4).

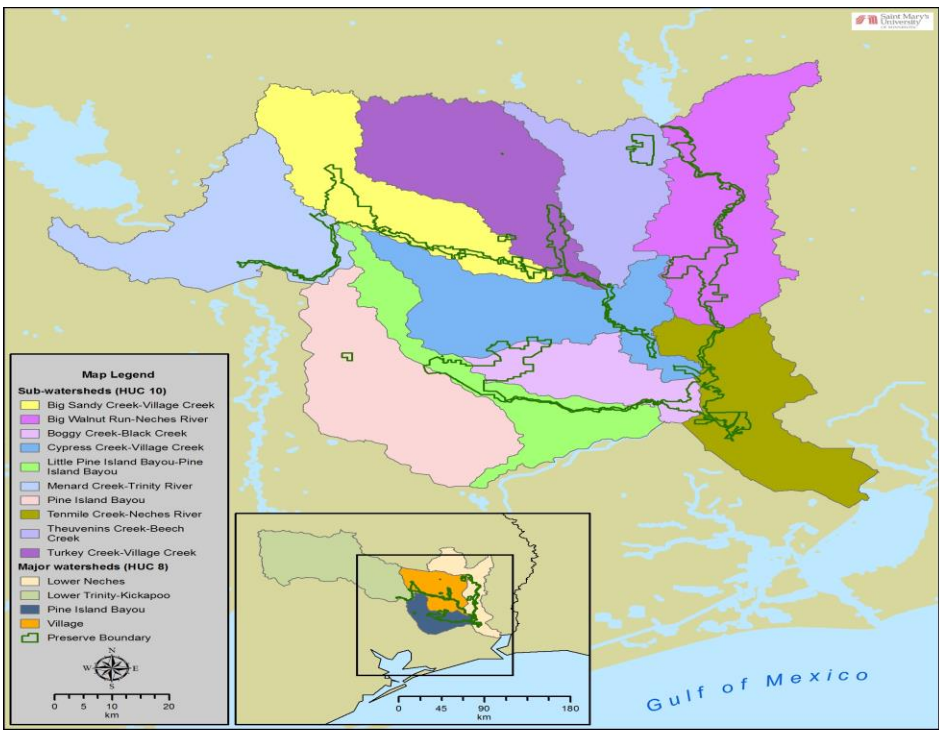

Figure 4. BITH major and sub-watersheds (HUC 8 and 10, respectively).

2.2.2 Resource Descriptions

Biological Resources

Due in part to the tremendous biodiversity of the preserve, BITH was added to the list of International Biosphere Reserves in 1981 by the United Nations Man and the Biosphere Program (UNMBP) and is referred to as the “biological crossroads of North America” (NPS 2013). The diversity in BITH can be attributed to a wide range of intermixed soil types, likely formed from sedimentary bedrock deposited during and post-Pliocene Epoch when the Gulf of Mexico and the Western Interior Seaway were regressing and transgressing across southeast Texas (Cooper et al. 2004). An influence of habitats converging in this area from the north, south, east and west has also greatly contributed to the high biodiversity of BITH (Cooper et al. 2004). The preserve continues to encourage species inventories with the help of the Big Thicket Association and a joint "Thicket of Diversity" program that provides oversight and funding to researchers to continue all-taxa biological inventory. Of note, this partnership effort, along with earlier research studies, has resulted in species counts for such taxa as Lepidoptera (over 1,600 species); macro fungi (400 species); mosses, spongeworts & liverworts (179), fungus and algae (137); slime molds (93); water striders and water scorpions (64), and dragon and damsel flies (34). A number of species new to the state, country, and science have been identified during the various inventory efforts (BTA 2016).

Many species of flora and fauna have been documented in the nine BITH land units and six aquatic corridors. An estimated 1,319 species of vascular plants occur in the preserve, hundreds of which are considered common (NPS 2015a). Abundant vascular plants in BITH include sweetgum (*Liquidambar styraciflua*), possumhaw (*Ilex decidua*), yaupon (*I. vomitoria*), calico aster (*Symphyotrichum lateriflorum* var. *latiflorum*), and crossvine (*Bignonia capreolata*) (NPS 2015a). Water oaks (*Quercus nigra*) and loblolly pines are considered abundant as well. Less common species in BITH include the orchids, with 21 species (nine genera) in the preserve, nearly half (10) of which are considered rare and the rest uncommon (NPS 2015a). Among the more unique flora of BITH, are the rare and uncommon carnivorous plants and orchid species. Carnivorous plants in BITH consist of four genera: *Utricularia*, *Drosera*, *Pinguicula*, and *Sarracenia*. These are species of bladderworts, sundew, butterworts, and pitcher plant, respectively (NPS 2015a). As a crossroads of many ecosystems found in the U.S., visitors can see grasses from the central prairies, cactus species from the southwest deserts, beech trees common to the eastern forests, longleaf pine which once covered large expanses of the southeast, and palmetto species from the southern coastal plains all within a short drive of each other in the preserve.

As of 2015, there were 293 species (173 genera) of birds in the preserve that were present or probably present according to the NPSpecies database. Abundant and common bird species in the preserve included: yellow-billed cuckoo (*Coccyzus americanus*), northern cardinal (*Cardinalis cardinalis*), indigo bunting (*Passerina cyanea*), tufted titmouse (*Parus bicolor*), Carolina chickadee (*Parus carolinensis*), and pine warbler (*Dendroica pinus*) (NPS 2015a). Many of the species listed as probably present consisted of migratory birds that are only seasonally present in the area. The diverse vegetation and habitats attract a high number of bird species; the riparian areas are particularly attractive to a wide variety of bird species.

Fifty-eight mammal species are associated with the preserve, 43 of which are documented as present (NPS 2015a). Some common mammal species in the preserve include the white-tailed deer (*Odocoileus virginianus*), striped skunk (*Mephitis mephitis*), mink (*Neovison vison*), and raccoon (*Procyon lotor*). The feral hog (*Sus scrofa*) is an invasive species considered a threat to the native ecology of the area (NPS 2015a), and has been documented in the preserve and the surrounding areas. There are several game and non-game mammal species that are harvested legally within the preserve. Game species include white-tailed deer, fox squirrels (*Sciurus niger*), and red squirrels (*Tamiasciurus hudsonicus*), and non-game species are mostly fur-bearer species such as beaver (*Castor canadensis*), fox (*Vulpes vulpes*), mink, river otter (*Lontra canadensis*), muskrat (*Ondatra zibethicus*), and several others.

Over 100 freshwater fish species are documented in the preserve, and some saltwater species have recently been documented (Winemiller 2014; NPS 2015a). There are diverse families common to the creeks and rivers of the preserve, including minnows (family: Cyprinidae, Fundulidae, Percidae), panfish (Centrarchidae), and suckers (Catostomidae). There are also species of gar (*Lepisosteus* spp.), catfish (*Icralurus* spp.), and the recently re-introduced paddlefish (*Polyodon spathula*), which has been listed as a state-threated species in Texas (TPWD 2015, NPS 2015).

There are 89 species of herpetofauna (32 amphibians and 57 reptiles) confirmed to inhabit the preserve (NPS 2015a). Many of the reptile species are snakes and turtles, with a few lizard and skink species. The year-round moisture availability and sub-tropical temperatures provide a desirable environment for reptiles and amphibians. The abundant vegetation and aquatic habitats also contribute greatly to the diversity of herptiles in BITH.

Many species of freshwater mussels can be found in the creeks and rivers of the preserve. Mussels are filter-feeding invertebrates that are sensitive to pollution and are recognized as an indicator species for water quality (Ford 2013). The impacts from channel manipulation (i.e., dams, reservoirs, and channelization), and over-harvest in the last 50-100 years have caused widespread declines in the abundance and diversity of freshwater mussel species (Ford 2013). There are currently 48 mussel species known to inhabit BITH’s waterways, including seven Texas state-threatened species. Threatened species include the Texas pigtoe (*Fusconaia askewi*), triangle pigtoe (*F. lananensis*), sandbank pocketbook (*Lampsislis satura*), southern hickorynut (*Obovaria jacksoniana*), Louisiana pigtoe (*Pleurobema riddelli*), Texas heelsplitter (*Potamilus amphichaenus*), and the Texas fawnsfoot (*Truncila macrodon*).There is limited information in terms of published studies or surveys of other aquatic invertebrates (Arthropoda or terrestrial invertebrate communities); the most studied genera are the aquatic species identified during water quality monitoring.

A remarkable feature of the many species of plants and animals at BITH is that they coexist in the same area; under their normal habitat conditions, these species would be isolated into less diverse communities (McHugh 2004). The area has also evolved with significant influence from fire, which likely contributed to vegetative diversity in the Big Thicket region (McHugh 2004). Forest types include upland pine forests and wetland pine savannas, sandhill pine forest, and hardwood-pine slope forests. These forest types, as well as the faunal communities, will be discussed in detail in Chapter 4.

2.2.3 Resource Issues Overview

Urban Development and Land Use

The units of the preserve are scattered near some significant urban interfaces, which represent a challenge to managers. Beaumont, Texas, which is directly adjacent on the southwest side of the BU, is populated by over 100,000 people (USCB 2015). The areas north of Beaumont are not densely populated, but the proximity to multiple urban and industrial centers, including Beaumont, Galveston, and Houston, has exposed the preserve to impaired water and air quality, terrestrial and aquatic disruption, and invasion by exotic plant and animal species (Cooper et al. 2004).

Water Threats

Water is a major component of the preserve and important to the ecology of the area. The development of dams and saltwater barriers have altered the hydrology and confined channels in some parts. Dams have impounded rivers and creeks, which impair the ability of certain fish and larval-stage freshwater mussel species to migrate up and down stream to critical spawning habitats. The altered flow regimes have also been implicated in the decline of freshwater mussels in large rivers such as the Neches River. There are several sources of industrial effluent that are of concern to aquatic resources in the preserve. These sources include oil and gas production waste, sewage treatment facility effluent, paper/pulp mill effluent, as well as land use within the watersheds contributing to storm water runoff, that have caused varying degrees of degradation to water quality. Pollution in waterways often originates from the land surface by way of runoff. Parking lots, streets, and bare land contribute large amounts of contaminants directly into creeks and rivers during storm events when runoff occurs (Hughs et al. 1987). Saltwater intrusion due to changes in the Sabine-Neches Waterway (near the salt water barrier) and climate change related sea-level rise is a concern. The permanent salt water barrier, although created to prevent intrusion of saltwater into freshwater systems, has been shown to disrupt the spawning migration of paddlefish and may have contributed to the drastic decline of this ancient species (Hughs et al. 1987, Jennings and Zigler 2000). It also affects freshwater flow during drought periods, resulting in significant salt water intrusion and retention in the southern portion of the BU.

Altered Fire Regimes

Of the total acreage of preserve land and corridors, there are between 6,070 and 8,094 ha (15,000-20,000 ac) of highly fire-dependent ecosystems (Ken Hyde, BITH Chief of Resources Management, personal communication, 2016). Over relatively recent history (100-150 years), much of the Big Thicket area has undergone human-induced changes to the floral community. Primarily, repeated logging, the absence of fire from the past 100 years, fire suppression, and other human activities has shifted the open pine savannas and sandhills with dense herbaceous understories, to mixed pine/hardwood with dense brush understories (McHugh 2004). In more recent years (20-30 years), the preserve's prescribed burn program has worked to control brush that accumulated during the absence of fire. The goal of the program is to eventually restore the longleaf pine ecosystem. So far, the removal of brush using prescribed burning has started to replace loblolly pine with longleaf pine seedlings and saplings (McHugh 2004). The fire managed units in the preserve include BSCU, Hickory Creek Savannah (HCSU), TCU, Beech Creek (BCU), Lance Rosier (LRU), Loblolly (LU), Big Sandy Creek Corridor Unit (BSCCU) and Canyonlands (CU) (McHugh 2004).

Invasive/exotic Animals and Plants

There are several non-native plants and animals that are a management concern in the preserve. Chinese tallow (*Triadica sebiferum*), a deciduous invasive tree, has been implicated in the reduction of desirable forest used by migratory bird species (Cooper et al. 2004). Water hyacinth (*Eichhorinia crassipes*) is an exotic invasive aquatic plant that has been of concern to preserve managers. Both the Chinese tallow tree and the water hyacinth are of particular concern in water corridors (Cooper et al. 2004). Japanese climbing fern (*Lygodium japonicum*) and trifoliate orange (*Ponicurus trifoliate*) are two recent plant invaders causing habitat impacts along forest edges and near waterways. Nine-banded armadillos (*Dasypus novemcinctus*), red imported fire ants (RIFA) (*Solenopsis invicta*), grass carp (*Ctenopharyngodon idella*), zebra mussels (*Dreissena polymorpha*), nutria (*Myocastor coypus*), feral hogs, dogs (*Canidis lupus*), and cats (*Felis catus*) are all present and pose a threat to the local ecology of the BITH units and corridors (Cooper et al. 2004).

<u>Climate Change</u>
Global climate change (GCC) is expected to impact the entire U.S. during this century, although the expected changes vary across the country. In regards to drought and sea level rise, the preserve has highly vulnerable areas of concern. The coastal wetlands of southern states that are in close proximity to the Gulf of Mexico are highly susceptible to increased flooding, saltwater intrusion into freshwater wetlands, and coastline erosion (Guntenspergen and Vairin 1998). More acute impacts to the area involve increases in the severity and frequency of tropical storms (Guntenspergen and Vairin 1998, Mann and Emanuel 2006). BITH is especially concerned with losing a significant portion of the cypress-tupelo swamps due to saltwater intrusion in the lower portion of the BU that is below the saltwater barrier on the Neches River.

Climate change may also alter the frequency, intensity, and timing of hurricanes and floods in the region (Harcombe et al. 1999). The hurricanes in 2005 and 2008 were particularly hard on the large beech and magnolia trees in the BCU, BSCU, and TCU with many being windthrown, damaged, or succumbing to disease and rot after the storms (Hyde, personal communication, 21 January 2016). BITH management is concerned that there appears to be little recruitment of young beech trees since the hurricanes in 2005 and 2008. This may be a combination of climate stressors, the 2011 drought, feral hog consumption of beech mast production, and competition from dense stands of native, early successional shrubs (e.g., yaupon and holly) (Hyde, written communication, 6 October 2015). Continued monitoring of the effects that hurricanes have on the native vegetative communities in BITH will be needed, especially as the threat of hurricanes appears to be increasing due to climatic change.

2.3 Resource Stewardship

2.3.1 Management Directives and Planning Guidance

The preserve's resource management plan (Strahan et al. 1996, p. 3) states that,

> *All decisions regarding the management, use, and development of the preserve are made toward the goal of achieving certain objectives relating to the following broad categories: Natural resource management, cultural resource management, land acquisition, infrastructure development, interpretation and resources education, maintenance, and special uses.*

The plan further outlines natural resources objectives to meet this goal, including:

- To perpetuate, protect, interpret, and where appropriate restore, the preserves unique mixture of temperate and subtropical botanical and biological communities.
- To establish and nurture partnerships with appropriate state and federal agencies and other entities for the purpose of managing significant scenic and natural resources of the preserve in a manner that will ensure their integrity and "health" of the greater ecosystem.
- To initiate joint planning, educational and natural resource management programs with neighboring landowners and the general public to promote good land stewardship and to minimize conflicting uses that might be detrimental to the resources of the preserve and region (Strahan et al. 1996, p. 3).

The 2004 BITH Fire Management Plan discussed historical conditions of the forests, prairies, and savannas, as well as how, when, and where the continued restoration of the fire-dependent ecosystems will be conducted (McHugh 2004). The role and function of the BITH corridor units are described in an assessment from 1997 along with the purpose of the Water Corridor Management Assessment (Harcombe and Callaway 1997). The new ordinances on personal watercraft (PWC) use in national parks are in effect at BITH after a careful review during the the BITH Personal Watercraft Use Environmental Assessment process (NPS 2002).

2.3.2 Status of Supporting Science

The Gulf Coast Network (GULN) identifies key resources network-wide and for each of its parks that can be used to determine the overall health of the parks. These key resources are called Vital Signs. In 2007, the GULN completed and released a Vital Signs Monitoring Plan (Segura et al. 2007); Table 2 shows the GULN Vital Signs selected for monitoring in BITH.

Table 2. GULN Vital Signs selected for monitoring in BITH (Segura et al. 2007).

Category	GULN Vital Sign	Category 1[a]	Category 2[b]	Category 3[c]	No Monitoring Planned
Air and Climate	Ozone		x		
	Air Contaminants		x		
	Weather/Climate		x		
Geology and Soils	Stream/River Channel Dynamics and Geomorphology				x
	Erosion and Deposition				x
	Soil Biota				x
	Soil Chemistry				x
	Soil Structure and Stability				x

Table 2 (continued). GULN Vital Signs selected for monitoring in BITH (Segura et al. 2007).

Category	GULN Vital Sign	Category 1[a]	Category 2[b]	Category 3[c]	No Monitoring Planned
Water	Groundwater Hydrology				x
	Water Chemistry	x			
	Water Nutrients	x			
	Water Toxics	x			
Biological Integrity	Non-native Vegetation	x			
	Non-native Animals			x	
	Riparian Communities	x			
	Forest Health	x			
Biological Integrity	Freshwater Invertebrates				x
	Terrestrial Invertebrates				x
	Amphibians	x			
	Non T&E Reptiles				x
	Migratory Birds	x			
	Resident Birds	x			
	Non T&E Small Mammals				x
Biological Integrity	Terrestrial Vegetation	x			
	T&E/Rare Birds			x	
	T&E/Rare Freshwater Fish			x	
	T&E/Rare Plants		x		
	T&E/Rare Reptiles				x
	Freshwater wetland communities	x			
Human Use	Visitor Usage				x
Landscapes (Ecosystem Pattern and Processes)	Fire and Fuel Dynamics	x			
	Land Cover/Land Use	x			
	Soundscape				x

[a] **Category 1** represents Vital Signs for which the network will develop protocols and implement monitoring.

[b] **Category 2** represents Vital Signs that are monitored by BITH, another NPS program, or by another federal or state agency using other funding.

[c] **Category 3** represents high-priority Vital Signs for which monitoring will likely be done in the future.

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Chapter 3 Study Scoping and Design

This NRCA is a collaborative project between the NPS and Saint Mary's University of Minnesota Geospatial Services (SMUMN GSS). Project stakeholders include the BITH resource management team and GULN Inventory and Monitoring Program staff. Before embarking on the project, it was necessary to identify the specific roles of the NPS and SMUMN GSS. Preliminary scoping meetings were held, and a task agreement and a scope of work document were created cooperatively between the NPS and SMUMN GSS.

3.1 Preliminary Scoping

A preliminary scoping meeting was held on 11-13 January 2014. At this meeting, SMUMN GSS and NPS staff confirmed that the purpose of the BITH NRCA was to evaluate and report on current conditions, critical data and knowledge gaps, and selected existing and emerging resource condition influences of concern to BITH managers. Following NRCA program guidance, this NRCA includes the following:

- Condition assessments are conducted using existing data and information;
- Identification of data needs and gaps is driven by the project framework categories;
- The analysis of natural resource conditions includes a strong geospatial component;
- Resource focus and priorities are primarily driven by BITH resource management.

This condition assessment provides a "snapshot-in-time" evaluation of the condition of a select set of preserve natural resources that were identified and agreed upon by the project team. Project findings will aid BITH resource managers in the following objectives:

- Develop near-term management priorities (how to allocate limited staff and funding resources);
- Engage in watershed or landscape scale partnership and education efforts;
- Consider new preserve planning goals and take steps to further these;
- Report program performance (e.g., Department of Interior Strategic Plan "land health" goals, Government Performance and Results Act [GPRA]).

Specific project expectations and outcomes included the following:

- For key natural resource components, consolidate available data, reports, and spatial information from appropriate sources including: BITH resource staff, the NPS Integrated Resource Management Application (IRMA) website, Inventory and Monitoring Vital Signs program, and available third-party sources. The NRCA report will provide a resource assessment and summary of pertinent data evaluated through this project.
- When appropriate, define a reference condition so that statements of current condition may be developed. The statements will describe the current state of a particular resource with respect to an agreed upon reference point.

- Clearly identify “management critical” data (i.e., those data relevant to the key resources). This will drive the data mining and gap definition process.
- Where applicable, develop GIS products that provide spatial representation of resource data, ecological processes, resource stressors, trends, or other valuable information that can be better interpreted visually.
- Utilize “gray literature” and reports from third-party research to the extent practical.

3.2 Study Design

3.2.1 Indicator Framework, Focal Study Resources and Indicators

Selection of Resources and Measures

As defined by SMUMN GSS in the NRCA process, a “framework” is developed for a park or preserve. This framework is a way of organizing, in a hierarchical fashion, bio-geophysical resource topics considered important in preserve management efforts. The primary features in the framework are key resource components, measures, stressors, and reference conditions.

“Components” in this process are defined as natural resources (e.g., birds, plant communities), ecological processes or patterns (e.g., natural fire regime), or specific natural features or values (e.g., geological formations) that are considered important to current preserve management. Each key resource component has one or more “measures” that best define the current condition of a component being assessed in the NRCA. Measures are defined as those values or characterizations that evaluate and quantify the state of ecological health or integrity of a component. In addition to measures, current condition of components may be influenced by certain “stressors,” which are also considered during assessment. A “stressor” is defined as any agent that imposes adverse changes upon a component. These typically refer to anthropogenic factors that adversely affect natural ecosystems, but may also include natural processes or disturbances such as floods, fires, or predation (adapted from GLEI 2010).

During the BITH NRCA scoping process, key resource components were identified by NPS staff and are represented as “components” in the NRCA framework. While this list of components is not a comprehensive list of all the resources in the preserve, it includes resources and processes that are unique to the preserve in some way, or are of greatest concern or highest management priority in BITH. Several measures for each component, as well as known or potential stressors, were also identified in collaboration with NPS resource staff.

Selection of Reference Conditions

A “reference condition” is a benchmark to which current values of a given component’s measures can be compared to determine the condition of that component. A reference condition may be a historical condition (e.g., flood frequency prior to dam construction on a river), an established ecological threshold (e.g., EPA standards for air quality), or a targeted management goal/objective (e.g., a bison herd of at least 200 individuals) (adapted from Stoddard et al. 2006).

Reference conditions in this project were identified during the scoping process using input from NPS resource staff. In some cases, reference conditions represent a historical reference before human activity and disturbance was a major driver of ecological populations and processes, such as "pre-fire suppression." In other cases, peer-reviewed literature and ecological thresholds helped to define appropriate reference conditions.

Finalizing the Framework

An initial framework was adapted from the organizational framework outlined by the H. John Heinz III Center for Science's "State of Our Nation's Ecosystems 2008" (Heinz Center 2008). Key resources for the preserve were adapted from the GULN Vital Signs monitoring plan (Segura et al. 2007). This initial framework was presented to preserve resource staff to stimulate meaningful dialogue about key resources that should be assessed. Significant collaboration between SMUMN GSS analysts and NPS staff was needed to focus the scope of the NRCA project and finalize the framework of key resources to be assessed.

The NRCA framework was finalized in July 2014 following acceptance from NPS resource staff. It contains a total of 15 components (Figure 5) and was used to drive analysis in this NRCA. This framework outlines the components (resources), most appropriate measures, known or perceived stressors and threats to the resources, and the reference conditions for each component for comparison to current conditions.

BITH NRCA Framework
Natural Resource Condition Assessment

	Component	Measures	Stressors	Reference Condition
Ecosystem Extent and Function				
Disturbance Regimes				
	Fire Regime	Frequency, severity, fuel loading and distribution, location, intensity	Hurricanes, drought, southern pine beetle, past logging practices, fire suppression, climate change, land development and fragmentation, invasive plant species	1 to 3-yr return interval as a broad definition. May vary for different vegetation types. Historical photos and accounts may provide insight. Pre-European settlement.
Biotic Composition				
Vegetation Communities				
	Pine Uplands	Herbaceous understory diversity, herbaceous understory density, midstory density, basal area, age class	Altered fire regimes, southern pine beetle, drought, dense midstory , invasive and exotic plants, hogs, past logging operations	Pre-European settlement
	Slope Forest	Canopy cover, presence of beech-magnolia assemblage, basal area, age class	Unplanned fire occurrence, hurricanes, invasive and exotic plants, hogs, drought	Pre-logging
	Arid Sand Hills	Endemic species richness, extent	Altered fire regimes, dense midstory, invasive and exotic plants, hogs, past oil and gas operations	Pre-European settlement
	Longleaf Pine Wetlands	Extent, herbaceous understory diversity, herbaceous understory density, midstory density	Altered fire regimes, drought, dense midstory, invasive and exotic plants, hogs, past logging operations, land development	Pre-European settlement
	Floodplain Hardwood Forest	Extent, Canopy cover, basal area, age class	Unplanned fire occurrence, hurricanes, invasive plants, hogs, drought, lack of flood pulse events, human disturbance/illegal activity/landowner issues, past oil and gas impacts	Pre-logging
	Estuarine Wetlands	Extent	Saltwater intrusion, hypoxia, cypress die off, invasive and exotic plants, hogs, lack of flood pluse events, pollution, subsidence/sea level rise/extraction, changes in port depth/width, cimate change	2012 vegetation map
Birds				
	Birds	Species abundance, richness, and distribution	Habitat loss/fragmentation, feral hogs, mosquito-borne exotic diseases, climax vegetation setback, degradation to breeding and wintering grounds of migratory species, fire ants	Fisher (1974)
Herpetofauna				
	Amphibians/Reptiles	Species abundance, richness, and distribution	Climate change, pollution, feral hogs, habitat loss and fragmentation including road mortality, drought, altered fire regimes, saltwater intrusion, invasive plants, fire ants, increasing visitor use of waterways as urban areas expand, poaching/unlawful killing by visitors	Fisher (1978)

Figure 5. Big Thicket National Preserve natural resource condition assessment framework.

BITH NRCA Framework
Natural Resource Condition Assessment

	Component	Measures	Stressors	Reference Condition
Biotic Composition				
Mammals				
	Harvested Mammals	Annual Harvest, Harvest Success	Illegal take, feral hogs, habitat loss and fragmentation, road mortality	Establishment of harvest cards
Invertebrates				
	Freshwater Mussels	Species abundance, richness, distribution	Pollution, drought, climate change, exotic and invasive species	Howells (1997)
Aquatics				
	Freshwater Fish	Species abundance, richness, distribution	Invasive and exotic aquatic plants and animals, drought, saltwater intrusion, pollution & impacts of bioaccumulation on fish health and reproductive success, reduced flood pulses.	Suttkus & Clemmer (1979)
Environmental Quality				
	Water Quality	Dissolved oxygen, temperature, pH, conductivity, turbidity, nutrients, *E. coli*, carbonate chemistry, TSS, Impact on Aquatic Insects	Pollution, Altered flow regimes, Industrial Discharge, (naturally low-oxygen and low-pH systems), non point source bacteria inputs, industrial discharge, mercury deposition	TX State water quality standards
	Air Quality	Ozone, mercury, atmospheric dep. of N and S, particulate matter, visitbility	Beaumont-Port Arthur Orange Airshed effects: point sources and development. Houston area. O&G contributes to this.	National air quality standards, TX state standards (TCEQ)
Physical Characteristics				
Geologic and Hydrologic				
	Hydrology	Flooding frequency and duration, drought frequency and duration	Dams, saltwater barrier, saltwater intrusion, fragmentation impacts on surface flows to shallow wetlands, pipelines incl. exposures & changes, drought, erosion, development/bank stabilization, flood control measures & reduced pulses, subsurface - shallow aquifers/Texas water laws, Beaumont shipping channel changes in depth/width	Pre-dam & pre-shipping canal

Figure 5 (continued). Big Thicket National Preserve natural resource condition assessment framework.

3.2.2 General Approach and Methods

This study involved gathering and reviewing existing literature and data relevant to each of the key resource components included in the framework. No new data were collected for this study; however, where appropriate, existing data were further analyzed to provide summaries of resource condition or to create new spatial representations. After all data and literature relevant to the measures of each component were reviewed and considered, a qualitative statement of overall current condition was created and compared to the reference condition when possible.

Data Mining

The data mining process (acquiring as much relevant data about key resources as possible) began at the initial scoping meeting, at which time BITH staff provided data and literature in multiple forms, including: NPS reports and monitoring plans, reports from various state and federal agencies, published and unpublished research documents, databases, tabular data, and charts. GIS data were also provided by NPS staff. Additional data and literature were acquired through online bibliographic literature searches and inquiries on various state and federal government websites. Data and literature acquired throughout the data mining process were inventoried and analyzed for thoroughness, relevancy, and quality regarding the resource components identified at the scoping meeting.

Data Development and Analysis

Data development and analysis was highly specific to each component in the framework and depended largely on the amount of information and data available for the component, as well as recommendations from NPS reviewers and sources of expertise including NPS staff from BITH and the GULN. Specific approaches to data development and analysis can be found within the respective component assessment sections located in Chapter 4 of this report.

Scoring Methods and Assigning Condition

Significance Level

A set of measures are useful in describing the condition of a particular component, but all measures may not be equally important. A “Significance Level” represents a numeric categorization (integer scale from 1-3) of the importance of each measure in assessing the component’s condition; each Significance Level is defined in Table 3. This categorization allows measures that are more important for determining condition of a component (higher Significance Level) to be more heavily weighted in calculating an overall condition. Significance Levels were determined for each component measure in this assessment through discussions with preserve staff and/or outside resource experts.

Table 3. Scale for a measure’s Significance Level in determining a components overall condition.

Significance Level (SL)	Description
1	Measure is of low importance in defining the condition of this component.
2	Measure is of moderate importance in defining the condition of this component.
3	Measure is of high importance in defining the condition of this component.

Condition Level

After each component assessment is completed (including any possible data analysis), SMUMN GSS analysts assign a Condition Level for each measure on a 0-3 integer scale (Table 4). This is based on all the available literature and data reviewed for the component, as well as communications with preserve and outside experts.

Table 4. Scale for Condition Level of individual measures.

Condition Level (CL)	Description
0	Of **NO** concern. No net loss, degradation, negative change, or alteration.
1	Of **LOW** concern. Signs of limited and isolated degradation of the component.
2	Of **MODERATE** concern. Pronounced signs of widespread and uncontrolled degradation.
3	Of **HIGH** concern. Nearing catastrophic, complete, and irreparable degradation of the component.

Weighted Condition Score

After the Significance Levels (SL) and Condition Levels (CL) are assigned, a Weighted Condition Score (WCS) is calculated via the following equation:

$$WCS = \frac{\sum_{i=1}^{\#\ of\ measures} SL_i * CL_i}{3 * \sum_{i=1}^{\#\ of\ measures} SL_i}$$

The resulting WCS value is placed into one of three possible categories: good condition (WCS = 0.0 – 0.33); condition of moderate concern (WCS = 0.34 - 0.66); and condition of significant concern (WCS = 0.67 to 1.0). Figure 6 displays all of the potential graphics used to represent a component's condition in this assessment. The colored circles represent the categorized WCS; red circles signify a significant concern, yellow circles a moderate concern and green circles that a resource is in good condition. White circles are used to represent situations in which SMUMN GSS analysts and preserve staff felt there were currently insufficient data to make a statement about the condition of a component. For example, condition is not assessed when no recent data or information are available, as the purpose of an NRCA is to provide a "snapshot-in-time" of current resource conditions. The arrows inside the circles indicate the trend of the condition of a resource component, based on data and literature from the past 5-10 years, as well as expert opinion. An upward pointing arrow indicates the condition of the component has been improving in recent times. A horizontal arrow indicates an unchanging condition or trend, and an arrow pointing down indicates deterioration in the condition of a component in recent times. These are only used when it is appropriate to comment on the trend of condition of a component. In situations where the trend of the component's condition is currently unknown, no arrow is given.

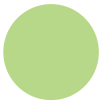
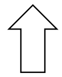
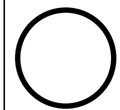
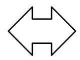
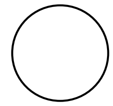
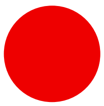
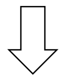
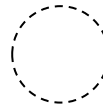
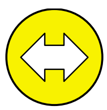
Condition Status		Trend in Condition		Confidence in Assessment	
	Resource is in Good Condition		Condition is Improving		High
	Warrants Moderate Concern		Condition is Unchanging		Medium
	Warrants Significant Concern		Condition is Deteriorating		Low

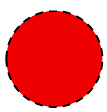
Figure 6. Description of symbology used for individual component assessments.

<u>Examples of how the symbols should be interpreted:</u>

Resource is in good condition, its condition is improving, high confidence in the assessment.



Condition of resource warrants moderate concern; condition is unchanging; medium confidence in the assessment.



Condition of resource warrants significant concern; trend in condition is unknown or not applicable; low confidence in the assessment.

Current condition is unknown or indeterminate due to inadequate data, lack of reference value(s) for comparative purposes, and/or insufficient expert knowledge to reach a more specific condition determination; trend in condition is unknown or not applicable; low confidence in the assessment.

<u>Preparation and Review of Component Draft Assessments</u>

The preparation of draft assessments for each component was a highly cooperative process among SMUMN GSS analysts and BITH and GULN staff. Though SMUMN GSS analysts rely heavily on peer-reviewed literature and existing data in conducting the assessment, the expertise of NPS resource staff also plays a significant and invaluable role in providing insights into the appropriate direction for analysis and assessment of each component. This step is especially important when data or literature is limited for a resource component.

The process of developing draft documents for each component began with a detailed phone or e-mail conversation with an individual or multiple individuals considered local experts on the resource components under examination. These conversations were a way for analysts to verify the most relevant data and literature sources that should be used and also to formulate ideas about current condition with respect to the NPS staff opinions. Upon completion, draft assessments were forwarded to component experts for initial review and comments.

Development and Review of Final Component Assessments

Following review of the component draft assessments, analysts used the review feedback from resource experts to compile the final component assessments. As a result of this process, and based on the recommendations and insights provided by BITH resource staff and other experts, the final component assessments represent the most relevant and current data available for each component and the sentiments of preserve resource staff and outside resource experts.

Format of Component Assessment Documents

All resource component assessments are presented in a standard format. The format and structure of these assessments is described below.

Description

This section describes the relevance of the resource component to the preserve and the context within which it occurs in the preserve setting. For example, a component may represent a unique feature of the preserve, it may be a key process or resource in preserve ecology, or it may be a resource that is of high management priority. Also emphasized are interrelationships that occur among the featured component and other resource components included in the NRCA.

Measures

Resource component measures were defined in the scoping process and refined through dialogue with resource experts. Those measures deemed most appropriate for assessing the current condition of a component are listed in this section, typically as bulleted items.

Reference Conditions/Values

This section explains the reference condition determined for each resource component as it is defined in the framework. Explanation is provided as to why specific reference conditions are appropriate or logical to use. Also included in this section is a discussion of any available data and literature that explain and elaborate on the designated reference conditions. If these conditions or values originated with the NPS experts or SMUMN GSS analysts, an explanation of how they were developed is provided.

Data and Methods

This section includes a discussion of the data sets used to evaluate the component and if or how these data sets were adjusted or processed as a lead-up to analysis. If adjustment or processing of data involved an extensive or highly technical process, these descriptions are included in an appendix for the reader or a GIS metadata file. Also discussed is how the data were evaluated and analyzed to determine current condition (and trend when appropriate).

Current Condition and Trend

This section presents and discusses in-depth key findings regarding the current condition of the resource component and trends (when available). The information is presented primarily with text but is often accompanied by detailed maps or plates that display different analyses, as well as graphs, charts, and/or tables that summarize relevant data or show interesting relationships. All relevant data and information for a component are presented and interpreted in this section.

Threats and Stressors Factors
This section provides a summary of the threats and stressors that may impact the resource and influence to varying degrees the current condition of a resource component. Relevant stressors were described in the scoping process and are outlined in the NRCA framework. However, these are elaborated on in this section to create a summary of threats and stressors based on a combination of available data and literature, and discussions with resource experts and NPS natural resources staff.

Data Needs/Gaps
This section outlines critical data needs or gaps for the resource component. Specifically, what is discussed is how these data needs/gaps, if addressed, would provide further insight in determining the current condition or trend of a given component in future assessments. In some cases, the data needs/gaps are significant enough to make it inappropriate or impossible to determine condition of the resource component. In these cases, stating the data needs/gaps is useful to natural resources staff seeking to prioritize monitoring or data gathering efforts.

Overall Condition
This section provides a qualitative summary statement of the current condition that was determined for the resource component using the WCS method. Condition is determined after thoughtful review of available literature, data, and any insights from NPS staff and experts, which are presented in the Current Condition and Trend section. The Overall Condition section summarizes the key findings and highlights the key elements used in determining and justifying the level of concern, if any, that analysts attribute to the condition of the resource component. Also included in this section are the graphics used to represent the component condition.

Sources of Expertise
This is a listing of the individuals (including their title and affiliation with offices or programs) who had a primary role in providing expertise, insight, and interpretation to determine current condition (and trend when appropriate) for each resource component.

3.3 Literature Cited

This is a list of formal citations for literature or datasets used in the analysis and assessment of condition for the resource component. Note: Citations used in appendices referenced in each section (component) of Chapter 4 are listed in that component's "Literature Cited" section.

Great Lakes Environmental Indicators Project (GLEI). 2010. Glossary, Stressor. http://glei.nrri.umn.edu/default/glossary.htm (accessed 31 January 2013).

The H. John Heinz III Center for Science, Economics, and the Environment. 2008. The state of the nation's ecosystems 2008: Measuring the land, waters, and living resources of the United States. Island Press, Washington, D.C.

Segura, M., R. Woodman, J. Meiman, W. Granger, and J. Bracewell. 2007. Gulf Coast Network Vital Signs monitoring plan. Natural Resource Report NPS/GULN/NRR–2007/015. National Park Service, Fort Collins, Colorado.

Stoddard. J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. J. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications 16(4):1267-1276.

Chapter 4 Natural Resource Conditions

This chapter presents the background, analysis, and condition summaries for the 15 key resource components in the project framework. The following sections discuss the key resources and their measures, stressors, and reference conditions. The summary for each component is arranged around the following sections:

1. Description
2. Measures
3. Reference Condition
4. Data and Methods
5. Current Condition and Trend (including threats and stressors factors, data needs/gaps, and overall condition)
6. Sources of Expertise
7. Literature Cited

The order of components follows the project framework (Figure 5):

4.1 Fire Regime
4.2 Pine Uplands
4.3 Slope Forests
4.4 Arid Sand Hills
4.5 Longleaf Pine Wetlands
4.6 Floodplain Hardwood Forests
4.7 Estuarine Wetlands
4.8 Birds
4.9 Amphibians/Reptiles
4.10 Harvested Mammals
4.11 Freshwater Mussels
4.12 Freshwater Fish
4.13 Water Quality
4.14 Air Quality
4.15 Hydrology

4.1 Fire Regime

4.1.1 Description

Photo 1. Prescribed burn in Big Sandy Creek Unit, August 2004 (NPS photo).

Fire has had a significant influence in the ecosystems of the southeast coastal plain, playing a key role in maintaining the mosaic of vegetation in areas such as BITH (McHugh 2004, NPS 2012a). Several vegetation communities within BITH, particularly those that supported longleaf pine (Pinus palustris), are considered "fire-dependent" and require periodic burning for maintenance and renewal (McHugh 2004, NPS 2012a; Photo 1). Without fire, vegetation communities such as longleaf pine uplands and arid sand hills, longleaf wetland savannas, and pitcher plant bogs are overgrown with brushy hardwood species (Liu et al. 1990, NPS 2012a). When these fire-dependent communities are maintained with regular burning, they are more resilient to environmental stressors such as drought, high winds, insects, and disease (NPS 2012a). For example, fire is known to control brown-spot needle blight, a disease of young longleaf pines, by burning and removing infected needles (Boyer and White 1989, Henderson 2006). Fire is also critical to the establishment of new longleaf pine seedlings, which are relatively slow growing and need full sunlight. However, they are also much more resilient than the other southern pine species because they put down a deep tap-root, have a tight and strong wood grain, and produce plentiful resins that allow them to withstand drought, hurricanes, and most wood rot issues. They also live for 300 of more years and reach heights exceeding 91 m (300 ft.). Historically, there were 36 million ha (90 million ac) of longleaf pine in the southeastern U.S., growing essentially in the "hurricane alley" of the Gulf of Mexico. Burning also favors new growth of herbaceous plants over woody species, providing more brows with higher nutritional value for wildlife (Henderson 2006). According to the BITH resource management plan (NPS 1996, p. 7, Hyde, personal communication, 2016), approximately 15-20% (6,070 – 10,117 ha [15,000-25,000 ac]) of the current preserve lands (45,325 ha [112,000 ac]) would have supported a mix of "highly fire dependent ecosystems" before humans interfered with the natural processes.

The term "fire regime" refers to several characteristics of fire occurrence in an area, including frequency, severity, and seasonality. The variation in these characteristics influences biodiversity, vegetative structure, and population dynamics in the area burned (Henderson 2006). It is widely believed that frequent, low-intensity fires were historically common in east Texas and throughout the Coastal Plain; severe fires involving the tree overstory were likely rare (McHugh 2004). Higher intensity burns could have occurred in extremely dry years or following blow-downs from high winds, when downed woody fuel built up (NPS 2012a). In the BITH area, hardwood bottomlands along riparian areas and wetlands often acted as natural barriers to fire spread (NPS 2012a). Although fires can occur at any time of year, there are typically two "fire seasons" in the BITH region: one in winter (January-April) due to increased fuel availability from leaf fall and drying grasses, and one in summer (July-September) when temperatures are high and precipitation is typically low (McHugh 2004).

Prior to European settlement, fires were ignited naturally by lightning or intentionally by Native Americans (NPS 2012a). The first European settlers, many of whom were ranchers, continued utilizing intentional fires to eliminate pests (e.g., snakes and insects) and to improve forage for livestock (Henderson 2006). Around 1910-1930, wildfire suppression policies began to spread throughout the south and suppression was effectively in place by the 1950s (Henderson 2006). These were partly for the protection of human settlements, pine plantations, agriculture, and, eventually, oil and gas development (Frost 1993, NPS 2012a). Unfortunately, fire suppression contributed to substantial changes in vegetation communities in BITH and throughout the south (MacRoberts and MacRoberts 2000, NPS 2012a). Open pine savannas and upland sandhills with a diverse herbaceous ground layer have shifted towards mixed loblolly pine/hardwood communities with a dense, brushy midstory (NPS 2012a), made up primarily of yaupon holly which has thrived after repeated logging events and the suppression of fire. Longleaf pine is often shaded out by the faster growing but less fire-tolerant loblolly (*Pinus taeda*) and shortleaf pine (*P. echinata*) (McHugh 2004, NPS 2012a) and recruitment of new longleaf seedlings is also very low without fire and the resultant full sunlight that this species needs. These shifts in community composition, particularly the increase in brushy under- and midstory which shades out the herbaceous understory, reduces the likelihood of fire occurrence (Streng and Harcombe 1982, McHugh 2004). However, when fires do occur, the increase in woody fuels can increase the intensity and severity of the burn, increasing the risk to both natural and human resources (McHugh 2004, Varner et al. 2005, Henderson 2006). Of particular concern is the ability of yaupon holly to grow to heights of 4.5 to 6.1 m (15 to 20 ft.) in the midstory which makes them a particular concern as a "ladder fuel" which carries the fire into the lower live branches of the pine overstory and can lead to high mortality of the pine during prescribed burns and even to wildfires as the fires crown and greatly increase in intensity and the ability to jump fire lines and spread into non-burn areas.

Fire behavior (e.g., intensity, rate of spread, flame height) can often be predicted using fuel models. These models, based largely on fuel and weather conditions, were first developed by Rothermel (1972) and later modified by Albini (1976). The fuel models that best describe vegetation communities within BITH were outlined by McHugh (2004) in BITH's fire management plan and are summarized in Table 5. The vegetation types and units where these fuel models occur (also according to McHugh 2004) are shown in Tables 6a and 6b.

Table 5. Fuel model descriptions for BITH vegetation communities from McHugh (2004).

Fuel Model	Description
2	Upland vegetation types composed of a relatively open tree layer, sparse shrub stratum, and a well-developed herbaceous layer; moderate fire intensity and rate of spread.
4	Upland and upper slope vegetation types with scattered areas of dense shrub and understory thickets, largely due to fire suppression over a number of years; highest predicted fire intensity and rate of spread, with flame heights greater than 6 m (20 ft.).
7	Moderately dense stands of flammable shrubs between two and six feet high, below a pine or mixed pine-hardwood canopy; low to moderate fire intensity and rate of spread.
8	Vegetation dominated by hardwoods; the fuel bed is normally a thin hardwood leaf mat. Intermittent drainages and permanent stream channels often dissect this fuel type. Fuel moistures are relatively high throughout the year; lowest fire intensity and rate of spread.
9	Mixed pine-hardwood forests, dominated by hardwoods in the canopy, with a moderately well-developed hardwood understory and scattered shrubs. Fuel bed is a hardwood leaf-pine needle mat; low fire intensity and rate of spread.
11	Dense understory of highly flammable brush. The open canopy allows wind penetration; exceptional fire behavior should be expected during the summer. High intensities and canopy scorch of mature pines are possible.

Table 6a. Vegetation type within BITH where each of the fuel models described in Table 5 can be found (McHugh 2004).

	Fuel Model					
Vegetation Type	**2**	**4**	**7**	**8**	**9**	**11**
Upland pine	x	x	x			
Wetland pine savanna	x	x	x			
Sandhill pine	x		x			
Upper slope pine oak		x	x		x	x
Mid slope pine oak			x		x	
Lower slope hardwood pine					x	
Floodplain hardwood pine				x		
Floodplain hardwood				x		
Flatland hardwood				x		
Wetland baygall				x		

Table 6b. Fire Management Units (FMU) within BITH where each of the fuel models described in Table 5 can be found (McHugh 2004).

	Fuel Model					
Fire Management Unit	**2**	**4**	**7**	**8**	**9**	**11**
Big Sandy		x	x	x	x	
Hickory Creek			x			x
Turkey Creek		x	x	x	x	
Beech Creek		x		x		
West Hardin*				x		
Neches River Floodplain			x	x	x	

*The West Hardin FMU includes the Lance Rosier and Loblolly Units.

NPS staff initiated a prescribed burning program at BITH in 1982 to restore and maintain fire-dependent habitats and to reduce hazardous fuel levels (McHugh 2004, NPS 2012a). Prescribed fire benefits native vegetation communities by returning nutrients to the soil, removing dense undergrowth, reducing competition with weedy species, and increasing seed production and germination of fire-adapted species (Liu 1995, NPS 2012a). Surveys of vegetation monitoring plots in prescribed burn treatment areas suggest that, "grasses and forbs are returning, longleaf pine is regenerating, loblolly pine regeneration is decreasing, and yaupon brush growth is being controlled in frequently burned areas" (McHugh 2004, p. 32; further discussion in Liu 1995). In terms of fuel models, repeated prescribed fires have helped to convert areas of BITH from Fuel Model 4 (highest intensity and rate of spread) to Fuel Model 7 (low to moderate intensity and spread; see Table 5). However, it will likely take 40-100 years of regular prescribed burning to restore longleaf pine to the canopy where it historically occurred (McHugh 2004). On some NPS properties, wildland fire use (e.g., allowing naturally ignited wildfires to burn) is an effective tool in restoring historic fire regimes. Given the unusual shapes and sizes of the disjunct preserve units, as well as concerns over surrounding land uses (e.g., residential communities, timber plantations), wildland fire use is not an appropriate management tool for BITH (McHugh 2004).

4.1.2 Measures

- Frequency
- Severity
- Fuel loading and distribution
- Location
- Intensity

4.1.3 Reference Conditions/Values

The reference condition for this component is the pre-European settlement fire regime. While exact information from this time is not available, research suggests that fire-dependent communities in the area experienced fires at an average frequency of 1-10 years (Chapman 1932, 1944, Christensen 1981, as cited by McHugh 2004; MacRoberts and MacRoberts 2000). Actual frequency likely varied with vegetation type and other characteristics (e.g., topography, weather, etc.). At this return interval, the vast majority of fires would have been low in severity and intensity.

4.1.4 Data and Methods

The BITH Fire Management Plan (McHugh 2004, p. 6) defines the objective of the preserve's fire management program as, "to allow fire to function in its natural ecological role, restore ecosystem balance (stand structure and diversity) of pyric communities, and manage hazardous fuels in the Urban Interface through the use of prescribed fire and mechanical treatments." The priority areas for the preserve's prescribed fire program are the three units that contain the majority of fire-dependent vegetation: BSCU, Hickory Creek Savannah (HCSU), and TCU (McHugh 2004). Secondary priorities would include portions of the LRU and CU where fire would have occurred historically and maintained longleaf wetland pine savannah and upland pine communities. The Fire Management Plan contains information on the region's historic fire regime, reviews the accomplishments of the prescribed fire program through 2003, outlines the preserve's fire affects monitoring program, and summarizes previous research on fire effects in BITH, as well as outlining future research needs.

Several fuel loading inventories were completed for various preserve units in the late 1970s and early 1980s (Streng and Harcombe 1978, 1979, Glitzenstein and Harcombe 1980, Harcombe and Schafale 1981). At that time, fire suppression had been in place for several decades and the prescribed burning program had not yet begun. Therefore, the information in these inventories is not helpful in assessing current fuel load conditions or in identifying a desirable reference condition and the data will not be utilized in this condition assessment.

Liu et al. (1990, 1992, and Liu 1995) studied the effects of fire on vegetation in BITH. Over 100 treatment (burned) and control sample plots were established in fire-prone habitats of four preserve units: BSCU, HCSU, TCU, and LRU (Liu et al. 1990). Vegetation community composition and structure were regularly surveyed to identify any changes following prescribed burn treatments. Data were also collected on fuel loads and fire intensity during prescribed burns (Liu et al. 1990, 1992). Fuels were divided into two groups: downed woody material (further divided into size classes) and fine fuels, sorted by type (e.g., litter, twigs, live material) (Liu et al. 1990).

Henderson (2006) used fire-scar data from longleaf pine tree ring analysis to study fire history in the BITH region. Samples were taken from the TCU. Study methods are described in detail in Henderson (2006). Parameters reported include mean, minimum, and maximum fire intervals. Henderson (2006) notes that information from fire-scar analysis is limited, as not all fires are "recorded" by every tree, and the age of fire-scarred stands in the eastern and southeastern U.S. does not typically exceed 500 years. This could be particularly applicable in the BITH region, where fires were historically low-intensity and may not have scarred the fire-resistant longleaf pines, and because nearly all of the area's mature longleaf pines were removed by logging.

Photo 2. A 2001 prescribed burn in the Hickory Creek Savanna Unit (NPS photo).

NPS (2004) and Hansen (2004) contain information on wildfire and prescribed burn occurrences in and around BITH from approximately 1980 through 2004. More recent data on prescribed burns and wildfires (i.e., any fire not set for management purposes by the NPS - natural or human-caused) were provided by BITH staff (NPS 2015a, NPS 2015b).

Burn severity data for six preserve fires were obtained through the Monitoring Trends in Burn Severity (MTBS) project website (MTBS 2012b). Additional information regarding fire return interval (i.e., frequency), fuel loading, and severity was obtained from the LANDFIRE website (http://www.landfire.gov/). LANDFIRE is an interagency mapping program that produces vegetation and fire-related spatial data layers (at a 30-m pixel resolution) for the entire country.

4.1.5 Current Condition and Trend

Frequency

Research suggests that low intensity fires were historically relatively frequent in the BITH region, approximately every 3-10 years on uplands and slopes (NPS 2012a). For upland pine forests, Chapman (1932) suggested that lightning-caused fires likely occurred 3-4 years apart. Christensen (1981) found that some arid sandhills on the Coastal Plain accumulated enough pine litter and fine fuels within 3-5 years to carry a fire; forests on these hills likely experienced fires every 4-7 years (McHugh 2004). Christensen (1981) also stated that natural fire frequency in Coastal Plain savannas was probably 2-8 years. This is supported by Glitzenstein and Harcombe's (1986) fire scar analysis from three HCSU longleaf pines, which indicated a fire interval of 2-7 years, with a mean of 3.9 years, from the period 1928-1967. The historic fire frequency in slope forests, such as those within BITH, is less clear. Based on the presence of longleaf pine and dominance of shortleaf pine in upper slope pine-oak forests, researchers conclude that fire occurred in these communities, but less frequently than in uplands and wetland savannas (McHugh 2004). According to Chapman (1944), shortleaf pine grows best on sites with fire intervals less than 10 years. Therefore, evidence suggests that fire intervals of 6-8 years would maintain the upper slope pine-oak forests (McHugh 2004). Shortleaf pine is also present in mid-slope oak-pine forests, although it is less dominant, suggesting that natural fire intervals in this community were probably 8-10 years (McHugh 2004). Fires were likely less frequent in lower slope hardwood pine forests, given the dominance of hardwoods. However, the presence of loblolly pine, which requires exposed mineral soil for seed germination, suggests that fires do occasionally occur in these forests, possibly during extreme droughts (McHugh 2004). The general frequency at which prescribed fires are conducted in BITH burn units is summarized in Table 7.

Table 7. General guidelines for prescribed burn frequency by vegetation type, based on estimations of natural fire regimes and restoration needs, according to the BITH fire management plan (McHugh 2004).

Vegetation Type	Burn Rotation
Upland pine	3-4 years
Wetland pine savanna	2-8 years
Sandhill pine	4-7 years
Upper slope pine-oak	6-8 years

Henderson (2006) used fire scar data from longleaf pines in the TCU to estimate historic fire return intervals for the area. The earliest fire scar detected in tree rings was from 1714 (Henderson 2006). From this time through 2003, the mean fire interval for the TCU was estimated at 10.6 years, with a minimum fire interval of 1 year and a maximum of 74 years (Henderson 2006). Fire frequency peaked between 1900 and 1950, occurring approximately every 5 years, and then declined dramatically in the last half of the 20th century due to fire suppression. Fire frequency appeared to be influenced by moisture conditions, which control the rate of fuel accumulation (Christensen 1981, Henderson 2006). Drier sites, like arid sand hills, burn less frequently than other vegetation types because it takes longer to accumulate enough fuel to carry a fire. Henderson (2006) noted that the 2 years prior to a fire in BITH were typically wetter than the fire year, allowing fuel to accumulate.

The LANDFIRE program utilized a vegetation and disturbance dynamics model (Vegetation Dynamics Development Tool [VDDT]) to generate a nationwide mean fire return interval (MFRI) GIS data layer (under a presumed historic regime) (LANDFIRE 2015). Due to its broad scale, this information is not as accurate as on-the-ground research, but can provide some insight into fire frequency where studies are minimal or non-existent. The modeled MFRI data for the BITH region are shown in Figure 7. This suggests that the majority of the area had a historic MFRI of 0-5 years, with an MFRI of 26-40 years also common (LANDFIRE 2013a).

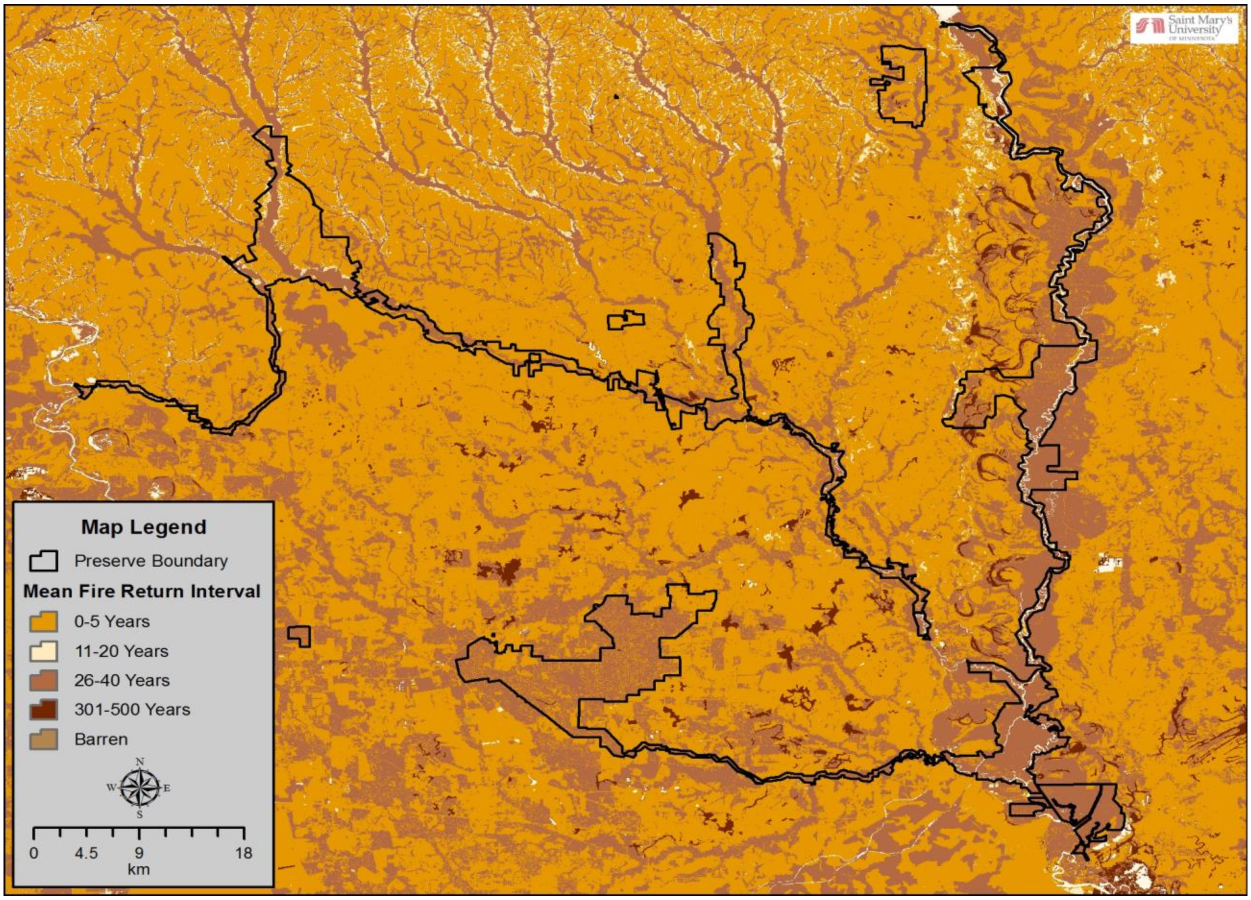


Figure 7. Mean fire return interval, under the presumed historical fire regime**,** for the BITH region from LANDFIRE (2013a).

Since 1981, over 150 prescribed burns have been conducted at BITH (NPS 2015a). According to fire occurrence data received from BITH, managers have conducted prescribed burns approximately every 3-4 years in portions of the BSCU since the early 1990s and throughout the HCSU since the early 1980s (NPS 2004, 2015a). In the TCU, the area around the Pitcher Plant Trail was burned every 2-4 years, with the exception of a gap between 2000 and 2010 (NPS 2004, 2015a). Other portions of the TCU burned every 4-6 years; the Sandhill Loop Trail area was burned in 3 years between 2003 and 2012 (NPS 2004, 2015a). In the LRU, only two small areas burned twice between 1983 and 2010 (NPS 2004, 2015a).

Since 2002, the BITH area has experienced an average of six to seven wildfires per year, ranging widely from zero to nearly 20 (NPS 2015b). Wildfire activity was especially high in 2005 and 2011 (a record-breaking drought year). Wildfires that started within or crossed into preserve units generally impacted only small areas (<5 ha [12.4 ac]); most were suppressed by NPS staff, although some burned out naturally (NPS 2015b).

The timing of fires (prescribed and wildland) in the BITH area since 1995 shows two peaks, one in January and one in July (Figure 8). The proportion of spring fires (March, April) has increased since 2002 (NPS 2004, 2015a, 2015b). Large fires are infrequent, with only nine prescribed fires (just one since 2002) covering over 405 ha (1,000 ac) and just one wildfire of over 405 ha extending into the preserve since 2002 (McHugh 2004; NPS 2015a, 2015b).

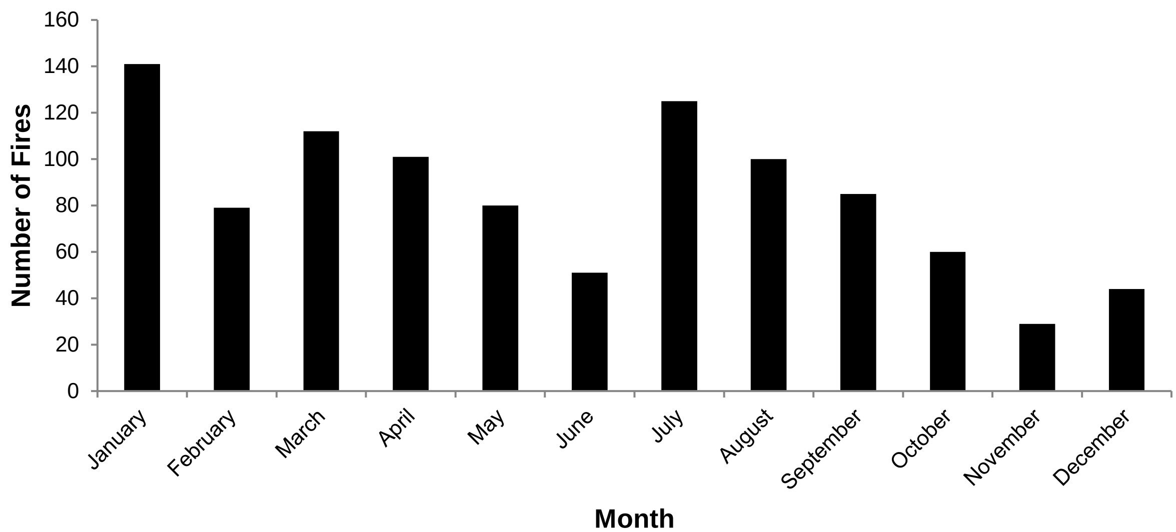


Figure 8. Fire occurrence (prescribed and wildland) in the BITH area by month, 1995-2014 (NPS 2004, 2015a, 2015b).

Severity

Fire (or burn) severity is a term used to describe the physical and chemical changes to the soil, the conversion of vegetation and fuels to inorganic carbon, and structural or compositional transformations that create new microclimates and species assemblages (Key and Benson 2006). Severity can be measured by amount of organic matter loss both above and below the surface of the ground after a fire (Keeley 2008). In cases of very high burn severity, the organic layer of the soil can be consumed and soils may become water-repellent (NPS 2012a). Severity is influenced by rate of fire spread and amount of fuel consumed (i.e., fuel load), among other characteristics (Oliver and Larson 1990). Studies suggest that high severity fires were historically rare in the BITH region, likely because fires occurred frequently, preventing heavy build-ups of fuels (Frost 2000, Henderson 2006, NPS 2012a).

A recently developed method for measuring burn severity is to compare Landsat imagery prior to and after a fire to determine a Differenced Normalized Burn Ratio (dNBR). The dNBR data, which represent continuous values, are separated into six categories. MTBS (2015b) classifies the six severity categories as unburned to low, low, moderate, high, increased greenness, and no data. According to MTBS (2015a), an analyst evaluates the dNBR data range and determines where significant thresholds exist to discriminate between severity categories. In Sorbel and Allen (2005), the accuracy of the dNBR method was tested by sampling Composite Burn Index (CBI) plots established on the ground in recently burned areas. CBI methods involve scoring burn severity based on 22 variables including soil cover/color change, duff and litter consumption, percent of colonizers, percent of altered foliage, and percent of canopy mortality (Sorbel and Allen 2005). A comparison of

CBI scores and dNBRs for the same areas shows that dNBR is "a suitable measure and predictor of burn severity" (Sorbel and Allen 2005, p. 9). MTBS (2015b) provided burn severity data in which acreage of severity categories were derived for five fires within BITH and one just outside preserve boundaries (Table 8). Spatial representations of MTBS data for the Marcus Fire are presented in Appendix A.

Table 8. Area (in acres) of different burn severity categories for five fires within BITH and one fire outside preserve boundries (MTBS 2015b).

	Severity Level (acres)				
Date of Fire Inside Preserve	**Unburned to Low**	**Low**	**Moderate**	**High**	**Increased Greenness***
24 March 1986	1,251.1	1,057.2	394.3	144.4	5.0
28 July 1998	56.7	210.9	151.8	128.3	--
13 July 2001	654.1	445.6	56.8	4.2	17.9
9 August 2001	304.8	182.6	69.2	11.8	1.1
21 July 2004	480.6	368.2	94.8	2.2	--
Total	**2,747.3**	**2,264.5**	**766.9**	**290.9**	**24.0**
Outside Preserve					
1 April 1996	30.7	180.7	449.0	1,214.2	--

*"Increased greenness" indicates an increased post -fire vegetation response.

LANDFIRE program has also generated nationwide fire severity GIS data using the vegetation and disturbance dynamics model VDDT. This includes a "percent of replacement-severity fires" layer and a "percent of low-severity" layer (under the presumed historic fire regime). Replacement severity is defined as "greater than 75 percent average top-kill within a typical fire perimeter for a given vegetation type," whereas low severity is described as "less than 25 percent average top-kill within a typical fire perimeter for a given vegetation type" (LANDFIRE 2015). These modeled severity data are presented in Figure 9 and Figure 10. As expected, less than 10% of fires in the vast majority of BITH are of replacement severity (Figure 9); similarly, over 76% of fires in most BITH units are considered low severity (Figure 10), based on the modeled data (LANDFIRE 2013b, c).

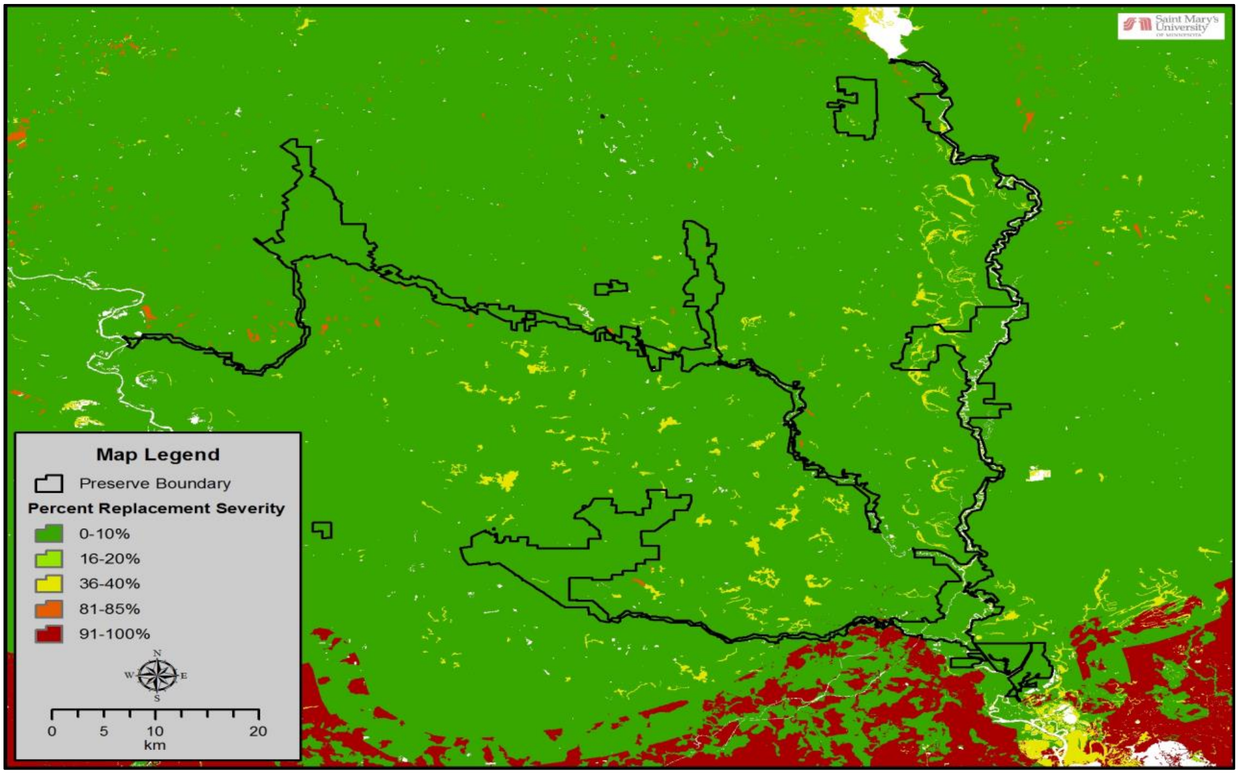


Figure 9. Percent of fires of replacement-severity in the BITH region, according to LANDFIRE (2013b).

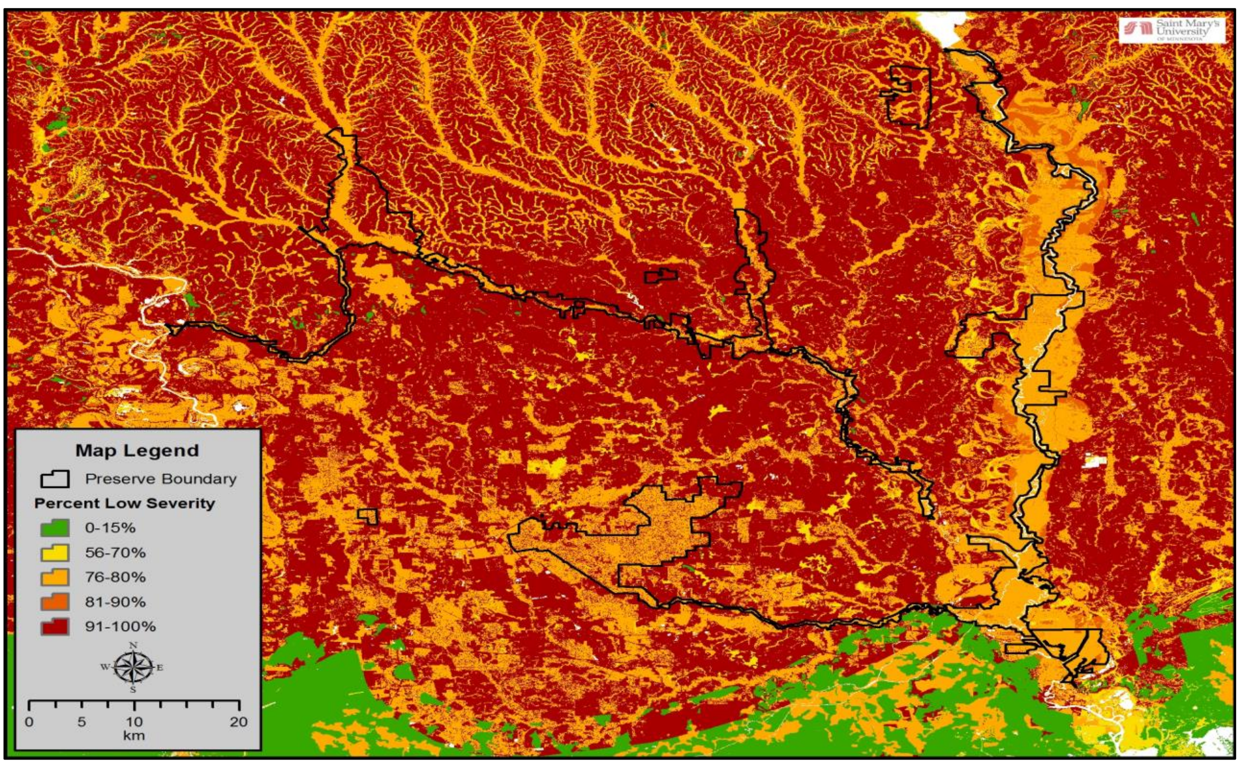


Figure 10. Percent of fires of low-severity in the BITH region, according to LANDFIRE (2013c).

Fuel Loading and Distribution

Fuel loading and distribution strongly influence the frequency, intensity, and severity of fires. When fuels build up due to a reduction in fire frequency, as has been the case in much of BITH, fire intensity and severity generally increase when fires do occur (McHugh 2004, Henderson 2006). Fuel distribution also influences a fire's ability to carry or spread across the landscape. Fuel loads are describes as "the net result of two processes - fuel production and fuel decomposition" (Liu 1995, p. 94). The highest fuel loads would be expected in vegetation communities where production is high and decomposition is low, while light fuel loads would be associated with low vegetation production and/or fast decomposition. At BITH, fuel loads can be influenced by forest composition, since pine needles typically decompose more slowly than deciduous, hardwood tree leaves (Streng and Harcombe 1979). Liu (1995) mapped fuel load and depth conditions by vegetation type in BITH during the early 1990s (Figure 11). Baygalls, which are a very productive community, had the highest fuel load; wetland savannas, which support few trees to produce needles and woody fuels, had the lowest fuel loads but the greatest fuel depths (Liu 1995). Fuel load conditions have likely changed in these communities over time, as the BITH prescribed burning program has continued, but relative comparisons between vegetation types may still apply (e.g., upland pine communities have higher f uel loads than mid and lower slope communities).

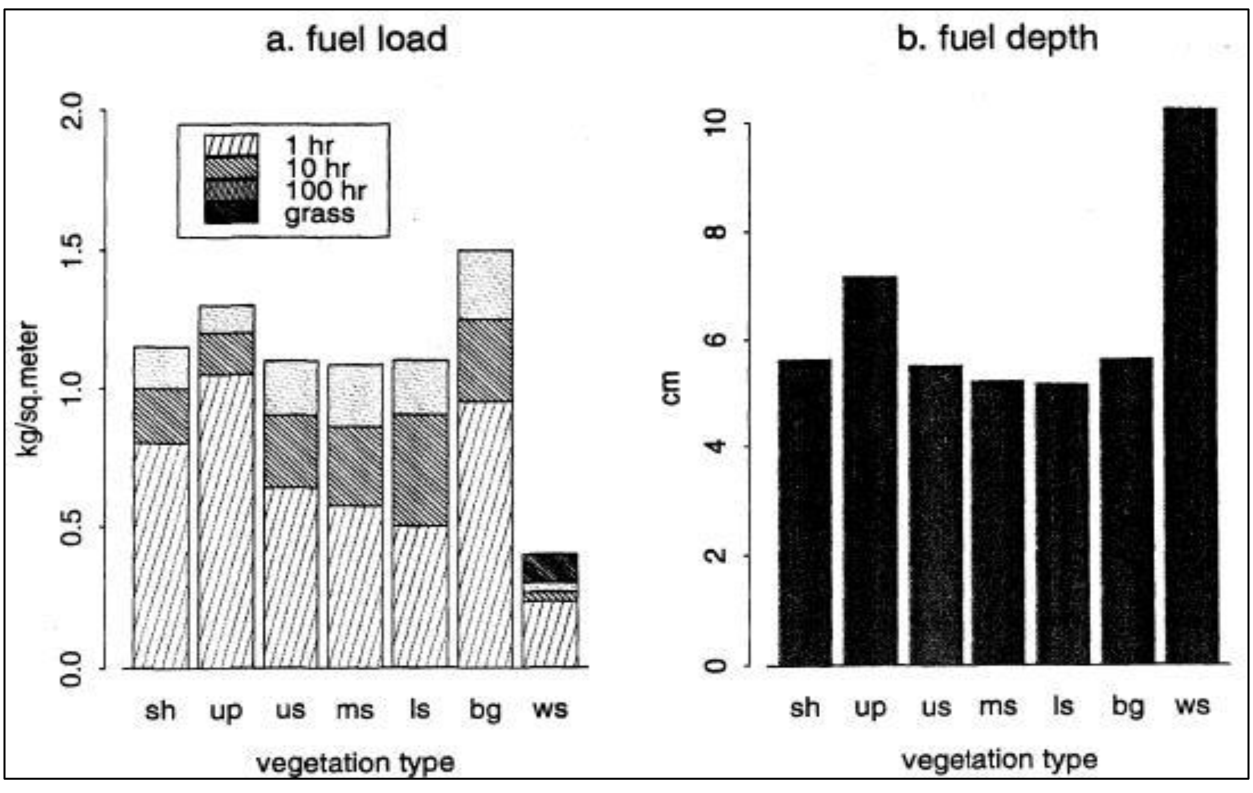


Figure 11. Fuel load (left) and fuel depth (right) data by vegetation type from Liu (1995). sh = sand hill, up = upland pine, us = upper slope, ms = midslope, ls = lower slope, bg = baygall, ws = wetland pine savanna. 1 hour = fine fuels (e.g., leaves, needles); 10 hr. = woody material, 0.25-1 inch diameter; 100 hr. = woody material, 1-3 inches diameter.

The LANDFIRE program has created a nationwide GIS data layer of the 13 Anderson fire behavior fuel models (LANDFIRE 2010). This model classifies fuels by type (e.g., grass, shrub, timber). Fuel type influences fire behavior, such as intensity and rate of spread (Liu 1995, McHugh 2004). This data layer can be used by land managers in fire behavior and effects software programs (LANDFIRE 2015). As mentioned previously, these modeled data are not as accurate as on-the-ground research, but it can provide some information on fuel loading in areas where it has not been monitored or studied. Figure 12 shows fuel model data for all BITH units while Figure 13 presents a closer look at fuel model data in the BSCU, where several prescribed burns have occurred in recent decades.

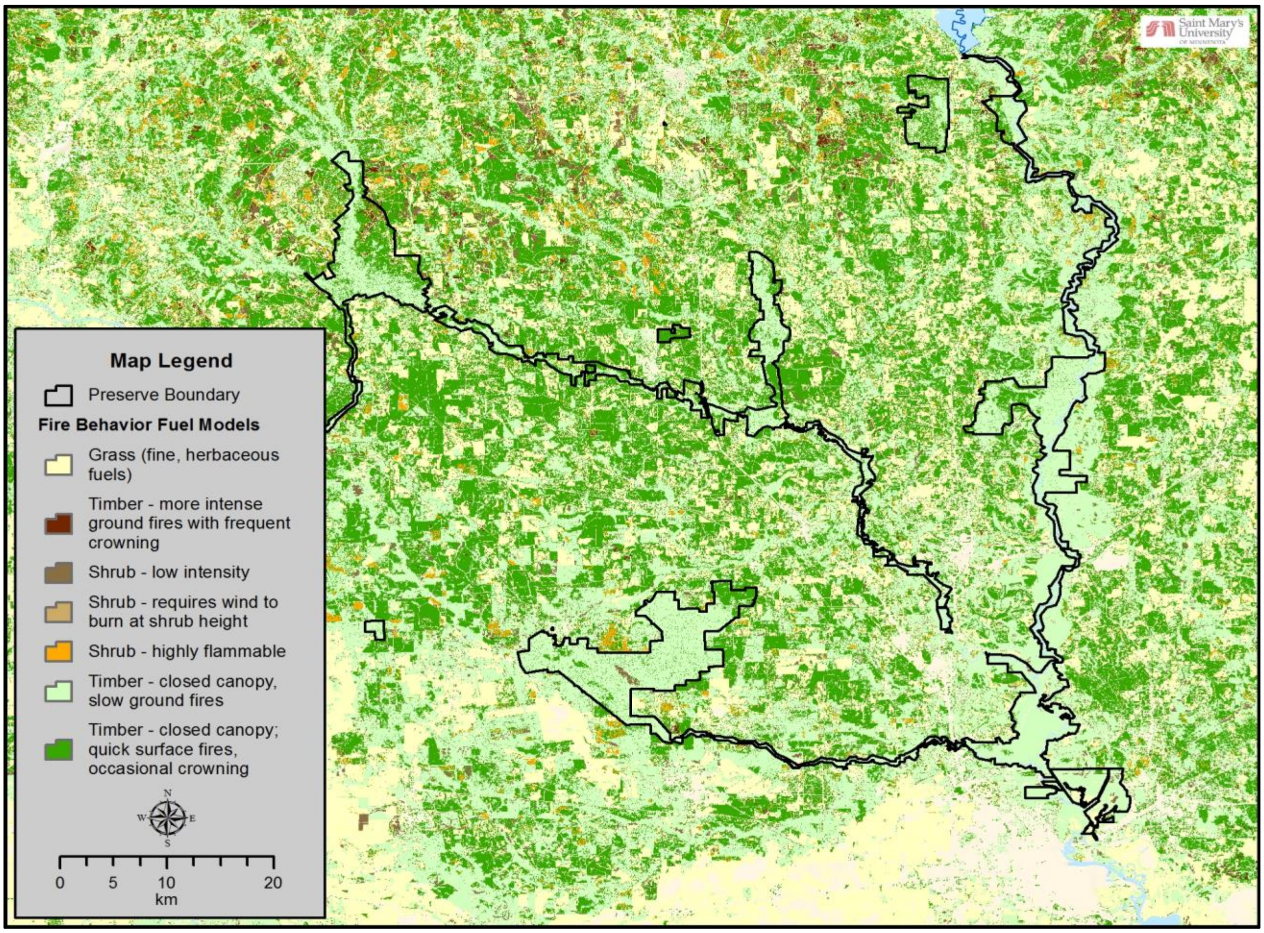


Figure 12. Fire behavior fuel model data for all BITH units from LANDFIRE (2010).

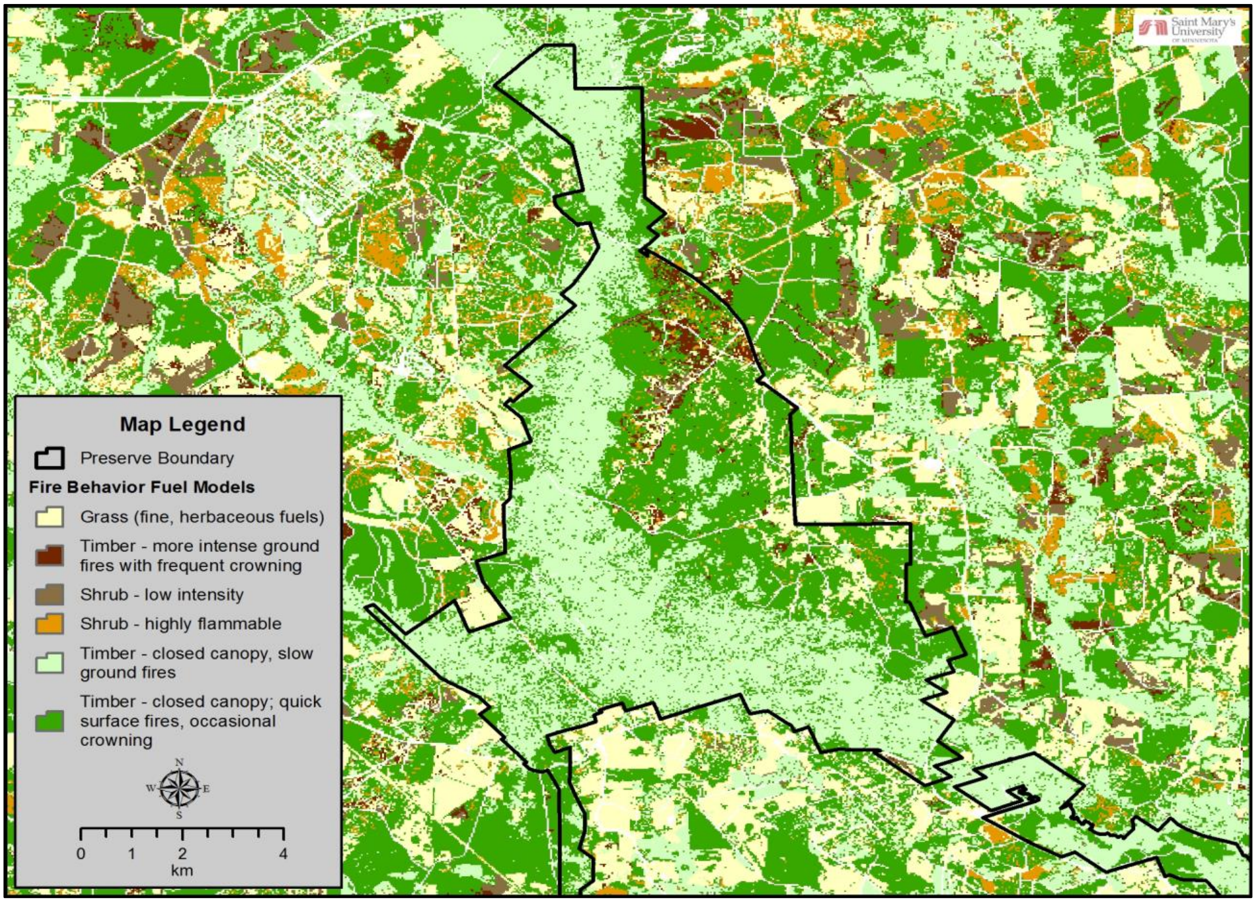


Figure 13. Fire behavior fuel model data for the BSCU (LANDFIRE 2010).

Threats and Stressors Factors

Threats to BITH's fire regime include land development/fragmentation, fire suppression, past logging practices, southern pine beetle (SPB) (*Dendroctonus frontalis*) damage, invasive plant species, hurricanes and drought, and climate change. Residential, agricultural, and industrial development has fragmented the natural landscape in the BITH region, preventing the spread of fire and reducing its frequency (Simberloff 2000). When natural fires do occur, they must be suppressed to protect homes, crops, or other structures (Simberloff 2000). The proximity of residential development has also limited the use of prescribed fire in some BITH units, particularly the HCSU which borders the Wildwood Community (NPS 2001). Residential subdivisions or rural homes occur along approximately 212 km (132 mi) of BITH's boundaries; commercial timber property borders nearly 1,000 km (621 mi) of preserve (NPS 2012).

Fire suppression was common throughout the U.S. during the 20th century, including in the BITH region (Frost 1993, McHugh 2004). When fire is suppressed, open vegetation communities are invaded by fire-intolerant trees, and native shrubs are able to form dense thickets (McHugh 2004, Varner et al. 2005). This increases the density and coverage of the midstory vegetation layer. A dense midstory and brushy understory increases fuel loads, along with the risk that wildfires will cause significant damage to the ecosystem when they do occur (McHugh 2004, Brockway et al. 2005).

Yaupon thickets can produce 24 m (80 ft.) flame lengths, which can kill mature longleaf pines (McHugh 2004). Increased intensity and severity of wildfires throughout the U.S. have been linked to hazardous fuel loads due to 20th-century fire suppression (Swetnam et al. 1999, Henderson 2006).

Historic logging has altered BITH's vegetation and fire regime in several ways. Initial logging activities in the early 20th century fragmented the landscape, preventing fires from spreading and reducing their extent and frequency (Simberloff 2000, NPS 2012). The logging of large pines altered fuel beds by removing a source of fine ground fuels (e.g., pine needles, bark, cones), which contributed to reduced fire frequency (McHugh 2004). Logged areas and former plantations also provided openings for brushy species such as yaupon, holly (*Ilex opaca*), and sweet gum to form dense thickets, which alter fire regime (NPS 2012).

Southern pine beetle outbreaks (which will be discussed further in Chapter 4.2) can cause tree mortality, which influences fuel loads. Dead pines contribute a heavy load of bark, needles, and cones to the ground layer, all of which are very flammable. Such conditions were observed in the BSCU and the LRU in the early 1980s following beetle infestations in the late 1970s (Glitzenstein and Harcombe 1980, Harcombe and Schafale 1981). The loss of mature canopy trees in the BITH region around that time also increased light availability for the understory, and allowed brushy vegetation to become dominant (McHugh 2004). This brush often burns with a high intensity that can damage any remaining large pines as well as pine saplings (McHugh 2004). Some infestations have left large trees on the ground, which can reduce accessibility for personnel conducting prescribed burns or fighting wildfires (McHugh 2004). McHugh (2004) noted that southern pine beetle activity had altered vegetation and fuel conditions in the BSCU, TCU, and BCU.

Hurricanes or other strong wind events can cause large blowdowns (i.e., trees uprooted or broken by wind) which increase woody fuel loads (Henderson 2006, NPS 2012). These downed trees may provide enough fuel to kill or severely damage nearby living trees (Henderson 2006). The blowdowns also increase light availability, which, as mentioned above, allows brushy vegetation to thrive. Dense brush also typically lacks grasses and other fine fuels, which makes them resistant to prescribed fire treatments (NPS 2012). After hurricanes in 2005 and 2008, BITH managers had to use mechanical treatments (i.e., cutting and removal) to reduce hazardous fuel loads (NPS 2012).

During droughts, fuels are drier and more flammable, increasing the likelihood of fires and their potential rate of spread (Henderson 2006). Nearly every vegetation type in BITH could experience fire during extended droughts, even the baygalls which are normally wet with frequent standing water (Liu 1995, McHugh 2004). Droughts can cause prescribed fire treatments to be postponed, as conditions are often too dangerous or unpredictable to conduct burns safely (NPS 2012). Droughts may increase in both frequency and duration in the BITH area due to global climate change (Harcombe et al. 1999).

Invasive plants can alter vegetation communities which, in turn, influences fuel loads and fire regime (Brooks et al. 2004, Brooks 2008). One of the non-native species of concern in BITH is Chinese tallow, a highly invasive tree. Tallow trees can shade out herbaceous ground layer vegetation, reducing the fine fuels necessary to start and carry a fire (Brooks 2008). This often reduces fire frequency, but increases intensity and severity when fires do occur (Brooks 2008). In turn, fire occurrence outside the historic fire regime may favor invasive species (Smith et al. 2008, Zouhar et al. 2008). Fire suppression in fire-adapted communities such as grasslands and savannas may allow woody non-native species to invade (Zouhar et al. 2008); in other communities, fire may actually favor invasive plants over natives due to their high competitive abilities (Smith et al. 2008, Zouhar et al. 2008).

Data Needs/Gaps

Actual data regarding the historic frequency of fires in the various BITH vegetation communities are limited. The lack of older trees throughout the southeast (due to logging and removal for other human activities) for fire scar analysis presents a challenge, as does the fact that most historic fires were likely low severity and may not have been hot enough to scar trees (McHugh 2004, Henderson 2006). However, fire-dependent communities at BITH could be searched for large trees that could contribute further information on historic fire frequency.

The effects of fire in some mesic communities (e.g., mid and lower slope forests) have not been well-researched (Christensen 1988, Liu 1995). This is partly because fires naturally occur less frequently here due to slightly wetter conditions. Wetland baygalls also have not burned during fire effects studies (Liu 1995). Fire impacts in this community could be severe due to the sensitivity of many common plant species and the presence of deep peat layers (Christensen 1981, Liu 1995).

Fire affects research in BITH has focused primarily on woody species. Further research is needed into the response of ground-layer plants to burning, particularly in longleaf pine communities known for their biodiversity (Liu et al. 1995). Additional information on post-fire vegetation responses such as re-sprouting and germination (e.g., hardwoods vs. pines, shrubs vs. tree seedlings) would also be useful (McHugh 2004). Lastly, research into the relationships between invasive species and fire in various vegetation communities is needed (Stocker and Hupp 2008, Zouhar et al. 2008). The GULN will be implementing a vegetation monitoring program at BITH in 2016 that will include some of the preserve's prescribed burn units and may provide some insight on these data needs over time (Robert Woodman, GULN Ecologist, written communication, 16 July 2015).

Overall Condition

Frequency

The project team assigned this measure a *Significance Level* of 3. Historically, the BITH region likely experienced frequent low-intensity fires (every 3-10 years, depending on vegetation type; McHugh 2004, NPS 2012a). After European settlement (early to mid-1900s), a policy of fire suppression was enforced, contributing to greatly reduced fire frequency in east Texas and across the U.S. (Frost 1993, Henderson 2006). In 1982, BITH initiated a prescribed burn program to return fire to the communities within the preserve where it naturally occurred (McHugh 2004). Due to the often dangerous conditions created by the accumulation of hazardous fuel levels during the decades of fire suppression and other constraints (e.g., personnel, weather, adjacent land uses), the NPS prescribed burn program has not yet been able to achieve the frequency at which fires historically occurred in all fire-dependent communities throughout the preserve. Therefore, fire frequency remains of moderate concern (*Condition Level* = 2).

Severity

The severity measure was also assigned a *Significance Level* of 3. Historically, low severity fires were likely common in the BITH region and high severity fires were extremely rare (Frost 2000, NPS 2012a). Decades of fire suppression have contributed to fuel build-ups that could increase the severity of fires when they do occur. Burn severity data from MTBS for five fires in BITH showed that a majority of burned area fell into the “unburned to low” and “low” severity categories (MTBS 2015b). However, on a 1996 fire just outside BITH boundaries, nearly 65% of the burned area showed high severity (MTBS 2015b). Since high severity fires are still a danger in the BITH area, this measure is of moderate concern (*Condition Level* = 2).

Fuel Loading and Distribution

The *Significance Level* of this measure is a 3. No recent on-site data are available for fuel loading in BITH. LANDFIRE fuel models show that much of the preserve area would be expected to experience only low intensity or slow moving ground fires (Figure 12, LANDFIRE 2010). However, the models show several areas containing fuels that are highly flammable or that could support high intensity ground fires with frequent crowning (LANDFIRE 2010). This supports observations by NPS staff and researchers of heavy fuel accumulations (due to fire suppression, bark beetle activity, and blowdowns) in some areas of BITH (Harcombe and Schafale 1981, Liu 1995, McHugh 2004). Because hazardous fuel loads are still present within the preserve, this measure is assigned a *Condition Level* of 2, indicating moderate concern.

Location

This measure was assigned a *Significance Level* of 1. Measures with a *Significance Level* of 1 are not discussed in depth in the current condition section of this assessment, but available information is summarized here in the overall condition section. Fire locations are mapped by date (1976-2002 and 2003-2015, varying by unit) in Appendix B. Over the past decade, prescribed burns in BITH have been limited to the BSCU, HCSU, TCU, LRU, and a single boundary area just east of preserve headquarters (NPS 2015a, Appendix B). Prior to 2000, smaller prescribed burns occurred in the Jack Gore Baygall Unit (JGBU) and BCU (NPS 2004). Wildland fire locations are dispersed throughout the BITH area; since 2002, wildfires have primarily impacted only very small areas within preserve boundaries (NPS 2015b, Appendix B). Since there is no evidence that fire locations are currently a cause for concern, this measure is assigned a *Condition Level* of 1 (low concern).

Intensity

The intensity measure also received a *Significance Level* of 1. Intensity is the energy or magnitude of heat produced by a fire (Key and Benson 2006, Keeley 2008). It can be an indicator to fire managers of the potential effects of fire on soil and vegetation (i.e., fire severity) during prescribed burns. Low intensity fires normally only impact herbaceous vegetation and small woody individuals (e.g., seedlings and saplings, small shrubs); high intensity fires can impact larger trees, even those considered fire resistant (Liu 1995). Pines are generally more fire resistant (i.e., able to handle more frequent and intense burns) than hardwoods such as oaks and gums, partly due to bark thickness

(McHugh 2004). As a result, fire intensity can influence both the composition and structure of vegetation communities.

To document fire intensity during burns at BITH, Liu (1995) recorded fire temperatures using fire-sensitive tablets (from Tempil, Big Three Industries) and measured scorch heights on trees after fires. The data collected during this study are presented in Table 9. Recorded fire temperatures ranged from 0°C to 399°C, with the highest temperatures occurring in upland pine communities (Liu 1995). Scorch heights varied from 3.2 cm (1.3 in) to 210.5 cm (82.9 in); the highest scorch heights also occurred in upland pine communities (Liu 1995). These data indicate that upland pine communities experienced the highest intensity fires during this study period.

Table 9. Fire temperature (°C) and scorch height data from early 1990s BITH fires (Liu 1995).

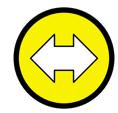
Unit	Vegetation Type	Fire Temp (°C)	Scorch Height (cm)
Big Sandy	Upper slope	N/A	12.7
		N/A	70.4
		N/A	21.9
		N/A	3.2
		204	N/A
		152	N/A
		<52	N/A
	Mid slope	N/A	22.1
		N/A	41.4
		N/A	32.2
		N/A	46.3
		N/A	11.8
	Upland pine	399	N/A
		253	N/A
		253	N/A
		343	N/A
		152	N/A
Lance Rosier	Wetland pine savanna	<52	18.6
		262	122.7
		0	11.6
		152	80.6
		0	15.0

Table 9 (continued). Fire temperature (°C) and scorch height data from early 1990s BITH fires (Liu 1995).

Unit	Vegetation Type	Fire Temp (°C)	Scorch Height (cm)
Lance Rosier	Savanna/lower slope	52	22.4
		101	6.9
		0	4.8
		0	6.9
		101	25.8
Turkey Creek	Upland pine	101	78.9
		262	70.5
		204	210.5
		153	171.3
		<52	54.5
	Upper slope	<52	52.4
		204	66.8
	Upper slope	204	73.0
		101	46.1
		<52	31.1
Hickory Creek	Wetland savanna	<52	N/A
		52	N/A
		153	N/A
		<52	N/A
		262	N/A
		<52	N/A
		262	N/A
		101	N/A
		<52	N/A
		153	N/A

Data regarding fire intensity in BITH are limited to this one source (Liu 1995), which is now two decades old and likely not indicative of current conditions in the preserve. However, NPS managers are aware of many areas within the preserve where brushy fuel loads are high and high intensity fires are a significant danger. As a result, this measure is assigned a *Condition Level* of 2, indicating moderate concern.

Weighted Condition Score
The WCS for BITH’s fire regime is 0.64, which indicates moderate concern. Conditions in many areas of the preserve have improved in recent decades due to the NPS prescribed fire program. However, some hazardous fuel loads still remain, meaning the risk of high severity fires continues to be a management concern.

Fire Regime			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.64**
Frequency	3	2	
Severity	3	2	
Fuel Loading and Distribution	3	2	
Location	1	1	
Intensity	1	2	

4.1.6 Sources of Expertise

- DW Ivans, BITH Fuels Specialist
- Ken Hyde, BITH Chief of Resources Management
- Ryan Desliu, BITH Environment Specialist and former Fire Effects Monitoring Crew Lead

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4.2 Pine Uplands

4.2.1 Description

Photo 3. Longleaf pine stand (NPS photo by Rudy Evenson).

The pine uplands of BITH occur on level or rolling hilltops with sandy soils (Harcombe and Marks 1979). Longleaf pine was the dominant species historically, occurring in relatively open stands of varying height and density, depending on stand history (Photo 3). Currently, longleaf remains in small pockets and as individual trees. Shortleaf and loblolly pine are also common in these uplands, while several oaks (bluejack [*Quercus incana*], blackjack [*Q. marilandica*], post [*Q. stellata*], southern red [*Q. falcata*]) and sweetgum may be present (Harcombe and Marks 1979, NPS 2012a). The understory in these stands can vary greatly depending on past disturbance and management, particularly fire history. Where fire has been absent, woody understory species are often dense, including flowering dogwood (*Cornus florida*), American beautyberry (*Callicarpa americana*), wax-myrtle (*Morella cerifera*), yaupon and flame-leaf sumac (*Rhus copallina*) (Harcombe and Marks 1979, NPS 2012a). When woody species are absent, a dense and diverse herbaceous layer of grasses and forbs is typically present, often dominated by bluestem species (Harcombe and Marks 1979).

Longleaf pine upland communities are known for their species diversity, supporting some of the highest levels of species richness outside the tropics (Brockway et al. 2005). Unfortunately, these communities are also among the most endangered ecosystems in the U.S., with just over 5% of their original extent remaining (1.9 million ha [4.7 million ac] of the original 36 million ha [90 million ac]) (Noss et al. 1995, Brockway et al. 2005, ALRI 2013). The U.S. Fish and Wildlife Service (USFWS) (USFWS 2009) has identified 30 federally listed threatened or endangered species that live in longleaf pine forests. One of the now rare species historically associated with upland pine forests in the BITH region is the red-cockaded woodpecker. These birds excavate nesting and roosting cavities from live pines, unlike most woodpecker species, which target dead trees (Belanger et al. 1988). The woodpeckers excavate small holes around their nest cavities that ooze resin, creating a barrier that prevents predatory snakes from reaching the cavities (Rudolph et al. 1990). Red-cockaded woodpeckers prefer older trees in mature, low-density pine stands (Belanger et al. 1988), which are now rare due to logging and fire suppression.

Recent reviews of historic information, soils, topography, and LiDAR mapping data have found 7,976 ha (19,710 ac) of historic, current, and/or potential habitat for longleaf pine restoration within BITH (Hyde, and Jeff Bracewell, GULN GIS Specialist, written communications, October 2015). A majority of this area would be pine uplands, although some longleaf pine wetlands may also be included (Hyde, written communication, 6 October 2015). Currently, pine uplands are known to occur in nearly all of the units of the preserve, with the largest areas located in the BSCU, TCU, BCU, HCSU, LRU, and the CU (Hyde, written communication, 6 October 2015). According to Harcombe and Marks (1979), pine uplands covered approximately 388.5 ha (960 ac) in BSCU and 71.2 ha (176 ac) in TCU for an estimated total of 459.7 ha (1,136 ac) (Figure 14). More recent mapping efforts (DESCO 2007) identified 209 ha (517 ac) of Longleaf Pine Woodland Alliance and 250 ha (618 ac) of Loblolly-Shortleaf Pine Forest Alliance in the TCU alone (Figure 14). Since 2000, BITH managers have aggressively used prescribed fire, mechanical removal of aggressive understory species, and planting of young seedlings to begin the restoration of longleaf pines to upland and wetland pine habitats (Hyde, written communication, 6 October 2015). As of 2015, they have also added herbicide treatments into the toolbox for both fire management planning and site restoration.

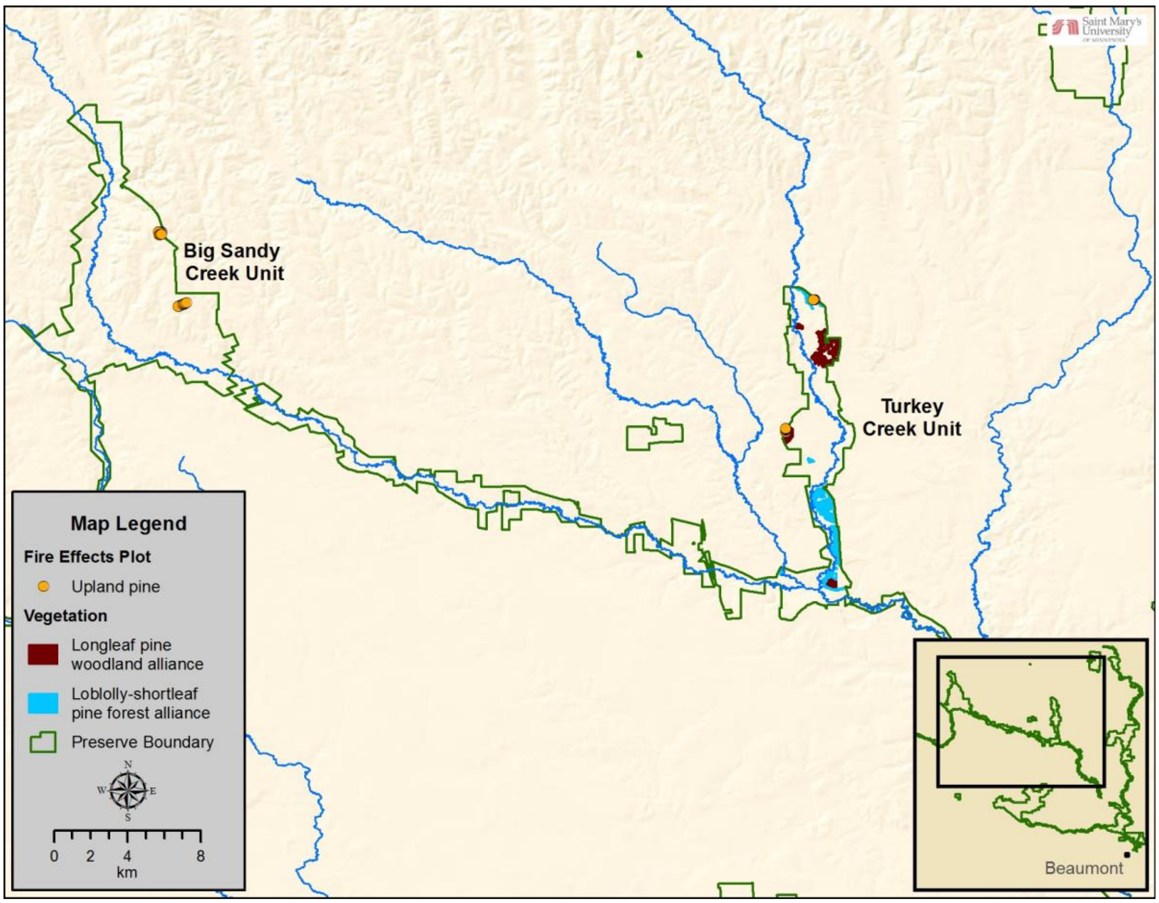

Figure 14. Pine uplands in TCU (DESCO 2007) and BITH fire effects monitoring plots located within pine uplands (NPS 2012b). Note that pine uplands occur in many other preserve units but have not been formally mapped.

4.2.2 Measures

- Herbaceous understory diversity
- Herbaceous understory density
- Midstory density

- Basal area
- Age class

4.2.3 Reference Conditions/Values

The reference condition for this component is the condition of the pine uplands prior to European settlement and extensive logging of the area. However, little information is available from this time period. The earliest known studies of vegetation within the current preserve boundaries occurred in the 1970s (Marks and Harcombe 1978, Harcombe and Marks 1979), when much of the region had already been harvested for timber several times. The information presented in this NRCA could serve as a baseline for future assessments.

4.2.4 Data and Methods

Harcombe and Marks (1979) sampled 56 vegetation stands throughout the various BITH units, covering the topographic range from floodplains to upland forests. The focus of the study was on woody vegetation, with little attention given to the herbaceous understory. Only three of the stands sampled were classified as upland pine forests. Harcombe and Marks (1975) also studied upland forest stands in the BSCU. Streng and Harcombe (1982) sampled one upland forest stand in BITH's HCSU. Watson (1982) provided a preserve-wide plant species list and information on the community types where each species was found; this provided information on herbaceous understory diversity.

Liu et al. (1990, 1992) sampled vegetation in TCU and BSCU pine uplands as part of a fire affects monitoring study. Data gathered included basal area and stand density. Different plots were sampled within the study area in the two survey efforts. Data were presented in these reports by stand and plot type (burn vs. control); SMUMN GSS analysts calculated means for pine uplands in each unit from these data.

Lewis et al. (2000) sampled forest vegetation in the BSCU as part of a study of the herpetofaunal community. The study identified the most dominant plant species in the overstory, midstory, understory, and herbaceous ground layer, as well as documenting density and canopy closure in the first three layers. To determine the most dominant species in each layer, Lewis et al. (2000) calculated "importance values," which factor in the species' frequency, density, and basal area.

During a 2006 vegetation assessment of the TCU, DESCO (2007) visited several upland pine stands (*Pinus taeda-Pinus echinata* Forest Alliance). Sixteen plots totaling 0.4 ha (1.0 ac) were sampled for woody vegetation; data gathered included basal area and density (total and by layer). Herbaceous vegetation was sampled in 140 1 m x 1 m plots, totaling 14 m^2 (151 ft^2) (DESCO 2007).

4.2.5 Current Condition and Trend

Herbaceous Understory Diversity

As mentioned previously, longleaf pine communities are known for their species diversity, and this includes the herbaceous understory. Watson (1982) provided a plant species list for the preserve that documented the community types where each species was found. SMUMN GSS analysts used this list to isolate herbaceous species (trees and shrubs were excluded) known to occur in longleaf pine uplands. According to this list, 168 herbaceous species have been documented in BITH's pine uplands (Appendix C).

Only one recent survey, limited to TCU (DESCO 2007), has addressed herbaceous understory diversity. DESCO (2007) documented 104 plant species in the understory of TCU pine upland plots. However, only 39 of these species were herbaceous plants; the remainder were seedlings or saplings of woody species (trees or shrubs). These species are also listed in Appendix C.

Herbaceous Understory Density

In the open setting typical of pine uplands prior to European settlement, the herbaceous understory was likely very dense. However, fire suppression has contributed to increased canopy cover in these woodlands, especially of midstory shrubs, reducing both the diversity and density of the herbaceous understory (Varner et al. 2005). Herbaceous understory density has not been specifically studied within BITH's pine uplands. While Lewis et al. (2000) reported understory density values, the "understory" was classified as plants between 0.5 and 3 m (1.6-9.8 ft.) in height; at these heights, the "understory" is likely dominated by young woody plants rather than herbaceous species. Lewis et al. (2000) did document "ground cover" (vegetation less than 0.5 m [1.6 ft.] in height), defined as the number of times a "meter stick touched per 10 point samples" (p. 145). In pine uplands, the mean herbaceous ground cover value was 4.0 and the mean woody species ground cover value was 4.1 (Lewis et al. 2000). DESCO (2007) also recorded "ground cover" in the herbaceous layer of TCU pine uplands. Herbaceous vegetation ground cover in sample plots averaged 22.71% (DESCO 2007).

Midstory Density

In pre-settlement pine upland communities, the midstory layer would have been open (i.e., low density) with scattered shrubs and hardwoods (primarily oak species) due to frequent fires. However, fire suppression, repeated logging opening the overstory, and other factors have caused the midstory density to increase in many pine uplands (Varner et al. 2005). This is especially the case for yaupon holly which produces abundant seed, is a re-sprouter, and is an early "colonizer" of disturbed sites Very little information is available regarding midstory density in BITH's upland pine communities. Lewis et al. (2000) reported a midstory density of 27.5 stems/100 m^2 in pine upland forest stands in BSCU, and Streng and Harcombe (1982) documented the density of shrub species in a Hickory Creek upland forest (Table 10).

Table 10. Density (stems/ha) of shrub species within an upland forest stand sampled by Streng and Harcombe (1982).

Scientific Name	Common Name	Density (stems/ha)
Morella cerifera	wax-myrtle	3,600
Symplocos tinctoria	common sweetleaf	2,476
Ilex vomitoria	yaupon	1,882
Rubus sp.	blackberry	1,160
Callicarpa americana	American beautyberry	120

Table 10 (continued). Density (stems/ha) of shrub species within an upland forest stand sampled by Streng and Harcombe (1982).

Scientific Name	Common Name	Density (stems/ha)
Cornus florida	flowering dogwood	128
Magnolia virginiana	sweetbay	1,016
Rhododendron oblongifolium	Texas azalea	620
Persea borbonia	redbay	182
Rhus copallina	flame-leaf sumac	2
Hypericum hypericoides ssp. *hypericoides*	St. Andrew's cross	60
Asimina parviflora	smallflower pawpaw	60
Frangula caroliniana	Carolina buckthorn	60
Sassafras albidum	sassafras	62
Vaccinium arboreum	farkleberry	198
Vaccinium stamineum	deerberry	40
Total		**11,666**

DESCO (2007) recorded midstory and shrub layer density in 16 sample plots within TCU pine uplands (*Pinus taeda-Pinus echinata* Forest Alliance). "Midstory" included stems 2.5-12 cm in diameter, whereas the "shrub" layer consisted of stems 0.5-2.5 cm in diameter. The average midstory density was 1,610 stems/ha and shrub density was 6,380 stems/ha (DESCO 2007). Densities by species are presented in Table 11.

Table 11. Midstory and shrub layer densities by species in TCU pine uplands (*Pinus taeda-Pinus echinata* Forest Alliance) (DESCO 2007).

Scientific Name	Common Name	Midstory Density (stems/ha)	Shrub Layer Density (stems/ha)
Quercus nigra	water oak	10.0	75.0
Quercus incana	bluejack oak	12.5	25.0
Quercus margaretta	sand post oak	20.0	--
Vitis rotundifolia	muscadine	10.0	50.0
Carya texana	black hickory	10.0	25.0
Ulmus alata	winged elm	10.0	--
Morus rubra	red mulberry	5.0	--
Prunus serotina	black cherry	5.0	--

Table 11 (continued). Midstory and shrub layer densities by species in TCU pine uplands (*Pinus taeda-Pinus echinata* Forest Alliance) (DESCO 2007).

Scientific Name	Common Name	Midstory Density (stems/ha)	Shrub Layer Density (stems/ha)
Viburnum rufidulum	rusty blackhaw	10.0	--
Halesia diptera	two-wing silverbell	7.5	--
Magnolia virginiana	sweetbay	5.0	--
Pinus palustris	longleaf pine	5.0	--
Juniperus virginiana	eastern redcedar	2.5	--
Crataegus marshallii	parsley hawthorn	2.5	--
Toxicodendron radicans	eastern poison ivy	2.5	--
Fraxinus caroliniana	Carolina ash	2.5	50.0
Styrax grandifolius	bigleaf snowbell	2.5	--
Bignonia capreolata	crossvine	2.5	--
Castanea pumila	chinquapin	2.5	25.0
Ilex vomitoria	yaupon	--	1,802.5
Cyrilla racemiflora	swamp titi	--	775.0
Quercus falcata	southern red oak	--	400.0
Vaccinium corymbosum	highbush blueberry	--	950.0
Persea palustris	swamp bay	--	500.0
Quercus hemisphaerica	Darlington oak	--	377.5
Liquidambar styraciflua	sweetgum	--	75.0
Ditrysinia fruticosa	Gulf Sebastian-bush	--	450.0
Pinus taeda	loblolly pine	--	150.0
Symplocos tinctoria	common sweetleaf	--	100.0
Ilex opaca	American holly	--	100.0
Callicarpa americana	American beautyberry	--	100.0
Asimina parviflora	smallflower pawpaw	--	75.0
Ulmus rubra	slippery elm	--	25.0
Morella cerifera	wax myrtle	--	75.0

Table 11 (continued). Midstory and shrub layer densities by species in TCU pine uplands (*Pinus taeda-Pinus echinata* Forest Alliance) (DESCO 2007).

Scientific Name	Common Name	Midstory Density (stems/ha)	Shrub Layer Density (stems/ha)
Nyssa sylvatica	blackgum	--	25.0
Smilax glauca	cat greenbrier	--	25.0
Vaccinium stamineum	deerberry	--	25.0
Sassafras albidum	sassafras	--	25.0
Vaccinium arboreum	farkleberry	--	25.0
Carpinus caroliniana	American hornbeam	--	25.0
Pinus echinata	shortleaf pine	--	25.0

Basal Area

Basal area is calculated by multiplying the cross-sectional area of all stems (or trunks) of a species within a known area (typically a hectare or acre) (Harcombe and Marks 1979). It is a density measurement that takes into account the *area* occupied by each species, rather than just the *number* of stems of each species within a given area. Stand density can impact longleaf pine regeneration in several ways. First, higher density stands typically have greater canopy cover, which limits the amount of light available for pine seedlings. Boyer and White (1989) also state that stand density affects longleaf cone production, with production peaking at basal areas between 6.9 and 9.2 m^2/ha (30-40 ft^2/ac) and dropping rapidly outside this range.

Basal area data are very limited for the pine uplands of BITH. Harcombe and Marks (1979) calculated basal areas for three upland pine stands. The basal areas for pine uplands by species and overall from Harcombe and Marks (1979) are shown in Table 12. Longleaf pine had the greatest basal area in these stands by far, comprising 81% of the total basal area.

Table 12. Mean total basal area (m^2/ha) by species within upland pine forest stands sampled by Harcombe and Marks (1979). Only species with basal areas >0.05 m^2/ha are included in the table.

Scientific Name	Common Name	Basal Area
Pinus palustris	longleaf pine	9.5
Pinus taeda	loblolly pine	0.7
Quercus incana	bluejack oak	0.5
Pinus echinata	shortleaf pine	0.4
Quercus marilandica	blackjack oak	0.2
Quercus falcata	southern red oak	0.2

Table 12 (continued). Mean total basal area (m^2/ha) by species within upland pine forest stands sampled by Harcombe and Marks (1979). Only species with basal areas >0.05 m^2/ha are included in the table.

Scientific Name	Common Name	Basal Area
Quercus stellata	post oak	0.1
Liquidambar styraciflua	sweetgum	0.1
Total		**11.7**

Streng and Harcombe (1982) calculated basal area for one upland forest stand in the HCSU of BITH. In this stand, loblolly pine had a slightly higher basal area than longleaf (Table 13). The total basal area was higher than the mean data for stands sampled by Harcombe and Marks (1979). However, it should be noted that Harcombe and Marks (1979) only included species with basal areas >0.05 m^2/ha, while the Streng and Harcombe (1982) total includes all species with basal areas >0.01 m^2/ha.

Table 13. Mean total basal area (m^2/ha) by species within an upland forest stand sampled by Streng and Harcombe (1982). Only species with basal areas >0.01 m^2/ha are included in the table.

Scientific Name	Common Name	Basal Area
Pinus taeda	loblolly pine	6.72
Pinus palustris	longleaf pine	5.85
Liquidambar styraciflua	sweetgum	2.41
Pinus echinata	shortleaf pine	1.80
Quercus falcata	southern red oak	1.05
Quercus laurifolia	laurel oak	0.82
Quercus nigra	water oak	0.69
Nyssa sylvatica	blackgum	0.59
Acer rubrum	red maple	0.07
Quercus stellata	post oak	0.05
Quercus alba	white oak	0.04
Total		**20.09**

Liu et al. (1990, 1992) gathered basal area data from pine uplands in the BSCU and TCU. All mean basal area values documented by Liu et al. (1990, 1992) were higher than those previously documented. In both survey years, TCU stands showed greater mean basal areas than BSCU stands (Table 14, Table 15). Longleaf pine had the highest individual species basal area in both units during the first survey (Liu et al. 1990), followed by loblolly pine (Table 14). In the second survey (Liu et al. 1992), longleaf pine showed the greatest basal area in TCU stands, but shortleaf pine dominated in BSCU stands (Table 15).

Table 14. Mean total basal area (m^2/ha) by species within pine uplands sampled by Liu et al. (1990). Values are means by unit based on stand data presented in Liu et al. (1990).

Species	BSCU	TCU
Acer rubrum	--	0.15
Cornus florida	--	0.15
Crataegus sp.	0.05	--
Ilex opaca	--	0.10
Ilex vomitoria	0.90	0.20
Liquidambar styraciflua	2.25	0.65
Magnolia virginiana	--	0.30
Myrica cerifera	0.05	--
Nyssa sylvatica	0.10	2.25
Persea borbonia	--	0.10
Pinus echinata	1.10	--
Pinus palustris	12.45	19.75
Pinus taeda	8.65	9.45
Quercus falcata	0.25	1.70
Quercus laurifolia	--	0.10
Quercus marilandica	1.15	--
Quercus nigra	--	1.05
Quercus stellata	0.45	--
Symplocos tinctoria	--	0.05
Total	**27.4**	**36.0**

Table 15. Mean total basal area (m^2/ha) by species within pine uplands sampled by Liu et al. (1992). Values are means by unit based on stand data presented in Liu et al. (1992). Note that the exact same plots within the pine uplands were not visited during this survey as in Liu et al. (1990).

Species	BSCU	TCU
Acer rubrum	--	0.1
Aralia spinosa	0.05	--
Cornus florida	0.15	0.3
Ilex vomitoria	--	0.2

Table 15 (continued). Mean total basal area (m^2/ha) by species within pine uplands sampled by Liu et al. (1992). Values are means by unit based on stand data presented in Liu et al. (1992). Note that the exact same plots within the pine uplands were not visited during this survey as in Liu et al. (1990).

Species	BSCU	TCU
Liquidambar styraciflua	0.25	0.2
Nyssa sylvatica	--	1.7
Pinus echinata	11.05	--
Pinus palustris	0.25	31.0
Pinus taeda	8.20	--
Quercus falcata	--	0.2
Quercus marilandica	0.80	--
Quercus nigra	--	0.6
Quercus stellata	1.55	--
Vaccinium arboreum	0.05	--
Viburnum rufidulum	0.05	--
Total	**22.45**	**34.3**

DESCO (2007) also reported basal areas for pine uplands in the TCU. In 16 sample plots, total basal area (overstory, midstory, and shrub layer) was 29.23 m^2/ha. Basal area of the overstory alone was 24.56 m^2/ha, dominated by loblolly pine with a basal area of 9.0 m^2/ha and shortleaf pine with 7.7 m^2/ha (DESCO 2007). This overstory basal area was lower than the values reported by Liu et al. (1990, 1992) for TCU pine uplands.

Threats and Stressors Factors

Threats to the pine uplands within BITH include altered fire regime, increased density of the midstory, invasive and exotic plants, feral hogs, drought, southern pine beetle, and past logging operations. The upland pine forests within BITH are strongly influenced by fire (Liu 1995, NPS 2012). The herbaceous understory species of longleaf pine communities have evolved with frequent, low intensity fires that often increased flowering, fruiting, and/or seed germination following a burn (Reinhart and Menges 2004, Caldwell 2005). Periodic fire has been shown to increase herbaceous species diversity in longleaf pine ecosystems (Brockway and Lewis 1997) and to stimulate regeneration of longleaf pine itself (Liu 1995). Historically, fires are thought to have occurred naturally every 2 to 8 years in longleaf pine forests (Brockway et al. 2005). Unfortunately, clearcutting by logging operations and agricultural development by European settlers resulted in habitat fragmentation, which prevented fires from spreading through forests, ultimately reducing their frequency (Frost 1993, Simberloff 2000). Active fire suppression was common in the BITH area and throughout the U.S. during the 20th century, especially after pine plantation expansion in the mid-1900s (Frost 1993). When fire is suppressed, hardwood species such as fire-intolerant oaks, sweetgum, and blackgum (*Nyssa sylvatica*) invade these open pine communities (Watson 1982, Varner et al. 2005). This invasion often increases the density of the midstory (e.g., shrubs such as dogwood and yaupon) (Watson 1982). Dense mid- and under-stories often act as "ladder fuels," carrying fire into the tree canopy. Combined with the increased fuel load, this can escalate fire intensity and severity, thereby increasing the risk that wildfires will cause catastrophic losses within the ecosystem and nearby residential areas when they do occur (Brockway et al. 2005). A dense midstory also shades out any longleaf seedlings and saplings, resulting in very low recruitment even around mature longleaf trees with abundant cone production (Hyde, written communication, 6 October 2015). BITH managers have been using prescribed fire on an ever-increasing portion of the landscape in an effort to restore the pre-settlement vegetation structure, composition, and function to these historically fire-maintained communities (NPS 2012). Managers also use mechanical vegetation removal to pre-treat areas with tall and dense understories, in order to reduce longleaf mortality from intense fires and to open the canopy. Herbicide treatments are another tool that is now being used to better control root-sprouting vegetation, such as yaupon and sweetgum, which quickly regenerates after prescribed burns (Hyde, written communication, 6 October 2015).

Feral hog numbers have increased across Texas and the U.S. in recent decades, including in the BITH region where reported hog damage to preserve resources has increased (Chavarria 2006). Using harvest survey data and track-count surveys, Chavarria (2006) estimated a nearly three-fold increase in the preserve's feral hog population between 1981 and 2004. The average number of hog tracks documented annually in the preserve increased from 0.5 tracks/km in 1987 to 2.1 tracks/km in 2004 (Chavarria 2006). Vegetation damage from hog activity averaged 28% across the three BITH units sampled (BSCU, TCU, and Lance Rosier; Chavarria 2006). In addition to direct damage from rooting, wallowing, trampling, and herbivory, hogs can alter nutrient cycling and litter dynamics, as well as facilitate the spread of non-native plants (NPS 2013). While hog impacts are often most severe in wetter habitats, such as floodplain forests, damage has also been observed in uplands (Chavarria 2006) and hogs are known to consume longleaf pine seedlings (Brockway et al. 2005).

Non-native and invasive plant species have the potential to outcompete native plants and can alter ecological processes (e.g., nutrient cycling, disturbance regimes such as fire) (Gordon 1998). The pine uplands have not been specifically inventoried for invasive plants, but 132 non-native plants (approximately 10% of all documented plant species) are included on the preserve's certified species list (NPS 2015; Appendix D).

Drought has been shown to have a negative impact on east Texas forests, especially on pine species. Glitzenstein et al. (1999) found that severe, prolonged droughts in Texas in the 1950s and 1980s caused growth declines in pines. Their findings suggest that changes in both the amount and seasonality of precipitation can impact species composition and competition in forests (Glitzenstein et al. 1999). According to Harcombe et al. (1999), drought frequency is likely to increase due to global climate change. An extended period of below-average rainfall in 2011 led to an unprecedented drought through much of Texas, including BITH (Nielson-Gammon 2012). This drought impacted the survival rates of some longleaf pine seedlings planted at BITH as part of ongoing restoration efforts (Hyde, written communication, 6 October 2015).

Southern pine beetle (SPB) damage is also a threat to BITH's pine uplands. The SPB is the most destructive insect pest in West Gulf Coastal Plain pine forests (Clarke et al. 2000). It is an aggressive native bark beetle capable of killing healthy trees; longleaf pine tends to be resistant to SPB due to its heavy resin production, but loblolly pine is particularly vulnerable (Clarke et al. 2000). SPB damage tends to increase with increases in pine stand density and age (Belanger et al. 1988). A study in Texas loblolly stands (Gara and Coster 1968) found that infestations were able to spread between trees up to 5.5 m (18 ft) apart and concluded that infestations were unlikely to expand if average tree spacing was 6.1 m (20 ft) or more. Beetle attacks often start in pine stands already stressed by disturbance, lack of water, intense competition, or overmaturity (>30 years old) (Belanger et al. 1988). Once SPBs have attacked and overcome a tree, additional pine beetle species may colonize the tree (Clarke et al. 2000). In areas where fire suppression has allowed hardwoods to invade the understory, pines may not be able to recover following beetle outbreaks, due to competition. SPB outbreaks occurred in the area that is now BITH during the mid-1970s and from 1992-1993, both impacting over 810 ha (2,000 ac) (Clarke et al. 2000). Also, this area of Texas is located in the hurricane alley coming up from the Gulf of Mexico. Longleaf upland pine forests are particularly resilient to hurricane damage from high winds and heavy rains. However, following pine beetle outbreaks, they can become much more prone to windthrow during hurricane events and wind storms if large areas of the forest canopy have been opened due to beetle mortality.

Human activity prior to preserve establishment is still impacting its vegetation communities. According to Allen (1996), logging and conversion to commercial loblolly or slash pine (*Pinus elliottii*) plantations contributed to declines in longleaf pine throughout the southeast. Harcombe and Marks (1979) found evidence of past logging in most BITH forest stands. Logging not only removed large trees from the community, but the associated activity damaged pine seedlings and herbaceous understory species as well (Boyer and White 1989). It also opened large areas to encroachment by aggressive native species such as yaupon and sweetgum (Hyde, written communication, 6 October 2015).

<u>Data Needs/Gaps</u>

Most of the data available for the selected measures presented here are over 10 years old. The only more recent information (DESCO 2007) is limited to the TCU. Updated surveys are needed in the pine uplands, focusing on the herbaceous understory, midstory density, and tree basal area and age structure. A search for invasive plant species could also help determine the threat that they pose to this community. A compilation of the past 15 years of BITH fire affects monitoring data (2000-2015) would be valuable, along with detailed maps of past efforts to use prescribed fire, physical vegetation treatments, herbicides, and seedling plantings to restore longleaf to historic habitats (Hyde, written communication, 6 October 2015). Since 2000, BITH has planted thousands of longleaf pine seedlings in order to restore the species to historic habitats. The goal of current restoration efforts is to return 121 ha (300 ac) or more to longleaf pine habitat and plant over 100,000 seedlings (Hyde, written communication, 6 October 2015).

During 2014-2015, BITH managers and a GULN GIS Specialist compiled information on potential longleaf pine habitat in the preserve using GIS maps and analysis tools (Hyde, written communication, 6 October 2015). Nearly 8,000 ha (over 19,700 ac) of potential longleaf pine habitat were identified, along with information on where current stands and recent restoration plantings are known to occur (Bracewell, written communication, 7 October 2015). Maps were derived from historic sources and an analysis of soils, drainage, and topography that are believed to be conducive to longleaf pine habitat. These maps have not yet been finalized and were not available for inclusion in this NRCA, but will provide critical information regarding potential pine upland extent for future assessments and restoration efforts.

The GULN is currently developing a vegetation map and monitoring protocol that will begin gathering data at several BITH units by 2016 (Woodman, written communication, December 2014). The areas of focus for the vegetation monitoring will be portions of the TCU, JGBU, BCU, and LRU (Martha Segura, GULN Program Manager, email communication, 18 February 2015) with additional information coming from the fire affects monitoring occurring in the BSCU and HCU. This sampling will provide information on plant community composition and coverage at the understory, midstory, and canopy levels, and will identify trends in those parameters and species richness (Woodman, written communication, October 2015).

Overall Condition

Herbaceous Understory Diversity

The project team assigned this measure a *Significance Level* of 3. Longleaf pine forests are known for their species diversity. Watson (1982) listed 168 herbaceous species known to occur within BITH's pine uplands. Although the pine uplands' herbaceous understory has not been specifically studied throughout the preserve in over 30 years, managers feel it is a serious concern (Hyde, written communication, 6 October 2015). As a result, a *Condition Level* of 3 is assigned.

Herbaceous Understory Density

This measure was also assigned a *Significance Level* of 3. While it is likely that herbaceous understory density has decreased in BITH's pine uplands since European settlement, insufficient data exist to confirm this. However, preserve management considers understory density of moderate concern (*Condition Level* = 2).

Midstory Density

A *Significance Level* of 3 was assigned for this measure. Historically, pine uplands were very open with a sparse or nonexistent midstory. Primarily due to fire suppression, the midstory in these communities has increased greatly and plays a significant role in inhibiting longleaf pine recruitment. Only three small studies (Streng and Harcombe 1982, Lewis et al. 2000, DESCO 2007) have documented midstory density at BITH, but preserve fire affects monitoring efforts have recognized the aggressive regrowth rates of native midstory shrubs and trees (Hyde, written communication, 6 October 2015). While it is known and documented that the midstory density has increased significantly in BITH's pine uplands since European settlement, limitations in staffing, funding, and the ability to use prescribed burns on large areas of a very scattered preserve have limited BITH's ability to restore the historic fire ecology to much of the preserve and deal with aggressive shrubs and trees (Hyde, written communication, 6 October 2015). This is a serious concern for BITH management and, as a result, a *Condition Level* of 3 is assigned to this measure.

Basal Area

The basal area measure was assigned a *Significance Level* of 2. Few studies have calculated basal area for BITH's pine uplands, and three of these are now more than 20 years old (Harcombe and Marks 1979, Streng and Harcombe 1982, Liu et al. 1990, 1992, DESCO 2007). Due to the outdated nature of the data, a *Condition Level* cannot be assigned.

Age Class

This measure was assigned a *Significance Level* of 1. Measures with a *Significance Level* of 1 are not discussed in depth in the current condition section of this assessment, but available information is summarized here in the overall condition section. Age structure is often studied using size class distributions and can be helpful in inferring the history and current successional status of a forest stand (Harcombe and Marks 1975). Tree species that are successfully regenerating will be present in a range of size classes and abundant in smaller size classes, while newly invading species will be common in the smallest size classes and absent from the larger ones (Harcombe and Marks 1975). Natural longleaf pine forests have been described as "an uneven-aged mosaic of even-aged patches" (Brockway et al. 2005, p. 3); the even-aged patches commonly form after fires sweep through the area (Allen 1996).

Harcombe and Marks (1975) studied the size class distributions of several upland forest stands in the BSCU of BITH (Table 16). They noted that large trees were generally lacking from these stands, partly due to past logging, but also because of poor site quality (e.g., low nutrient soils). Only one of the stands sampled by Harcombe and Marks (1975) exhibited a tree species composition typical of upland pine forest (Site BS-1); the other two were more typical of oak woodlands, and may represent pine uplands that have been invaded by oaks due to fire suppression (NPS 2012a). Because this is the only age structure information available for pine uplands and it is 30 years old, a *Condition Level* was not assigned for this measure.

Table 16. Size class distributions (diameter in cm) for three forest stands in BSCU (Harcombe and Marks 1975). Stand BS-1 was classified as true upland pine forest. BS-2 and BS-3 occurred on uplands but the vegetation composition was more typical of an oak woodland (Harcombe and Marks 1975). These stands may be pine uplands that have been invaded by oaks due to fire suppression.

Forest Stands in BSCU	Size Class Distributions (diameter in cm)					
BS-1	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**
Pinus echinata	70	32	26	18	--	--
P. palustris	168	112	106	48	8	2
Quercus marilandica	30	20	4	--	--	--
Total	**268**	**164**	**136**	**66**	**8**	**2**

Table 16 (continued). Size class distributions (diameter in cm) for three forest stands in BSCU (Harcombe and Marks 1975). Stand BS-1 was classified as true upland pine forest. BS-2 and BS-3 occurred on uplands but the vegetation composition was more typical of an oak woodland (Harcombe and Marks 1975). These stands may be pine uplands that have been invaded by oaks due to fire suppression.

Forest Stands in BSCU	Size Class Distributions (diameter in cm)					
BS-2	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**
P. echinata	92	68	48	28	12	4
P. palustris	--	12	16	12	4	--
Q. marilandica	112	108	56	36	--	4
Q. stellata	120	16	--	--	--	--
Total	**324**	**204**	**120**	**76**	**16**	**8**
BS-3						
Liquidambar styraciflua	28	14	6	8	--	--
P. echinata	112	62	12	6	2	--
P. palustris	12	4	8	--	2	--
P. taeda	46	14	10	2	--	--
Q. falcata	2	8	--	6	2	6
Q. marilandica	82	64	26	14	4	2
Q. stellata	84	22	22	10	--	--
Total	**366**	**188**	**84**	**46**	**10**	**8**

Weighted Condition Score

The WCS for BITH’s pine uplands is 0.89, suggesting significant concern. Limitations in staffing, funding, and the ability to use prescribed burns on large areas of a scattered preserve have limited management’s ability to restore fire ecology to much of the preserve, which has slowed the restoration of pine upland habitats. Given the lack of recent data for several of the selected measures, a trend could not be assigned for this component.

Pine Uplands			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.89**
Herbaceous Understory Diversity	3	3	
Herbaceous Understory Density	3	2	
Midstory Density	3	3	
Basal Area	2	n/a	
Age Structure	1	n/a	

4.2.6 Sources of Expertise

- Ken Hyde, BITH Chief of Resources Management
- Jeff Bracewell, GULN GIS Specialist
- Robert Woodman, GULN Ecologist

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4.3 Slope Forests

4.3.1 Description


Photo 4. A lower slope forest in BITH (NPS photo).

Slope forests, as the name implies, occur on the gentle slopes within BITH where surface soils are fine sand or sandy loams (Harcombe and Marks 1979). These areas are generally dominated by loblolly and shortleaf pine, a variety of oaks (*Quercus* spp.), and other hardwoods, with a more closed canopy than the preserve's upland forests. Slope forests can be further divided into three types: upper slope pine oak, mid slope oak pine, and lower slope hardwood pine (Harcombe and Marks 1979). Canopy density and height, hardwood abundance, and soil moisture all tend to increase from upslope to downslope (Marks and Harcombe 1978, Harcombe and Marks 1979). On upper slopes, shortleaf and loblolly pine are dominant, along with blackjack oak, southern red oak and some longleaf pine (Harcombe and Marks 1979). Common mid and understory species include yaupon, flowering dogwood, and American beautyberry (*Callicarpa americana*). The mid slopes are typically dominated by loblolly pine, southern red oak, shortleaf pine, and white oak (*Q. alba*) (Harcombe and Marks 1979). Additional tree species present include sweetgum, blackgum, and red maple (*Acer rubrum*). The understory is similar to upper slopes, with the addition of American holly and red maple saplings. On the lower slopes, southern magnolia (*Magnolia grandiflora*), loblolly pine, white oak, and water oak are generally codominant (Photo 4; Harcombe and Marks 1979). In some lower slope areas of the preserve, American beech is also present and dominant. Additional tree species include laurel oak (*Q. laurifolia*) and willow oak (*Q. phellos*), while American holly and yaupon are most common in the understory (Harcombe and Marks 1979).

The slope forests are sometimes referred to as Beech-Magnolia-Loblolly forests, due to the prevalence of these three species (NPS 2006). Because of its rarity in the state, the beech-magnolia assemblage within this forest type is considered imperiled (NPS 2006). East Texas represents the southwestern range limit for both American beech (Jha et al. 2004) and southern magnolia (NRCS 2015).

Slope forests occur in many BITH units: BSCU, TCU, HCSU, BCU, LRU, Menard Creek Corridor, Upper Neches, Beaumont, LPI-PIBCU, and Neches Bottom Unit (NBU)/ JGBU (Harcombe and Marks 1979, Watson 1982). The total area of slope forests in BITH during the late 1970s was estimated at 18,126 ha (44,791 ac) (Harcombe and Marks 1979). Available distribution information for slope forest communities is presented in Figure 15 and Figure 16.

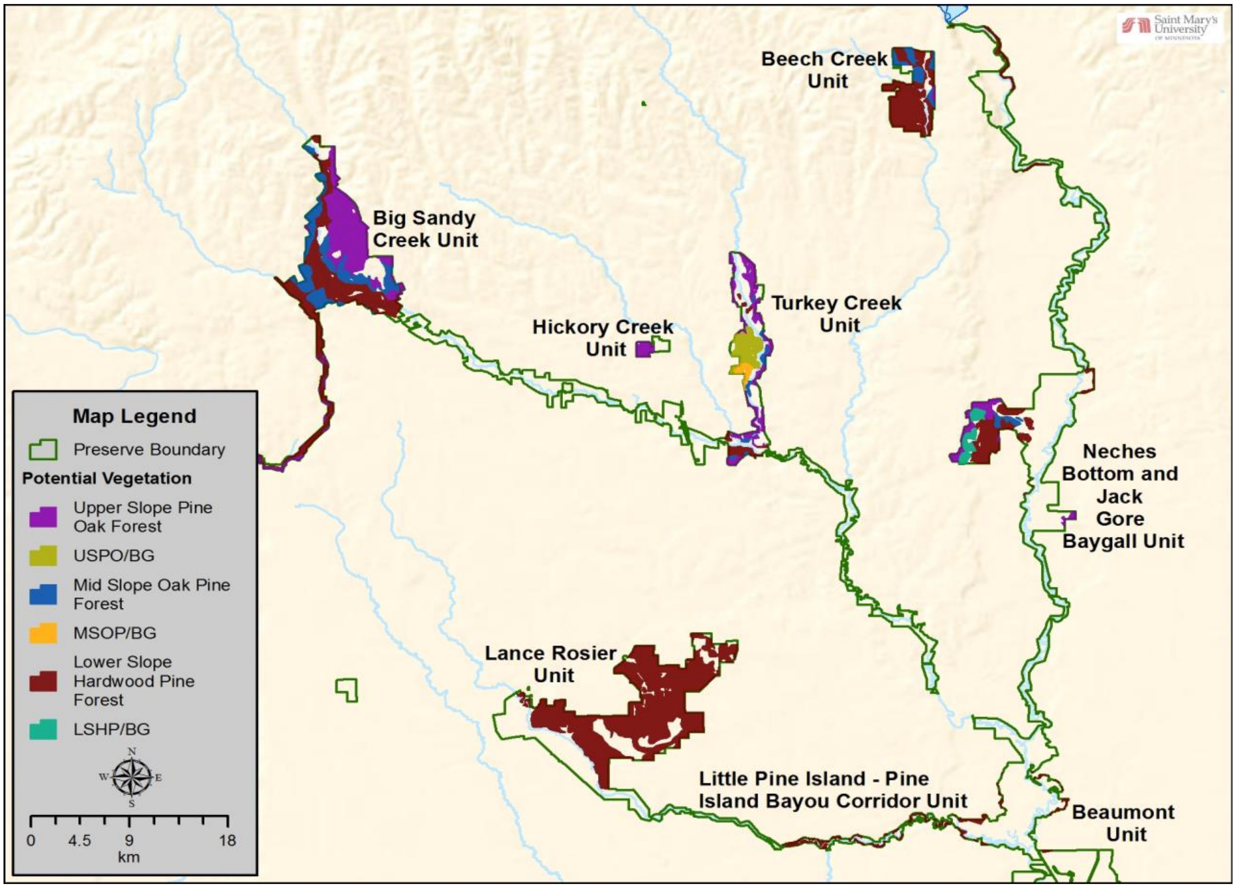

Figure 15. Locations within BITH where slope forests (or a slope forest/baygall mix) are the potential natural vegetation communities (NPS 2003, based on Harcombe and Marks 1979). USPO = Upper slope pine oak, BG = baygall, MSOP = Mid slope oak pine forest, LSHP = Lower slope hardwood pine.

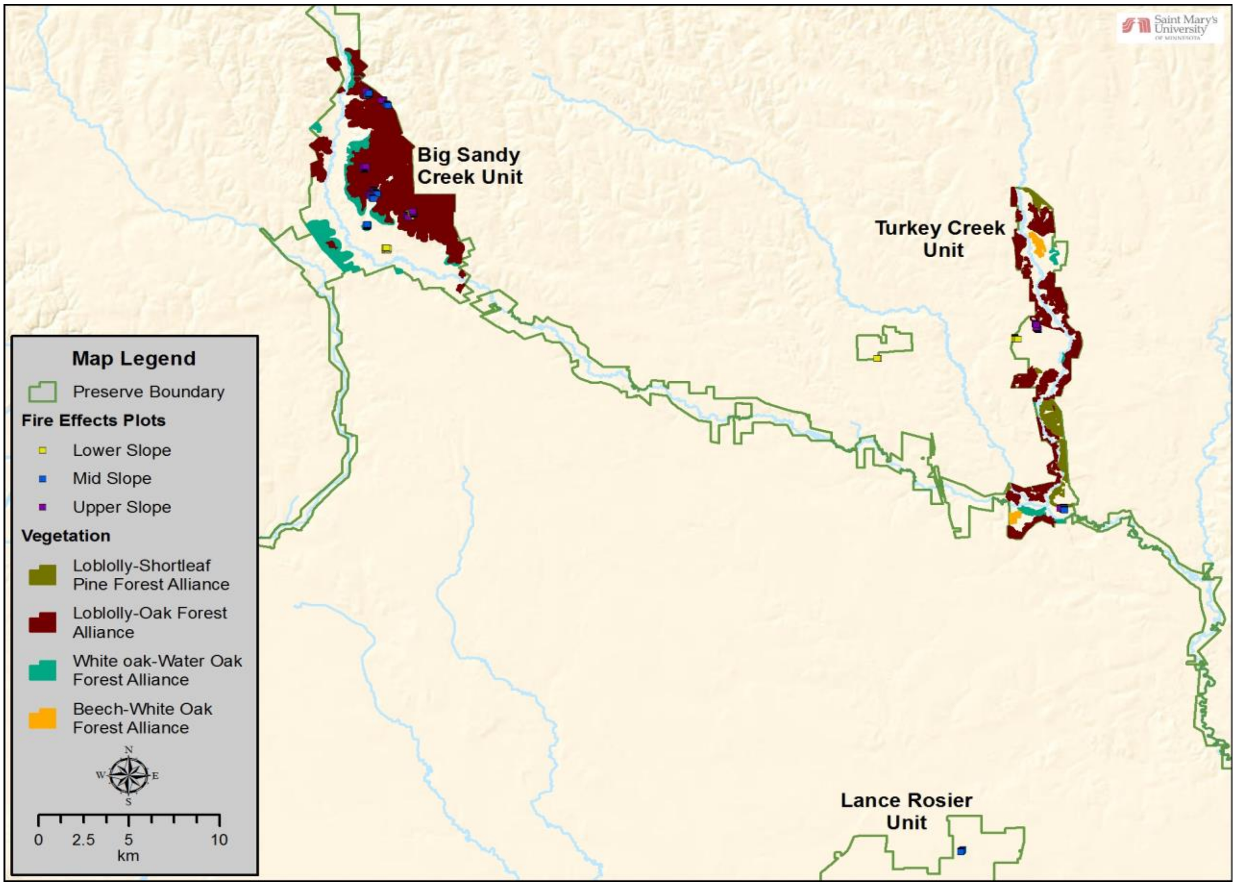

Figure 16. Slope forest vegetation within the Big Sandy Creek Unit (PBS&J 2003) and Turkey Creek Unit (DESCO 2007) in the early to mid-2000s and BITH fire effects monitoring plots located within slope forests (NPS 2012a).

4.3.2 Measures

- Canopy cover
- Presence of beech-magnolia assemblage
- Basal area
- Age class

4.3.3 Reference Conditions/Values

The reference condition for this component is the condition of the slope forests prior to major logging operations in the area (around the late 19th century). However, little scientific information is available from this time. The earliest known studies of forests within current BITH boundaries occurred in the 1970s (Marks and Harcombe 1978). The information presented in this NRCA could serve as a baseline for future assessments.

4.3.4 Data and Methods

Harcombe and Marks (1979) sampled 56 vegetation stands throughout the BITH units, covering the topographic range from floodplains to upland forests. The focus of the study was on woody vegetation, with little attention given to the herbaceous understory. Eighteen of the stands sampled were within slope forests (seven upper slope, two mid slope, and nine lower slope). Additional descriptions of slope forests were found in Marks and Harcombe (1978) and Watson (1982). Fountain (1984) also collected data from slope forests during a study of oil and gas drilling impacts in the preserve. Five sample sites were located in Upper Slope Pine Oak (USPO), one in Mid Slope Oak Pine (MSOP) and seven in Lower Slope Hardwood Pine (LSHP). Harcombe et al. (1999) included basal area data from a long-term study site within a (TCU) USPO stand.

Liu et al. (1990, 1992) sampled vegetation in several slope forest types in the TCU and Big Sandy Creek Unit (BSCU) as part of a fire affects monitoring study. Data gathered included basal area and stand density. Different plots were sampled within the study area in the two survey efforts. Data were presented in these reports by stand and plot type (burn vs. control); SMUMN GSS analysts calculated means for each slope forest type sampled (e.g., mid slope, upper slope, etc.) from these data.

Lewis et al. (2000) sampled forest vegetation in the BSCU as part of a study of the herpetofaunal community. Communities sampled included USPO and LSHP. The study documented density and canopy closure in the overstory, midstory, and understory. The overstory and midstory included all trees over 3 m (9.8 ft) in height; trees with crowns in the dominant canopy layer were considered overstory and trees below the dominant canopy layer were midstory. The understory consisted of all plants between 0.5 m and 3 m (1.6-9.8 ft) in height.

PBS&J (2003) sampled several slope forest types in the BSCU during a 2003 vegetation survey. Basal area data were collected from 22 plots in the *Quercus alba*-(*Quercus nigra*) Forest Alliance and 81 plots in the *Pinus taeda*-*Quercus* (*alba, falcata, stellata*) Forest Alliance. DESCO (2007) collected similar data from five different slope forest vegetation types in the TCU in 2006.

4.3.5 Current Condition and Trend

Canopy Cover

Anecdotally, canopy cover has been described as increasing from the upper slope forests to the lower slope forests, with cover so dense in the lower slope forests that shade restricts the development of an herbaceous ground layer (Marks and Harcombe 1978, Harcombe and Marks 1979). Very little scientific data on canopy cover have been collected in BITH's slope forests, as only Lewis et al. (2000) reported on canopy closure in LSHP and USPO forests. In this study, the LSHP showed greater canopy cover than the USPO in the overstory and understory layers, while midstory canopy cover was higher in the USPO (Table 17). However, these differences were not statistically significant (Lewis et al. 2000).

Table 17. Canopy closure in lower slope hardwood pine (LSHP) and upper slope pine oak (USPO) forests. Note that the differences in canopy coverage between the two types were not statistically significant (Lewis et al. 2000).

	Forest Type	
Canopy Closure	**LSHP**	**USPO**
Overstory	80.0	77.6
Midstory	65.6	76.0
Understory	36.4	16.8

Presence of Beech-Magnolia Assemblage

As mentioned previously, American beech and southern magnolia reach the southwestern extent of their ranges in the Big Thicket region (Jha et al. 2004, NRCS 2015). The beech-magnolia assemblage is of interest to preserve management due to its rarity, both in Texas and globally (NPS 2006). In addition, studies suggest that American beech has been declining in east Texas forests in recent decades (Harcombe et al. 2002, Jha et al. 2004). The hurricanes in 2005 and 2008 were particularly hard on the large beech and magnolia trees in the BCU, BSCU, and TCU with many being windthrown, damaged, or succumbing to disease and rot after the storm (Hyde, personal communication, 21 January 2016).

Since BITH does not have a current vegetation map, the preserve-wide distribution of the beech-magnolia assemblage is unknown. Harcombe and Marks (1979) do not separate the beech-magnolia assemblage from other slope forest types, so the community's potential distribution within the preserve is also unknown. Harcombe and Marks (1979) and Watson (1982) included species lists by unit, which may provide some insight into the presence of beech-magnolia stands. New areas of beech-magnolia lower slope forests were added to the preserve when the CU was acquired. Study areas or units where American beech and southern magnolia were documented by research studies are listed in Table 18.

Table 18. Study areas or preserve units where American beech and southern magnolia have been documented (Harcombe and Marks 1979). Letter/number codes following unit names indicate specific study sites; these locations are described in Harcombe and Marks (1979).

Harcombe and Marks 1979	Beech and Magnolia	Beech Only
Jack Gore Baygall- 2	x	
Upper Neches - FLPL		x
Upper Neches - FLPU	x	
Lance Rosier- 770-1	x	
Big Sandy - BSB	x	
Big Sandy - BSU-4		x
Beech Creek - BCB	x	

Table 18 (continued). Study areas or preserve units where American beech and southern magnolia have been documented (Harcombe and Marks 1979, Watson 1982). Letter/number codes following unit names indicate specific study sites; these locations are described in Harcombe and Marks (1979).

Harcombe and Marks 1979	Beech and Magnolia	Beech Only
Beech Creek - BCC	x	
Beech Creek - BCE	x	
Beech Creek - BCU	x	
Beech Creek - BCE-2	x	
Turkey Creek - TCBG	x	
Turkey Creek - TCSH-2		x
Watson 1982		
Big Sandy Creek (NW side)	x	
Menard Creek Corridor	x	
Beaumont Unit (northern part)	x	
Pine Island Bayou - Little Pine Island Bayou Corridor	x	
Lance Rosier	x	
Turkey Creek	x	
Jack Gore Baygall/Neches Bottom	x	

More recent vegetation surveys of individual units found the beech-magnolia assemblage in the BSCU (PBS&J 2003) and TCU (DESCO 2007) of BITH. Only one stand of beech-magnolia was identified in the TCU, covering 24.8 ha (69.3 ac) in the far southwestern part of the unit (DESCO 2007). In the BSCU, the beech-magnolia assemblage typically occurred between white oak-water oak communities and Big Sandy Creek itself (PBS&J 2003). However, none of the beech-magnolia areas were large enough to map.

Basal Area

As described in Chapter 4.2 of this document, basal area is a density measurement that takes into account the *area* occupied by each species, rather than just the *number* of stems of each species within a given area. Basal area data are very limited for BITH's slope forests. Harcombe and Marks (1979) calculated basal areas for seven upper slope, two mid slope, and nine lower slope forest stands. The basal areas for these forest types by species and overall from Harcombe and Marks (1979) are shown in Table 19. Total basal area was greatest in lower slope stands and lowest in upper slope stands. Species with the greatest individual basal areas were shortleaf pine on upper slopes, and loblolly pine on both mid and lower slopes (Harcombe and Marks 1979). Basal area of pine species was higher than oak species in the upper slope forests while oak basal area was higher than pine on lower slopes, and pine and oak basal area was nearly equal in mid slope stands (Table 19).

Table 19. Mean total basal area (m^2/ha) by species within slope forest stands sampled by Harcombe and Marks (1979). Only species with basal areas >0.05 m^2/ha are included in the table. USPO = Upper slope pine oak forest, MSOP = Mid slope oak pine forest, LSHP = Lower slope hardwood pine forest.

Scientific Name	Common Name	USPO	MSOP	LSHP
Quercus marilandica	blackjack oak	2.4	--	--
Quercus stellata	post oak	1.3	0.2	--
Pinus palustris	longleaf pine	2.6	--	--
Pinus echinata	shortleaf pine	7.3	4.1	--
Carya tomentosa	mockernut hickory	0.2	0.1	--
Quercus falcata	southern red oak	3.0	4.6	1.0
Cornus florida	flowering dogwood	0.2	0.9	0.2
Callicarpa americana	American beautyberry	0.1	--	--
Ilex vomitoria	yaupon	0.7	0.5	0.2
Pinus taeda	loblolly pine	3.4	6.5	5.1
Quercus alba	white oak	0.5	3.9	3.8
Persea borbonia	red bay	--	0.1	0.1
Symplocos tinctoria	common sweetleaf	--	1.4	0.2
Sassafras albidum	sassafras	0.1	0.1	0.1
Magnolia grandiflora	southern magnolia	--	0.1	3.8
Ostrya virginiana	hophornbeam	--	--	0.1
Fagus grandifolia	American beech	--	--	4.7
Ilex opaca	American holly	0.2	1.1	1.6
Magnolia virginiana	sweet bay	--	--	0.4
Nyssa sylvatica	black gum	0.4	1.1	0.9
Quercus laurifolia	laurel oak	0.1	0.7	1.3
Acer rubrum	red maple	0.1	1.2	0.4
Liquidambar styraciflua	sweetgum	0.8	1.1	1.0
Quercus phellos	willow oak	--	0.6	1.2
Quercus nigra	water oak	--	0.5	2.7
Quercus michauxii	swamp chestnut oak	--	--	0.1
Fraxinus pennsylvanica	green ash	--	0.1	0.1
Carpinus caroliniana	American hornbeam; ironwood	--	--	0.1
Carya glabra	pignut hickory	--	--	0.4

Table 19 (continued). Mean total basal area (m^2/ha) by species within slope forest stands sampled by Harcombe and Marks (1979). Only species with basal areas >0.05 m^2/ha are included in the table. USPO = Upper slope pine oak forest, MSOP = Mid slope oak pine forest, LSHP = Lower slope hardwood pine forest.

Scientific Name	Common Name	USPO	MSOP	LSHP
	Total Pine	**13.3**	**10.6**	**5.1**
	Total Oak	**7.2**	**10.5**	**10.1**
	Total Overall	**23.4**	**28.9**	**29.5**

Fountain (1984) also recorded basal areas in slope forest plots. Total basal areas were higher than Harcombe and Marks (1979) for two of the slope forest types (USPO and MSOP) and slightly lower in one type. Averages were 27.7 m^2/ha for the USPO, 32.4 for the MSOP, and 28.9 for the LSHP (Fountain 1984).

Liu et al. (1990, 1992) gathered basal area data from several slope forest types in the BSCU and TCU. In the first round of surveys, TCU upper slope forests showed the highest mean basal area, contrary to earlier results (Table 20; Liu et al. 1990). Among BSCU slope forest stands, mid-slope stands had the highest mean basal area. In the second survey period, results were similar to previous studies, with the highest mean basal area found in lower slope forests in the TCU and lowest basal area in BSCU upper slope forests (Table 21; Liu et al. 1992). Pines yielded the highest individual species basal area in every forest type (Table 20, Table 21; Liu et al. 1990. 1992).

Table 20. Basal areas (m^2/ha) by species in BSCU and TCU slope forest plots (Liu et al. 1990). Values are means by slope forest type based on stand data presented in Liu et al. (1990). LS = Lower slope pine-hardwood, LU = Lower upper slope, MS = Mid-slope pine oak, US = Upper slope oak-pine, UU = Upper upper slope.

	BSCU					TCU
Species	**US**	**UU**	**LU**	**MS**	**LS**	**US**
Acer rubrum	--	--	--	0.35	0.60	0.05
Carpinus caroliniana	0.05	--	--	--	1.85	--
Carya texana	2.15	--	--	0.02	0.85	--
Cornus florida	0.15	0.50	1.1	0.65	0.70	--
Crataegus spp.	0.45	--	--	0.02	--	--
Cyrilla racemiflora	--	--	--	--	--	0.40
Fagus grandifolia	--	--	--	--	3.15	--
Fraxinus americana	0.05	--	--	0.55	1.50	--
Ilex coriacea	--	--	0.05	--	--	--
Ilex opaca	--	--	0.05	0.05	--	0.25
Ilex vomitoria	0.70	0.30	0.70	0.45	--	0.70

Table 20 (continued). Basal areas (m^2/ha) by species in BSCU and TCU slope forest plots (Liu et al. 1990). Values are means by slope forest type based on stand data presented in Liu et al. (1990). LS = Lower slope pine-hardwood, LU = Lower upper slope, MS = Mid-slope pine oak, US = Upper slope oak-pine, UU = Upper upper slope.

	BSCU					TCU
Species	**US**	**UU**	**LU**	**MS**	**LS**	**US**
Liquidambar styraciflua	1.40	0.10	0.20	2.70	2.65	0.80
Magnolia grandiflora	--	--	--	--	--	0.50
Nyssa sylvatica	1.10	0.10	0.20	0.45	0.35	1.25
Persea borbonia	--	--	--	0.10	0.20	0.35
Pinus echinata	7.95	8.25	6.20	7.35	--	0.45
Pinus palustris	--	0.60	1.20	--	--	0.45
Pinus taeda	2.25	5.50	3.70	12.40	5.45	25.9
Quercus alba	1.05	--	--	1.90	1.50	0.30
Quercus falcata	1.35	0.15	1.05	0.45	--	2.80
Quercus incana	--	--	--	--	--	0.05
Quercus laurifolia	--	--	--	2.80	0.90	0.35
Quercus marilandica	--	1.05	4.65	--	--	--
Quercus michauxii	--	--	--	--	0.80	--
Quercus nigra	--	--	--	0.02	0.40	1.60
Quercus stellata	0.90	2.25	1.90	--	--	0.05
Sassafras albidum	0.05	--	0.25	0.10	0.05	0.05
Symplocos tinctoria	--	--	--	0.02	--	0.20
Ulmus alata	--	--	--	--	0.15	--
Vaccinium arboreum	0.10	0.10	--	0.05	--	0.10
Viburnum nudum	0.10	--	--	0.10	--	--
Viburnum rufidulum	0.25	--	0.05	0.25	--	--
Total*	**20.00**	**19.30**	**21.70**	**30.45**	**21.00**	**36.65**

* Due to rounding, in calculating basal area means by species, the sum of individual species may not exactly match the “Total” value at the bottom of each column.

Table 21. Basal areas (m2/ha) by species in BSCU and TCU slope forest plots (Liu et al. 1992). Values are means by slope forest type based on stand data presented in Liu et al. (1992). Note that different plots within the slope forest types were visited during this survey than in Liu et al. (1990). MS = Mid-slope pine oak, US = Upper slope oak-pine, LS = Lower slope pine-hardwood.

	BSCU		**TCU**	
Species	**US**	**MS**	**US**	**LS**
Acer rubrum	--	0.45	0.25	1.20
Carpinus caroliniana	0.03	--	--	1.25
Catalpa speciosa	--	0.03	--	--
Carya spp.	--	--	0.03	--
Carya texana	1.70	1.05	0.03	0.15
Cornus florida	0.10	0.60	0.10	--
Crataegus spp.	0.05	0.03	--	--
Cyrilla racemiflora	--	--	0.25	--
Fraxinus americana	0.03	0.25	--	--
Ilex opaca	--	--	0.70	0.45
Ilex vomitoria	--	0.10	0.25	0.15
Liquidambar styraciflua	--	4.15	3.10	2.95
Magnolia virginiana	--	0.10	--	0.45
Myrica cerifera	--	--	0.02	--
Nyssa sylvatica	0.08	3.45	1.00	1.90
Persea borbonia	--	0.20	0.20	--
Pinus echinata	10.95	1.35	0.10	0.60
Pinus palustris	0.50	--	0.75	--
Pinus taeda	3.10	10.35	15.40	17.15
Pyrus arbutifolia	0.05	--	--	--
Quercus alba	0.95	2.30	0.10	0.90
Quercus falcata	0.60	0.40	1.10	--
Quercus incana	--	--	0.30	--
Quercus laurifolia	--	2.50	0.25	0.75
Quercus marilandica	0.60	--	--	--
Quercus nigra	--	0.15	2.20	6.30
Quercus stellata	2.55	--	2.40	--
Symplocos tinctoria	--	0.03	--	--

Table 21 (continued). Basal areas (m2/ha) by species in BSCU and TCU slope forest plots (Liu et al. 1992). Values are means by slope forest type based on stand data presented in Liu et al. (1992). Note that different plots within the slope forest types were visited during this survey than in Liu et al. (1990). MS = Mid-slope pine oak, US = Upper slope oak-pine, LS = Lower slope pine-hardwood.

	BSCU		TCU	
Species	**US**	**MS**	**US**	**LS**
Ulmus alata	--	--	--	0.05
Vaccinium arboreum	0.50	0.03	0.15	--
Viburnum nudum	0.03	0.05	--	--
Viburnum rufidulum	--	0.05	--	--
Total*	**22.00**	**27.65**	**28.90**	**34.35**

* Due to rounding, in calculating basal area means by species, the sum of individual species may not exactly match the “Total” value at the bottom of each column.

Harcombe et al. (1999) presented basal area data by species from a long-term study site within a TCU Upper Slope Pine Oak stand. Basal area increased from 21.7 m^2/ha in 1982 to nearly 27 m^2/ha in 1993 (Table 22), at a mean rate of 1.7% a year. The majority of individual tree species increased in basal area over this time, with the exception of flowering dogwood and bluejack oak.

Table 22. Total basal area (m^2/ha) by species and annualized percent change from 1982-1993 in a TCU upper slope forest (Harcombe et al. 1999). Annual percent change: difference between 1993 and initial basal area divided by the initial basal area and the number of years since the initial basal area reading.

Species	1993 Basal Area	Annual % Change in Basal Area (since 1982)
Pinus palustris	6.07	0.02
Quercus stellata	5.14	0.00
Quercus falcata	4.91	0.01
Pinus echinata	1.94	0.01
Ilex vomitoria	0.71	1.07
Cornus florida	0.19	-0.02
Quercus incana	0.05	-0.06
Carya sp.	1.54	0.03
Pinus taeda	4.31	0.04
Quercus alba	0.15	0.04
Ilex opaca	0.22	1.52
Quercus laurifolia	0.13	0.00
Magnolia grandiflora	0.05	--

Table 22 (continued). Total basal area (m^2/ha) by species and annualized percent change from 1982-1993 in a TCU upper slope forest (Harcombe et al. 1999). Annual percent change: difference between 1993 and initial basal area divided by the initial basal area and the number of years since the initial basal area reading.

Species	1993 Basal Area	Annual % Change in Basal Area (since 1982)
Nyssa sylvatica	0.04	1.47
Liquidambar styraciflua	0.87	0.05
Acer rubrum	0.03	0.51
Other	0.53	--
Total	**26.88**	**--**

More recently, PBS&J (2003) gathered basal area data for two slope forest types in the BSCU. In the Quercus alba-(Quercus nigra) Forest Alliance sample plots, total basal area (overstory, midstory, and shrub layer) was 27.04 m2/ha. The overstory was dominated by white oak with an average basal area of 6.82 m2/ha (PBS&J 2003). Total basal area in Pinus taeda-Quercus (alba, falcata, stellata) Forest Alliance plots averaged 30.04 m2/ha; loblolly pine was dominant in the overstory with a basal area of 12.35 m2/ha (PBS&J 2003). DESCO (20007) also reported basal area data for five slope forest vegetation communities in the TCU. Total basal areas in these sample plots ranged from 18.99 m2/ha in the Quercus nigra Forest Alliance to 31.84 m2/ha in the Pinus echinata - Quercus (alba, falcata, stellata) Forest Alliance (Table 23; DESCO 2007).

Table 23. Basal area data (m^2/ha) for five slope forest alliances in TCU (DESCO 2007). Total basal area is for all woody vegetation (overstory, midstory, and shrub layer).

Species	Total Basal Area	Overstory Basal Area	Dominant Species Basal Area
Fagus grandifolia - Magnolia grandifolia Forest Alliance	26.98	23.25	American beech - 11.05
Pinus echinata - Quercus (*alba, falcata, stellata*) Forest Alliance	31.84	25.77	shortleaf pine - 17.15
Pinus taeda - Quercus (*alba, falcata, stellata*) Forest Alliance	31.14	26.24	loblolly pine - 10.26
Fagus grandifolia – Quercus alba Forest Alliance	26.15	20.10	American beech - 12.87
Quercus nigra Forest Alliance	18.99	12.59	water oak - 5.50

Age Class

Forest age structure is often studied using size class distributions and can be helpful in inferring the history and current successional status of a forest stand (Harcombe and Marks 1975). Tree species that are successfully regenerating will be present in many size classes and abundant in smaller size classes, whereas newly invading species will be common in the smallest size classes and absent from the larger ones (Harcombe and Marks 1975). Unfortunately, no actual data have been gathered for age or size class distribution in BITH's slope forests. Harcombe and Marks (1977, p. 24) did note that dominant tree species in the upper slope pine oak forests appeared to be well represented in all size classes, while dominant species in the mid and lower slope forests were "poorly represented or completely absent in one or more of the sapling size classes." The authors hypothesized that this was due to the greater canopy coverage (i.e., lower light availability in the understory) in the mid and lower slopes (Harcombe and Marks 1977).

Threats and Stressors Factors

Threats to BITH's slope forests include invasive plants, feral hogs, unplanned fire occurrence, insect outbreaks, hurricanes, and drought. The slope forests have not been specifically inventoried for invasive plants, but over 100 non-native plants have been documented in the preserve (NPS 2015). Of particular concern preserve-wide is Chinese tallow. This aggressive species can out-compete native plants in slope forest openings created by disturbances (e.g., hurricanes or severe fires), eventually becoming the dominant species (NPS 2012b). According to Liu (1995), the historical role of fire in slope forests is understudied and unclear.

As mentioned in Chapter 4.2, feral hog numbers have increased across Texas in recent decades, including in the BITH region (Chavarria 2006). Hog damage to all three slope forest types has been documented in the BSCU, TCU, and LRU (Chavarria 2006). The hardwoods of the slope forests can provide significant food resources (e.g., acorns, tubers, herbs, seeds) for feral hogs. Hog impacts are often most severe in wetter habitats, such as floodplain forests, but these areas are sometimes flooded in BITH, which may push feral hogs into slope forests (Chavarria 2006).

Due to its location near the Gulf of Mexico, BITH is impacted by tropical storms and hurricanes relatively frequently (Harcombe and Marks 1979). While the effects of these storms on slope forests are rarely catastrophic, they can influence forest structure and composition by creating "light gaps" in the tree canopy (Harcombe et al. 2009). While the creation of some canopy gaps is a natural forest process, large gaps may create opportunities for invasive plant species to become established. Harcombe et al. (2009) studied the impacts of Hurricane Rita, a Category 3 hurricane which made landfall on 29 September 2005, on a mesic slope forest near BITH. Wind gusts at this site during the storm were around 145-177 km/hr (90-110 mi/hr) (Harcombe et al. 2009). Within the slope forest, 31% of trees were dead or severely damaged following the storm. Among canopy tree species at this site, Harcombe et al. (2009) observed above average mortality in white and water oak, and below average mortality in loblolly pine, blackgum, and American beech. In the subcanopy, mortality was higher for red maple, yaupon, and common sweetleaf (*Symplocos tinctoria*), and lower for American holly and sweetgum (Harcombe et al. 2009). No simple explanation has been found for these differences in mortality during hurricanes; it is likely a combination of factors including wood density, rooting characteristics, and tree form and height (Brokaw and Everham 1996, Harcombe et al. 2009). Hurricane Ike in 2008 resulted in additional damage to slope forests, particularly along the edges of openings created previously by Hurricane Rita (Hyde, written communication, 6 October 2015).

Glitzenstein et al. (1999) showed that severe droughts decreased tree growth rates in east Texas forests. Hardwood species, such as those common in slope forests, experienced a severe growth decline during an early-1980s drought in the Big Thicket region (Glitzenstein et al. 1999). Much of Texas, including BITH, experienced a drought of unprecedented intensity in 2011 due to an extended period of below-average rainfall (Nielson-Gammon 2012). According to Harcombe et al. (1999), drought frequency is likely to increase in east Texas due to global climate change.

Climate change may also pose a threat to American beech in the slope forests. As mentioned previously, the BITH region represents the southwestern range limit for American beech and declines in this species have been observed in the area (Harcombe et al. 1999, Jha et al. 2004). The typical climate within the beech's range is moist with maximum daily temperatures between 17°C and 29°C (62.6°-84.2°F) (Jha et al. 2004). Since 2009, mean August temperatures at Beaumont have been above 29°C (NCDC 2015). Several climate models predict that mean summer (June-August) temperatures in the BITH area will exceed 29.5°C (85°F) by 2050 (Maurer et al. 2007). If summer temperatures continue to increase, American beech trees will experience climate stress, which may increase their vulnerability to pathogens and other stresses (Jha et al. 2004). Although no research has been conducted, BITH management is concerned that there appears to be little recruitment of young beech trees since the hurricanes in 2005 and 2008. This may be a combination of climate stressors, the 2011 drought, feral hog consumption of beech mast production, and competition from dense stands of native, early successional shrubs (e.g., yaupon and holly) (Hyde, written communication, 6 October 2015).

Data Needs/Gaps

Very little information is available for most of the selected measures in BITH's slope forests. For example, no actual scientific data have been collected for slope forest age class structure within BITH. Although basal area data are available, some of it is outdated and some of it is geographically limited to individual units within the preserve. Additional studies in the beech-magnolia assemblage are important, given the community's rarity and an apparent recent decline in beech in the area (Jha et al. 2004).

A preserve-wide vegetation map does not exist, although mapping efforts are expected to be initiated in the next few years. An invasive plant survey could also help determine how much of a threat these species pose to the preserve's slope forests. The GULN is developing a vegetation monitoring protocol that will begin gathering data on plant community composition and coverage in several BITH units by 2016 (Woodman, written communication, December 2014). Data collection will include tree and understory species composition (including invasives), tree size (diameter), and canopy closure. The focus of this monitoring will be the TCU, JGBU, BCU, and LRU (Segura, email communication, 18 February 2015), all of which include slope forest vegetation.

Overall Condition

Canopy Cover

The project team assigned this measure a *Significance Level* of 3. Vegetation reports for BITH state that canopy cover generally increases from upper slope to lower slope, with lower slope forests having the greatest canopy coverage (Marks and Harcombe 1978, Harcombe and Marks 1979). However, very little data have been collected regarding canopy cover within BITH's slope forests. As a result, a *Condition Level* could not be assigned for this measure.

Presence of Beech-Magnolia Assemblage
This measure was also assigned a *Significance Level* of 3. Data are very limited regarding the presence of the beech-magnolia assemblage within BITH. Historically, American beech and southern magnolia were documented in seven different preserve units (Watson 1982). More recent unit-specific vegetation surveys identified small areas of beech magnolia in the TCU (DESCO 2007) and BSCU (PBS&J 2003). Due to a lack of preserve-wide data, a *Condition Level* was not assigned for this measure.

Basal Area
The basal area measure was assigned a *Significance Level* of 2. Basal area data for BITH's slope forests are limited. The most recent data (PBS&J 2003, DESCO 2007) are restricted to individual preserve units (BSCU and TCU). Because data are limited, a *Condition Level* was not assigned for this measure.

Age Class
A *Significance Level* of 2 was assigned for this measure. Due to a lack of data for age or size class distributions, a *Condition Level* could not be assigned.

Weighted Condition Score
A WCS was not calculated for this component, due to a lack of data for the selected measures. The current condition of BITH's slope forests is unknown.

Slope Forests			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Canopy cover	3	n/a	
Presence of beech-magnolia assemblage	3	n/a	
Basal area	2	n/a	
Age class	2	n/a	

4.3.6 Sources of Expertise

- Ken Hyde, BITH Chief of Resource Management
- Herbert Young, BITH Biologist

- Robert Woodman, GULN Ecologist

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4.4 Arid Sand Hills

4.4.1 Description

The arid sand hills within BITH support open woodlands comprised primarily of short oaks (*Quercus* spp.) with a scattered overstory of pines (*Pinus* spp.) (Harcombe and Marks 1979; Photo 5). These communities occur on sandy soils associated with old stream terraces and river bluffs. The soils are extremely well-drained (i.e., moisture is not held in the soil for long), contributing to the short-statured and sparse nature of the vegetation (Harcombe and Marks 1979, NPS 2012). Tree, shrub, and herb density are all low, and exposed sand areas are common. The sand hill woodlands are the driest wooded communities in southeast Texas; prickly pear (*Opuntia* spp.) and yucca (*Yucca* spp.) are often present in the understory (Marks and Harcombe 1978, NPS 2012). The arid sand hill woodland is the rarest plant community within the preserve and in the surrounding region (NPS 2006), which is to be expected in an area receiving an average of 137 cm (54 in) of rain a year.

Photo 5. Arid sand hill pine stand in BITH (NPS photo).

The three pine species commonly found on arid sand hills are longleaf pine, loblolly pine, and shortleaf pine (Harcombe and Marks 1979, NPS 2012). The dominant oak species include bluejack oak and post oak. The shrub layer is somewhat indistinct with no dominant species, but the most abundant shrubs are yaupon and flowering dogwood (Harcombe and Marks 1979). Although the herbaceous understory is sparse, the arid sand hills support some endemic species, such as Texas trailing phlox (*Phlox nivalis* ssp. *texensis*), a federally endangered species (Harcombe 2007).

4.4.2 Measures

- Endemic species richness
- Extent

4.4.3 Reference Conditions/Values

The reference condition for this component is the condition of the arid sand hills prior to European settlement of the area. Unfortunately, little information is available for this period. The earliest known studies of vegetation within the current BITH boundaries occurred in the 1970s (Marks and Harcombe 1978, Harcombe and Marks 1979). The information presented in this NRCA could serve as a baseline for future assessments.

4.4.4 Data and Methods

Harcombe and Marks (1979) sampled 56 vegetation stands throughout the various BITH units, covering the topographic range from floodplains to upland forests. Their focus was on woody vegetation, with little attention given to the herbaceous understory. Only two of the stands sampled were classified as arid sand hills (called "sand hill pine forest" by Harcombe and Marks [1979]). Additional descriptions of arid sand hills were found in Marks and Harcombe (1978), Watson (1978, 1982), and NPS (2012). More recently, Harcombe (2007) completed a vascular plant survey for BITH, which included both review of existing specimens and collection of new specimens.

Caldwell (2005) studied restoration efforts on a former slash pine (*P. elliotii*) plantation in the TCU. Despite its conversion to a pine plantation in the 1960s, the site was classified as a sand hill pine forest (Caldwell 2005). Restoration began in June 2003 with canopy reduction, burning, and selective herbicide treatments. After additional herbicide treatments in 2004, Caldwell (2005) documented the species composition of the site's herb, shrub, and canopy layers.

MacRoberts et al. (2002) generated a list of plant species endemic to the West Gulf Coastal Plain, and then used literature, personal experience, and herbarium specimens to identify those species associated with "xeric sandyland" habitat. This list could be used as a potential list of endemic species for BITH's arid sand hills. Matos and Rudolph (1985) conducted a vascular plant survey of the Roy E. Larsen Sandylands Sanctuary, which lies just south of BITH's Village Creek Corridor Unit and is managed by The Nature Conservancy. One stand sampled was described as a "sandy upland community in an arid, open area" (Matos and Rudolph 1985, p. 230). This survey identified many endemic understory species that occurred within the Sanctuary, providing additional potential endemic species for BITH.

A preserve-wide vegetation map is not available for BITH, but several individual units have been mapped, including Turkey Creek (DESCO 2007), where a majority of remaining arid sand hills occur. These individual unit maps have been combined to form one GIS layer, which was acquired from the GULN. A potential natural vegetation map was created for the entire preserve by Harcombe and Marks (1979); a GIS version of this map (NPS 2003) was also obtained from the GULN.

4.4.5 Current Condition and Trend

<u>Endemic Species Richness</u>

Arid sandy habitats are known to support a high number of West Gulf Coastal Plain endemic plants. MacRoberts et al. (2002) found that 53% of species identified as endemic to the region were associated with "xeric sandylands". The arid sand hills in BITH have not been inventoried specifically for endemic species. While a current plant species list could be used to identify endemic species that occur within BITH, the list does not identify which community type each species occurs in. MacRoberts et al. (2002) generated a list of plant species endemic to the West Gulf Coastal Plain and classified each by habitat. SMUMN GSS analysts identified species that occurred in xeric sandylands and searched BITH records to determine whether or not these endemic species had been documented in the preserve. Twenty-three of the species identified by MacRoberts et al. (2002) have been observed within BITH, although two are no longer included on the current preserve species list (Harcombe 2007, NPS 2015) (Table 24).

Table 24. West Gulf Coastal Plain endemic species identified by MacRoberts et al. (2002) as occurring on "xeric sandylands" and their status in BITH. BSCU = Big Sandy Creek Unit, TCU = Turkey Creek Unit.

Scientific Name	Common Name	BITH Status
Yucca louisianensis	Gulf Coast yucca	documented in arid sand hills[d]; present in preserve[a]
Berlandiera pumila var. scabrella	soft greeneyes	present in preserve[a]
Coreopsis intermedia	goldenwave tickseed	documented in TCU (Brown et al. 2005)
Echinacea sanguinea	sanguine purple coneflower	present in preserve[a]
Evax candida	silver pygmycudweed	present in preserve[a]
Gaillardia aestivalis var. winkleri	Winkler's blanketflower	documented in arid sand hills[d]; present in preserve[a]
Helianthus debilis	cucumberleaf sunflower	historically documented in arid sand hills of BSCU[b]; present in preserve[a]
Hymenopappus artemisiifolius var. artemisiifolius	oldplainsman	historically documented on sand hills in TCU[b]; present in preserve[a]
Palafoxia reverchonii	Reverchon's palafox	present in preserve[a]
Solidago ludoviciana	Lousiana goldenrod	present in preserve[a]
Tetragonotheca ludoviciana	Lousiana nerveray	present in preserve[a]
Thelesperma flavodiscum	east Texas greenthread	present in preserve[a]
Vernonia texana	Texas ironweed	present in preserve[a]
Polanisia erosa	large clammyweed	historically documented on sand hill in TCU[c]; not on current preserve species list[a]
Paronychia drummondii	Drummond's nailwort	historically documented on sand hills in the TCU[c]; not on current preserve species list[a]
Tradescantia reverchonii	Reverchon's spiderwort	present in preserve [a]; documented in TCU in sand hill pine by Caldwell (2005)
Baptisia nuttalliana	Nuttal's wild indigo	documented in arid sand hills[d]; present in preserve [a]
Dalea phleoides var. phleoides	slimspike prairie clover	documented in arid sand hills[d]; present in preserve [a]
Dalea villosa var. grisea	silky prairie clover	documented in arid sand hills[d]; present in preserve [a]

[a] Harcombe 2007

[b] Watson 1978

[c] Watson, n.d.

[d] Watson 1982

Table 24 (continued). West Gulf Coastal Plain endemic species identified by MacRoberts et al. (2002) as occurring on "xeric sandylands" and their status in BITH. BSCU = Big Sandy Creek Unit, TCU = Turkey Creek Unit.

Scientific Name	Common Name	BITH Status
Mimosa hystricina	porcupine mimosa	present in preserve [a]
Scutellaria cardiophylla		documented in arid sand hills[d]; present in preserve [a]
Phlox nivalis ssp. texensis	Texas trailing phlox	confirmed in BSCU[a]; historically documented in TCU on sand hills[c] and reintroduced there in 2003 (Hungate 2003)
Delphinium carolinianum ssp. vimineum	Carolina larkspur	documented in arid sand hills[d]; present in preserve [a]

[a] Harcombe 2007

[b] Watson 1978

[c] Watson, n.d.

[d] Watson 1982

Additional endemic species identified by Matos and Rudolph (1985) on the Roy E. Larsen Sandylands Sanctuary near BITH have also been documented in the preserve (Table 25). Two of the six species have been observed on arid sand hills, although one is no longer included on the preserve's species list (Harcombe 2007, NPS 2015). The remaining four species are known to be present in the preserve, but the vegetation community they occur in has not been documented.

Table 25. Endemic herbaceous species documented in Roy E. Larsen Sandylands Sanctuary (Matos and Rudolph 1985) and their status in BITH. BSCU = Big Sandy Creek Unit, TCU = Turkey Creek Unit.

Scientific Name	Common name	Endemic to*	BITH status
Loeflingia squarrosa	spreading pygmyleaf	Texas	present in preserve [a]
Lupinus subcarnosus	Texas bluebonnet	Texas	present in preserve [a]
Amsonia tabernaemontana var. *tabernaemontana* (*A. glaberrima*)	eastern bluestar	Texas & Lousiana	documented in arid sand hills[d]; present in preserve[a]
Symphyotrichum pratense (Aster pratensis)	barrens silky aster	Texas & Lousiana	historically documented in TCU, but not in arid sand hills habitat[b]; present in preserve[a]
Berlandiera betonicifolia	Texas greeneyes	Texas & Lousiana	historically documented on sand hill in TCU[c]; not on current preserve species list[a]
Silphium gracile	slender rosinweed	Texas & Lousiana	present in preserve [a]

*According to Matos and Rudolph (1985)

[a] Harcombe 2007

[b] Watson 1978

[c] Watson .n.d.
[d] Watson 1982

Extent

Arid sand hill vegetation (also known as sand hill pine forest) has been documented in the BSCU and TCU of BITH (Harcombe and Marks 1979, NPS 2012). According to Harcombe and Marks (1979), the best example of sand hill pine in the preserve is found just northeast of the confluence of Turkey and Village Creeks (Figure 17). Although not shown on the map below, the sand hill pine forest within BSCU occurs in the northern portion of the unit near its eastern boundary (Harcombe and Marks 1979). In the late 1970s, sand hill pine forest reportedly covered approximately 8.9 ha (22 ac) in BSCU and 44.5 ha (110 ac) in TCU for a total area of 53.4 ha (132 ac) (Harcombe and Marks 1979). NPS (2012) stated that 93.1 ha (230 ac) of sand hill pine forest occurred within the preserve. In recent mapping efforts (Blanton and Associates 2002, PBS&J 2003, DESCO 2007), the arid sand hills were not mapped separately but were grouped with other pine-dominated upland communities.

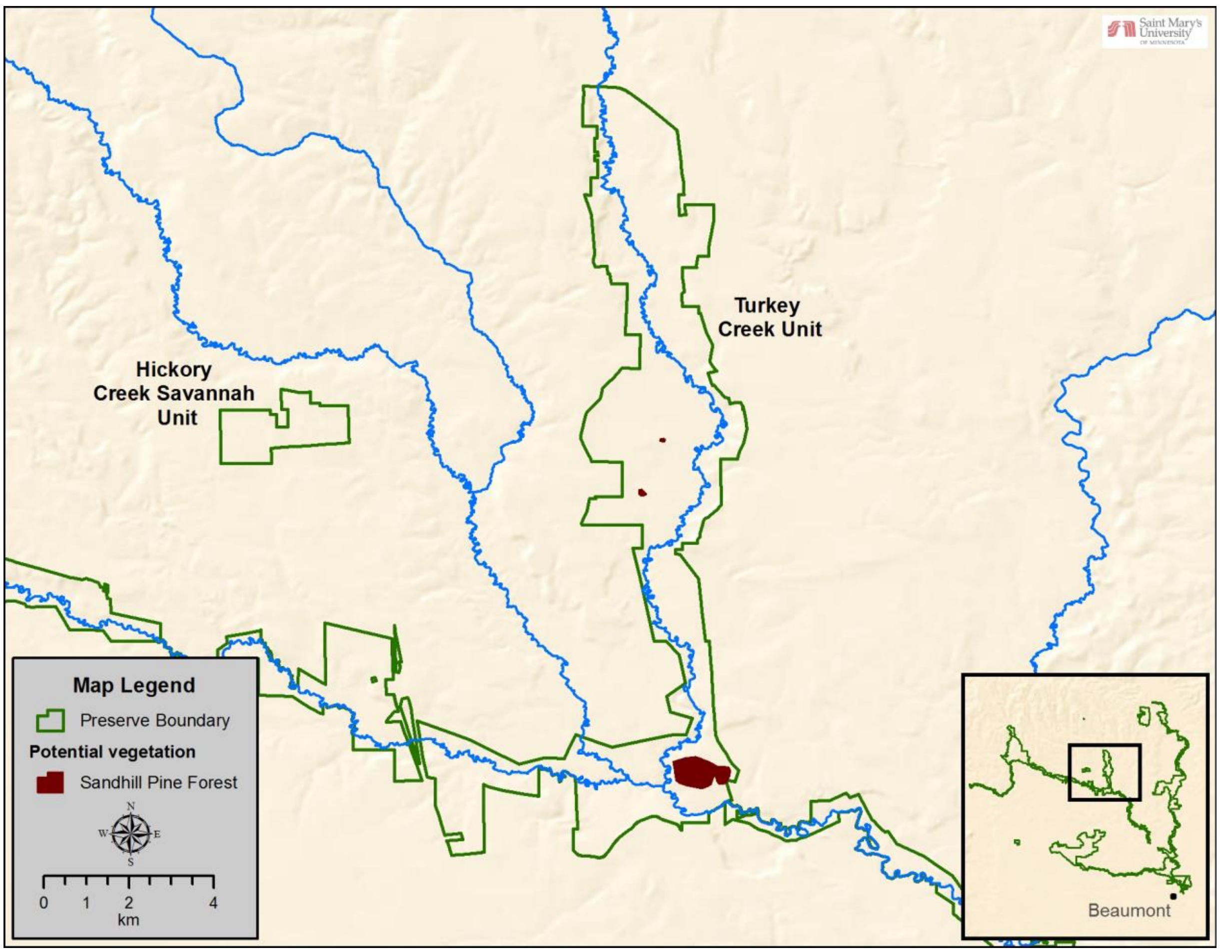

Figure 17. Locations within the Turkey Creek Unit of BITH where sand hill pine forest is the potential natural vegetation community (NPS 2003, based on Harcombe and Marks 1979).

Threats and Stressors Factors

Threats to the arid sand hills community include altered fire regime, invasive and exotic plants, feral hogs, past oil and gas operations, and increased density of the midstory. The upland vegetation communities within BITH, including the arid sand hills, are strongly influenced by fire (Liu 1995, NPS 2012). The herbaceous understory species of sand hill pine communities have evolved with frequent, low intensity fires and often benefit from burning (Reinhart and Menges 2004, Caldwell 2005). Fire is known to reduce the density of woody species (trees and shrubs) that would shade out and compete with the herbaceous understory (Liu 1995; Photo 6). Active fire suppression was common in the BITH region and throughout the U.S. during the 20th century (Frost 1993). When fire is suppressed, fire-intolerant hardwoods invade these open pine communities (Watson 1982, Varner et al. 2005), often increasing the density of the midstory. On the sand hills, the shade and leaf litter from these hardwoods cools the soil and adds organic matter, leading to the replacement of the original xeric plants with more mesic species (Watson 1982). The expansion of yaupon into these sites is a significant concern; although native, it quickly returns after fire, grows in dense patches, and can reach heights of 15 to 20 feet in a few years. It can quickly outcompete other native herbaceous and shrubs and poses a threat as a ladder fuel to the pine overstory (Hyde, written communication, June 2015). BITH managers have begun to return fire to the landscape in an effort to restore the pre-settlement vegetation structure, composition, and function to these historically fire-maintained communities (NPS 2012).

Photo 6. 2003 prescribed burn on a TCU sand hill (NPS photo).

Feral hog numbers have increased across Texas in recent decades, including the BITH region where reported hog damage to preserve resources has increased (Chavarria 2006). Hog impacts are typically most severe in wetter habitats, but damage has been observed in uplands (Chavarria 2006). For further discussion of feral hogs and their impacts, refer to Chapter 4.2 of this assessment.

Invasive plant species have the potential to outcompete native plants and can alter ecological processes (e.g., nutrient cycling, disturbance regimes) (Gordon 1998). The arid sand hills have not been specifically inventoried for invasive plants; however, Caldwell (2005) documented Chinese tallow, a highly invasive non-native tree, in 15% of plots within a sand hill pine forest restoration area in TCU.

Human activity prior to preserve establishment is still impacting the vegetation communities. Marks and Harcombe (1978) noted that pine density and basal area had been reduced by repeated logging in arid sand hill areas of BITH. The logging exacerbated brush encroachment by opening gaps in the understory, allowing brushy species to expand in coverage and density (Hyde, written communication, June 2015). Because of its rarity, the arid sand hills communities are designated as a "Special Management Area" and now receive protection from oil and gas operation impacts (NPS 2006). However, pre-preserve establishment drilling pad sites within the sand hill pine communities were shown to have lower plant species richness and diversity than adjacent control sites (Fountain 1984).

Data Needs/Gaps

The arid sand hill communities within BITH have not been surveyed specifically for endemic plant species. This type of survey would be needed to accurately assess the measure of endemic species richness. A preserve-wide vegetation map also does not exist, although mapping efforts are expected to be completed in 2018 (Segura, written communication, May 2015). Vegetation maps recently completed for several individual units in the preserve do not map the arid sand hills as a separate community. Further research into or documentation of the threats to the arid sand hills at BITH (e.g., invasive species, dense midstory due to fire suppression) could also be helpful for preserve managers. The GULN is developing a vegetation monitoring protocol that will begin gathering data on plant community composition and coverage in several BITH units by 2016 (Woodman, written communication, December 2014).

Overall Condition

Endemic Species Richness

The project team assigned this measure a *Significance Level* of 3. Some endemic plant species have been documented in arid sand hill habitat within BITH, but the sand hills have not been specifically inventoried for endemic species. Because of the rarity of these species and the threats facing the arid sand hill community, preserve managers consider this measure of moderate concern (*Condition Level* = 2).

Extent

The extent measure was also assigned a *Significance Level* of 3. Arid sand hills are the rarest vegetation community within BITH and the surrounding region, covering less than 100 ha within the preserve. While there is no direct evidence that the extent of arid sand hills is declining, the small size and limited number of these communities alone makes them vulnerable to habitat loss. As a result, this measure is assigned a *Condition Level* of 2, indicating moderate concern.

Weighted Condition Score

The WCS for arid sand hills is 0.67, which is at the lower end of the high concern category. A trend could not be identified due to a lack of recent data. Managers have been working on restoring this habitat, primarily through prescribed fire (Hyde, written communication, June 2015), so condition may be improving in some areas of the preserve.

Arid Sand Hills			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.67**
Endemic Species Richness	3	2	
Extent	3	2	

4.4.6 Sources of Expertise

- Ken Hyde, BITH Chief of Resource Management
- Herbert Young, BITH Biologist

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4.5 Longleaf Pine Wetlands

4.5.1 Description

Photo 7. Wetland pine savanna in BITH (NPS photo).

Longleaf pine wetlands (often called wetland pine savannas) occur in shallow, poorly drained depressions or flats within the sandy uplands of BITH (Harcombe and Marks 1979). The vegetation typically consists of a dense herb layer with some wetland shrubs and widely scattered longleaf pine (Photo 7), although loblolly pine has become the dominant tree species in many areas following the logging of longleaf (Fountain 1984). The shrub layer often includes stunted blackgum, sweetgum, southern red oak, sweetbay (*Magnolia virginiana*), wax-myrtle, and swamp titi (*Cyrilla racemiflora*) (Harcombe and Marks 1979). The diverse understory includes sedges and grasses, orchids, sphagnum moss, ferns, insectivorous plants (e.g., pitcher plants and sundews), and other forbs (Harcombe and Marks 1979, DESCO 2006). Many of these herbaceous species are often associated with poor soils and acidic sites (Marks and Harcombe 1978). At BITH, longleaf pine wetlands include pitcher plant bogs and baygalls with a sparse pine overstory. "Baygall" is a local name for a wetland shrub thicket, derived from the shrubs sweetbay and gallberry holly (Harcombe and Marks 1979).

The soils in longleaf pine wetlands are typically saturated throughout the winter and spring, and regularly during the year after precipitation events (MacRoberts and MacRoberts 1998). These waterlogged soils likely prevent the establishment of many woody species common in other preserve vegetative communities, particularly oaks (*Quercus* spp.) (Streng and Harcombe 1982, MacRoberts and MacRoberts 2000). Fire is also important in maintaining the open nature of these wetlands and the diverse herbaceous understory (Harcombe and Marks 1979).

Wetland pine savannas and pitcher plant bogs were historically extensive in the southeastern U.S., with southeast Texas representing the western limit of their range (Grace 1997, MacRoberts and MacRoberts 1998). Today, less than 3% of the original communities remain, making wetland pine savannas one of the rarest plant communities in the region and within BITH (NPS 2012a). Wetlands are an important part of the BITH environment, as they provide habitat for wildlife, temporarily store precipitation, and facilitate groundwater recharge (Zygo 1999).

4.5.2 Measures

- Extent
- Herbaceous understory diversity
- Herbaceous understory density
- Midstory density

4.5.3 Reference Conditions/Values

The reference condition for this component is the condition of longleaf pine wetlands prior to European settlement of the area. However, little information is available from this time. The earliest known studies of vegetation within current BITH boundaries occurred in the 1970s (Marks and Harcombe 1978, Harcombe and Marks 1979), when much of the region had already been harvested for timber several times. The information presented in this NRCA could serve as a baseline for future assessments.

4.5.4 Data and Methods

Harcombe and Marks (1979) sampled 56 vegetation stands throughout BITH, focusing on woody vegetation. Only two of the stands sampled were classified as wetland pine savanna. Additional descriptions of longleaf pine wetlands were found in Marks and Harcombe (1978), DESCO (2006), and NPS (2012a). Fountain (1984) collected some data on shrub density and understory coverage in two wetland pine savanna plots as part of a study of past oil and gas development impacts within preserve boundaries.

Streng and Harcombe (1982) studied two savannas within the HCSU. Only one of these was a pine wetland; the other was a drier, upland savanna type. On the wetland site, a clayey subsoil reportedly contributed to the presence of several centimeters of standing water for 6-9 months out of the year (Streng and Harcombe 1982). Streng and Harcombe (1982) gathered information on the tree, shrub, and herbaceous layers at this site.

Photo 8. Pale pitcher plant (*Sarracenia alata*) (NPS photo).

MacRoberts and MacRoberts (1998) completed a floristic inventory of two longleaf pine wetlands within BITH, visiting sites monthly (except for mid-winter) between July 1997 and November 1998. The first site, within the LRU was described as a “classic” wetland pine savanna (MacRoberts and MacRoberts 1998). The second site, in the TCU, was noteworthy for its “extensive stands of pitcher plants" (MacRoberts and MacRoberts 1998, p. 41). The TCU site was burned during the winter of 1997-1998, while the LRU site had not burned since 1990. MacRoberts and MacRoberts (1998) produced a species list for each site, which provides information on herbaceous understory diversity for this assessment. Watson (1982) produced a preserve-wide plant list with information on the community types where each species was found, which provided additional information on herbaceous diversity.

Blanton and Associates, Inc. (2002) sampled pine wetlands (*Pinus taeda* Seasonally Flooded Woodland Alliance) in the LRU during 1999 and 2000. Thirty-two plots totaling 0.8 ha (2.0 ac) were sampled for woody vegetation, and herbaceous vegetation was studied in 320 1 m x 1 m plots. During a 2006 vegetation assessment of the TCU, DESCO (2007) visited several pine wetland stands. Four plots totaling 0.1 ha (0.2 ac) were sampled for woody vegetation, while herbaceous vegetation was sampled in 30 1 m x 1 m plots (DESCO 2007).

As mentioned previously, a preserve-wide vegetation map is not available for BITH, but several individual units have been mapped, including LRU (Blanton and Associates, Inc. 2002) and TCU (DESCO 2007). These maps have been combined to form one GIS layer, which was acquired from the GULN (NPS 2012b). Additional insight into vegetation community distribution can be obtained from BITH fire affects monitoring plots, which are classified by vegetation type (NPS 2012b). A potential natural vegetation map was created for the entire preserve by Harcombe and Marks (1979); a GIS version of this map (NPS 2003) was also obtained from the GULN.

4.5.5 Current Condition and Trend

<u>Extent</u>

Longleaf pine wetlands are known to occur within three BITH units: LRU, TCU, and HCSU (Figure 18) (Harcombe and Marks 1979, MacRoberts and MacRoberts 2000). According to Harcombe and Marks (1979), approximately 374.3 ha (925 ac) occurred within LRU, 148.5 ha (367 ac) in HCSU, and 210.8 ha (521 ac) in TCU, for a total of 733.6 ha (1813 ac). This accounts for just 1-2% of the preserve's current total area.

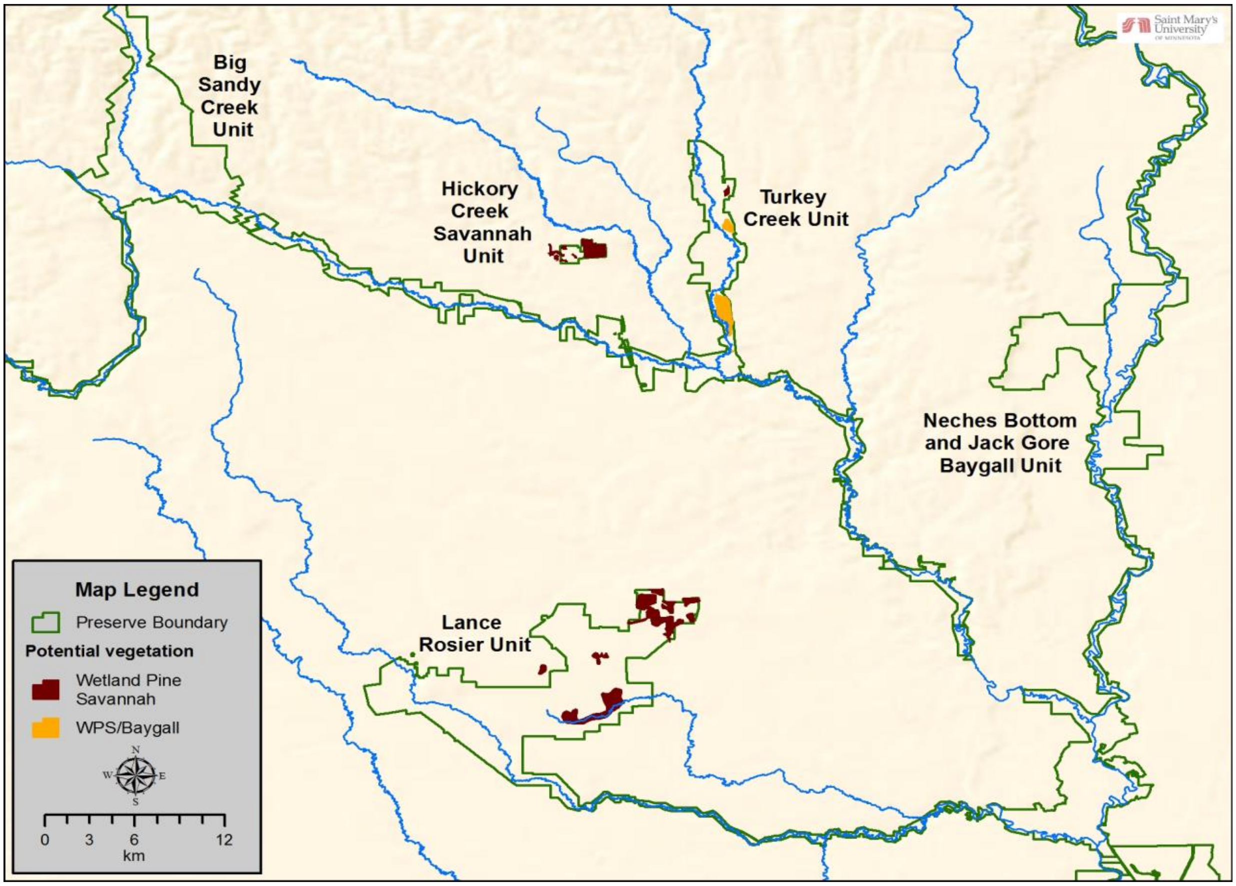

Figure 18. Locations within BITH where wetland pine savanna (or a wetland pine savanna/baygall mix) is the potential natural vegetation community (NPS 2003, based on Harcombe and Marks 1979).

In more recent mapping efforts, the vegetation community which correlates to Harcombe and Marks (1979) wetland pine savanna type was identified as "Loblolly Pine Seasonally Flooded Woodland Alliance" (Blanton and Associates, Inc. 2002). Only 134.8 ha (333 ac) of this type was mapped in the LRU and TCU (Figure 19; Blanton and Associates, Inc. 2002, DESCO 2007). While neither the historic or current extent of longleaf pine wetlands in BITH is known, MacRoberts and MacRoberts (2000) believe that less than 1% of the original wetland pine savannas remain.

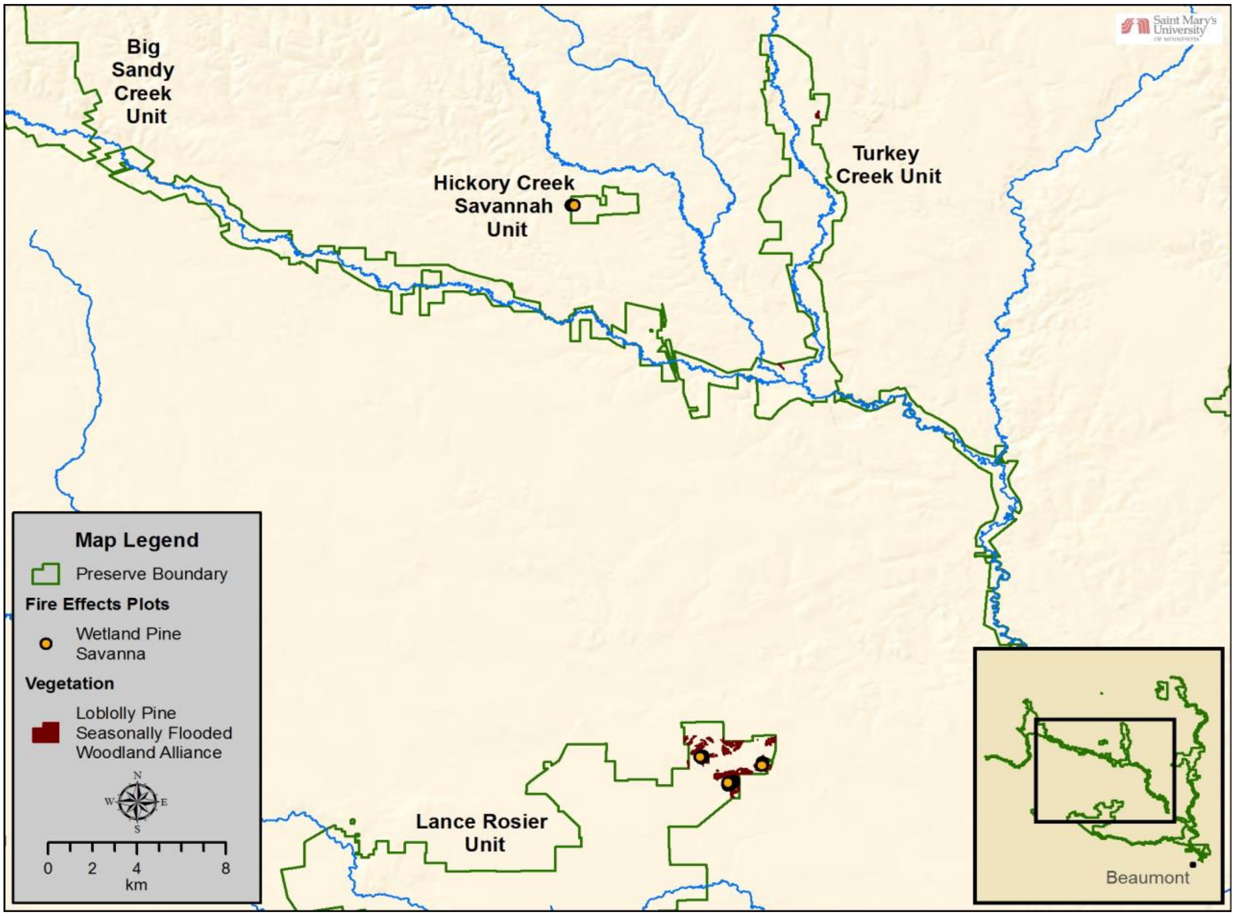

Figure 19. Loblolly pine seasonally flooded woodlands in LRU (Blanton and Associates 2002) and TCU (DESCO 2007) and BITH fire effects monitoring plots located within wetland pine savanna (NPS 2012b).

Herbaceous Understory Diversity

Wetland pine savannas are thought to support the highest plant diversity of all vegetation communities in BITH, with an estimated 100 species of forbs per acre (NPS 2012a). Approximately 300 herbaceous species have been documented within the preserve's wetland pine savannas (Appendix E). Watson's (1982) preserve-wide plant list includes 205 of these species. More recently, MacRoberts and MacRoberts (1998) documented 100 and 88 herbaceous species in LRU and TCU wetland pine savannas, respectively. Notable plants include nine orchid species and six insectivorous species (Appendix E).

Blanton and Associates, Inc. (2002) identified 107 herbaceous plant species in pine wetland plots (*Pinus taeda* Seasonally Flooded Woodland Alliance) in the LRU. In the TCU, DESCO (2007) documented 57 herbaceous species in pine wetland sample plots. The species documented in these two studies are also noted in Appendix E.

Herbaceous Understory Density

Due to the typically open nature of longleaf pine wetlands, the herbaceous understory is normally dense in these communities (Harcombe and Marks 1979). However, no understory density data are available for this community in the preserve. The only information similar to density is "canopy coverage" measurements for two wetland pine savanna plots from Fountain (1984). While plant cover cannot be directly correlated to density, this information may provide some insight into total herbaceous ground cover and the species that are contributing the greatest coverage (Table 26). DESCO (2007) also recorded ground cover in the herbaceous layer of TCU pine wetlands, estimating coverage at 68.3%.

Table 26. Average crown canopy coverage in the herbaceous layer by species within two wetland pine savanna control plots (i.e., not influenced by oil and gas development) (Fountain 1984).

Scientific Name	Common Name	Average Crown Canopy Coverage
Carex sp.	sedge	26.2
Andropogon sp.	bluestem	11.5
Hyptis alata	clustered bushmint	6.3
*Pteridium aquilinum**	western brackenfern	6.3
Rhexia lutea	yellow meadowbeauty	6.3
Xyris ambigua	coastal plain yelloweyed grass	6.3
*Dichanthelium commutatum**	variable panicgrass	5.6
Centella sp.	centella	3.4
Drosera brevifolia	dwarf sundew	3.4
Eupatorium hyssopifolium	hyssopleaf thoroughwort	3.0
Eriocaulon decangulare	tenangle pipewort	0.8
Lycopodiella sp.	clubmoss	0.4
Osmunda regalis	royal fern	0.4
Panicum sp.	panic grass	0.4
Polygala mariana	Maryland milkwort	0.4
Rhexia virginica	handsome Harry	0.4
Solidago sp.	goldenrod	0.4
Tephrosia onobrychoides	multibloom hoarypea	0.4
Viola sp.	violet	0.4
Total		**82.3**

* These species were not listed as occurring in wetland pine savannas by either Watson (1982) or MacRoberts and MacRoberts (1998), possibly suggesting that Fountain's (1984) sites had been invaded by some upland species.

Threats and Stressors Factors

Threats to longleaf pine wetlands identified by preserve staff include altered fire regimes, increased midstory density, drought, invasive species (plants and feral hogs), past logging, and land development around the preserve which has impacted surface hydrologic flow. As with the other longleaf communities at BITH, the pine wetlands are strongly influenced by fire (Liu 1995, NPS 2012a; see Chapter 4.2 threats and stressors). Mize et al. (2005, p. 200) stated that lack of frequent fire is "the most pervasive detrimental impact to existing pitcher plant bogs." In the absence of fire, savanna wetlands are invaded by shrubs such as sweetbay, gallberry holly, and swamp titi, which often shade out the characteristic insectivorous plants, orchids, and ferns (Watson 1982). MacRoberts and MacRoberts (2000, p. 4) observed that nearly all the remaining wetland pine savannas in BITH "have clearly been degrading and losing ground to shrub encroachment and are being transformed to shrub thickets." Fire-scar evidence from trees in the HCSU suggested that fires occurred there every 3.9 years on average between 1928 and 1967, but was effectively suppressed between 1967 and 1983 (Liu 1995).

Drought has been shown to impact wetland pine savannas in BITH. Streng and Harcombe (1982) found a depression in tree age distribution within a HCSU wetland savanna that correlated with the 1956 Texas drought. The authors hypothesized that the drought caused a decline in tree seedling recruitment and/or survival and may have influenced seed production as well (Streng and Harcombe 1982). Watson (1982) also noted that drought had negatively impacted the number of wetland and ephemeral plants in the TCU. Much of Texas, including BITH, experienced a drought of unprecedented intensity in 2011 due to an extended period of below-average rainfall (Nielson-Gammon 2012). According to Harcombe (1999), climate change is likely to increase the frequency and intensity of both droughts and floods in the future.

Although invasive plants have not yet been documented in longleaf pine wetlands, these species have the potential to outcompete native plants and can alter ecological processes (e.g., nutrient cycling, disturbance regimes such as fire) (Gordon 1998). Chinese tallow and kudzu are of particular concern, as they are already invading other areas of the preserve (Hyde, written communication, 6 October 2015). Feral hogs are also a threat to these wetlands and, as discussed previously, hog numbers have been increasing in BITH and the surrounding region (Chavarria 2006). Hog wallows tend to be concentrated near wet areas, such as the wetland pine savannas in the LRU, and trampling damage from regularly used travel corridors primarily occurs on poorly drained soils (Chavarria 2006).

Past logging operations appear to have impacted the tree composition of longleaf pine wetlands. Fountain (1984) noted that logging activity removed many longleaf pines prior to the establishment of BITH, leaving loblolly pine as the dominant species in some areas. Loblolly tends to regenerate more quickly than longleaf pine, even in areas where some mature longleaf remains in the overstory (Hyde, written communication, 6 October 2015). This may have contributed to the fact that areas where the potential vegetation was classified as "wetland pine savanna" (typically described with sparse longleaf pines) by Harcombe and Marks (1979) were mapped as "Loblolly Pine Seasonally Flooded Woodland Alliance" by Blanton and Associates (2002).

Data Needs/Gaps

Most of the data available for the measures presented here are over 10 years old, and some sources are over 30 years old. In addition, no actual data are available at this time for density of the herbaceous understory in these communities. DESCO Environmental Consultants have conducted a survey of BITH's largest pitcher plant bog (Hyde, written communication, 6 October 2015), but data and analysis were not available in time for inclusion in this NRCA. Updated surveys focusing on the herbaceous understory and midstory density are needed to fully assess the condition of this community within BITH. A preserve-wide vegetation map does not exist, although mapping efforts are expected to be initiated in the next few years. An invasive plant survey could also help determine how much of a threat these species pose to the preserve's longleaf pine wetlands. The GULN is developing a vegetation monitoring protocol that will begin gathering data on plant community composition and coverage in several BITH units by 2016 (Woodman, written communication, December 2014). Areas of focus for long-term monitoring will include the TCU and LRU (Segura, email communication, 18 February 2015), two of the units where much of the remaining longleaf pine wetland is found.

Overall Condition

Extent

The project team assigned this measure a *Significance Level* of 3. Although the current extent of longleaf pine wetlands in BITH is not known, it is likely that less than 1% of the original wetland pine savannas remain (MacRoberts and MacRoberts 2000). Much of the remaining community is threatened by woody species invasion, particularly due to lack of fire (MacRoberts and MacRoberts 2000). Therefore, this measure is assigned a *Condition Level* of 2, indicating moderate concern.

Herbaceous Understory Diversity

The herbaceous understory diversity measure was assigned a *Significance Level* of 3. Over time, approximately 300 herbaceous species have been documented within the preserve's wetland pine savannas (Appendix E). While high herbaceous diversity has been documented in the preserve's longleaf pine wetlands historically (Watson 1982, MacRoberts and MacRoberts 1998), more recent surveys have been limited to individual units and have not confirmed that this large number of understory species is still present. As a result, a *Condition Level* could not be assigned for this measure.

Herbaceous Understory Density

The density measure was also assigned a *Significance Level* of 3. Understory density is normally high in these open communities, but no actual data on understory density in BITH's longleaf pine wetlands are available at this time. Due to this lack of data, a *Condition Level* could not be assigned.

Midstory Density

This measure was assigned a *Significance Level* of 1. Measures with a *Significance Level* of 1 are not discussed in depth in the current condition section of this assessment, but available information is summarized here in the overall condition section. Historically, the midstory layer in longleaf pine wetlands would have been open (i.e., low density), due to saturated soils and frequent fires. However, fire suppression and other factors have caused the midstory density to increase in many longleaf pine communities (Varner et al. 2005). Little information is available on midstory density in BITH's wetland pine savannas. Streng and Harcombe (1982) recorded the density of shrub species in one longleaf pine wetland in HCSU (Table 27). Fountain (1984) also calculated total density for the shrub layer within 0.01 ha plots. Within two wetland pine savanna control plots, Fountain (1984) found 5.0 stems/plot, which equates to approximately 500 stems/ha. The large difference between these two density measurements may be due to each study's definition of "shrub"; Streng and Harcombe (1982) considered woody species greater than 0.5 m (19.7 in) tall but less than 4.5 cm (1.8 in) in diameter as shrubs, while Fountain (1984) defined shrubs as stems between 1.0 and 9.9 cm (.4 and 3.9 in) in diameter.

Table 27. Density (stems/ha) of shrub species within a longleaf pine wetland sampled by Streng and Harcombe (1982).

Scientific Name	Common Name	Density
Morella cerifera	wax-myrtle	1,987
Ilex vomitoria	yaupon	27
Rubus sp.	blackberry	587
Cyrilla racemiflora	swamp titi	1060
Magnolia virginiana	sweetbay	8,970
Persea borbonia	redbay	43
Diospyros virginiana	common persimmon	80
Hypericum hypericoides ssp. hypericoides	St. Andrew's cross	320
Asimina parviflora	smallflower pawpaw	40
Vaccinium arboreum	farkleberry	93
Total		**13,207**

Blanton and Associates, Inc. (2002) calculated midstory and shrub layer density in pine wetland plots in the LRU. Any stems 7-20 cm in diameter were considered "midstory," whereas the "shrub" layer consisted of stems 0-7 cm in diameter. The average midstory density in LRU plots was 469 stems/ha and shrub layer density was 5,850 stems/ha (Blanton and Associates, Inc. 2002). DESCO (2007) also calculated midstory and shrub layer density for pine wetlands in the TCU. In this study, "midstory" included stems 2.5-12 cm in diameter, whereas the "shrub" layer consisted of stems 0.5-2.5 cm in diameter. Midstory density in TCU plots averaged 1,130 stems/ha, with the shrub layer averaging 14,100 stems/ha (DESCO 2007). Midstory and shrub layer densities by species for these two studies are presented in Table 28. Because all of the data are geographically limited and some are over 30 years old, a *Condition Level* was not assigned for this measure.

Table 28. Midstory and shrub layer densities by species in LRU and TCU pine wetlands (*Pinus taeda* Seasonally Flooded Woodland Alliance) (Blanton and Associates, Inc. 2002, DESCO 2007).

	Blanton & Assoc. (2002) (LRU)		DESCO (2007) (TCU)	
Scientific Name	**Midstory**	**Shrub Layer**	**Midstory**	**Shrub Layer**
Pinus taeda	266.25	1,212.5	160.0	100.0
Nyssa sylvatica	108.75	625.0	10.0	100.0
Nyssa biflora	--	--	70.0	100.0
Morella cerifera	12.5	962.5	50.0	800.0
Morella caroliniensis	--	--	100.0	100.0
Liquidambar styraciflua	20.0	412.5	10.0	100.0
Persea palustris	--	400.0	30.0	500.0
Acer rubrum	5.0	437.5	--	100.0
Magnolia virginiana	15.0	450.0	250.0	4,900.0
Ilex vomitoria	1.25	312.5	20.0	200.0
Ilex opaca	2.5	187.5	60.0	--
Pinus palustris	8.75	112.5	--	--
Ilex coriacea	--	137.5	210.0	100.0
Diospyros virginiana	--	187.5	--	--
Quercus nigra	6.25	62.5	--	200.0
Quercus laurifolia	3.75	75.0	110.0	--
Quercus falcata	--	--	10.0	--
Quercus alba	--	--	10.0	--
Cyrilla racemiflora	--	37.5	20.0	6,500.0
*Triadica sebiferum**	--	75.0	--	--
Viburnum nudum	--	87.5	--	--
Pinus elliottii	--	25.0	--	--
Aronia arbutifolia	--	25.0	--	--
Callicarpa americana	--	12.5	--	--
Crataegus opaca	3.75	12.5	--	--
Crataegus spathulata	--	--	10.0	--
Pinus echinata	15.0	--	--	--
Smilax laurifolia	--	--	--	300.0

* Invasive species

Weighted Condition Score

A WCS was not calculated for BITH's longleaf pine wetlands due to a lack of recent data. The current condition and trend of this community in the preserve are unknown.

Longleaf Pine Wetlands			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Extent	3	2	
Herbaceous Understory Diversity	3	n/a	
Herbaceous Understory Density	3	n/a	
Midstory Density	1	n/a	

4.5.6 Sources of Expertise

- Ken Hyde, BITH Chief of Resource Management
- Herbert Young, BITH Biologist

4.5.7 Literature Cited

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4.6 Floodplain Hardwood Forest

4.6.1 Description

Floodplain forests make up a large portion of BITH and perform valuable ecological functions for the region. These forests provide habitat not only for terrestrial wildlife, but also for aquatic life by providing snags in streams and shade that keeps water temperatures lower (Harcombe 1996). Floodplains store and slow floodwaters and facilitate groundwater recharge (Zygo 1999, Allen et al. 2001). Floodplain forests also improve water quality by buffering streams from run-off containing pesticides, fertilizers, and other pollutants, and from siltation due to erosion on adjacent lands (Harcombe 1996, Allen et al. 2001). During the 20th century, a significant amount of bottomland hardwood forest (a type of floodplain forest) was lost across the United States, including approximately 63% of the original bottomland hardwood area in East Texas (Frye 1987, Allen et al. 2001). Factors causing this loss included logging, diking and draining the lands for agricultural production, conversion to large industrial sites, and urbanization.

Floodplain forests occur within the broad flats between the bluffs and along the riparian corridors of the Neches River and other streams where soil moisture is abundant for much of the year (Harcombe and Marks 1979). The forests receive new sediments and nutrients during flood pulses on the waterways, and especially those not controlled by dams. Leaf litter is often lacking, as it is regularly washed away by flooding (Marks and Harcombe 1978). These forests can be further divided into three types: Floodplain hardwood pine forest, floodplain hardwood forest, and cypress tupelo forest. Floodplain hardwood pine is typically found in smaller stream floodplains. The dominant trees are loblolly pine and American beech, with sweetgum, black gum, southern magnolia, and water oak also common in the overstory (Harcombe and Marks 1979). Shrubs are rare, as the understory typically consists of small trees such as American hornbeam (*Carpinus caroliniana*), and the herbaceous groundlayer tends to be sparse (Marks and Harcombe 1978, Harcombe and Marks 1979).

Floodplain hardwood forests occur in larger stream floodplains and are dominated by sweetgum and water oak (Harcombe and Marks 1979). Additional common species include American hornbeam, oaks, black gum, water hickory (*Carya aquatica*), and red maple. Overstory trees often grow to large diameters and contribute to a dense canopy, which limits shrub and understory growth (Marks and Harcombe 1978, Harcombe and Marks 1979). Native vines, such as muscadine (*Vitis rotundifolia*) and Alabama supplejack (*Berchemia scandens*), are common and can also reach a large size (>10 cm [3.9 in] diameter) (Harcombe and Marks 1979).

Photo 9. Bald cypress (USFWS photo).

Cypress tupelo forest (or swamp) is found in deep sloughs, oxbows, river inlets, and other floodplain depressions (Harcombe and Marks 1979). These stands are dominated by bald cypress (*Taxodium distichum*; Photo 9) and water tupelo (*Nyssa aquatica*); both of these species can reach enormous size (>100 cm [39.4 in] in diameter) and form large buttressed roots. Other trees that occur, mostly towards the edges of these stands, include black gum, Carolina ash (*Fraxinus caroliniana*), and common buttonbush (*Cephalanthus occidentalis*) (Harcombe and Marks 1979, DESCO 2006).

4.6.2 Measures

- Extent
- Canopy cover
- Basal area
- Age class

4.6.3 Reference Conditions/Values

The reference condition for this component is the condition of the floodplain forests prior to major logging operations in the area (around the mid- to late 19th century). Unfortunately, little information is available for the selected measures from this time. The earliest known studies of forests within current preserve boundaries occurred in the 1970s (Marks and Harcombe 1978). The information presented in this NRCA could serve as a baseline for future assessments.

4.6.4 Data and Methods

Harcombe and Marks (1979) sampled 56 vegetation stands throughout the various BITH units, covering the topographic range from floodplains to upland forests. The focus of the study was on woody vegetation, with little attention given to the herbaceous understory. Eighteen of the stands sampled were within floodplain forests (two floodplain hardwood pine forest, 15 floodplain hardwood forest, and one swamp cypress tupelo forest). Harcombe and Marks (1975) provided size class data for a bottomland hardwood forest in the BCU. Fountain (1984) documented basal area and several other variables in floodplain forests within the preserve. Harcombe et al. (1999) included basal area data from a long-term study site within a floodplain forest in the NBU.

Lewis et al. (2000) sampled forest vegetation in the BSCU as part of a study of the herpetofaunal community. Communities sampled included a floodplain hardwood forest along Big Sandy Creek. The study documented density and canopy closure in the overstory, midstory, and understory.

More recently, vegetation surveys have been completed in individual preserve units: the LRU (Blanton & Associates 2002), BSCU (PBS&J 2003), and TCU (DESCO 2007). All three surveys collected extent and basal area data for several floodplain forest community types in the respective units.

4.6.5 Current Condition and Trend

<u>Extent</u>

According to Harcombe and Marks (1979), floodplain forest covered approximately 11,000 ha (27,182 ac) in the preserve during the late 1970s. The approximate area of each floodplain forest type by unit is presented in Table 29. The locations in BITH where floodplain forest or a floodplain/flatland forest mix are the potential natural vegetation communities (according to Harcombe and Marks 1979) are shown in Figure 20 below.

Table 29. Approximate area (in ha) of floodplain forest community types by unit, according to Harcombe and Marks (1979). FHPF = Floodplain hardwood pine forest, FHF = Floodplain hardwood forest, CTF = Cypress tupelo forest.

Communtiy Type	Beaumont	Lower Neches	Neches Bottom	Upper Neches	Pine Island Bayou	Lance Rosier	Menard Creek	Big Sandy	Turkey Creek	Beech Creek	Total
FHPF	--	--	--	--	--	--	--	39.7	887.9	158.2	**1,085.8**
FHF	2,119.7	1,000.0	3,335.8	1,775.8	372.7	181.3	93.1	374.7	85.8	70.4	**9,409.3**
CTF	352.1	4.0	142.5	--	--	--	--	20.6	4.9	--	**524.1**
Total	**2,471.8**	**1,004.0**	**3,478.3**	**1,775.8**	**372.7**	**181.3**	**93.1**	**435.0**	**978.6**	**228.6**	**11,019.2**

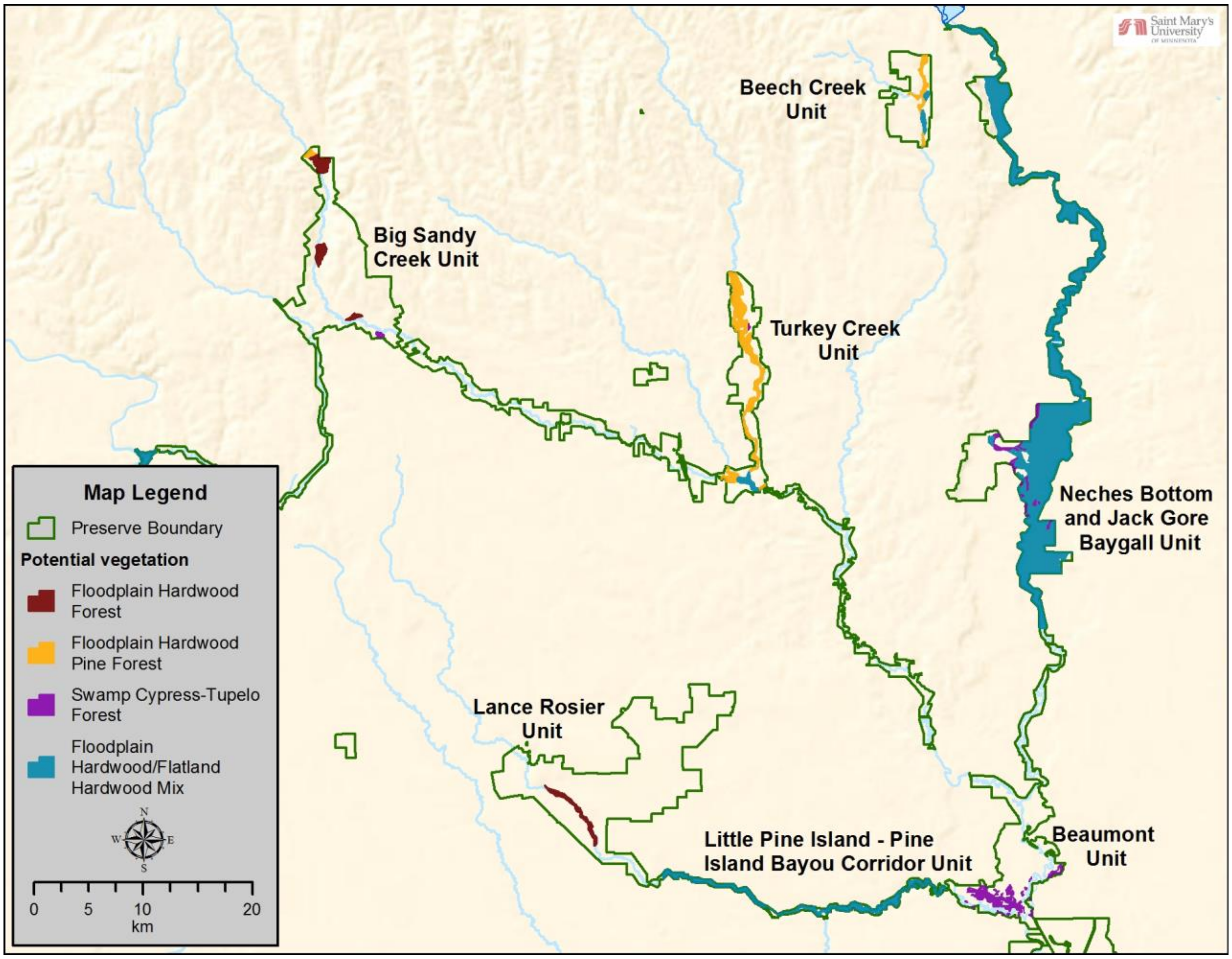

Figure 20. Locations within BITH where floodplain forest or a floodplain/flatland mix are the potential natural vegetation communities (NPS 2003, based on Harcombe and Marks 1979).

More recent vegetation surveys have mapped floodplain forests in individual units of the preserve. PBS&J (2003) recorded 2,708.6 ha (6,693.1 ac) of floodplain forest in the BSCU (Figure 21), while DESCO (2007) and Blanton and Associates Inc. (2002) documented 1,204.6 ha (2,976.6 ac) and 1,308 ha (3,232.1 ac) of floodplain forest in the TCU (Figure 22) and LRU (Figure 23), respectively. Lastly, DESCO (2011) mapped 1,714.2 ha (4,235.9 ac) of floodplain forest in the lower portion of the Beaumont Unit (Figure 24). Forest area by community type and unit is presented in Table 30.

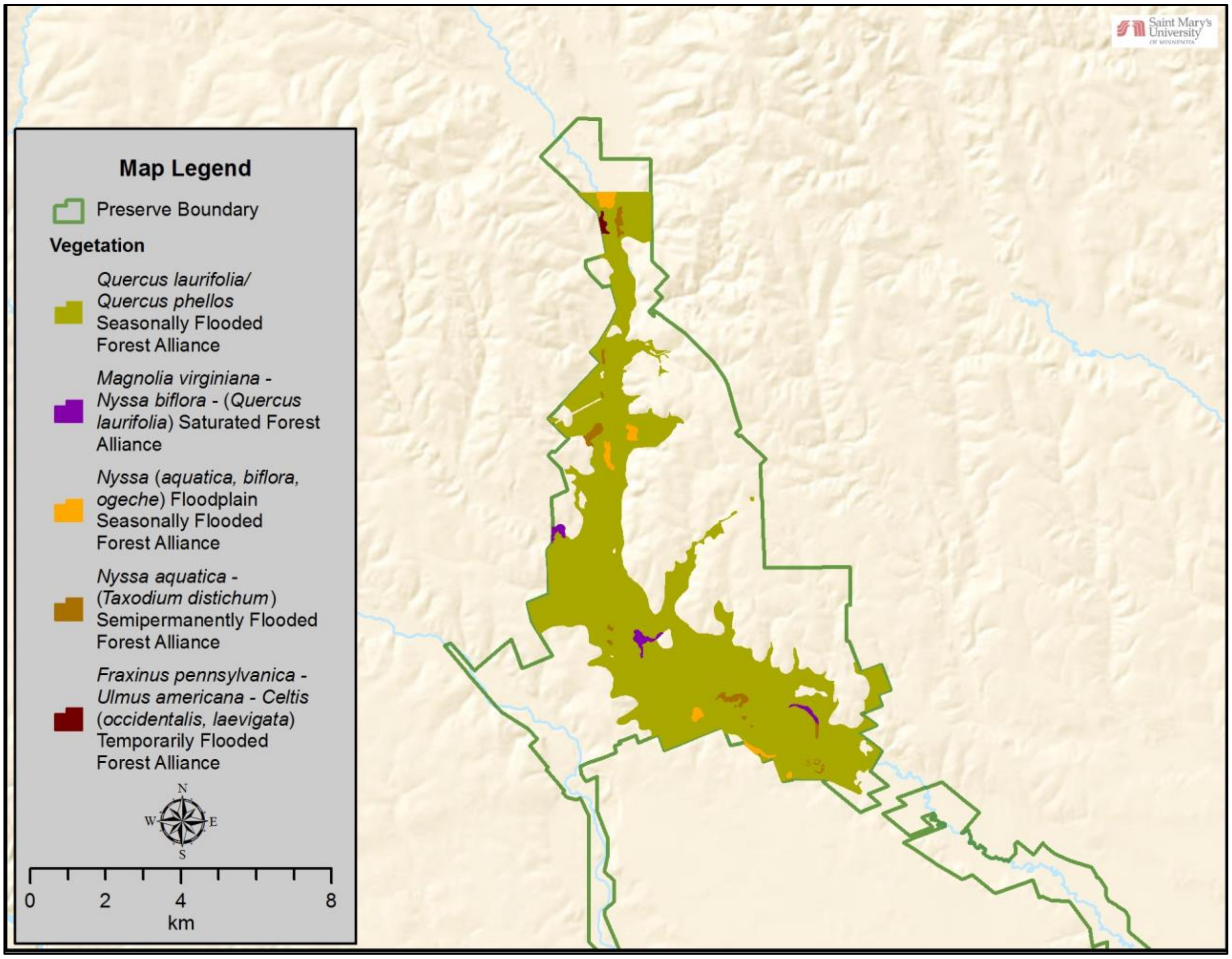

Figure 21. Floodplain forest vegetation within the Big Sandy Creek Unit (PBS&J 2003)

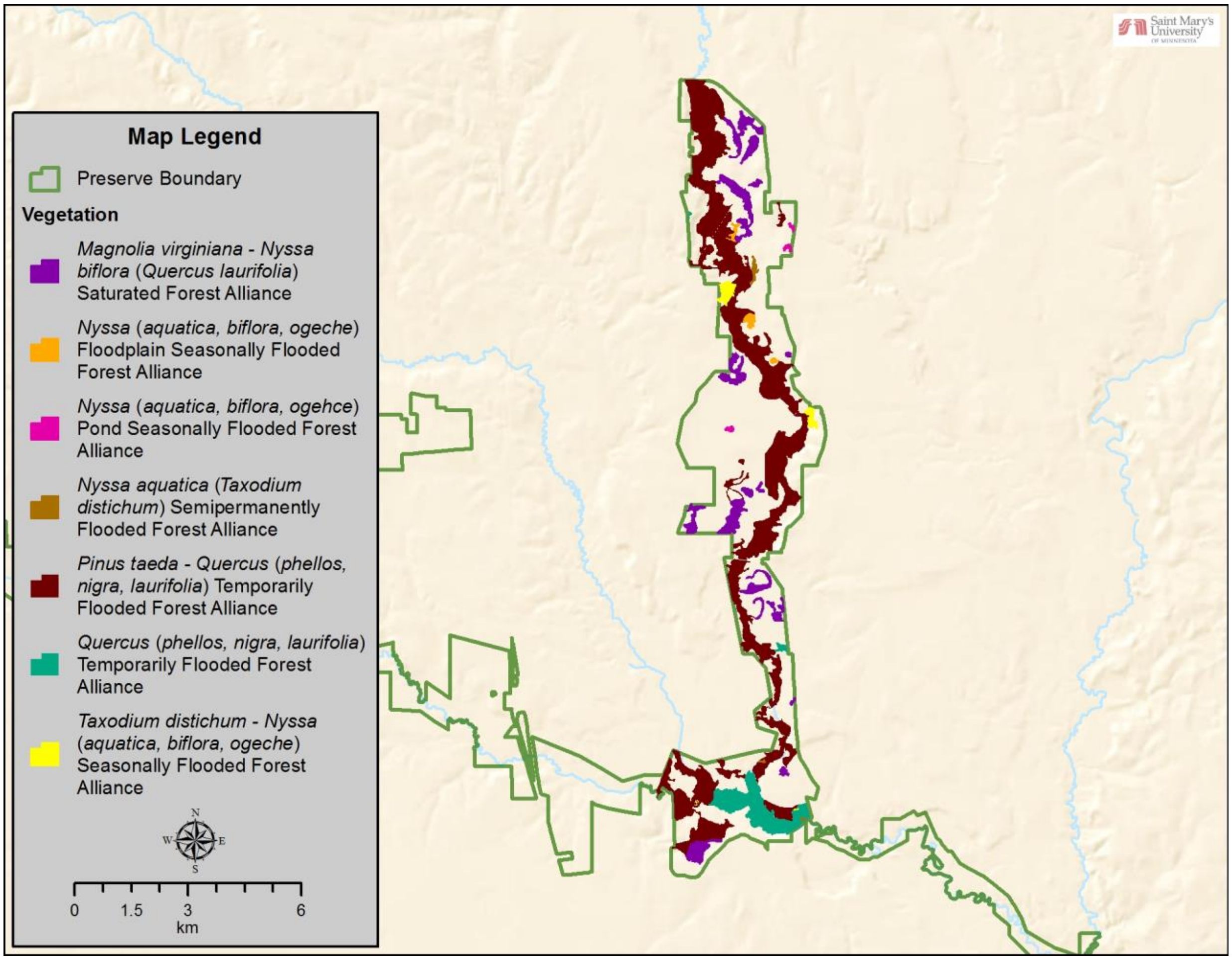

Figure 22. Floodplain forest vegetation within the Turkey Creek Unit (DESCO 2007).

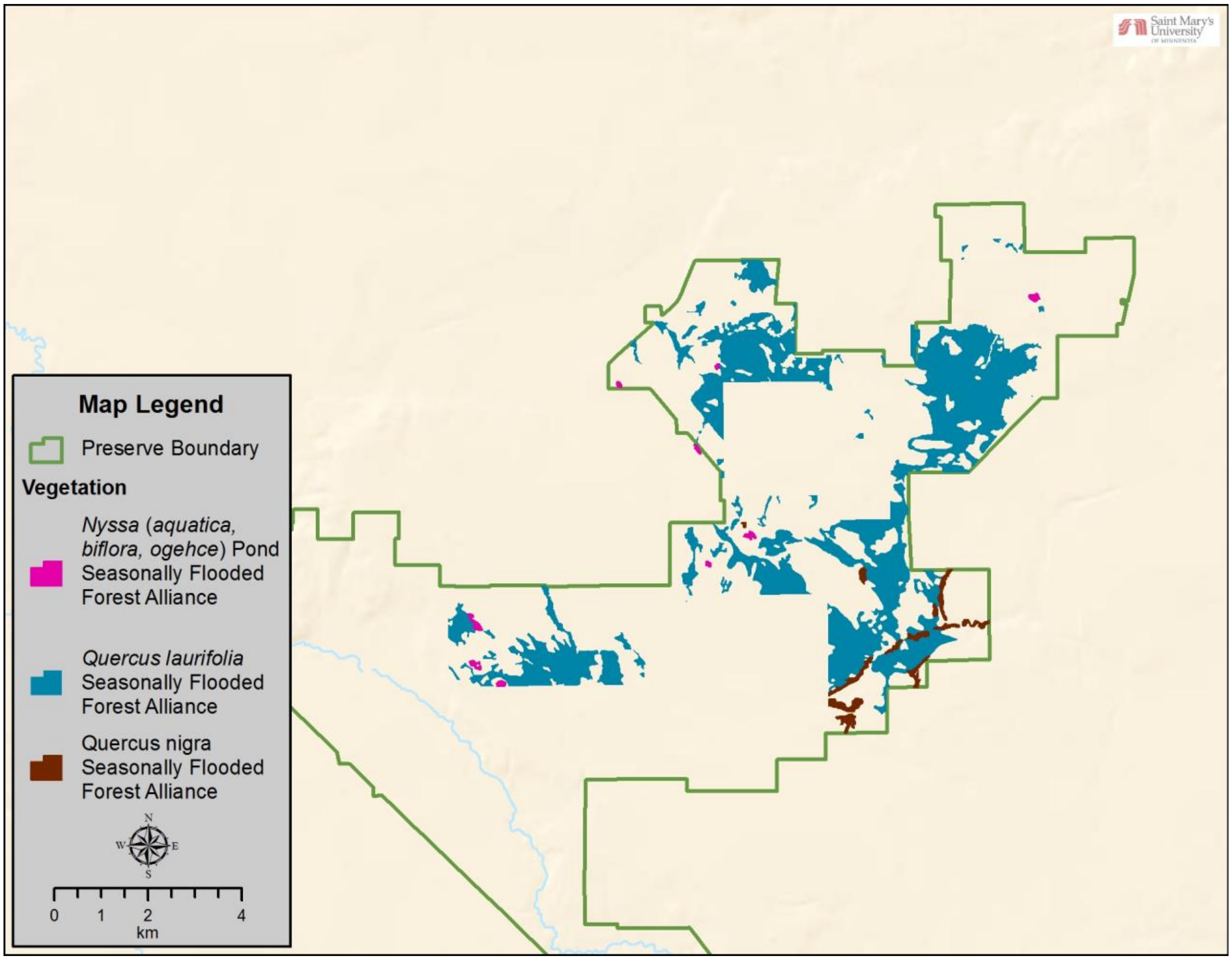

Figure 23. Floodplain forest vegetation within the Lance Rosier Unit (Blanton and Associates 2002).

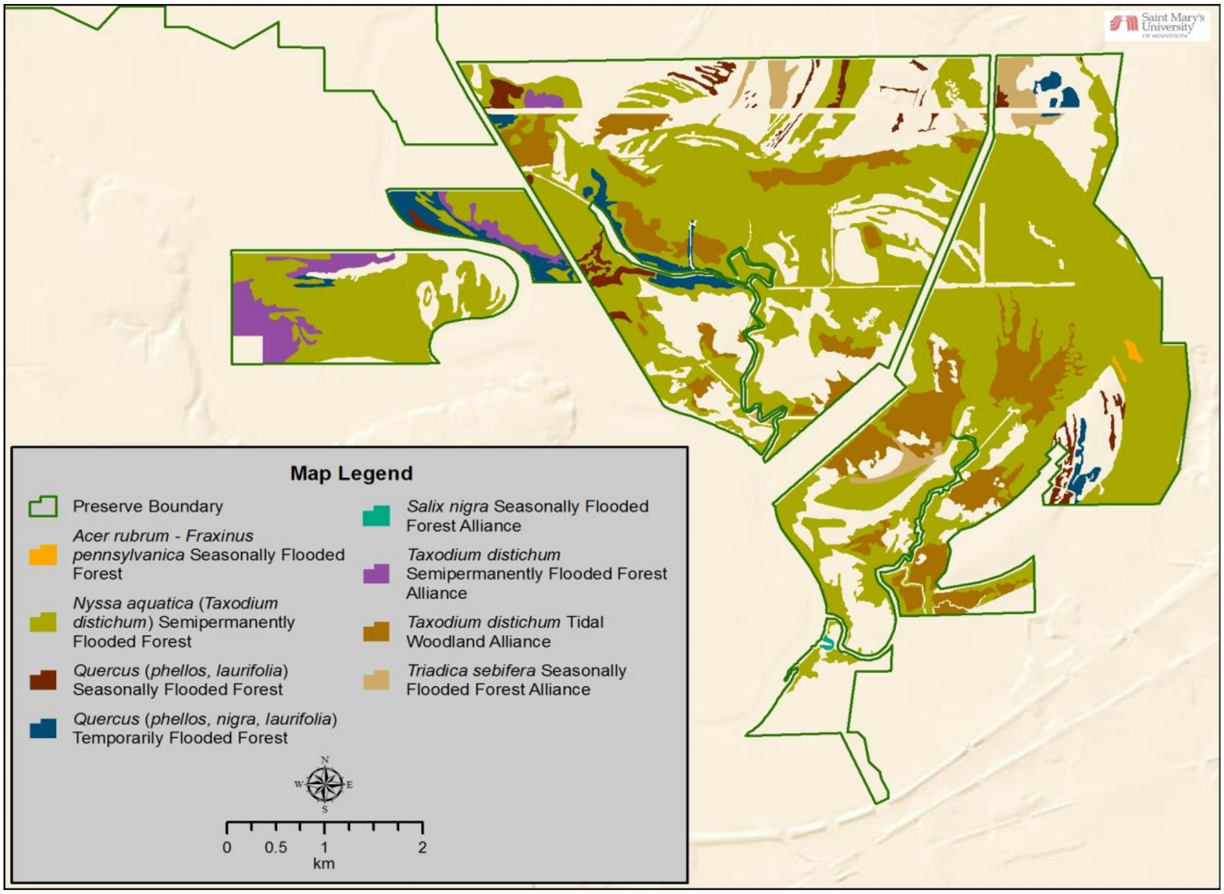

Figure 24. Floodplain forest vegetation within the lower Beaumont Unit (DESCO 2011).

Table 30. Floodplain forest extent (in ha) by community type (alliance) in the BSCU (PBS&J 2003), LRU (Blanton and Associates Inc. 2002), TCU (DESCO 2007) and the lower portion of the Beaumont Unit (LBU) (DESCO 2011).

Alliance	BSCU	LRU	TCU	LBU
Nyssa aquatica- (Taxodium distichum) Semi-permanently Flooded Forest	43.6	--	6.2	1,292.7
Taxodium distichum - Nyssa (aquatica, biflora, ogeche) Seasonally Flooded Forest	--	--	20.7	--
Fraxinus pennsylvanica - (Ulmus americana - Celtis (occidentalis, laevigata) Temporarily Flooded Forest	5.9	--	--	--
Quercus (laurifolia, phellos) Seasonally Flooded Forest	2,590.7	1,261	--	42.3
Magnolia virginiana-Nyssa biflora-(Quercus laurifolia) Saturated Forest	24.3	--	155.6	--
Nyssa (aquatica, biflora, ogeche) Floodplain Seasonally Flooded Forest	44.1	--	11.4	--

Table 30 (continued). Floodplain forest extent (in ha) by community type (alliance) in the BSCU (PBS&J 2003), LRU (Blanton and Associates Inc. 2002), TCU (DESCO 2007) and the lower portion of the Beaumont Unit (LBU) (DESCO 2011).

Alliance	BSCU	LRU	TCU	LBU
Nyssa (aquatica, biflora, ogeche) Pond Seasonally Flooded Forest	--	18	4.7	--
Quercus nigra Seasonally Flooded Forest	--	29	--	--
Quercus (phellos, nigra, laurifolia) Temporarily Flooded Forest	--	--	129.6	57.4
Pinus taeda – Quercus (phellos, nigra, laurifolia) Temporarily Flooded Forest	--	--	876.4	--
Taxodium distichum Semipermanently Flooded Forest Alliance	--	--	--	56.0
Taxodium distichum Tidal Woodland	--	--	--	227.4
Triadica sebifera Seasonally Flooded Forest Alliance	--	--	--	35.4
Acer rubrum-Fraxinus pennsylvanica Seasonally Flooded Forest Alliance	--	--	--	2.4
Salix nigra Seasonally Flooded Forest Alliance	--	--	--	0.6
Total	**2,708.6**	**1,308**	**1,204.6**	**1,714.2**

Canopy Cover

Very little scientific data on canopy cover has been collected in BITH's slope forests. Only Lewis et al. (2000) reported on canopy closure in a BSCU floodplain hardwood forest. These results show a high percentage of canopy cover in the overstory and midstory with a very sparse understory layer (Table 31).

Table 31. Percent canopy closure in floodplain hardwood forest plots (Lewis et al. 2000).

Forest Plots	Canopy Closure
Overstory	88.8
Midstory	84.8
Understory	14.4

Basal Area

As described in Chapter 4.2 of this document, basal area is a density measurement that takes into account the *area* occupied by each species, rather than just the *number* of stems of each species within a given area. Basal area data are limited for BITH's floodplain forests. Harcombe and Marks (1979) calculated basal areas for one swamp cypress tupelo forest, two floodplain hardwood pine forest, and 15 floodplain hardwood forest stands. The basal areas for these forest types by species and overall from Harcombe and Marks (1979) are shown in Table 32. Total basal area was much greater in the cypress tupelo stand than in the other floodplain forest types (Harcombe and Marks 1979).

Table 32. Mean total basal area (m^2/ha) by species within floodplain forest stands sampled by Harcombe and Marks (1979). Only species with basal areas >0.05 m^2/ha are included in the table. FHPF = Floodplain hardwood pine forest, FHF = Floodplain hardwood forest, CTF = Cypress tupelo forest.

Scientific Name	Common Name	FHPF	FHF	CTF
Cornus florida	flowering dogwood	0.2	-	-
Pinus taeda	loblolly pine	10.2	1.4	-
Quercus alba	white oak	1.6	-	-
Magnolia grandiflora	southern magnolia	2.3	0.2	-
Ostrya virginiana	hophornbeam	0.4	-	-
Fagus grandifolia	American beech	7.3	1.2	-
Ilex opaca	American holly	0.9	1.1	-
Magnolia virginiana	sweet bay	1.1	-	-
Nyssa sylvatica	black gum	3.1	1.3	10.8
Quercus laurifolia	laurel oak	1.0	0.3	-
Acer rubrum	red maple	0.2	1.1	2.5
Liquidambar styraciflua	sweetgum	2.3	5.8	0.6
Quercus phellos	willow oak	-	0.9	-
Quercus nigra	water oak	1.9	6.0	-
Quercus pagoda	cherrybark oak	-	0.9	-
Quercus michauxii	swamp chestnut oak	0.6	2.2	-
Cornus foemina	stiff dogwood	-	0.1	-
Fraxinus pennsylvanica	green ash	0.4	0.4	-
Ulmus alata	winged elm	0.2	0.2	-
Halesia diptera	two-wing silverbell	-	0.1	-
Carpinus caroliniana	American hornbeam; ironwood	1.4	4.2	-
Diospyros virginiana	common persimmon	-	-	0.1
Carya aquatica	water hickory	0.1	1.1	0.3
Ilex decidua	possumhaw	-	0.1	-
Taxodium distichum	bald cypress	-	0.3	22.5

Table 32 (continued). Mean total basal area (m^2/ha) by species within floodplain forest stands sampled by Harcombe and Marks (1979). Only species with basal areas >0.05 m^2/ha are included in the table. FHPF = Floodplain hardwood pine forest, FHF = Floodplain hardwood forest, CTF = Cypress tupelo forest.

Scientific Name	Common Name	FHPF	FHF	CTF
Quercus lyrata	overcup oak	-	0.5	0.4
Crataegus sp.	hawthorn	0.1	-	-
Carya glabra	pignut hickory	-	0.2	-
Nyssa aquatica	water tupelo	-	-	95.1
Planera aquatica	planertree; water elm	-	-	0.3
Cephalanthus occidentalis	common buttonbush	-	-	0.6
Fraxinus caroliniana	Carolina ash	-	-	4.9
Total		**35.3**	**29.6**	**138.1**

Fountain (1984) also documented basal areas in floodplain hardwood pine forest and floodplain hardwood forest plots. Basal areas were slightly lower than those documented by Harcombe and Marks (1979), with a mean total of 27.23 m^2/ha for floodplain hardwood pine and 27.85 m^2/ha for floodplain hardwood stands (Fountain 1984).

Harcombe et al. (1999) presented basal area data by species from a long-term study site within a NBU floodplain forest. Basal areas fluctuated over time, increasing from 28.1 m^2/ha in 1980 to 29.1 m^2/ha in 1989, before declining again by 1994 (Table 33). Most species increased in basal area over time, but American holly, American hornbeam, water hickory, and American elm (*Ulmus americana*) decreased.

Table 33. Total basal area (m^2/ha) by species and annualized percent change from 1980-1994 in a Neches Bottom floodplain forest (Harcombe et al. 1999). Annual percent change is the difference between 1994 and initial basal area divided by the initial basal area and the number of years since the initial basal area reading.

Species	1994 Basal Area	Annual % Change in Basal Area (since 1980)
Ilex opaca	0.62	-0.02
Quercus laurifolia	0.35	0.06
Nyssa sylvatica	0.99	0.01
Liquidambar styraciflua	6.74	0.01
Acer rubrum	2.56	0.00
Quercus nigra	2.90	0.03

Table 33 (continued). Total basal area (m^2/ha) by species and annualized percent change from 1980-1994 in a Neches Bottom floodplain forest (Harcombe et al. 1999). Annual percent change is the difference between 1994 and initial basal area divided by the initial basal area and the number of years since the initial basal area reading.

Species	1994 Basal Area	Annual % Change in Basal Area (since 1980)
Quercus michauxii	3.09	0.01
Carpinus caroliniana	2.76	-0.04
Taxodium distichum	1.72	0.03
Nyssa biflora	1.61	0.00
Quercus lyrata	1.36	0.02
Carya aquatica	0.85	-0.01
Ulmus americana	0.66	-0.02
Other	1.84	--
Total	**28.05**	--

More recent unit-specific surveys documented basal areas for a variety of floodplain forest vegetation alliances (Table 34; Blanton and Associates, Inc. 2002, PBS&J 2003, DESCO 2007). Basal areas in these surveys ranged from 20.73 m^2/ha (*Fraxinus pennsylvanica* - [*Ulmus americana* - *Celtis* [*occidentalis*, *laevigata*] Temporarily Flooded Forest in the BSCU) to 65.23 m^2/ha (*Taxodium distichum* - *Nyssa* [*aquatica*, *biflora*, *ogeche*] Seasonally Flooded Forest in the TCU).

Table 34. Basal area data (m^2/ha) for floodplain forest alliances in the BSCU (PBS&J 2003), LRU (Blanton and Associates, Inc. 2002), and TCU (DESCO 2007). Total basal area is for all woody vegetation (overstory, midstory, and shrub layer). NR = not reported

BSCU Floodplain Forest Alliances	Total Basal Area	Overstory Basal Area	Dominant Species - Basal Area
Nyssa aquatica- (*Taxodium distichum*) Semi-permanently Flooded Forest	55.17	NR	water tupelo - 33.41
Fraxinus pennsylvanica - (*Ulmus americana* - *Celtis* (*occidentalis, laevigata*) Temporarily Flooded Forest	20.73	NR	green ash - 7.23
Quercus (*laurifolia, phellos*) Seasonally Flooded Forest	32.73	NR	sweetgum - 5.02
Magnolia virginiana-*Nyssa biflora*-(*Quercus laurifolia*) Saturated Forest	41.09	NR	black gum - 16.42
Nyssa (*aquatica, biflora, ogeche*) Floodplain Seasonally Flooded Forest	38.35	NR	black gum - 5.62

Table 34 (continued). Basal area data (m^2/ha) for floodplain forest alliances in the BSCU (PBS&J 2003), LRU (Blanton and Associates, Inc. 2002), and TCU (DESCO 2007). Total basal area is for all woody vegetation (overstory, midstory, and shrub layer). NR = not reported

LRU Floodplain Forest Alliances	Total Basal Area	Overstory Basal Area	Dominant Species - Basal Area
Quercus nigra Seasonally Flooded Forest	28.07	22.39	water oak - NR
Quercus laurifolia Seasonally Flooded Forest	28.06	17.55	laurel oak - NR
Nyssa biflora Pond Seasonally Flooded Forest	51.75	29.31	black gum - NR
TCU Floodplain Forest Alliances			
Nyssa aquatica- (*Taxodium distichum*) Semi-permanently Flooded Forest	36.57	33.93	water tupelo - 12.84
Nyssa (*aquatica, biflora, ogeche*) Floodplain Seasonally Flooded Forest	42.66	37.16	black gum - 21.4
Quercus (*phellos, nigra, laurifolia*) Temporarily Flooded Forest	25.94	23.04	sweetgum - 8.92
Nyssa (*aquatica, biflora, ogeche*) Pond Seasonally Flooded Forest	43.14	39.55	black gum - 35.27
Taxodium distichum - *Nyssa* (*aquatica, biflora, ogeche*) Seasonally Flooded Forest	65.23	63.27	bald cypress - 37.26
Magnolia virginiana-Nyssa biflora-(*Quercus laurifolia*) Saturated Forest	31.21	25.05	sweet bay - 6.81
Pinus taeda – *Quercus* (*phellos, nigra, laurifolia*) Temporarily Flooded Forest	33.56	29.91	loblolly pine - 10.05

Age Class

Forest age structure is often studied using size class distributions and can be helpful in inferring the history and current successional status of a forest stand (Harcombe and Marks 1975). Tree species that are successfully regenerating will be present in many size classes and abundant in smaller size classes, whereas newly invading species will be common in the smallest size classes and absent from the larger ones (Harcombe and Marks 1975). To date, only one available study has reported on size classes in a BITH floodplain forest. Harcombe and Marks (1975) documented size class distribution by species in a BCU bottomland forest (Table 35). The results for all overstory species combined are presented graphically in Figure 25.

Table 35. Size class distributions (diameter in cm) of overstory and understory trees for a bottomland forest in the BCU (Harcombe and Marks 1975).

Overstory Trees	**5-9**	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**	**45-49**	**50-54**	**≥55**
Acer rubrum	12	12	2	--	2	--	--	--	--	--	--
Fagus grandifolia	--	4	2	6	18	6	14	10	--	4	2
Liquidambar styraciflua	12	6	2	8	10	2	6	--	--	--	--
Nyssa sylvatica	90	28	28	4	8	8	2	--	--	--	--
Pinus taeda	2	--	8	10	18	10	22	16	12	20	10
Quercus nigra	8	6	6	--	8	8	--	4	--	--	--
Q. michauxii	8	4	--	--	--	--	--	2	--	--	2
Total	**132**	**60**	**48**	**28**	**64**	**34**	**44**	**32**	**12**	**24**	**14**
Understory Trees											
Carpinus caroliniana	164	68	24	8	--	--	--	--	--	--	--

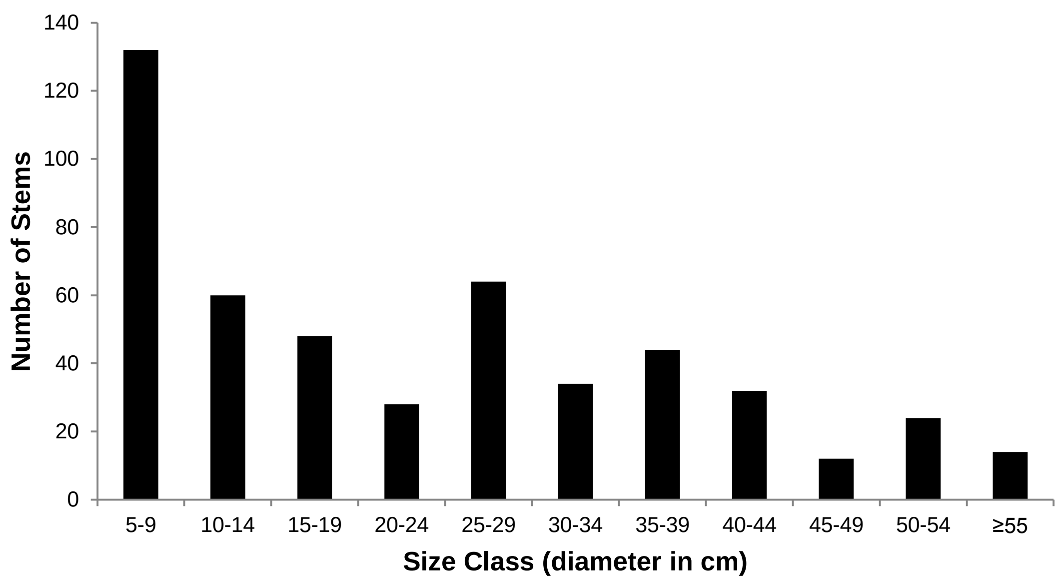

Figure 25. Size class distribution of overstory trees in a BCU bottomland forest (Harcombe and Marks 1975).

Threats and Stressor Factors

Threats to BITH's slope forests include invasive plants, feral hogs, lack of flood pulse events, unplanned fire occurrence, hurricanes, drought, and past human disturbance (e.g., oil and gas impacts, logging). Although the floodplain forests have not been specifically inventoried for invasive plants, Chinese tallow has been documented in several floodplain forest communities. This woody non-native species can displace native species and alter ecosystem structure and function (Gordon 1998, Keay et al. 2000, McCormick 2005). According to Keay et al. (2000, p. 57), Chinese tallow "may be the most serious threat to the biotic integrity of native coastal prairies and floodplain forests." Floodplain forests may be more vulnerable to invasive plant invasion than other communities due to the open nature of the understory (Harcombe et al. 1999) and the easy transport that water-borne seeds have to be distributed into the floodplain areas. Harcombe and Marks (1979) documented Chinese tallow invading established floodplain hardwood forest as early as the mid-1970s in the southwestern part of the BU. Fountain (1984) also recorded Chinese tallow at abandoned oil and gas well sites within the preserve's floodplain forests. In a Neches Bottom floodplain forest, Harcombe et al. (1999) noted that Chinese tallow increased by a factor of 30 between 1981 and 1995. Blanton and Associates, Inc. (2002) documented the invasive species in several of the LRU's floodplain forest alliances; in the *Quercus nigra* Seasonally Flooded Forest Alliance, Chinese tallow comprised nearly 4% of the canopy (based on relative importance values) (Blanton and Associates, Inc. 2002). Hardy orange (*Poncirus trifoliata*), an invasive small tree used as rootstock in the citrus industry, has become a serious concern in the bottomlands of the BSCU. Numerous invasive vines (e.g., Japanese climbing fern, kudzu [*Pueraria montana* var. *lobata*]) are also a threat and are invading along the forest edges of roads, pipelines, and utility corridors (Hyde, written communication, 26 August 2015).

Feral hog numbers have increased across the southern United States in recent decades, including in Texas and the BITH region (Chavarria 2006). Floodplains often experience more hog damage than other vegetation communities, as hogs generally prefer mesic and wet areas near water sources for wallowing and rooting for food (Chavarria 2006). In the BSCU, for example, Chavarria (2006) documented extensive hog damage in the cypress tupelo forest. The hogs eat a majority of the mast crops produced by the native hardwoods, thereby greatly limiting those tree's ability to repopulate any disturbed areas.

According to Allen et al. (2001, p. 14), "hydrology is the most important factor affecting the local distribution of bottomland tree species within their natural ranges." Hydrology includes an area's flooding regime (e.g., frequency, duration, timing, source). In the BITH region, human activities have altered the area's flood regime. In a study of the NBU-JGBU, Hall (1993) identified eight impoundments on the Neches River upstream of BITH. The two impoundments closest to the preserve are Lake Rayburn and Steinhagen (or Town Bluff) Lake, completed 50-60 years ago (Hall 1993). Hall (1993) found that upstream impoundments reduced flow variability on the Neches River by significantly reducing annual peak flows while increasing median daily flow. The frequency of large floods has decreased dramatically, from an average of more often than once every 2 years to just once in every 2-5 years. Harcombe et al. (1999) noted that 1975-1989 was the longest period of low flooding since record-keeping began in 1921. This reduction in the frequency and severity of flooding has contributed to increased sapling survivorship and recruitment, particularly among typically flood-intolerant species (Hall 1993). These changes could alter the structure and composition of floodplain forest vegetation (Harcombe et al. 1999). Impoundments and the related flood regime changes could further impact forests through effects on soil moisture and aeration, sediment deposition, and seed dispersal (Hall 1993).

The preserve’s floodplain forests have also been impacted by oil and gas development infrastructure (e.g., drilling pads, pipelines). Preserve records indicate that over 215 wells have been drilled within BITH boundaries, although most were plugged and abandoned before preserve establishment in 1974 (NPS 2006; Hyde, written communication, 26 August 2015). Several wells are still operational in the preserve and, with associated production facilities, resulted in a total disturbed area of 4.5 ha (11 ac) as of 2005. In conjunction with short-term disturbances from seismic data collection on deep oil and gas reserves, which have occurred across most of the larger units of the preserve, at least 30 directional wells have been drilled from locations outside preserve boundaries to reach targets deep (1,524-4,572 m[5,000-15,000 ft]) under the preserve (NPS 2006). At two of the abandoned well sites, the NPS has documented contamination from saltwater, hydrocarbons, and heavy metals. Approximately 20 of the abandoned wells fall within the Neches River floodplain and associated bottomland hardwood forest habitats and could become exposed due to river migration (NPS 2006). To date, this has occurred at two capped wells (Hyde, written communication, 26 August 2015). Fountain (1984) found that plant species richness and diversity was lower in abandoned well pad areas than in adjacent control (undisturbed) plots. The impacts of this disturbance appeared to be greater as soil moisture increased among preserve vegetation communities.

There are also 71 oil and gas pipeline segments crisscrossing the preserve for a total of 162.5 km (101 mi) (NPS 2006; Figure 26); the rights-of-way associated with these pipelines cover 238 ha (589 ac). These pipelines carry crude oil, natural gas, liquid petroleum gas, natural gas liquids, and saltwater, and can pose a serious threat to preserve resources if not managed and maintained properly (NPS 2006). The open right-of-way areas along the pipelines can fragment forests and potentially alter vegetation composition on forest edges (Watson 1982). These areas are maintained as grasslands with all tree saplings and shrubs removed during periodic maintenance. Current best management practices would allow that many of these pipelines will be replaced over time using directional drilling methods from outside the preserve. However, ground disturbance may still occur if pipeline anomalies are found and need to be repaired. The right-of-ways are still maintained as mowed grasslands. Similarly, 20 or more utility rights-of-way, including above-ground and buried electric, phone, and fiber optic lines, also criss-cross the preserve with similar impacts due to annual maintenance (Hyde, written communication, 26 August 2015).

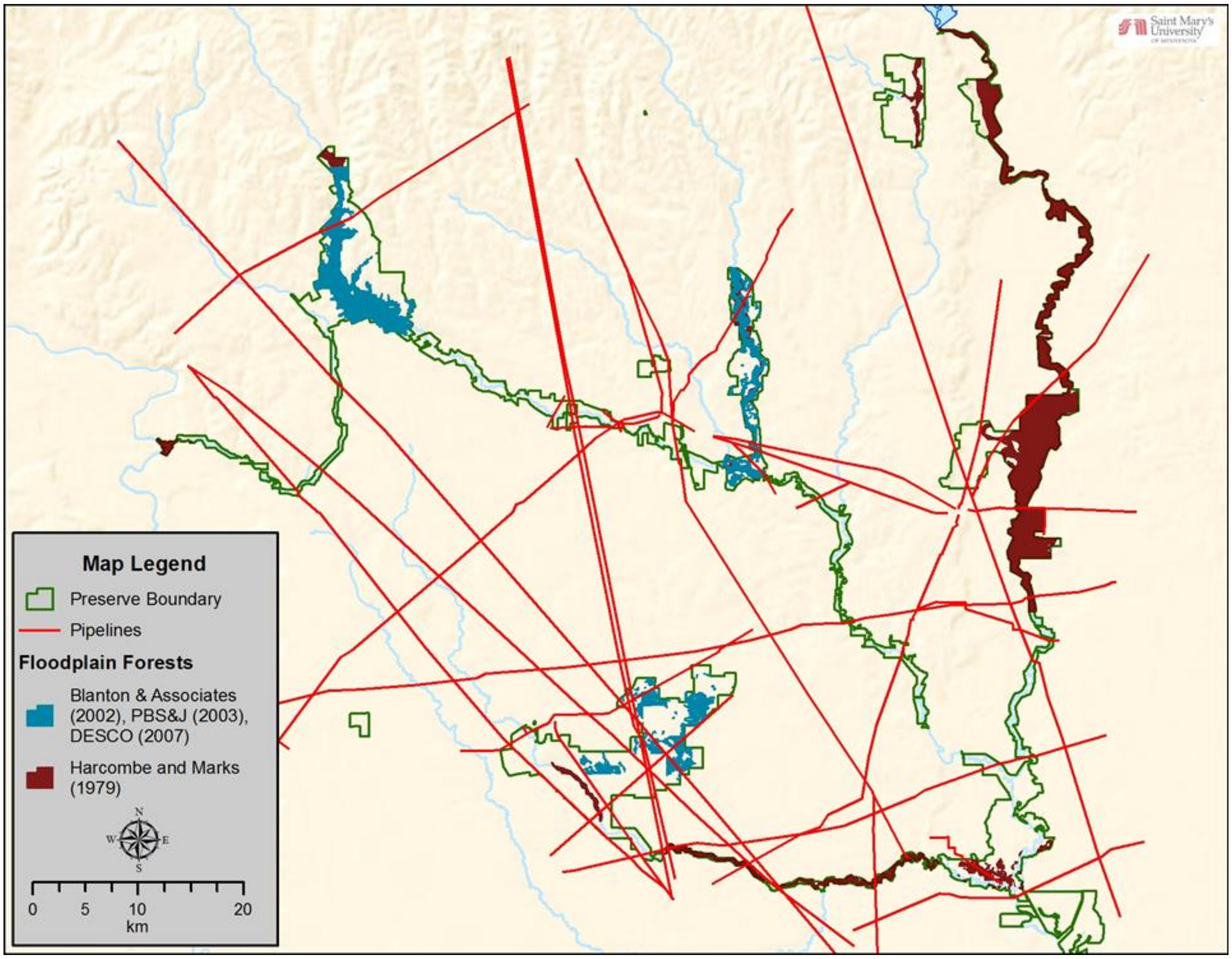

Figure 26. Oil and gas pipelines in the BITH area (Hebert 2003), shown crossing mapped floodplain forest vegetation.

Due to its location near the Gulf of Mexico, BITH is impacted by tropical storms and hurricanes relatively frequently (Harcombe and Marks 1979). Although the effects of these storms on floodplains are rarely catastrophic, they can influence forest structure and composition by creating "light gaps" in the tree canopy (Harcombe et al. 2009). Harcombe et al. (2009) studied the impacts of Hurricane Rita, which made landfall in September 2005, on a river floodplain forest in the NBU. Wind gusts at this site during the storm were around 145-177 km/hr (90-110 mi/hr) (Harcombe et al. 2009). Within the floodplain forest, 22% of trees were dead or severely damaged following the storm. Among canopy tree species at this site, Harcombe et al. (2009) observed above average mortality in red maple, American hornbeam, and water hickory; bald cypress exhibited below average mortality. No simple explanation has been found for these differences in mortality during hurricanes; it is likely a combination of factors including wood density, rooting characteristics, and tree form and height (Brokaw and Everham 1996, Harcombe et al. 2009). Hurricane Ike in 2008 resulted in additional extensive damage, particularly in bottomland hardwood areas of the TCU and BCU, as its wind rotation made landfall rotating in the opposite direction of that of Hurricane Rita (Hyde, written communication, 26 August 2015).

Glitzenstein et al. (1999) showed that severe droughts decreased tree growth rates in east Texas forests. Drought also impacts seedling composition, recruitment, and mortality in floodplain forests (Streng et al. 1989). Seedlings of light-seeded species, such as elm and sweetgum, seemed to experience greater impacts than heavier-seeded species, like oaks (Streng et al. 1989). According to Harcombe et al. (1999), drought frequency is likely to increase in east Texas due to global climate change. Climate change may also alter the frequency, intensity, and timing of hurricanes and floods in the region (Harcombe et al. 1999).

Data Needs/Gaps

Very little information is available for two of the selected measures in BITH's floodplain forests: canopy cover and age class. The limited age/size class data (Harcombe and Marks 1975) are now over 30 years old. Although basal area data are available, some of it is outdated and some of it is geographically limited to individual units within the preserve. Studies of Chinese tallow invasion would help to better understand the full impact this invasive species is having in floodplain forests.

A preserve-wide vegetation map does not exist, although mapping efforts are expected to be initiated in 2016. NPS (2006) noted specifically that little information exists on the locations of old-growth cypress stands. The GULN is developing a vegetation monitoring protocol that will begin gathering data on plant community composition and coverage in several BITH units by 2016 (Woodman, written communication, December 2014). The focus of this monitoring will be the TCU, JGBU, BCU, and LRU (Segura, email communication, 18 February 2015), all of which support floodplain forest vegetation.

Overall Condition

Extent

The project team assigned this measure a *Significance Level* of 3. In the late 1970s, floodplain forests covered approximately 11,000 ha of BITH (Harcombe and Marks 1979). More recent vegetation mapping efforts have been limited to individual units of the preserve, so the current preserve-wide extent of floodplain forests is unknown. Therefore, a *Condition Level* was not assigned.

Canopy Cover

This measure was also assigned a *Significance Level* of 3. Only one study (Lewis et al. 2000) has reported on floodplain forest canopy closure, and sampling was limited to one unit of the preserve. Due to this lack of data, a *Condition Level* could not be assigned for this measure.

Basal Area

The basal area measure was assigned a *Significance Level* of 2. Although some basal area data are available for the preserve, much of this is outdated (Harcombe and Marks 1979) or limited to individual preserve units (Blanton and Associates, Inc. 2002, PBS&J 2003, DESCO 2007). As a result, a *Condition Level* was not assigned for this measure.

Age Class

A *Significance Level* of 2 was assigned for this measure. Age or size class distribution data for the preserve is limited to one outdated study (Harcombe and Marks 1975) which sampled floodplain forest in only one unit. Therefore, a *Condition Level* could not be assigned for this measure at this time.

Weighted Condition Score
A WCS was not calculated for this component, due to a lack of data for the selected measures. The current condition of BITH's floodplain forests is unknown.

Floodplain Forests			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Extent	3	n/a	
Canopy cover	3	n/a	
Basal area	2	n/a	
Age class	2	n/a	

4.6.6 Sources of Expertise

- Ken Hyde, BITH Chief of Resource Management

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4.7 Estuarine Wetlands

4.7.1 Description

According to Cowardin et al. (1979, p. 4-7), an estuarine system

> *consists of deepwater tidal habitats and adjacent tidal wetlands that are usually semi-enclosed by land but have open, partly obstructed, or sporadic access to the open ocean, and in which ocean water is at least occasionally diluted by freshwater runoff from the land... The estuarine system extends upstream and landward to where ocean-derived salts measure less than 0.5 ppt during the period of average annual low flow" (ppt = parts per thousand).*

With the recent completion of the saltwater barrier on the lower Neches River, the dredged and soon to be deepened Sabine-Neches Waterway shipping channel, and the ever-growing threat of sea level rise from climate change impacts, BITH managers felt it was important to review and include this section on estuarine wetlands. The drought of 2011-2012 in Texas was one of the hottest and driest droughts in Texas history, and clearly demonstrated the impacts of saltwater intrusion on the primarily freshwater wetland habitats currently found in the lower portion of the BU. Within BITH, the potential areas for estuarine wetlands to develop are limited to the BU, on those lands below where a permanent saltwater barrier was constructed on the Neches River in 2003 (Winemiller at al. 2014). This portion of the preserve was acquired by the NPS in 2009 (Winemiller et al. 2014) and is located between river mile 24 and 29 of the Neches River. Currently, a majority of this portion of the BU is covered with cypress-tupelo forests or open cutgrass-cattail wetlands, both of which were showing significant signs of saltwater induced stress during the drought of 2011-2012. The wetlands in this area provide crucial ecosystem services, including water quality maintenance, flood mitigation, groundwater recharge, and habitat for a wide variety of wildlife (Tremblay and Calnan 2009, Winemiller et al. 2014). Remaining wetlands are increasingly important, as the Neches River Valley has experienced the most widespread loss of contiguous wetlands of any Texas coastal area (White and Tremblay 1995).

The Neches River drains into Sabine Lake, which is connected to the Gulf of Mexico by Sabine Pass (Figure 27; Winemiller et al. 2014). Saltwater enters Sabine Lake through Sabine Pass and continues up the Neches River to the saltwater barrier at Beaumont. The barrier was put in place to protect upstream freshwater supplies including those for the the City of Beaumont, from saltwater intrusion (TTWP 1998). Constructed by the U.S. Army Corps of Engineers and finished in 2003, the permanent barrier replaced temporary barriers that were periodically constructed further upstream during low flows, on the Neches River and Pine Island Bayou within BITH (Figure 28; TTWP 1998).

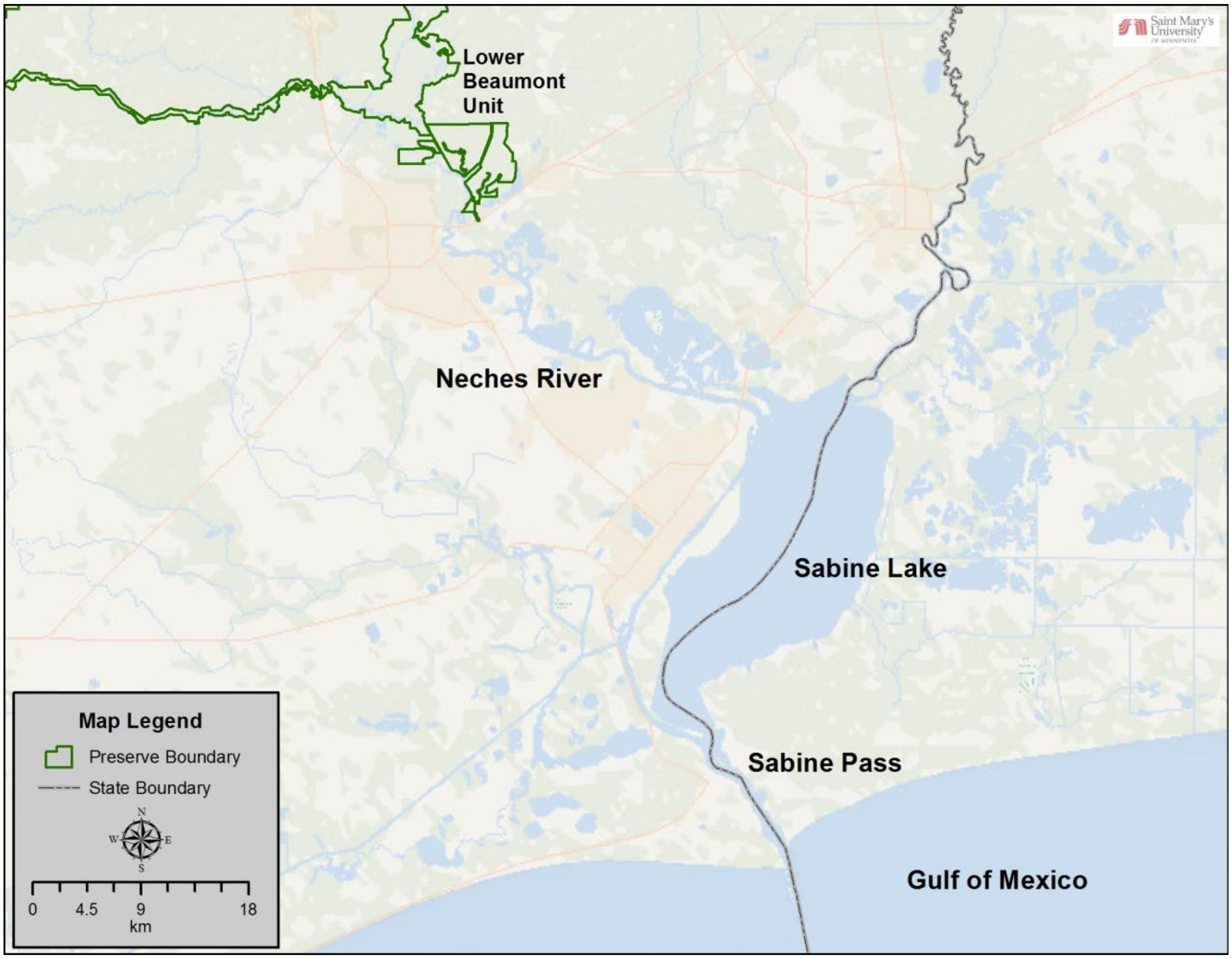

Figure 27. Water bodies connecting the Beaumont Unit to the Gulf of Mexico.

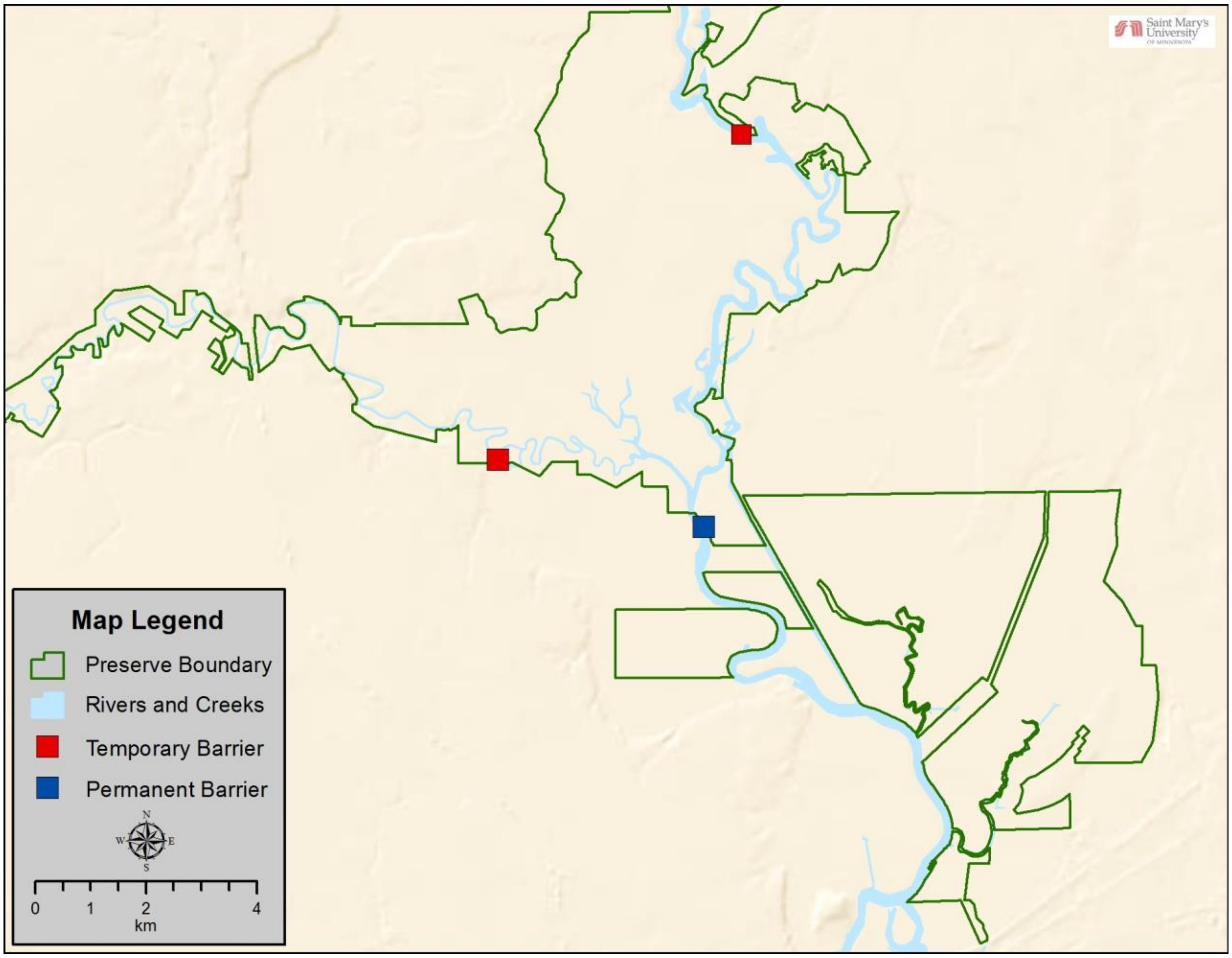

Figure 28. Approximate locations of former temporary saltwater barriers and the permanent saltwater barrier.

The area below the saltwater barrier is presently dominated by a bald cypress and water tupelo forested swamp with open areas supporting graminoids such as giant cutgrass (*Zizaniopsis miliacea*) (DESCO 2013, Winemiller et al. 2014). Other native species present include sweetgum, red maple, and California bulrush (*Schoenoplectus californicus*) (DESCO 2011, 2013). Nearly all of the trees are "secondary growth," as the area was heavily logged in the early 20th century (Winemiller et al. 2014). A series of channels were dredged during the timber harvesting and these allow saltwater flows to further access and impact the current cypress-tupelo and cutgrass habitats. With little overland flow entering these areas except during periods of high rainfall, and reduced or heavily managed flows coming down the Neches River, these areas tend to be stagnant (Herbert Young, BITH Biologist, written communication, 26 August 2015). As a result, saltwater is not flushed back towards the ocean as often as it might be in a naturally functioning system.

Photo 10. View of the permanent saltwater barrier from upstream (left, November 2011) and downstream (right, July 2012) (photos from Winemiller et al. 2014).

4.7.2 Measures

- Extent

4.7.3 Reference Conditions/Values

The reference condition for this component is the extent of estuarine wetlands mapped by DESCO (2011, 2013) in the lower portion of the BU. While it is unclear exactly which of these wetlands would meet the Cowardin et al. (1979) definition of "estuarine" (>0.5 ppt during the period of average annual low flow), all wetlands below the saltwater barrier are likely already (or soon will be) impacted by saltwater intrusion.

4.7.4 Data and Methods

DESCO (2011, 2013) completed vegetation assessments of BITH's BU prior to and after 2012 seismic survey activities in the area (Photo 11). Field work was conducted from April-June 2011 and again in April and May 2013 (DESCO 2013). Assessment efforts resulted in a vegetation classification and map for the entire BU, with the exception of a small southern portion that was not included in the study area.

Photo 11. A bald cypress tidal woodland plot (photo from DESCO 2013).

Some insight into wetland extent can also be gained from National Wetland Inventory (NWI) data. The NWI is a nation-wide wetland mapping database managed by the USFWS (USFWS 2015). Data can be downloaded from the NWI website at http://www.fws.gov/wetlands/Data/Data-Download.html. NWI data for the BITH area (USFWS 2014) are based on photointerpretation of 1990s aerial imagery of the region.

Winemiller et al. (2014) studied environmental flow needs for the lower Neches River just downstream of the saltwater barrier, with field work taking place in 2011 and 2012. Although the primary targets of this study were water quality and fish populations, researchers also observed and documented evidence of recent cypress and tupelo mortality during 2012, following the severe drought of 2011 (Winemiller et al. 2014).

4.7.5 Current Condition and Trend

Extent

According to DESCO (2011, 2013), wetland vegetation covers 2,003.3 ha (4,950.3 ac) of their study area in the lower portion of the BU (Table 36, Figure 29). The most common vegetation type is the *Nyssa aquatica*-(*Taxodium distichum*) Semipermanently Flooded Forest (Photo 12), occupying 1,292.7 ha (3,194.3 ac). Only two other types comprised more than 200 ha (494 ac) of area: *Zizaniopsis miliacea* Tidal Herbaceous at 263.3 ha (650.6 ac) and *Taxodium distichum* Tidal Woodland with 227.4 ha (561.9 ac) (DESCO 2011, 2013; Table 36). Except for a small area along the northern boundary (around 275 ha [680 ac]), all of these wetlands lie below the saltwater barrier (Young, written communication, 26 August 2015).

Table 36. Area (in ha) of wetland vegetation communities in the lower portion of the Beaumont Unit (DESCO 2013).

Alliance	Area (ha)
Acer rubrum-Fraxinus pennsylvanica Seasonally Flooded Forest Alliance	2.4
Alternanthera philoxeroides Semipermanently Flooded Herbaceous Alliance	13.4
Cephalanthus occidentalis Semipermanently Flooded Shrubland Alliance	0.9
Nyssa aquatica-(Taxodium distichum) Semipermanently Flooded Forest	1,292.70
Mixed Herbaceous Temporarily Flooded Alliance	9.4
Rhyncospora corniculata Seasonally Flooded Herbaceous Alliance	1.5
Quercus (phellos, laurifolia) Seasonally Flooded Forest Alliance	42.3
Quercus (phellos, nigra, laurifolia) Temporarily Flooded Forest Alliance	57.4
Salix nigra Seasonally Flooded Forest Alliance	0.6
Schoenoplectus californicus Tidal Herbaceous	0.6

Table 36 (continued). Area (in ha) of wetland vegetation communities in the lower portion of the Beaumont Unit (DESCO 2013).

Alliance	Area (ha)
Taxodium distichum Semipermanently Flooded Forest Alliance	56
Taxodium distichum Tidal Woodland	227.4
Triadica sebifera Seasonally Flooded Forest Alliance	35.4
Zizaniopsis miliacea Tidal Herbaceous	263.3
Total	**2,003.3**
Total Forested/Shrub	**1,715.1**
Total Herbaceous	**288.2**

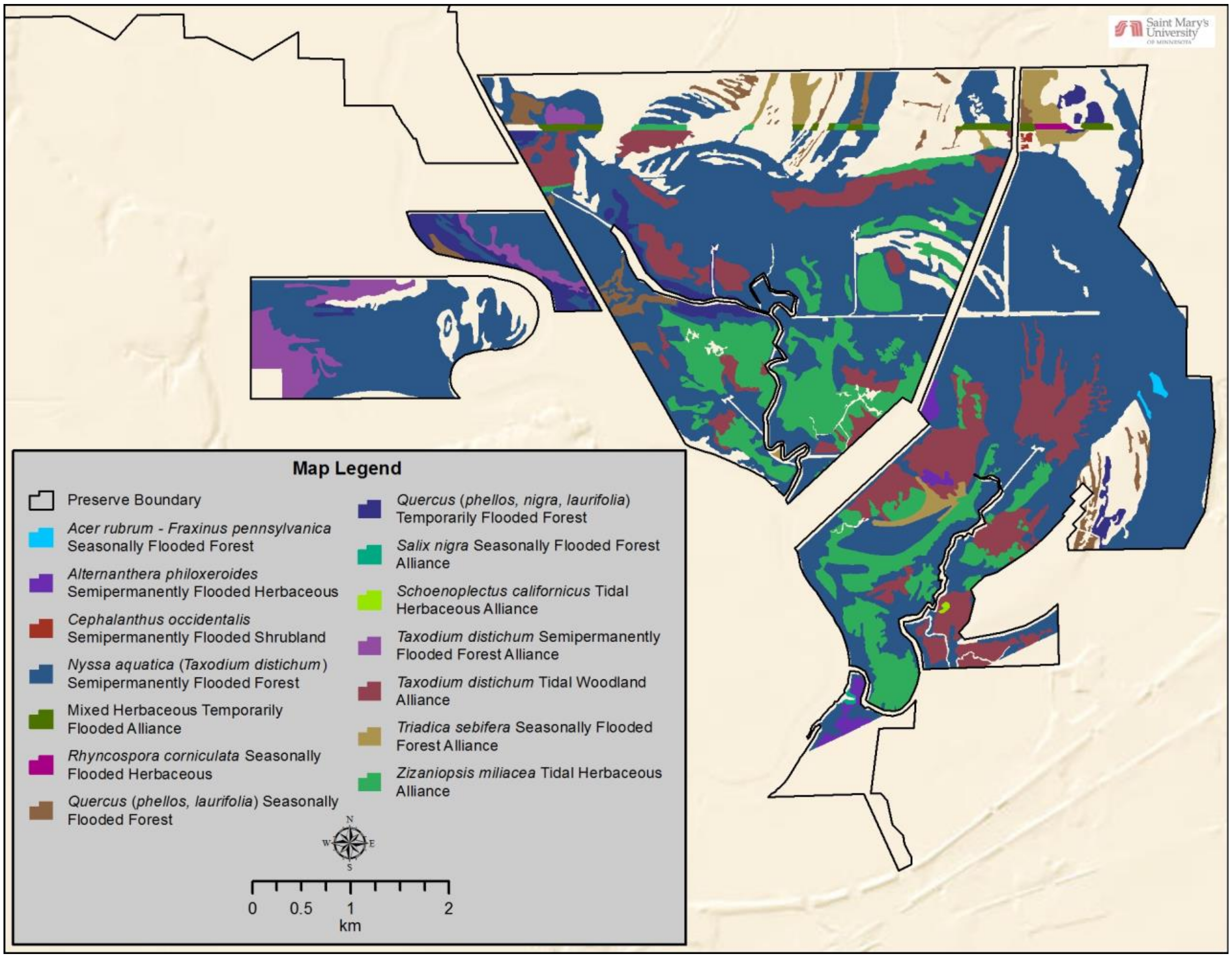

Figure 29. Wetland vegetation in the lower portion of the Beaumont Unit as mapped by DESCO (2011, 2013). Note that the southernmost portion of the unit was not included in the study area.

Photo 12. *Nyssa aquatica*-(*Taxodium distichum*) Semipermanently Flooded Forest (left) and *Zizaniopsis miliacea* Tidal Herbaceous Alliance (right) (photos from DESCO 2013).

NWI data can also provide some insight into wetland extent in the BITH area. Current NWI data for the region are based on aerial imagery from the 1990s. Because this is a nation-wide dataset, it covers the southernmost portion of the unit that was not included in the DESCO (2011, 2013) study area. This mapping is based largely on photointerpretation and would not include extensive field verification, as was conducted by DESCO (2011, 2013). As a result, NWI data are not as detailed and are likely not as accurate as DESCO (2011, 2013) results. However, the DESCO (2011, 2013) studies were also conducted during and just after one of the hottest and driest droughts in Texas history, and included a period of several months where almost no fresh river water was released below the saltwater barrier. In contrast, the areas would receive 175 cm (69 in) of rainfall in 2015, and due to heavy releases out of fears that upstream dams on the Neches River would be overtopped by floodwaters, the river ran at flood stage for nearly 4 months from March to June. During this time, the saltwater gates were never closed. Current NWI data indicates that none of the wetlands within the lower portion of the BU are classified as estuarine; all wetlands are classified as palustrine (i.e., freshwater) (USFWS 2014). The current wetlands are considered by BITH managers to be freshwater wetlands that have been impacted by saltwater intrusion with many of the cypress-tupelo forested areas showing major stress and much higher mortality rates. These wetlands areas are expected to be subjected to an ever increasing set of water quality parameters similar to those found by DESCO (2011, 2013), and would in time convert over to estuarine plant communities better able to thrive in the saline aquatic environments.

According to NWI data, vegetated wetlands covered 2,862 ha (7,072 ac) of the lower portion of the BU (Figure 30). This includes 2,363 ha (5,840 ac) of forested or shrub wetlands and 499 ha (1,232 ac) of emergent (i.e., herbaceous) wetlands (USFWS 2014). This total is slightly higher than that mapped by DESCO (2011, 2013; see Table 36), partly due to the inclusion of the southernmost portion of the unit which was not mapped by DESCO. It is also possible that some vegetated wetlands were lost between the 1990s imagery and DESCO's more recent mapping, particularly in the part of the unit west of the Neches River which butts up against the City of Beaumont (Figure 31).

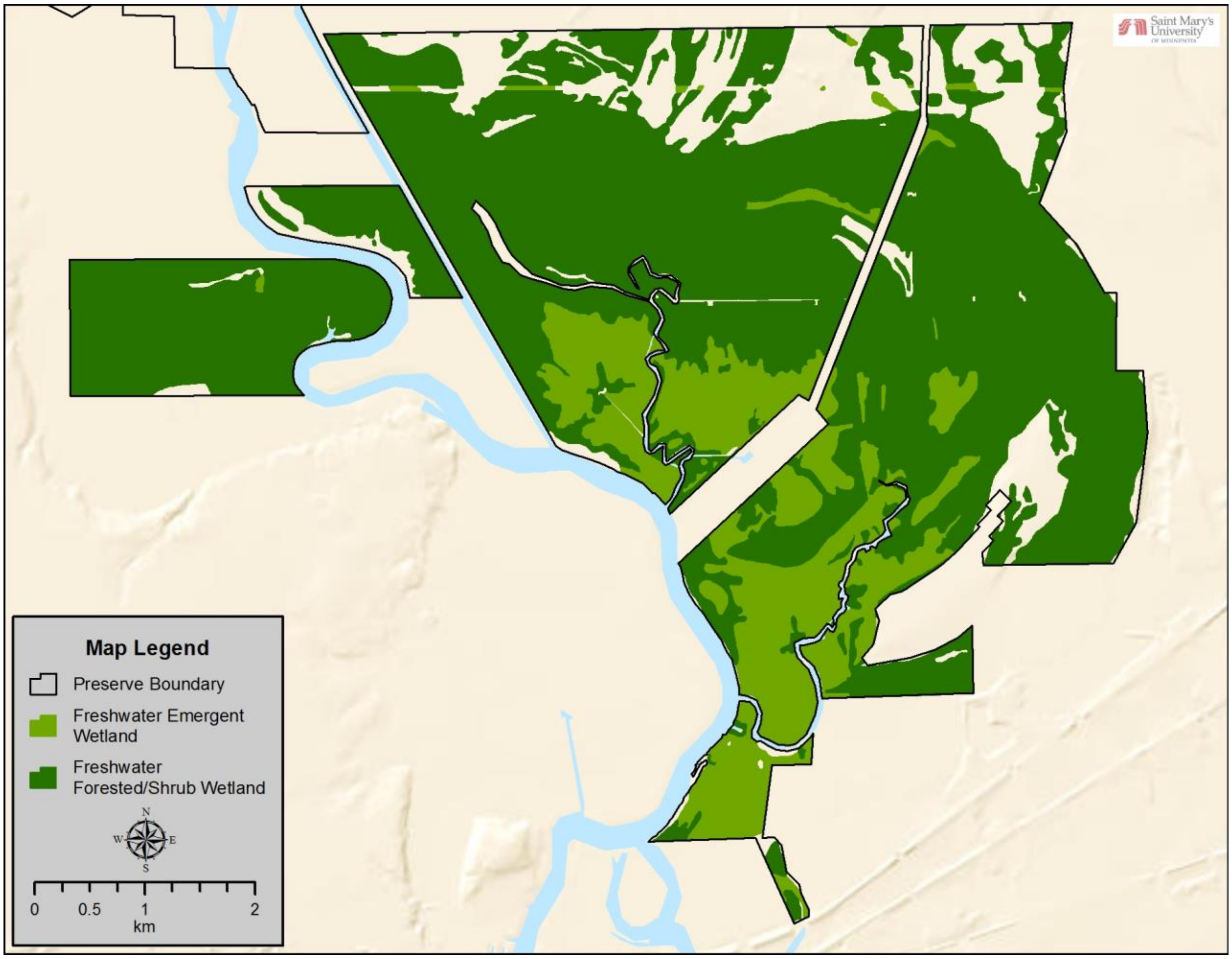

Figure 30. Wetland extent in the lower portion of the Beaumont Unit according to NWI data, based on 1990s aerial imagery (USFWS 2014). Note that some area along the northernmost boundary lies above the saltwater barrier.

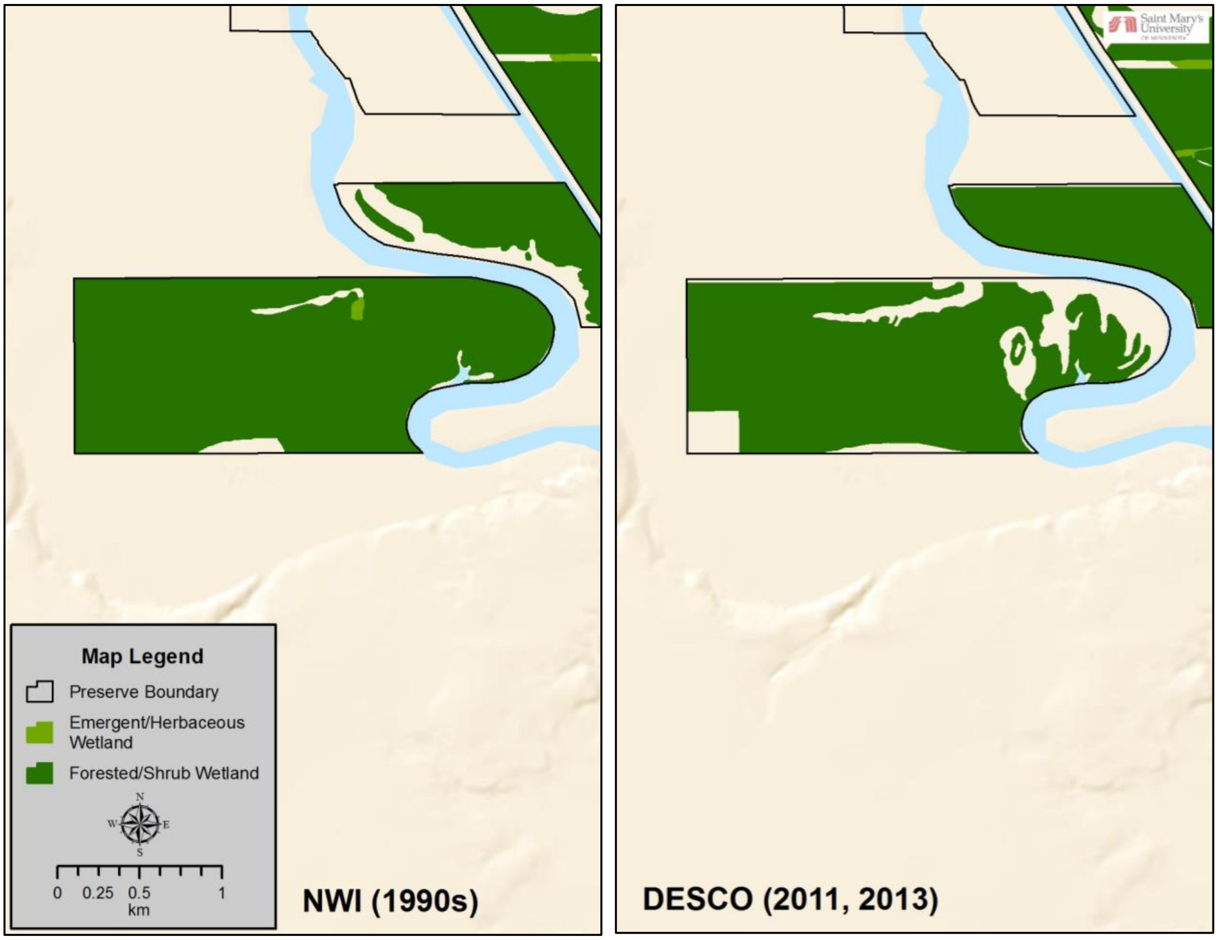

Figure 31. Wetland extent in the portion of the lower Beaumont Unit west of the Neches River according to the NWI (left, USFWS 2014) based on 1990s imagery and as mapped by DESCO (2011, 2013; right). It is unclear whether differences represent actual changes over time or simply differences in methodology.

<u>Threats and Stressors Factors</u>

The wetlands of BITH's BU face many threats and stressors. These include saltwater intrusion, hypoxia (i.e., low dissolved oxygen levels), lack of flooding (freshwater), pollution (especially from the many industrial plants just downstream), invasive species, subsidence, sea level rise, changes in port width/depth, a raising of the coastal diking system, and climate change. Saltwater intrusion first became a problem in the Neches River in the early 1900s, following the excavation of several large navigation channels between Sabine Pass and the Port of Beaumont (TTWP 1998). These channels provided an opportunity for saltwater to migrate upstream during periods of low river flow or storm surge events (TTWP 1998). While the permanent saltwater barrier at Beaumont prevents saltwater from travelling any further upstream when it is closed, it also reduces the flow of freshwater into the river and wetlands below the barrier, particularly during droughts (Winemiller et al. 2014). These downstream freshwater flows and flood pulses have historically prevented or "counteracted" upstream intrusion of saltwater. As a result, the difference in salinity levels above and just below the barrier can be dramatic. During a severe drought in November 2011, the salinity level in the Neches

River above the barrier was 0.08 ppt, while the salinity levels below the barrier ranged from 13.3-15.8 ppt (Winemiller et al. 2014).

Prolonged elevated salinity levels are a serious threat to cypress-tupelo stands and many other native wetland species (Shaffer et al. 2009, Winemiller et al. 2014). Bald cypress and water tupelo are flood tolerant and are more tolerant of temporary low-level salinity (≤2 ppt) than many other native tree species (Allen et al. 1998). However, higher salinities from increased saltwater intrusion will impact the structure, composition, and growth of forested estuarine wetlands (Krauss et al. 2009, Winemiller et al. 2014). In a North Carolina study, Hackney et al. (2007) found that 2 ppt is the salinity threshold above which forested swamp begins converting to oligohaline and brackish marshes. Bald cypress and water tupelo exposed to salinities above 2 ppt are damaged by salt ion (Na^+, Cl^-) accumulation, which causes necrotic leaf patches, leaf drop, and twig dieback (Krauss et al. 2009, Winemiller et al. 2014). Salinities as low as 0.5 ppt can inhibit tree and seedling growth by reducing water uptake and may also limit seed germination (Conner et al. 1997, Kozlowski 1997, Winemiller at al. 2014). Winemiller et al. (2014) observed dead and dying bald cypress and water tupelo along waterways in the lower portion of the BU in summer 2012, following elevated salinity levels and hypoxic conditions during the 2011 drought (Photo 13).

Photo 13. Recently killed bald cypress (foreground) along the Neches River below the saltwater barrier, May 2012 (photo from Winemiller et al. 2014).

Subsidence (i.e., sinking of land) has been known to reduce the elevation of wetlands relative to sea level, which may allow increased flooding and saltwater intrusion (Tremblay and Calnan 2009). Subsidence is frequently caused by shifts in subsurface materials or water levels (USGS 2014a). In southeast Texas, subsidence has been associated with groundwater withdrawals and oil and gas extraction (Tremblay and Calnan 2009). Drought conditions, which often lower groundwater levels, have also caused wetland elevation declines in Texas (Cahoon et al. 2011).

The construction of the saltwater barrier in 2003 and other upstream impoundments (e.g., Steinhagen Lake) has reduced the magnitude and frequency of flood pulses in the lower portion of the BU (Hall 1993, Winemiller et al. 2014). Winemiller et al. (2014) estimated flow rates at the saltwater barrier location since 1968. These estimates show a drastic decrease in the magnitude of high flows and a lack of flood pulses over the past decade (Figure 32). Wetland tree species including bald cypress and water tupelo require periodic inundation for successful seed dispersal, germination, and seedling recruitment (Sharitz and Mitsch 1993, Winemiller et al. 2014). Flooding also reduces competition from flood-intolerant plant species and maintains sediment dynamics (Hall 1993, Winemiller et al. 2014).

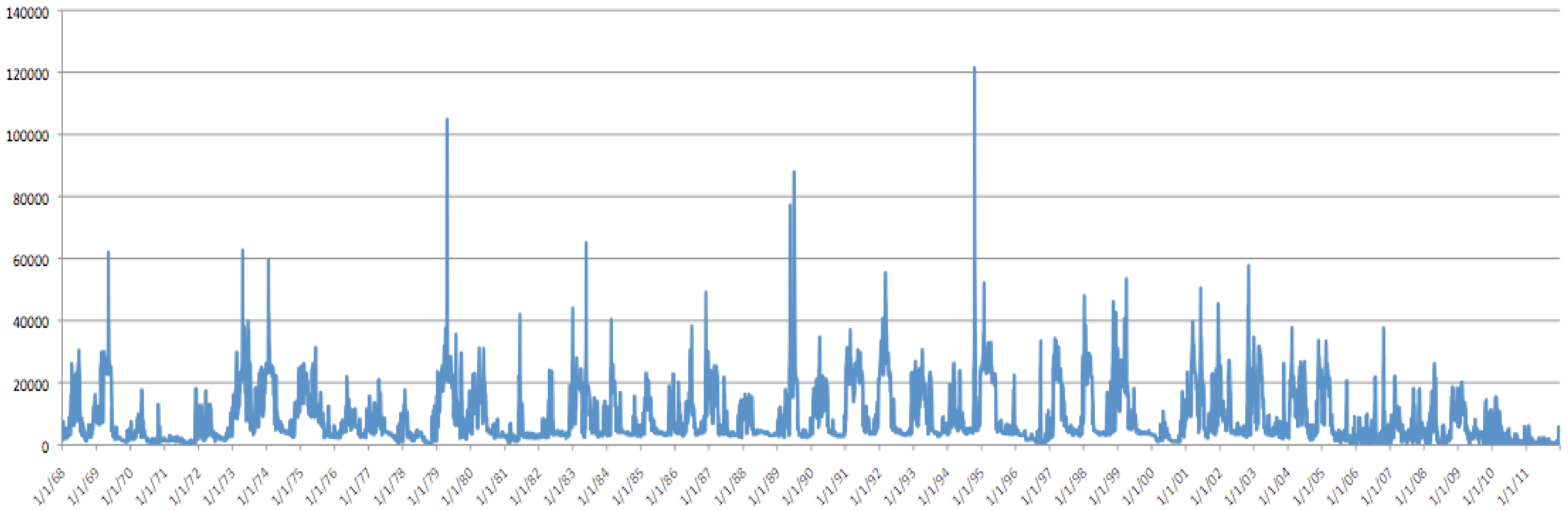

Figure 32. Estimated flows at the Neches River saltwater barrier site, 1968-2011 (from Winemiller et al. 2014).

The lower Neches River receives effluent (i.e., liquid wastes) from the MeadWestvaco kraft pulp and paper mill in Evadale, Texas (Winemiller et al. 2014). This effluent often creates an "overload" of dissolved organic matter, which leads to high biochemical oxygen demand and low dissolved oxygen levels. This creates hypoxic conditions where there may not be enough dissolved oxygen to sustain aquatic organisms (Winemiller et al. 2014). Hypoxia occurs when dissolved oxygen levels drop below about 2 mg/l (USGS 2014b). These conditions are exacerbated during droughts when upstream freshwater flows, which normally would dilute or "flush out" this effluent, are limited (Winemiller et al. 2014). There are also many large refineries and manufacturing plants that have acquired TCEQ permits to release treated waste waters into the lower Neches River. The contaminants remaining in these waters can be carried back upstream and into the preserve by saltwater intrusion events.

The U.S. Army Corps of Engineers (USACE) is planning to deepen and widen the Sabine-Neches Waterway, which connects the Port of Beaumont to the Gulf of Mexico (USACE 2011, Winemiller et al. 2014). The waterway ranks fourth in the nation in terms of total tonnage and is considered a strategic military out load port (USACE 2012). This waterway, which is currently 12.2 m (40 ft) deep, will be dredged to a depth of 14.6 m (48 ft) to allow larger vessels to travel up to Beaumont (USACE 2011, Winemiller et al. 2014). Plans to widen channels downstream of the Neches (around Taylors Bayou) have also been proposed (USACE 2011). This deepening and widening will allow greater saltwater intrusion into the Neches River and increase tidal influence on BITH's estuarine wetlands (Brown et al. 2007, Winemiller et al. 2014). A secondary project is also proposed and being planned by the USACE to raise the height and strengthen most of the dikes along the Sabine-Neches Waterway in order to better protect the surrounding industrial and urban lands from hurricane-related storm surges and flood events. This again would channelize the incoming ocean waters and allow them to be pushed upstream in ever increasing volumes.

Invasive plants pose a threat to native wetland plants and ecological processes (Gordon 1998, Keay et al. 2000). DESCO (2013) identified Chinese tallow and alligator weed (*Alternanthera philoxeroides*) as the most widespread exotic species in the BU. Alligator weed was the most dominant herbaceous species in *Zizaniopsis miliacea* Tidal Herbaceous Alliance plots and the third most dominant herbaceous species in *Taxodium distichum* Tidal Woodland Alliance plots (DESCO 2013). Other exotic species documented within the BU include water hyacinth (*Eichhornia crassipes*), woodrush flatsedge (*Cyperus entrerianus*), Japanese climbing fern, and giant salvinia (*Salvinia molesta*) (DESCO 2013). Chinese tallow may pose the greatest threat, as several studies have found that the species is more tolerant of occasional saltwater intrusion than native wetland tree species (Allen et al. 1998, McCormick 2005). Conner et al. (1997) found that Chinese tallow seedlings could survive for 6 weeks when flooded with 10 ppt saltwater while bald cypress and water tupelo seedlings only survived for 2 weeks. Some seedlings were also treated with a simulated "storm surge" of 32 ppt saltwater; Chinese tallow was the only species to survive this treatment (Conner et al. 1997). Invasive wildlife species that pose significant threats to BITH's ecosystems in these areas include red imported fire ants (RIFA), nutria (*Myocastor coypus*), and the Cuban tree frog (*Osteopilus septentrionalis*) (Hyde, written communication, 10 September 2015). The Cuban tree frog is a predatory species that could further impact the native frogs in the park, which are already susceptible to impacts from the higher salinity in the waters they inhabit.

Climate change could influence estuarine wetlands in several ways, but the most significant is through sea level rise (Guntenspergen et al. 1998, Winemiller et al. 2014). Climate change can cause sea level rise in two ways: through the melting of ice caps and glaciers and by thermal expansion of the oceans (warmer water "expands" to take up more space than cooler water) (Guntenspergen et al. 1998). For several hundred years, coastal wetlands were able to keep up with an annual sea level rise of 1-2 mm through accretion (i.e., sediment accumulation). Due to increasing rates of sea level rise and shifts in sediment dynamics, wetlands may no longer be able to keep up (Guntenspergen et al. 1998, Cahoon et al. 2010). The mean sea level rise at Sabine Pass from 1958-2014 has been approximately 5.5 mm/year, which is equivalent to an increase of 0.55 m (about 1.8 ft) over 100 years (NOAA 2015, Figure 33). Global sea level rise is projected to accelerate over the next century, with estimated maximum increases ranging from 0.6 m to over 1 m (approximately 2-3.3 ft) by 2100 (Nicholls et al. 2007, Rahmstorf 2007). Additional potential impacts of climate change include reduced freshwater flows (due to projected warmer and drier conditions) to counteract saltwater intrusion and an increase in the frequency and intensity of tropical storms and hurricanes, which could magnify saltwater storm surges (Winemiller et al. 2014). One study found that the annual number of Atlantic hurricanes doubled between 1900 and 2005, largely due to global warming and shifts in sea surface temperatures (Holland and Webster 2007).

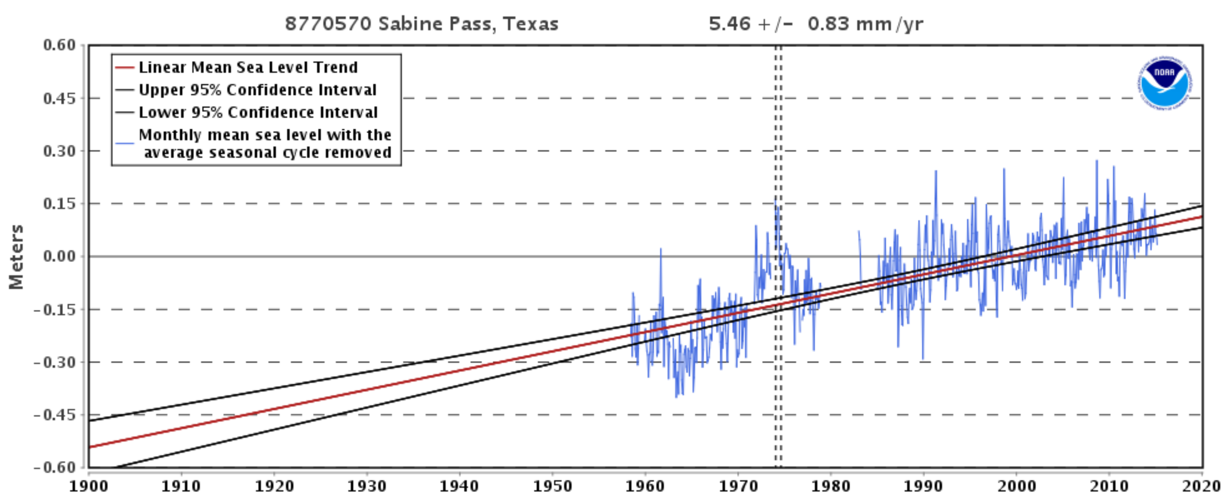

Figure 33. Mean trend in sea level at Sabine Pass, 1958-2013; dashed vertical lines bracket periods of questionable data (NOAA 2015).

<u>Data Needs/Gaps</u>

Since the lower portion of the BU did not become part of BITH until 2009, little is known about the estuarine wetlands it contains. A focused mapping of their extent has only occurred once (DESCO 2011, 2013), so it is unknown if wetlands are decreasing or increasing, or shifting between types (e.g., forested vs. herbaceous). It is also unclear exactly which wetland areas or types would meet the "estuarine" classification as defined by Cowardin et al. (1979). Since NWI data are based on different mapping methodologies and at a broader scale (e.g., regional or state-wide), they are likely not directly comparable to the more detailed mapping efforts of DESCO (2011, 2013).

Winemiller et al. (2014) recommended studying the vegetation dynamics of the lower portion of the BU, as conditions are likely to change due to human impacts on hydrology (e.g., channel modification), pollution, and sea level rise associated with climate change. Research could focus on the growth, mortality, and recruitment dynamics of bald cypress and water tupelo in relation to physiochemical and hydrologic conditions (Winemiller et al. 2014). A water quality monitoring program near the MeadWestvaco paper mill discharge would also be useful, particularly during dry summer months when dissolved oxygen levels are typically low (Winemiller et al. 2014). Weekly monitoring could help managers identify and forecast degradation levels that could cause aquatic plant and animal mortality (Winemiller et al. 2014).

Overall Condition

Extent

The project team assigned this measure a *Significance Level* of 3. Information on estuarine wetland extent is limited due to the fact that the lower portion of the BU did not become part of the preserve until 2009. According to recent mapping by DESCO (2011, 2013), wetland vegetation covers approximately 2,003.3 ha (4,950.3 ac) in the lower portion of the BU. This is slightly lower than the extent of vegetated wetlands mapped by the NWI, based on 1990s aerial imagery (USFWS 2014). It is unclear if this is due to an actual decrease in wetland extent or because of differences in mapping methodology. Because information on BITH's estuarine wetlands is so limited, a *Condition Level* could not be determined at this time. The data presented here can be used as a baseline to determine condition in future assessments.

Weighted Condition Score

Due to limited information, a WCS was not calculated for BITH's estuarine wetlands. Their current condition and trend are unknown.

Estuarine Wetlands			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Extent	3	n/a	

4.7.6 Sources of Expertise

- Herbert Young, BITH Biologist
- Ken Hyde, BITH Chief of Resource Management

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4.8 Birds

4.8.1 Description

Bird populations often act as excellent indicators of an ecosystem's health (Morrison 1986, Hutto 1998, NABCI 2009). Birds are often highly visible components of ecosystems, and bird communities often reflect the abundance and distribution of other organisms with which they co-exist (Blakesley et al. 2010). BITH is home to several unique habitat types, including pine uplands, slope forests, arid sand hills, floodplain hardwood forests and swamps, and longleaf pine wetlands.

The rich diversity of habitats found in BITH and its proximity to the Gulf Coast provides bird species with excellent stopover and overwintering habitats, and represents a vital area for many migratory bird species in North and South America. The ABC has identified BITH as a Globally IBA. In order to be listed as a Globally IBA, a site must, during some part of the year, contain habitat that supports:

- A significant population of an endangered or threatened species;
- A significant population of a U. S. WatchList species;
- A significant population of a species with a limited range, or
- A significantly large concentration of breeding, migrating or wintering birds, including waterfowl, seabirds, wading birds, raptors or landbirds (ABC 2010).

BITH has more than 290 species of birds that are either confirmed as present or are listed as probable species (NPS 2015b, Appendix F). BITH is located along two of the major migration flyways in North America (Figure 34), and many species, such as the chestnut-sided warbler (*Setophaga pensylvanica*) and the black-and-white warbler (*Mniotilta varia*), pass through the preserve on their way from wintering grounds in the south to breeding grounds in the north. BITH may act as an important over-wintering area for migratory species, such as the ruby-crowned kinglet (*Regulus calendula*), as these species spend the winter months along BITH's corridors and dense forests before returning to their breeding grounds in the spring.

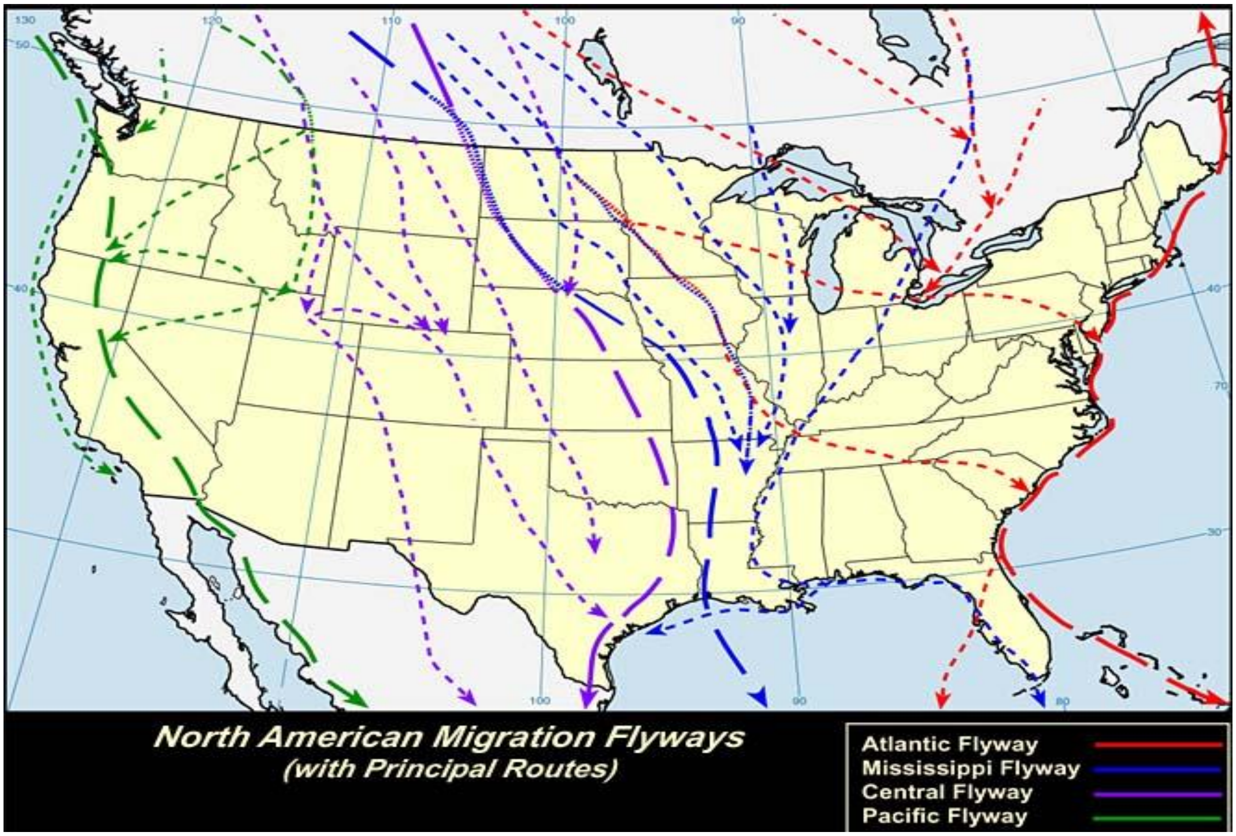

Figure 34. Major North American migratory flyways. BITH is located at a bottleneck of the Central and Mississippi Flyways (NPS 2015a).

Long-distance migratory species are highly informative indicator species, as their overall health depends on several different ecosystems. Global Christmas Bird Count (CBC) data indicate significant declines in migratory bird numbers in recent years (Peterjohn and Sauer 1999, Vicerky and Herkert 2001). Nearctic-Neotropic migrants, hereafter Neotropical migrants, are bird species that breed in the temperate latitudes of the U.S. and Canada, but migrate to the tropical latitudes of Central and South America in the winter months (Figure 35, TPWD 2015). Stotz et al. (1996) estimates that approximately 420 bird species are classified as Neotropical migrants, and 333 of these species have been recorded in Texas (TPWD 2015). TPWD (2015) estimates that nearly half of all the documented bird species in Texas are Neotropical migrants.

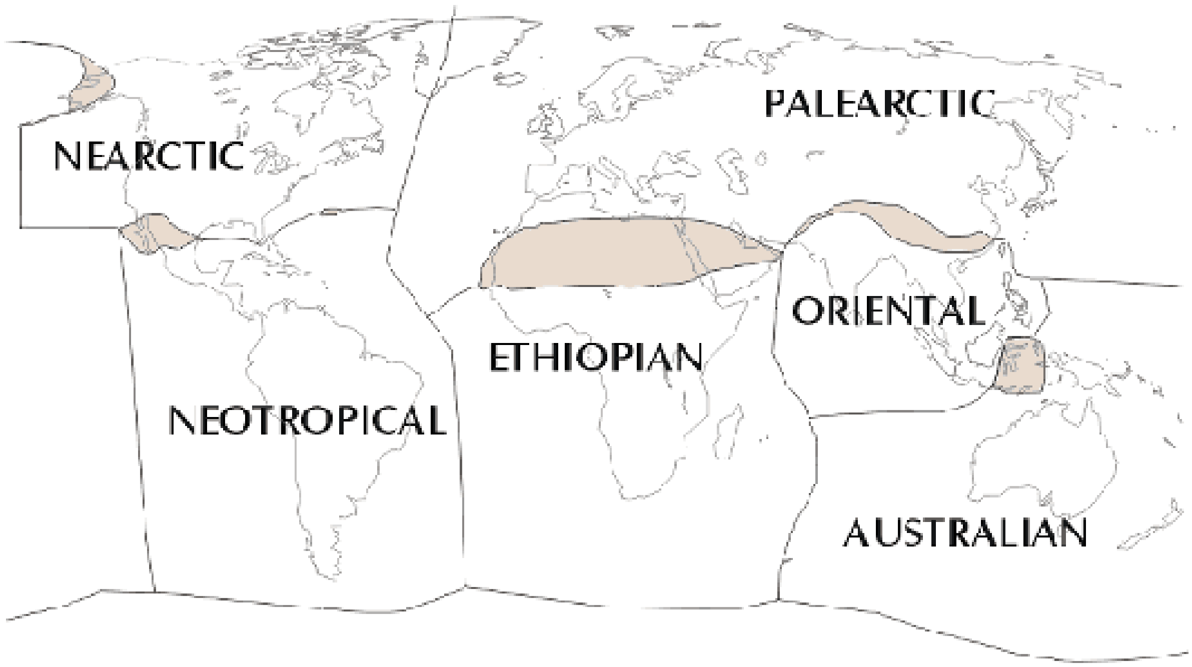

Figure 35. Zoogeographic regions of the world; shaded areas represent transition areas between regions (TPWD 2015).

BITH is located in a unique area, as it lies close to the perceived boundary between the Nearctic and Neotropical zoogeographic regions. TPWD (2015) has identified all Neotropical migrant species that are known to occur in Texas; species identified in bold text in Appendix F indicate the species listed by TPWD (2015) that are present in BITH.

4.8.2 Measures

- Abundance
- Species Richness
- Species Distribution

4.8.3 Reference Conditions/Values

During project scoping, NPS staff selected Fisher (1974) to serve as the reference condition for the bird component. Fisher (1974) represents the earliest effort at the preserve to compile bird data/observations from the entire area of the preserve; this list also represents the approximate species list for the preserve at the time of establishment (1974). Because this data source only contains a species list, its utility as a reference condition for the abundance and distribution measures will be limited. For those measures, best professional judgment will be used to determine condition and trend.

4.8.4 Data and Methods

The NPS Certified Bird Species List (NPS 2015b) for BITH was used for this assessment; this list represents all the confirmed and probably present bird species in the preserve (Appendix F).

Fisher (1974) was the first attempt to document the avian species that were present in the area where BITH was to be established. Published accounts of birds in the area were synthesized and summarized to create a species list for the preserve. Examples of data sources include Wolfe (1956), AOU (1957), Peterson (1963), Fisher (1972, 1973), Oberholser (1974), and museum specimens from museums and universities in the BITH area.

Bryan et al. (1976) was one of the first quantitative surveys to occur in the BITH area. Thirty line transects were selected in the preserve based on forest condition, stand size, and uniformity of the vegetation; care was taken to make sure transects did not traverse man-made features (e.g., roads) or streams/rivers. Transects traversed four forest types in the preserve: mixed-pine hardwood, floodplain hardwood, shortleaf pine-hardwood and palmetto hardwood.

In 1975, observers walked the transects in the early morning and recorded all bird species seen within 15 m (50 ft) of the transect line and all birds seen beyond 15 m (50 ft) of the transect line; birds seen beyond 30 m (100 ft) were generally not recorded. In addition to transect surveys, Bryan et al. (1976) also conducted canoe censuses and general surveys of the BITH area that were intended to document birds that were not detected on line transects. A 1-day search for red-cockaded woodpeckers and suspected colonies was conducted in the BCU, and an aerial survey was also conducted over the whole preserve to search for nesting heron and egret rookeries.

Deuel and Fisher (1977) surveyed the BSCU, BCU, TCU, NBU, JGBU, BU, LU, LPI-PIBCU, Neches River Corridor Unit (NRCU), and Village Creek Corridor Unit (VCU) in 1976 (Figure 36). Deuel and Fisher (1977) represented a follow-up survey effort to the work of Bryan et al. (1976), and utilized the same survey methodology and surveyed the same forest types (types A-D above). Parameters reported included species diversity, species richness (variety), number of individuals (abundance), and density. Canoe surveys were conducted four times, with surveys occurring in Village Creek (10 river km [6.25 river mi]), twice in Pine Island Bayou (29.77 river km [18.5 river mi], and 13.28 river km [8.25 river mi]), and the Neches River (21.32 river km [13.25 river mi]).

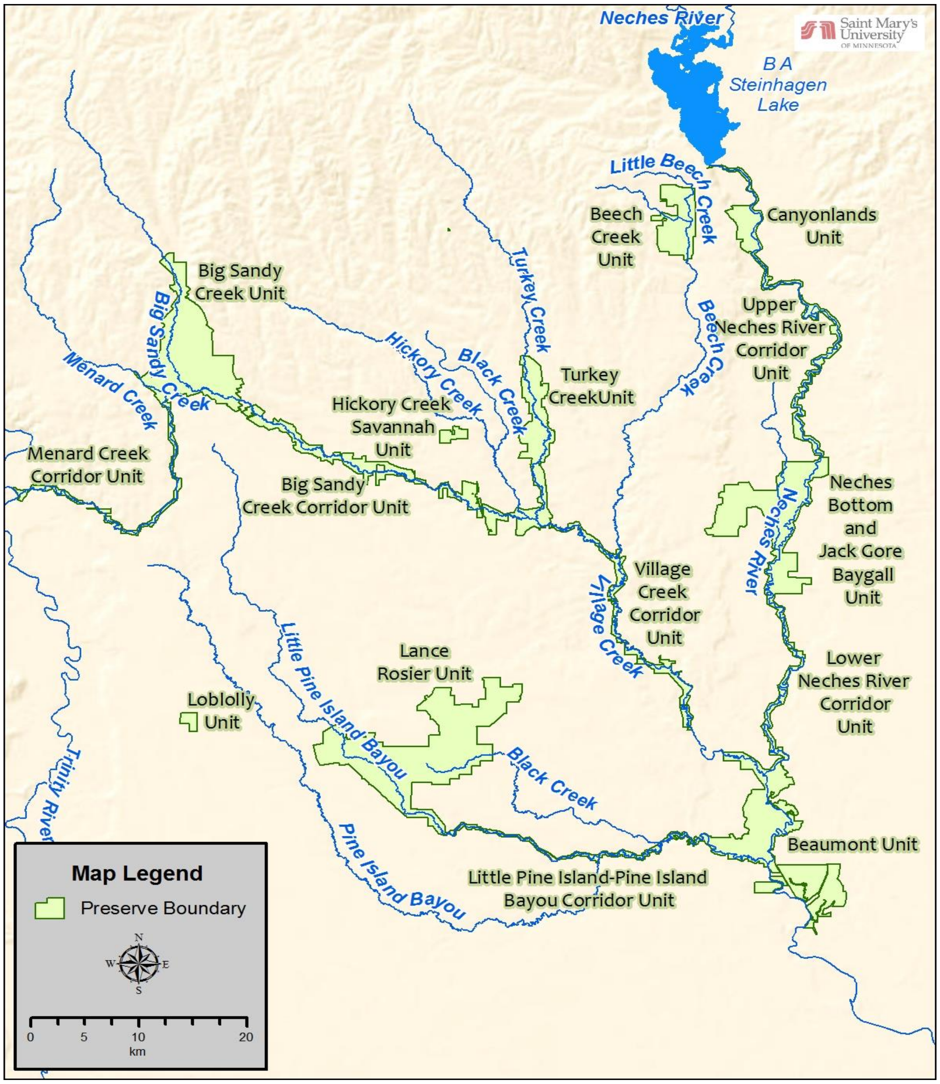

Figure 36. BITH boundaries and Unit and Corridor names across the seven county area.

Biercevicz (1977) conducted a brief survey of BITH and several areas in the immediate vicinity of the preserve from 13 May to 21 October 1977. Birds were observed in the BCU, LU, HCSU, BSCU, BU, Lower Neches River Corridor Unit (LNRCU), and TCU. Survey methodology is not included in the discussion of Biercevicz (1977), as the document primarily represents an avifauna list coupled with distribution locations.

Ramsey (1980) conducted abbreviated surveys of the BU in 1975 and 1976. Surveys were conducted in the early morning and followed existing routes in the unit; a single observer recorded all species heard and seen along the route. Surveys were conducted weekly during the fall, spring, and winter, while two or three surveys were completed per week during the breeding season.

McGuffin (1984) censused the avifauna of the LU of BITH from 8 January to 4 December 1983. One line transect was surveyed within 30 minutes of sunrise during each month of the study; survey methodology on the line transect was similar to that utilized by Bryan et al. (1976) and Deuel and

Fisher (1977). The observer recorded all birds that were observed or heard within 0-15 m (50 ft) and within 15-125 m (50-412 ft).

There exists a substantial data gap for the birds of BITH after McGuffin (1984), as the next bird-specific study to take place within the preserve was the initiation of the GULN long-term breeding bird monitoring project in 2014. This monitoring initiative uses a methodology developed by Daniel Twedt (Research Wildlife Biologist, USGS Patuxent Wildlife Research Center), and involves annual surveys of the TCU in the preserve. Using the methodology of Twedt (2010), breeding birds in the TCU were

> *…monitored using random-location 10 minute point counts with time and distance variables. Hawth's Analysis Tool (Ver. 3.27) within ArcMap 9.2 GIS was used to select 40 random survey points (separated by ≥250 meters [820 ft]) for the Turkey Creek Unit. The survey points were divided into four panels, and two panels were sampled each year during the breeding season. Surveys were conducted between one-half hour before sunrise and four hours after sunrise (~10:00 hours) during clement weather (i.e., no rain or high winds). At the first detection of each individual bird, observers recorded the species identity, the time within a 1-minute interval (i.e., 0:00-:59 minutes, 1:00-1:59 minutes, 2:00-2:59 minutes, 3:00-3:59 minutes, 4:00-4:59 minutes, 5:00-5:59 minutes, 6:00-6:59 minutes, 7:00-7:59 minutes, 8:00-8:59 minutes, 9:00-9:59 minutes), and the estimated distance within four distance annuli (0 - <25 meters, 25 - <50 meters, 50 - <100 meters, and >100 meters). Individual birds were recorded only at their first detection and not in each time interval within which they were detected (Granger 2015, p. 3).*

The breeding birds in BITH will continue to be monitored as part of the GULN monitoring project each year. 2014 monitoring work was completed by Dr. Jim Armacost (Director of Environmental Science, Lamar University) through an agreement with the Gulf Coast Bird Observatory, and summary reports and analyses will be completed every 5 years; panels that are surveyed are to be rotated every year.

Breeding bird survey routes in the preserve are part of the large-scale North American Breeding Bird Survey (BBS), which began in 1966 and is coordinated by the United States Geological Survey (USGS) and the Canadian Wildlife Service (Robbins et al. 1986). The standard BBS route is approximately 40 km (25 mi) long with survey points every 0.8 km (0.5 mi). The survey begins ½ hour before sunrise, and at each survey point the number of birds seen and heard within a 0.4-km (0.25-mi) radius during a three-minute interval is recorded. The preserve has four BBS routes that pass through BITH property: FRED (route 83321), Big Sandy-BITH (route 83904), Lance Rosier-BITH (route 83905), and Neches-BITH (route 83906) (Figure 37).

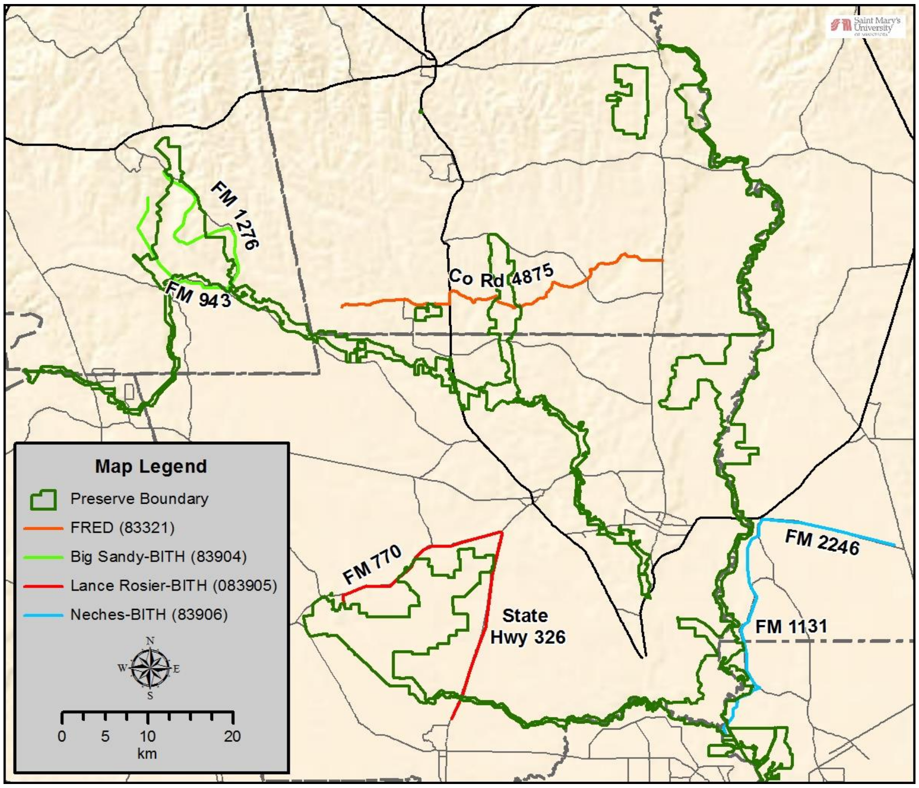

Figure 37. The four BBS routes that run through or adjacent to BITH property. When applicable, the road name that the route follows is indicated in black text.

Two CBCs fall within BITH boundaries (Turkey Creek CBC and Beech Creek CBC); these CBCs are part of the International CBC, which started in 1900 and is coordinated internationally by the Audubon Society. The preserve's CBCs have been conducted annually since 1978. During a CBC, multiple volunteers survey a 24-km (15-mi) diameter on one day, typically between 14 December and 5 January. The center point of the 24-km diameter count circle for the Turkey Creek CBC is 30°31'00.4"N, 94°19'00.2"W, while the center point for the Beech Creek CBC is 30°46'0.2964"N, 94°12'0.0180"W (Figure 38). Unlike the BBS, the CBC surveys overwintering and resident birds that are not territorial and singing; this often results in different survey results than the BBS and should not be directly compared to the BBS. The total number of species and individuals are recorded each year. Data for the BITH CBCs are current through 2013; counts were completed in 2014, however the data are not yet available through the Audubon data retrieval database.

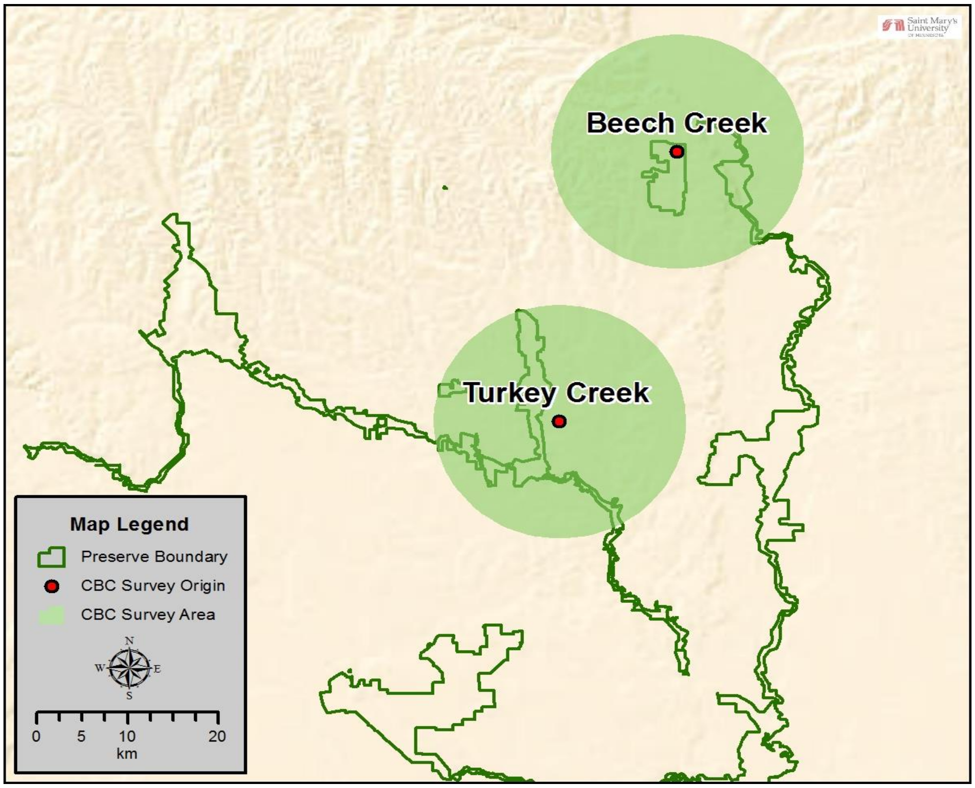

Figure 38. The two CBC areas that fall within BITH land. The diameter of the count circle is 24-km (15 mi) and is surveyed by volunteers each winter.

The organization of the BITH CBC data (obtained from http://netapp.audubon.org/CBCObservation/Historical/ResultsByCount.aspx#) required SMUMN GSS to make some adjustments:

- Observations that were not specific to a bird species (e.g., vireo sp., wren sp.) were omitted from analyses;
- Observations for northern flicker, red-shafted northern flicker, and yellow-shafted northern flicker were merged and renamed to *Colaptes auratus*. Yellow- and red-shafted flickers were previously believed to be separate species, but genetic analysis has classified them as one species (Sibley and Ahlquist 1983);
- Yellow-rumped warbler, Audubon's warbler, and Myrtle warbler observations were treated as one species (*Dendroica coronata*) (Sibley and Ahlquist 1983, Hunt and Flaspohler 1998);
- Dark-eyed junco, gray-headed dark-eyed junco, dark-eyed junco (Oregon race), pink-sided dark-eyed junco, and slate-sided dark-eyed junco observations were treated as one species (*Junco hyemalis*) (Sibley and Ahlquist 1983);
- Eastern rufous-sided towhee observations were combined with observations of the eastern towhee (*Pipilo erythrophthalmus*) to reflect current taxonomic classification;
- Green-backed heron observations were combined with green heron (*Butorides virescens*) observations as this represents the currently accepted common name;

- Observations of rock dove and rock pigeon were combined as both names are commonly accepted common names for *Columba livia*.
- Observations of blue- and white-form snow goose were combined to form a single *Chen caerulescens* observation.

These adjustments were made to update the data to the currently accepted taxonomic standards, and to eliminate duplicate or historic references that were erroneous. After the adjustments were made, the data were analyzed and organized for an accurate assessment of the survey's results.

4.8.5 Current Condition and Trend

<u>Abundance</u>

Bryan et al. (1976)
Bryan et al. (1976) documented 9,035 individual birds during surveys of the BITH area. Surveys were conducted using 30 line transects across four habitat types (A-D as listed previously above, Table 37), using canoe surveys, and during a general search of the longleaf pine savanna habitat type. Canoe surveys documented the highest number of individuals (5,606), although this methodology greatly differed from that used during forest line transects (see Bryan et al. 1976). Forest surveys documented 3,359 individuals, while an abbreviated (1-day) general survey of the longleaf pine savanna habitat yielded 70 individuals.

Table 37. Habitat types and the number of line transects and observed abundance within each group (Bryan et al. 1976).

Group	Forest Type	Transects Selected	Number of Individuals
A	Mixed pine-hardwood	1,2,3,5,6,9,15,17	1,196
B	Floodplain hardwood	10,14,19,20,21,22,24,30	1,290
C	Shortleaf pine-hardwood	12,13,29	339
D	Palmetto hardwood	26,27,28	534

The habitat group with the highest number of transects in Bryan et al. (1976) yielded the highest abundance estimates (Table 37). The white-eyed vireo (*Vireo griseus*) was the most abundant species in Group A (162 individuals), B (171), and D (72) (Table 38). Generalist species such as the northern cardinal (*Cardinalis cardinalis*) and Carolina wren (*Thryothorus ludovicianus*; which thrives in thick vegetation and tangled understories common to BITH) were among the five most abundant species in all four habitat groups (Table 38). The brown-headed nuthatch (*Sitta pusilla*) is a more habitat-specialized species and requires southern pine forests; this species was only documented in Group C (shortleaf pine-hardwood).

Table 38. The most abundant bird species by habitat Group, as determined by Bryan et al. (1976). Forest Group letter corresponds to the designations in Table 37.

Abundance Rank	Forest Group A	B	C	D
1	white-eyed vireo (162)	white-eyed vireo (171)	northern cardinal (44)	white-eyed vireo (72)
2	Carolina wren (100)	northern cardinal (150)	Carolina wren (39)	Carolina wren (51)
3	tufted titmouse (95)	red-eyed vireo (147)	pine warbler (39)	northern cardinal (50)
4	northern cardinal (85)	northern parula (147)	blue jay (32)	tufted titmouse (48)
5	blue-gray gnatcatcher (79)	Carolina wren (89)	tufted titmouse (26)	hooded warbler (30)

The red-cockaded woodpecker (Photo 14) is at the western edge of its native range in the BITH area, and requires mature longleaf pine or loblolly pine forests for nesting. This species was listed as endangered by the USFWS in 1970, and has been infrequently observed in BITH. Bryan et al. (1976) documented three individuals in Group C in 1975 and an additional two individuals during the area search of the preserve's longleaf pine savanna habitat. These observations, coupled with a few sporadic observations during the preserve's CBC efforts, represent the only published examples of red-cockaded woodpecker abundance in the preserve.

Photo 14. The red cockaded woodpecker, an endangered species that occurs at the western edge of its range in the BITH area (NPS Photo).

Deuel and Fisher (1977)

Deuel and Fisher (1977) represent a follow-up study to Bryan et al. (1976). 3,238 individuals were observed during Deuel and Fisher (1977) surveys in 1976, with 2,137 individuals observed on forest line transects (Table 39) and 1,101 individuals observed during canoe surveys. These abundance estimates were lower in all categories when compared to Bryan et al. (1976) (Table 37, Table 39). Deuel and Fisher (1977) did not replicate Bryan et al. (1976)'s survey of the longleaf pine savanna habitat in the preserve.

Table 39. Habitat types and the number of line transects and observed abundance within each group (Deuel and Fisher 1977).

Group	Forest Type	Number of Transects	Number of Individuals	Avg. # of Ind./Census
A	Mixed pine-hardwood	12	823	69
B	Floodplain hardwood	11	902	78
C	Shortleaf pine-hardwood	3	175	58
D	Palmetto hardwood	3	237	79

Similar to Bryan et al. (1976), habitat groups with the highest number of transects in Deuel and Fisher (1977) yielded the highest abundance estimates (Table 39). In both studies, the white-eyed vireo was the most abundant species in both the mixed-pine hardwood group and the palmetto hardwood group (Table 38, Table 40). Unlike 1975 surveys, the northern parula (*Setophaga americana*) was the most abundant species in the floodplain hardwood forest type (Group B), with 164 individuals observed in 1976 (Table 40). The northern parula breeds in mature floodplain forests and was found in comparatively low numbers across the other habitat types. The Carolina wren was the most abundant species in the shortleaf pine-hardwood habitat type (Group C), although abundance values were more evenly distributed in this habitat type (Table 40). Much like 1975, the northern cardinal was among the five most abundant species in each of the habitat types (Table 40). The American goldfinch (*Carduelis tristis*) was a new species observed in 1976, and was documented in relatively high numbers (45 individuals) exclusively in the floodplain hardwood forest type.

Table 40. The most abundant bird species by habitat Group, as determined by Deuel and Fisher (1977). Forest Group letter corresponds to the designations in Table 37.

Abundance Rank	Forest Group			
	A	**B**	**C**	**D**
1	white-eyed vireo (93)	northern parula (164)	carolina wren (18)	white-eyed vireo (36)
2	northern cardinal (88)	northern cardinal (103)	pine warbler (16)	blue-gray gnatcatcher (23)
3	hooded warbler (65)	white-eyed vireo (94)	red-eyed vireo (15)	tufted titmouse (22)
4	tufted titmouse (58)	blue-gray gnatcatcher (50)	hooded warbler (15)	carolina wren (20)
5	carolina wren (55)	red-eyed vireo (50)	northern cardinal (14)	northern cardinal (19)

McGuffin (1984)

McGuffin (1984) investigated the avifauna of the LU in BITH and documented avian abundance from January-December 1983. Survey methodology mimicked the line transect protocol used by Bryan et al. (1976) and Deuel and Fisher (1977). One line transect was used in the LU, and all individuals recorded within 125 m (412 ft) were documented. Abundance was reported as relative abundance and was calculated "…by taking the total avian absolute density for each month and then determining what percentage of this total was composed of each species" (McGuffin 1984, p. 13) (Appendix G). Because McGuffin (1984) used only one transect, it is not possible to draw conclusions or trends regarding distribution of species.

In total, the five most abundant species each month featured 12 different species in McGuffin (1984) (Table 41). The white-throated sparrow (*Zonotrichia albicollis*) dominated the winter months of the study, and was the most abundant species in December, January, and February; this species was completely absent from the study area from May-November. Spring was dominated by resident species in the LU, with the northern cardinal and tufted titmouse being the most abundant species in March (northern cardinal), April (northern cardinal), and May (tufted titmouse). Deuel and Fisher (1977) completed surveys in BITH during the spring, and when those results are compared to McGuffin (1984) it is apparent that three species dominated in both studies: white-eyed vireo, northern cardinal, and white-throated sparrow (McGuffin 1984). The summer months of surveys were dominated by the white-eyed vireo (June-Sept). Bryan et al. (1976) surveyed BITH in the summer months, and when results from McGuffin (1984) are compared to that study the dominant species are the same, with the white-eyed vireo being the most abundant (McGuffin 1984). The only species in McGuffin (1984) to be among the five most abundant species in each month was the red-headed woodpecker (*Melanerpes erythrocephalus*) (Table 41).

Table 41. The top five most abundant species observed during each month of the McGuffin (1984) survey of the avifauna of the Loblolly Unit of BITH. Numbers represent the overall percentage of total bird observations for a given month.

Species	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
white-throated sparrow	24.62	17.19	23.35	8.05	8.37	--	--	--	--	--	--	15.42
red-headed woodpecker	10.83	6.98	7.30	10.99	11.33	6.69	7.25	9.84	12.01	12.98	11.10	5.43
Carolina chickadee	8.99	10.27	7.24	--	8.49	--	--	--	--	--	8.04	8.67
red-bellied woodpecker	8.44	--	--	6.97	--	--	--	--	--	--	--	--
tufted titmouse	6.56	9.31	9.38	--	--	23.17	9.91	10.27	11.02	8.53	14.74	--
brown thrasher	--	8.04	--	--	--	--	--	--	--	--	18.20	--
white-eyed vireo	--	--	9.56	8.69	13.66	16.03	18.03	13.72	22.65	23.97	--	--
northern cardinal	--	--	--	18.86	15.70	8.87	9.86	10.09	14.70	9.49	8.88	--
Carolina wren	--	--	--	--	--	5.78	5.71	9.72	--	10.75	--	--
Acadian flycatcher	--	--	--	--	--	--	5.71	--	7.77	--	--	--
American robin	--	--	--	--	--	--	--	--	--	--	--	28.04
northern flicker	--	--	--	--	--	--	--	--	--	--	--	6.21

Granger (2015)
During the first year of landbird monitoring in the TCU of BITH, 328 individual landbirds were documented at the 20 survey points used in 2014 (Appendix H). The northern cardinal was the most abundant species (61 individuals), with the white-eyed vireo (40 individuals), and tufted titmouse (29 individuals) representing the second and third most abundant species during monitoring (Appendix H). The northern cardinal and white-eyed vireo were observed at all 20 survey points.

Turkey Creek and Beech Creek Christmas Bird Counts
The total number of individual birds observed during the Turkey Creek CBC from 1978-2013 is represented in Figure 39. For the duration of the survey, the average number of individuals observed was 3,237 (Figure 39); annual abundance values ranged from 498 (1981) to 8,021 (1986). The Beech Creek CBC has recorded higher abundance estimates in the majority of survey years (Figure 39). The average number of individuals observed on the Beech Creek CBC is 6,009 (Figure 39); abundance values have ranged from 1,131 (1981) to 13,486 (1995).

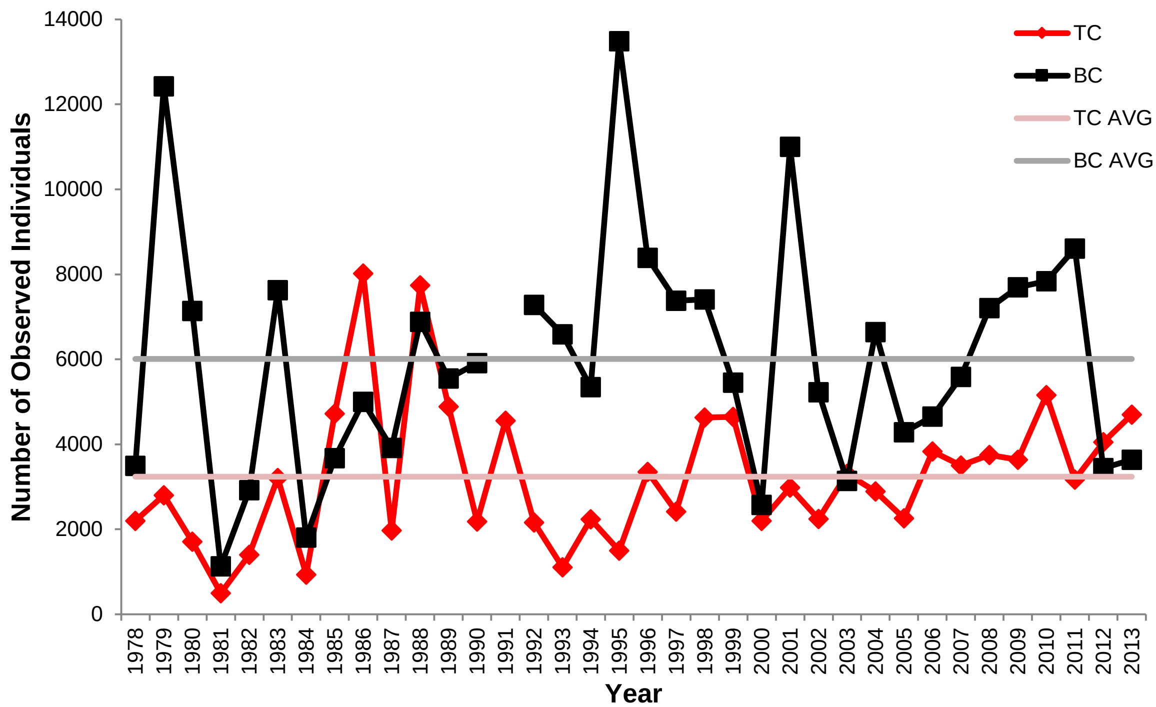

Figure 39. Total abundance values from the Turkey Creek CBC (TC) and the Beech Creek CBC (BC) from 1978-2014. Solid lines represent the average annual abundance value for each CBC for the duration of the count. The average abundance for the TC CBC was 3,237, while the average abundance for the BC CBC was 6,009 (data from: http://netapp.audubon.org/CBCObservation/Historical/ResultsByCount.aspx#).

Care must be taken when interpreting count data, as the data are largely dependent upon the effort of the observers, and may not always provide an accurate depiction of the species abundance. The ability of the observer to identify bird species by appearance and auditory calls is essential for accurate count data. A count that includes observers who may not possess the necessary skills could lead to a lower count when compared to years where highly skilled observers are used. In addition, the number of observers involved in the count may influence the number of species and individuals detected during a year. 1981 had the lowest reported annual abundance for both CBCs; this year also had the lowest number of participants for both counts (two observers) in the 36-year span of the CBCs.

Breeding Bird Surveys (FRED [route 83321], Big Sandy-BITH [route 83904], Lance Rosier-BITH [route 83905], and Neches-BITH [route 83906])

The average annual abundance of birds on the FRED BBS route ranged from 338 individuals (2011) to 677 individuals (1999) (Figure 40). The average number of individuals observed on the FRED BBS route (535) was the highest when compared to the other three routes in the preserve; however, the FRED route has been surveyed annually since 1995, whereas the other three routes have only been surveyed since 2010. Annual abundance values have been below historic averages since 2004, as no survey has documented abundance levels that have exceeded the 19-year average for the route (Figure 40). The northern cardinal, white-eyed vireo, and Carolina wren were the three most abundant species observed on the FRED BBS route.

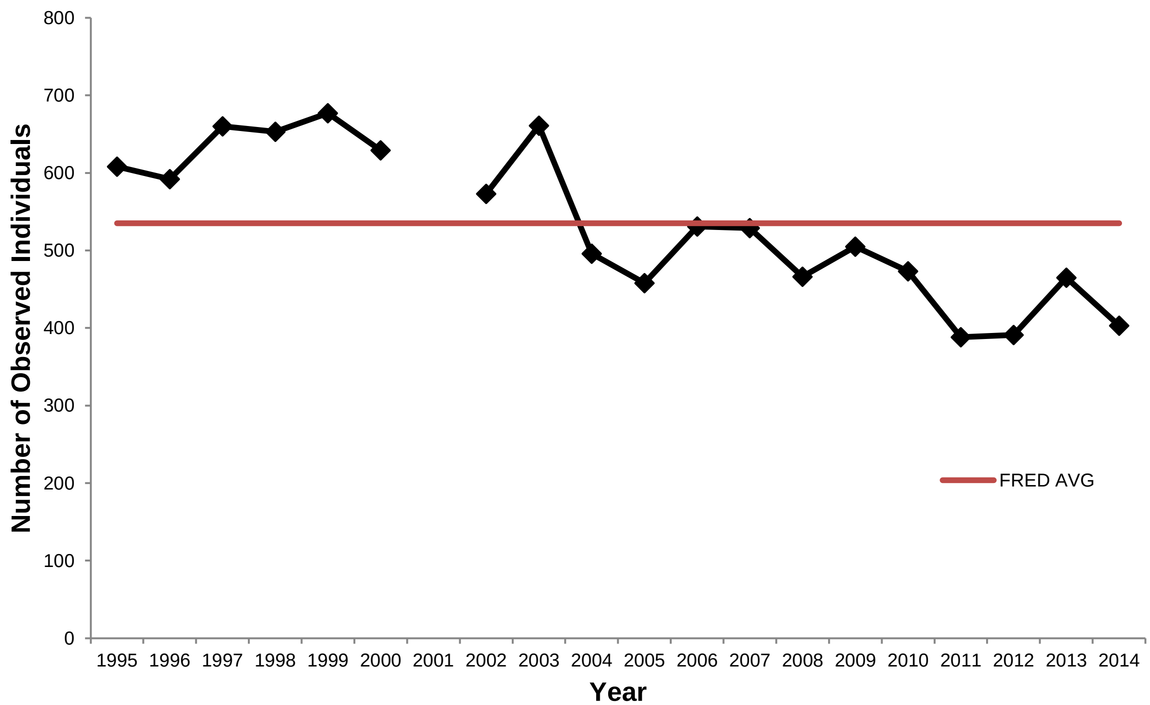

Figure 40. Annual abundance data from the FRED BBS route (route 83321) from 1995-2014. The solid red line represents the average annual abundance (535 individuals) for the duration of the BBS (data from: https://www.pwrc.usgs.gov/BBS/PublicDataInterface/index.cfm?fuseaction=PublicDataInterface.viewPublic).

The average number of individuals observed during the 3 years of surveys at the Big Sandy-BITH BBS route was 379 individuals. Annual abundance values have ranged from 343 (2011) to 424

(2014; Figure 41). The most abundant species observed on this route include the northern cardinal, mourning dove (*Zenaida macroura*), and white-eyed vireo.

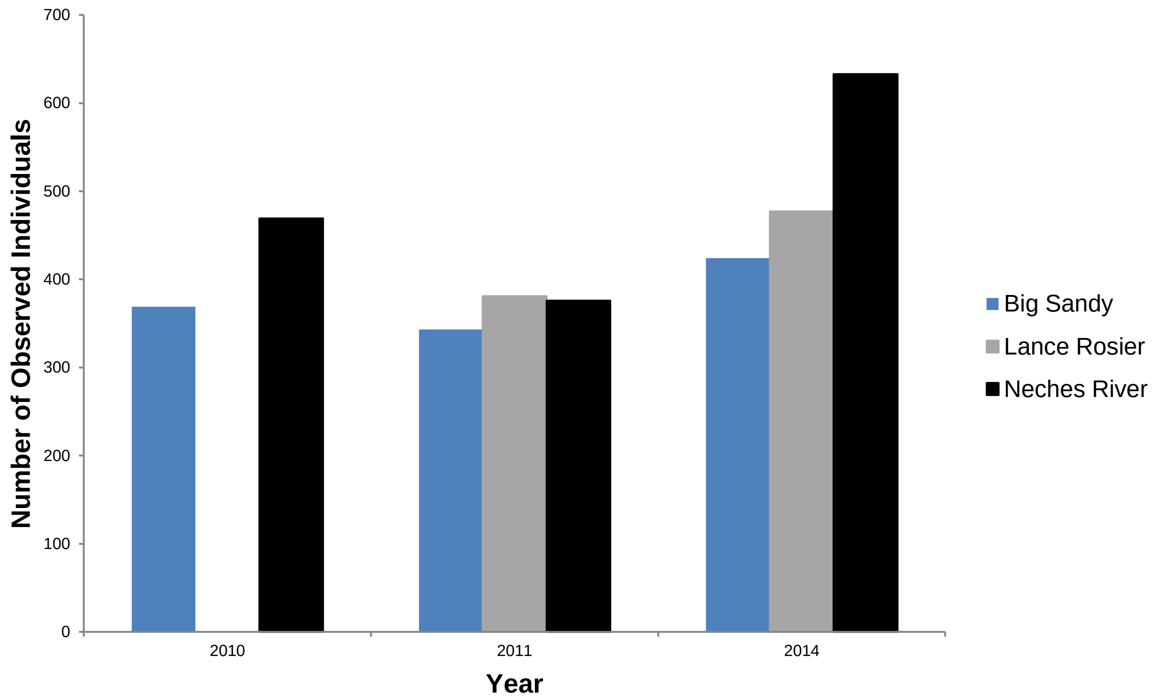

Figure 41. Annual abundance data from the Big Sandy-BITH, Neches River-BITH, and Lance Rosier-BITH BBS routes from 2010-2014. Lance Rosier-BITH route was not surveyed in 2010 (data from: https://www.pwrc.usgs.gov/BBS/PublicDataInterface/index.cfm?fuseaction=PublicDataInterface.viewPublic).

Annual abundance values on the Neches River-BITH BBS route ranged from 376 (2011) to 633 (2014; Figure 41). The average number of individuals observed during the 3 years of surveys was 493 individuals. The most abundant species observed during the three years of surveys were the northern cardinal, cattle egret (*Bubulcus ibis*), and American crow (*Corvus brachyrhynchos*).

The Lance Rosier-BITH BBS route has been surveyed only twice (2011, 2014). Abundance values were highest in 2014 (477 individuals, compared to 381 in 2011) (Figure 41), and average annual abundance was 429 individuals. The most abundant species included the northern cardinal, northern mockingbird (*Mimus polyglottos*), American crow, and the mourning dove, with the white-eyed vireo also appearing in high numbers.

Species Richness

The species richness measure allows simultaneous assessment of abundance or presence for the entire breeding bird community. This measure can also indicate overall habitat suitability for birds, and is vital to understand the effects of changing landscapes on native biodiversity.

NPS Certified Species List (NPS 2015b)

The NPS Certified Bird Species List contains 295 species that have either been confirmed or are listed as probably present in the preserve (Appendix F). This list, however, does not allow for a specific analysis of species richness, as no data were collected other than the presence (or historic presence) of the identified species; no determination can be made from this list when the species was present in the preserve.

Fisher (1974)

Fisher (1974) represents the reference condition for the species richness measure. While this study did not utilize intensive survey or census methodologies, it did synthesize and summarize all existing data related to the avifauna of the BITH area. Analysis of existing literature in 1974 resulted in a species list for BITH of 266 species, with an additional 27 species that are probable to occur in the preserve (Appendix F).

Bryan et al. (1976)

During surveys of BITH in 1975, Bryan et al. (1976) documented 92 bird species within four distinct habitat types (Figure 42). Additionally, Bryan et al. (1976) successfully documented red-cockaded woodpeckers in the preserve.

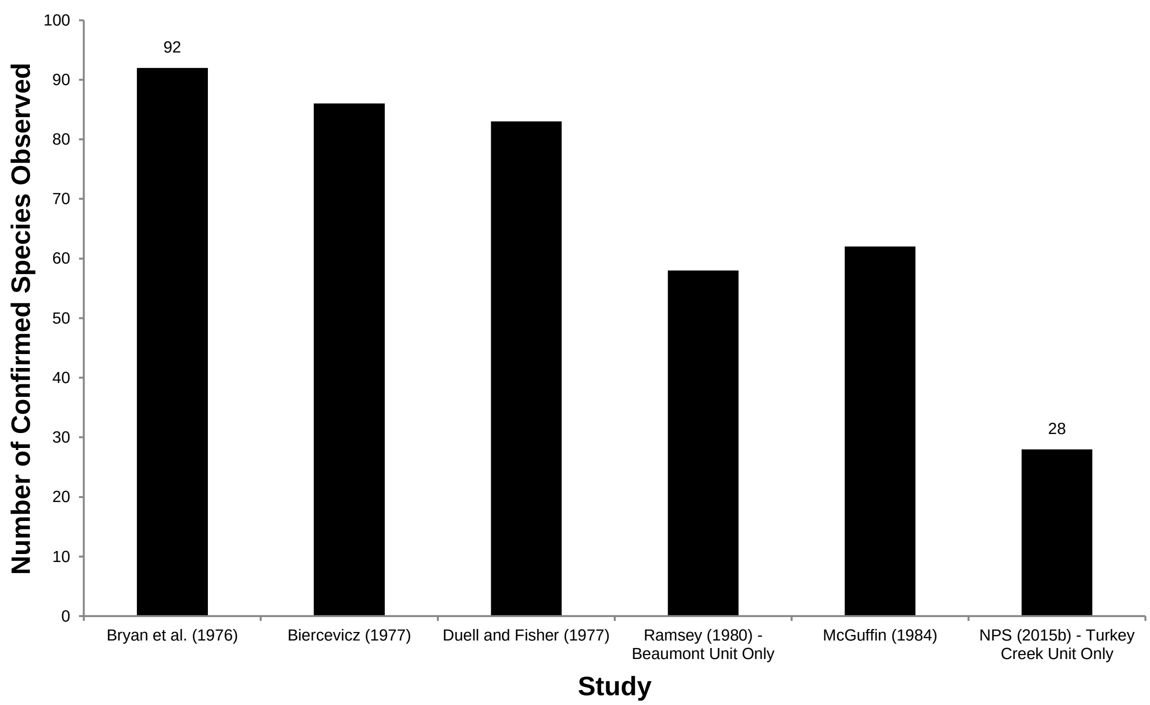

Figure 42. Avian species richness during bird surveys in BITH from 1975-2014. Species richness is reported here as the number of confirmed species observed and does not include species identified as "possibly present".

Species richness varied across the Units of BITH, and ranged from 33 species (LU, BU) to 67 (NRCU) (Figure 43); the average number of species observed in a unit during Bryan et al. (1976) was 42. Across forest Groups A-D, Groups A and B had the highest species richness values at 37 and

36 species, respectively (Table 42). Canoe surveys of the corridor units in the preserve resulted in 64 species being detected, while an independent survey of the longleaf pine savanna habitat resulted in 19 species being documented (Table 42).

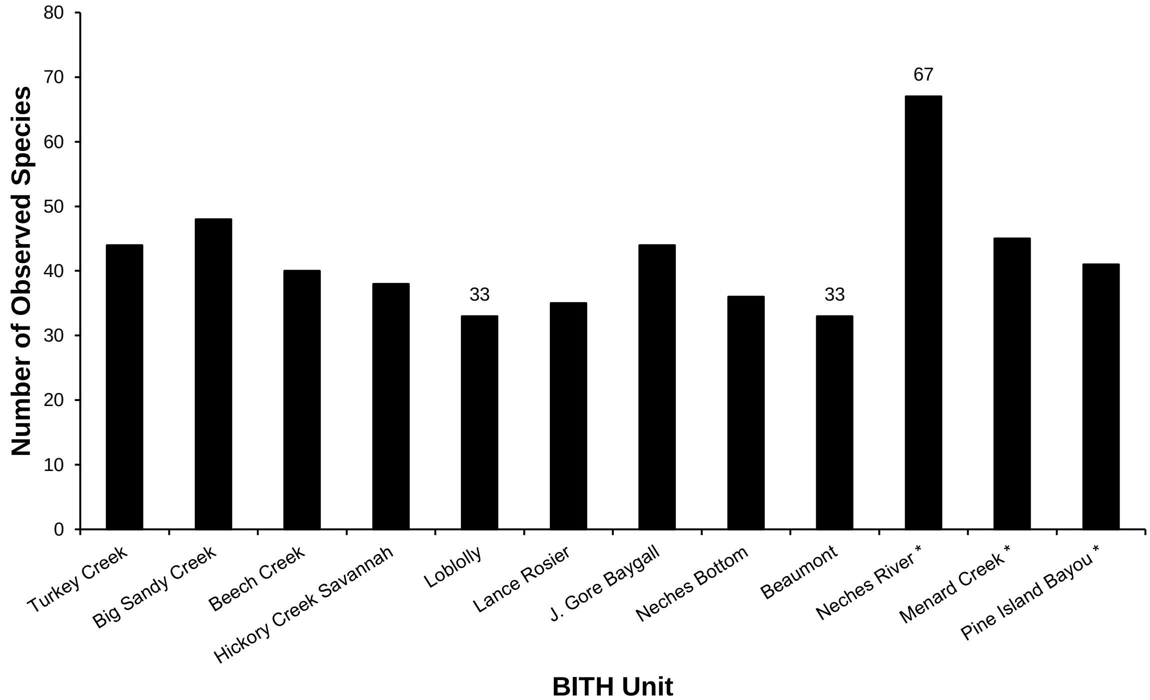

Figure 43. Species richness values observed across BITH Units during Bryan et al. (1976) line transect, canoe, and investigative surveys. Units marked with an * indicate a corridor unit that was surveyed by canoe

Table 42. Species richness values observed in each of the habitat groups and survey type during Bryan et al. (1976).

Group	Forest Line Transects	Canoe Surveys	Longleaf Pine Savanna Survey
Group A	37	-	-
Group B	36	-	-
Group C	29	-	-
Group D	27	-	-
Total	**44**	**64**	**19**

Deuel and Fisher (1977)

Deuel and Fisher (1977)'s 1976 survey of the BSCU, BCU, TCU, NBU, JGBU, BU, LU, LPI-PIBCU, NRCU, and the VCU resulted in the documentation of 83 bird species. This survey was a follow-up to Bryan et al. (1976) and used the same methodology in order to produce comparable results between years; the total number of species observed in 1976 decreased by nine species when compared to 1975 results (Figure 43). However, the total number of species observed in three of the four habitat Groups increased in Deuel and Fisher (1977) compared to Bryan et al. (1976) (Table 42, Table 43); the total number of species observed on the line transects also increased from 44 species in 1975 (Table 42) to 61 species in 1976 (Table 43). Only Group C exhibited a decline in 1976 surveys, declining from 29 species in 1975 to 26 species in 1976. Canoe surveys of the corridor Units resulted in the detection of 59 species, a decline of five species when compared to Bryan et al. (1976).

Table 43. Species richness values observed in each of the habitat groups and survey type during Deuel and Fisher (1977).

Group	Forest Line Transects	Canoe Surveys
Group A	50	-
Group B	48	-
Group C	26	-
Group D	33	-
Total	**61**	**59**

Biercevicz (1977)

Biercevicz (1977)'s brief avian survey in 1977 resulted in the confirmation of 86 bird species, with an additional 68 species listed as probable species (Figure 42). No discussion was made regarding the distribution of species within the study area in Biercevicz (1977)

Ramsey (1980)

During a 1975-76 survey of the BU of BITH, Ramsey (1980) documented 58 bird species (Figure 42). Transects were surveyed during the migratory, winter, and breeding seasons and used existing routes in the unit.

McGuffin (1984)

McGuffin (1984) documented 62 species in the LU during censuses of the unit in 1983 (Appendix G). Because only one transect was used in the unit, a discussion of distribution is not applicable to this study. However, species richness was documented for each month of the census; the spring months (April and May) had the highest species richness values (Figure 44). This is not surprising, as the preserve lies along two major migratory flyways (Figure 34), and April and May represent the migratory period for many species.

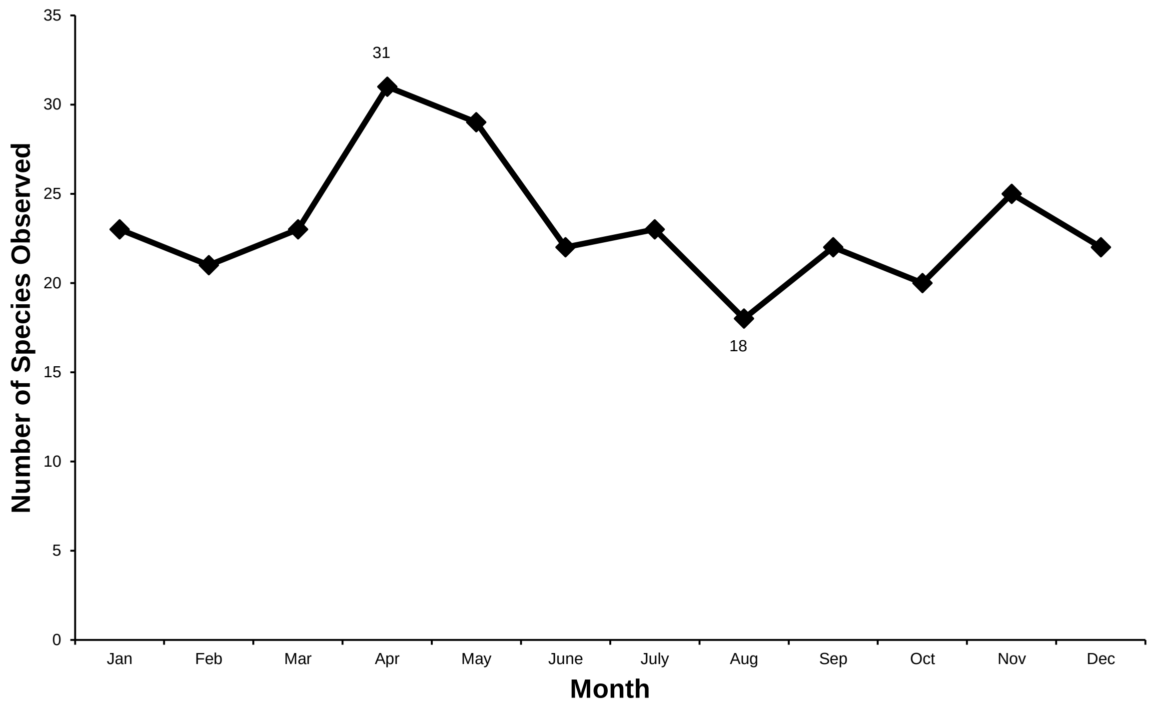

Figure 44. Species richness, by month, during the 12-month McGuffin (1984) avifaunal survey of the LU of BITH. Total species richness for the study was 62 species.

NPS (2015b)

2014 represented the first year of GULN landbird monitoring in BITH. Point counts were used at Panel One and Panel Two in the TCU, and sites were visited between 15 May and 15 June (NPS 2015b). Initial results from the landbird monitoring indicated 28 species were observed at point count locations (Figure 42). Panel Three and Panel Four will be monitored in 2015 to provide a more complete picture of the landbird species composition of the unit.

Turkey Creek and Beech Creek Christmas Bird Counts

The Turkey Creek and Beech Creek CBCs represent the most continuous sources of bird data in the BITH region, with counts occurring almost every year from 1978-present. The CBC methodology, much like that of the BBS, is an example of an index count, which is a methodology that tallies the number of bird detections during surveys of points, transects, or other defined regions (Kendeigh 1944, Verner 1985, Bibby et al. 1992, Ralph et al. 1995, Rosenstock et al. 2002). Index counts quantify bird species' distribution, occurrence, habitat relationships, and population trends (Rosenstock et al. 2002).

The CBCs survey only a portion of BITH (Figure 38), so results from the survey may not be completely indicative of the species richness trends for bird species in all habitat types of BITH. Counts such as the CBC (or other index counts, e.g., breeding bird surveys) are neither censuses nor density estimates, and results should only be viewed as indices of population size (Link and Sauer 1998). Possible bias of count locations and the number of observers limit the overall usefulness of index count data, and it is often not advisable to estimate overall population sizes from these data alone (Link and Sauer 1998); these biases may influence how many individuals are observed in a given year, and may potentially explain the annual variation observed in species each year.

The total number of bird species identified annually during the preserve's two CBCs from 1978-2013 is represented in Figure 45. The Turkey Creek CBC had an average of 61.6 species/year, with a peak species richness value of 76 species (1986) and a low value of 45 species (1994; Figure 45). The Beech Creek CBC had an average of 79.5 species/year, with a peak species richness value of 99 (2004), and a low value of 55 species (1981). When looking at all CBCs across all years (1978-2014), the CBCs in the preserve have identified 176 unique species within the general BITH area (Appendix F).

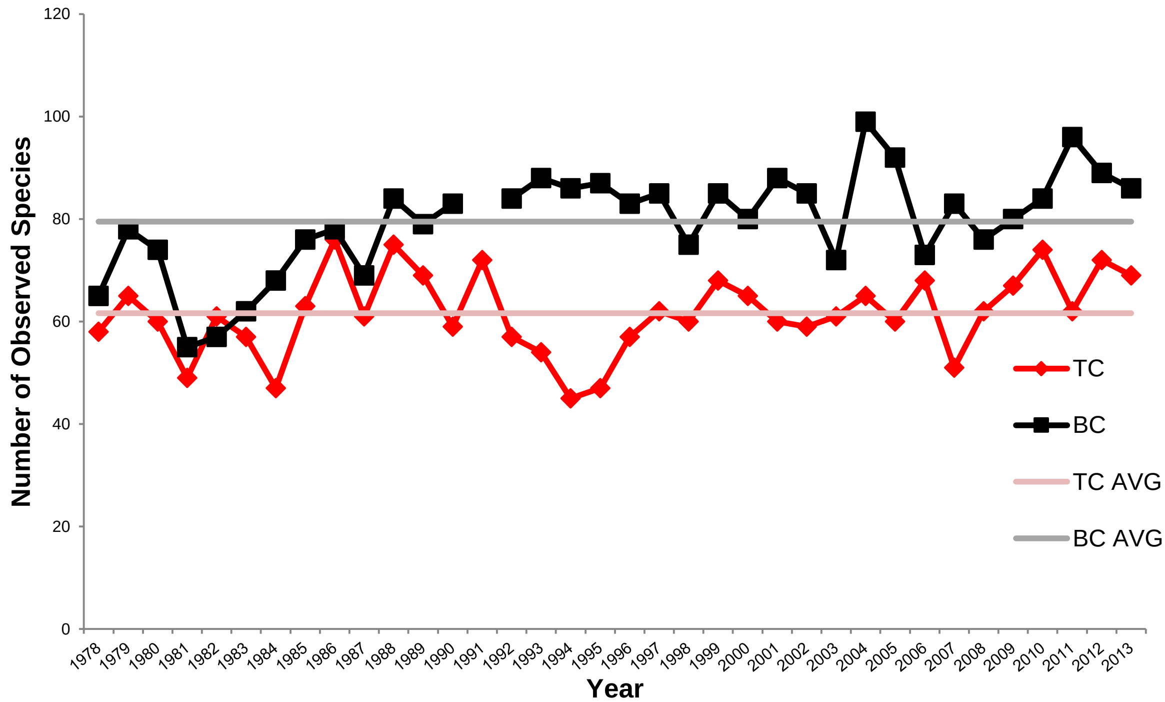

Figure 45. Species richness values from the Turkey Creek CBC (TC) and the Beech Creek CBC (BC) from 1978-2014. Solid lines represent the average species richness value for each CBC for the duration of the count (data from: http://netapp.audubon.org/CBCObservation/Historical/ResultsByCount.aspx#).

Breeding Bird Surveys (FRED [route 83321], Big Sandy-BITH [route 83904], Lance Rosier-BITH [route 83905], and Neches-BITH [route 83906])

When looking at all routes across all years (1995-2014), the BBSs in the preserve have identified 100 unique species within the general BITH area (Appendix F). Of the four active BBS routes in the BITH region, the FRED route (BBS route 83321) has been surveyed for the longest period of time (19 years). The FRED route runs east to west and bisects the TCU and follows the northern boundary of the HCSU (Figure 37). The number of species observed on this route has ranged from 43 (2010, 2012) to 54 (2002, 2003, 2004, 2006) (Figure 46); the average number of species observed on this route was 49.5.

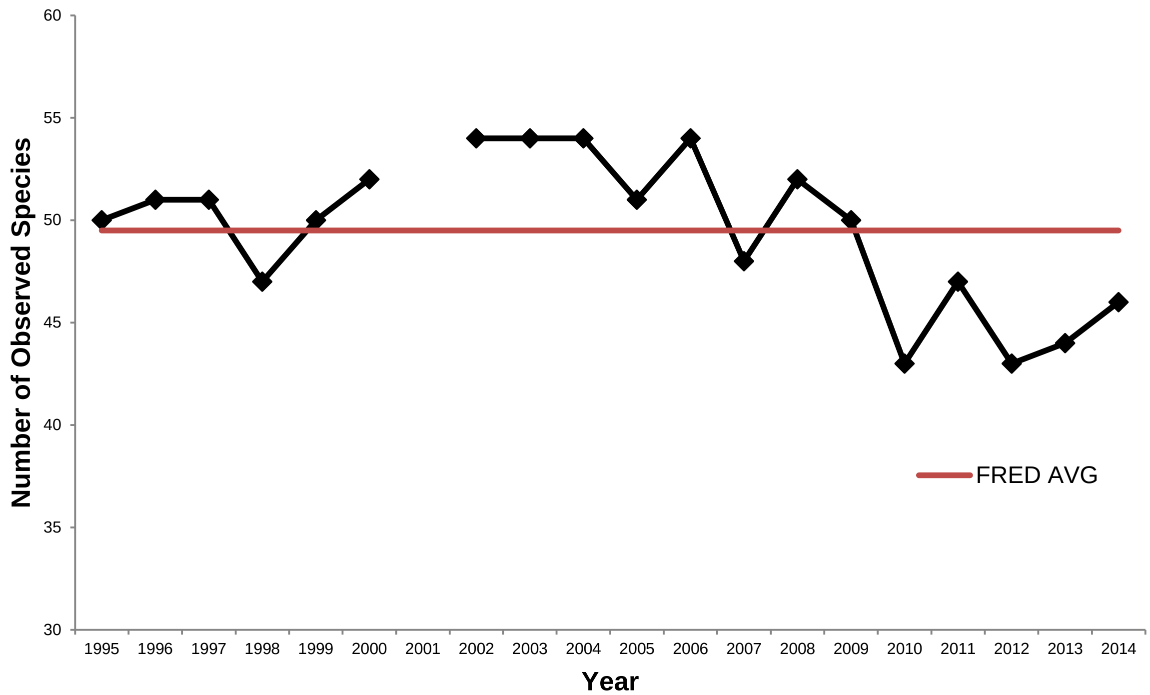

Figure 46. Species richness data from the FRED BBS route (route 83321) from 1995-2014. The solid red line represents the average species richness (49.5 species) for the duration of the BBS (data from: https://www.pwrc.usgs.gov/BBS/PublicDataInterface/index.cfm?fuseaction=PublicDataInterface.viewPublic).

The remaining BBS routes in BITH were established in 2010. The Big Sandy-BITH route corkscrews through much of the unit (Figure 37) and utilizes FMR 1276, Lily Road, Sunflower Road, FMR 943, and Firelane Road. The Big Sandy-BITH route has been surveyed in 2010, 2011, and 2014, with species richness values ranging from 36 (2010) to 42 (2011, 2014; Figure 47). The average number of species observed during the 3 years of surveys was 40 species.

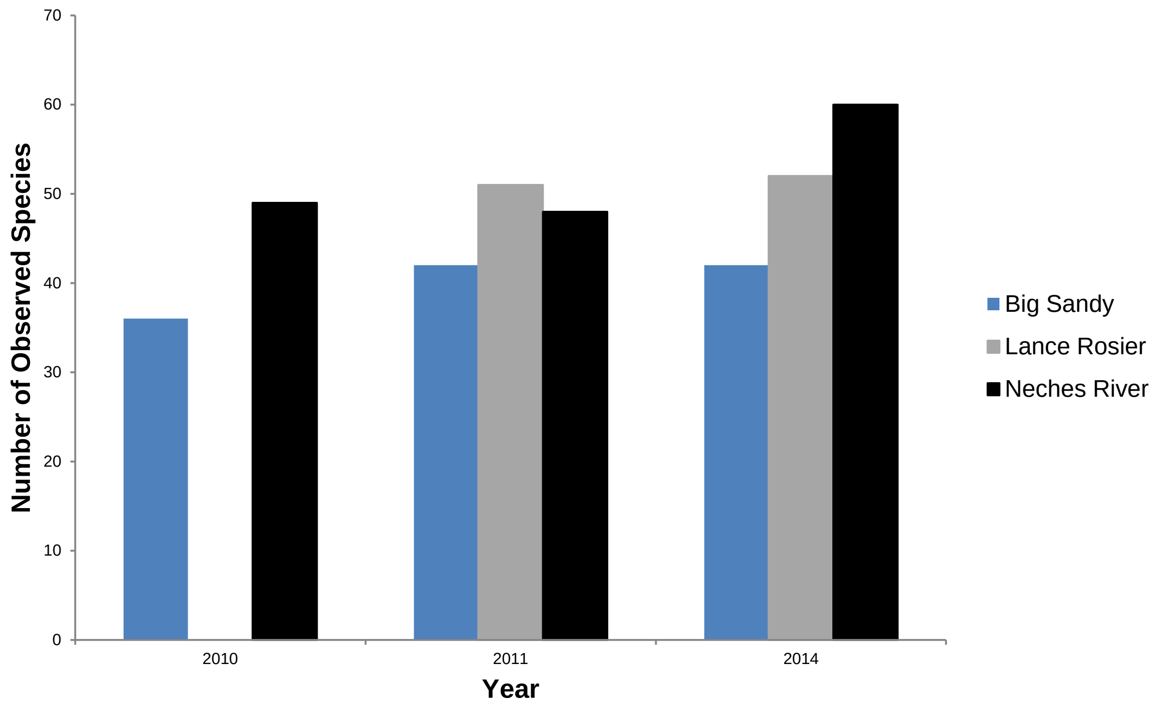

Figure 47. Species richness data from the Big Sandy-BITH, Neches River-BITH, and Lance Rosier-BITH BBS routes from 2010-2014 (data from: https://www.pwrc.usgs.gov/BBS/PublicDataInterface/index.cfm?fuseaction=PublicDataInterface.viewPublic).

The Neches River-BITH route runs adjacent to the LNRCU and BUs of BITH, following FMR 1131 and Four Oaks Ranch Road for much of the survey (Figure 37). The Neches River-BITH route was also surveyed in 2010, 2011, and 2014, with species richness values ranging from 48 (2011) to 60 (2014; Figure 47). The average number of species observed during the 3 years of surveys was 52.3 species.

The Lance Rosier-BITH route runs along portions of the northern boundary of the LRU on FMR 770, and bisects the western portion of the LPI-PIBCU when the route turns onto FMR 326 (Figure 37). This route has only been surveyed twice (2011, 2014). Both years have had similar numbers of species observed, with 51 species observed in 2011 and 52 species observed in 2014 (Figure 47).

Threats and Stressors Factors

There are many threats facing the bird community of BITH; examples include mosquito-borne diseases such as West Nile Virus, climax vegetation setback due to extreme weather events (i.e., hurricanes), and invasive/exotic species. One of the major threats facing bird populations across all habitat types is land cover change (Morrison 1986). Land cover change is not restricted to the breeding habitat; many species depend on specific migratory and wintering habitat types that are also changing. The encroachment of non-native plant species may be a contributor to land cover change in all habitats. Altered habitats can also compromise the reproductive success or wintering survival rates of species adapted to that habitat. They can also allow generalist, non-native species, such as the European starling (*Sturnus vulgaris*), to move in and outcompete native bird species. Other non-native birds, such as rock doves and Eurasian collared-doves (*Streptopelia decaocto*), are larger and can displace native doves and other forest birds from the better nesting and feeding areas.

Migratory bird species face deteriorating habitat conditions along their migratory routes and wintering grounds. Most of the birds that breed in the United States winter in the Neotropics (MacArthur 1959); deforestation rates in these wintering grounds have occurred at an annual rate up to 3.5% (Lanly 1982). While forest and habitat degradation does occur in the United States, it does not approach the level of degradation seen in the tropics (WRI 1989). Furthermore, Robbins et al. (1989) supported the suggestion that deforestation in the tropics has a more direct impact on Neotropical migrant populations than deforestation and habitat loss in the United States.

Feral hogs, a non-native species, may be a direct and indirect threat to the bird population in BITH. Feral hogs have been known to negatively affect native wildlife through habitat loss and depredation, as feral hogs cause habitat loss by foraging on native vegetation (Jolley et al. 2010). Feral hogs not only cause habitat loss by foraging on native vegetation, but their wallowing also destroys the root system of many species and alters the soil in specific areas. Feral hogs also prey upon ground-nesting bird species, and can have impacts on nesting success and productivity. This may be one factor in the very low eastern wild turkey (*Meleagris gallopavo silvestris*) and quail populations currently of concern at BITH.

Fire ants, specifically RIFA, were accidentally introduced into the U.S. in the 1930s and have expanded their range dramatically, with established populations now present in much of the American Southeast (Willcox and Giuliano 2006). RIFA are extremely aggressive and possess a powerful sting that can decimate ground nesting bird species such as the Bachman's sparrow (*Aimophila aestivalis*), northern bobwhite (*Colinus virginianus*), eastern wild turkey, and waterbird species such as the great egret (*Ardea alba*) and great blue heron (*Ardea herodias*). Drees (1994) found that an infestation of RIFA in Texas was responsible for a 92% reduction in offspring survival in nesting waterbirds. Mortality due to RIFA is usually due to stinging, predation of young, or competition for food resources in a given area (Willcox and Giuliano 2006).

<u>Data Needs/Gaps</u>
Continuation of the annual GULN monitoring is needed in BITH to create a long-term dataset for the preserve. While the BBS and CBC represent long-term data sources, both studies have inherent biases (previously discussed) that make their data of limited use outside of population estimates.

Many of the early surveys that were completed in the preserve used similar methodologies, which allowed for comparisons between studies/years/units. Currently, the GULN monitoring is in its infant stages and is only monitoring the TCU. Expansion of these survey efforts would allow for comparisons between units, and could potentially identify critical areas/habitat types within the many units and corridors of BITH. Additionally, expanding surveys to include the migratory and winter periods would provide managers with a more complete picture of the health of the avifauna of the preserve; current monitoring captures only the breeding bird species of the TCU.

Overall Condition

Abundance

The abundance measure was assigned a *Significance Level* of 3 during project scoping. Historic surveys of several BITH units indicated that abundance levels were high, especially during the migration period (McGuffin 1984). The most abundant species were fairly consistent across many of the study years, as the white-eyed vireo, northern cardinal, and tufted titmouse were observed in high numbers in all the preserve's early surveys (Bryan et al. 1976, Deuel and Fisher 1977, McGuffin 1984). These species were also the most abundant species observed during the first year of GULN monitoring in the TCU (Appendix H). The CBCs in the preserve have had highly variable abundance levels; this is likely due to biases in the count methodology, but cannot be attributed to that with absolute certainty. The number of individuals observed in the Beech Creek CBC has been well below average during the past two counts (Figure 39); over the duration of that count, 16 of the 35 (46%) count years have been below average. The number of individuals observed in the Turkey Creek CBC has been above average in seven of the last eight counts (Figure 39); however, over the duration of the count, only 15 of the 36 (42%) count years have been above average.

A *Condition Level* of 1 was assigned to this measure, using primarily the professional opinion of BITH managers, as a sizeable time gap exists between studies in the preserve (1984 to 2014). While the GULN breeding bird monitoring project has kicked off in BITH, only one unit is currently being surveyed, and drawing conclusions regarding current condition using only 1 year of data is not advisable. Although a good deal of data exists from the two CBCs in the preserve, there are inherent biases that exist in the survey's methodology that makes assessment of current condition problematic. The CBCs survey only a portion of BITH (Figure 38), so results from the survey may not be completely indicative of the abundance trends for bird species in the entire preserve. Count locations and the number of observers limit the overall usefulness of index count data, and it is often not advisable to estimate overall population sizes from these data alone (Link and Sauer 1999); these biases may influence how many individuals are observed in a given year, and may potentially explain the annual variation observed in species each year. While the data provide a useful glimpse into the abundance trends of birds in BITH, the data may not accurately describe the current trends and condition for the preserve as a whole.

Species Richness

The species richness measure was assigned a *Significance Level* of 3 during project scoping. The defined reference condition (Fisher 1974) identifies 91 species that are confirmed in the preserve; this list also identifies an additional 203 species as probable species in the preserve (Appendix F). The only confirmed species found in Fisher (1974) that has not been confirmed in BITH by another study is the house finch (*Carpodacus mexicanus*); all other confirmed species have been observed at some time between 1975-2014 (Appendix F). The number of species confirmed during studies from 1975-1984 ranged from 58 (Ramsey 1980) to 92 (Bryan et al. 1976). GULN monitoring in 2014 found only 28 species; however, this study is looking specifically at breeding species in one unit of the preserve, and surveys are timed in a manner that will miss many migratory or non-breeding species.

It is difficult to assess the current condition of species richness for the avifaunal community of BITH, as there exists a substantial data gap from 1984-2014. However, the results of the GULN monitoring effort, combined with the best professional opinion of BITH managers indicate that this measure may be of higher concern at this time. With GULN monitoring investigating only the breeding community of the preserve, and only surveying one unit, the results obtained from that study may not be truly indicative of the overall health of the bird community as a whole in BITH, but the results may still indicate a decline in richness or potential area of concern for preserve managers. While it is unlikely that there have been significant alterations to the species richness of this community, this cannot be said for certain. Despite the lack of current data, it is the preserve managers' opinions that this measure warrants a *Condition Level* of 2 at this time.

Weighted Condition Score
The birds component was assigned a WCS of 0.50, indicating moderate concern. This designation relied heavily on input received from BITH resource managers, largely due to a lack of data for the specified measures. Because of the lack of data mentioned here and above, a low confidence border was applied to this graphic.

Birds			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.50**
Abundance	3	1	
Species Richness	3	2	

4.8.6 Sources of Expertise

- Ken Hyde, BITH Chief of Resources Management

4.8.7 Literature Cited

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4.9 Amphibians and Reptiles

4.9.1 Description

Amphibians and reptiles are considered a Vital Sign and are indicator species of the overall health and condition of all GULN park's aquatic and wetland systems, including BITH (Segura et al. 2007). The dendritic layout of the preserve, with nine land units and six water corridor units, does provide travel corridors for reptile and amphibians, but has contributed to the habitat fragmentation issues typical of disjunct parcels. It also makes reptile and amphibian survey efforts and long-term monitoring a challenge in the 9,065 km^2 (3,500 mi^2) area encompassing the preserve (Segura et al. 2007).

Photo 15. Louisiana pine snake (*Pituophis ruthveni*) may occur in BITH and is a threatened species in the state of Texas (USFWS 2004). Squirrel treefrogs (*Hyla squirella*) are uncommon and Woodhouse's toads (*Bufo woodhousii*) are abundant in BITH (NPS photos).

BITH is known for its incredible biodiversity of flora and fauna, which is largely due to the preserve's intermingling of ecosystems. Currently, 22 amphibians and 39 reptiles are confirmed to inhabit the preserve while an additional 10 amphibians and 18 reptiles are unconfirmed, but likely occurring in the preserve due to their regional distributions (NPS 2015). The land units of BITH have become more connected through the additions of waterway corridor units, but the preserve was never envisioned by Congress as being one large, contiguous block of land. This layout heavily increases the potential for fragmentation of crucial amphibian and reptile habitats as well as increasing the level of human disturbances caused by roadways, pipe and utility lines, and neighboring housing developments. Some amphibian and reptile species are more intolerant of habitat fragmentation than others. While some of the preserve includes very small fragments of good habitat for the current and expected amphibian and reptile species, the extensive boundary length increases the general potential for impacts from adjacent landuse and human activities (Woodman, written communication, 1 October 2015). This is particularly a concern in narrow corridor units with extensive amounts of boundary exposed to an urban interface, which has substantial implications in terms of prioritizing management focus and efforts onto larger patches or units of better habitat (Woodman, written communication, 1 October 2015).

The Louisiana pine snake (*Pituophis ruthveni*), for example, needs large acreages of continuous longleaf pine forest and savannas and is highly susceptible to roadway mortality due to its large size (average length is 1.2-1.5 m [4-5 ft]) (USFWS 2014) (Photo 15). It also needs extensive herbaceous understories that support large populations of gophers, its primary prey species and in whose burrows it spends much of its life.The Louisiana pine snake has yet to be confirmed in BITH, but is listed in NPS (2014) since its distribution includes Jasper and Tyler counties in Texas (USFWS 2014, NPS 2014). Currently, the Louisiana pine snake is a candidate for federal listing in addition to the state-level threatened status; as of 2007, it is also listed by the IUCN as an endangered species (USFWS 2014, IUCN 2014). Another state-threatened species known to occur in BITH is the timber rattlesnake (*Crotalus horridus*), which prefers habitats like those found throughout the preserve (i.e., moist lowland forests, hilly woodlands, and thickets) (TPW 2015). The staff at BITH have photographs and have had numerous sightings of the timber rattlesnake, particularly in the BSCU and LRU (Hyde, pers. communication, 21 September 2015). Due to its venomous qualities and the generally bad public image that it has been given, there are few neighbors and visitors who do not immediately dispatch this snake whenever it is sighted. As in most parks, there are a range of varied abundances in the documented herptile community; for example the Woodhouse's toad (*Bufo woodhousii*) is considered abundant while the squirrel treefrog (*Hyla squirella*) is rare (Photo 15).

4.9.2 Measures

- Species richness
- Species abundance
- Species distribution

4.9.3 Reference Conditions/Values

The reference condition, as defined by preserve management, is based on the survey results of Fisher and Rainwater (1978). This will be used as the baseline for comparisons with subsequent research to assess trends in richness, abundance, and distribution of amphibians and reptiles in the preserve. The purpose of Fisher and Rainwater (1978, p. 1) was:

> *To provide information on the kinds and relative numbers of amphibians and reptiles inhabiting the Big Thicket National Preserve in southeastern Texas. Emphasis will be placed on forest species. Comparisons will be made between different kinds of forests and between different times of the year, and species diversity and relative abundance indices will be calculated from data gathered by means of systematic censuses.*

Species Richness

Fifty-two reptile and amphibian species were documented within the preserve units and two on adjacent lands. A total of 16 amphibians and 36 reptiles, of which there were three salamander (one newt) species, 13 frog and toad species, 10 turtle species, six lizard (and skink) species, and 19 snake species were recorded between 20 May 1975 and 25 May 1976 (Appendix I; Fisher and Rainwater 1978).

Species Abundance
Relative abundance of these species is depicted in Appendix J as a count of individuals. Total number of amphibians observed was over twice the total number of reptiles, with 1,014 amphibians and 456 reptiles recorded during the duration of the study (Fisher and Rainwater 1978).

Species Distribution
Amphibian and reptile distributions are described by Fisher and Rainwater (1978) in tables indicating the areas where observations were made at BITH during 59 daytime censuses. The bulk of observations for both amphibians and reptiles were made in lowland forests, which are a combination of bottomland hardwood forest and palmetto forests (Table 44; Fisher and Rainwater 1978). It should be noted that this does not include all units in the preserve since several were not surveyed during the study.

Table 44. Distribution of amphibians and reptiles (by number of individuals observed) in four forest types at BITH (recreated from Fisher and Rainwater 1978).

Habitat	Forest Type	Amphibians	Reptiles
Lowland forests	Bottomland hardwood forest	414	120
	Palmetto-hardwood forest	78	26
Upland forests	Wet pine-hardwood forest	134	99
	Dry pine-hardwood forest	16	27

4.9.4 Data and Methods
Fisher and Rainwater (1978) gathered data in summer (20 May – 3 July 1975) and spring (10 March – 25 May 1976) to provide a list of species and their general abundances at BITH. The surveys were largely conducted within the boundaries of the preserve, with an occasional adjacent-area that was investigated. Daytime censuses on foot were carried out in four major forest types (bottomland hardwood, palmetto hardwood, wet pine hardwood, and dry pine-hardwood forests) and comprise the bulk of the total observations made. Methods of data collection on foot were non-systematic in that the observer did not follow defined transects or trails, but rather a meandering path with intent to pass through herptile habitats. Observers performed systematic daytime censuses on foot and by canoe and systematic nighttime censuses by car along roads and highways, recording species and number of individuals observed per hour per mile traveled, as well as general surveys using non-systematic data recording (Fisher and Rainwater 1978).

On all censuses, a single observer recorded all herptile encounters by species while making frequent stops to check under rotted logs, leaf litter, or other cover material where a reptile or amphibian may hide; time of day and weather conditions were also recorded (Fisher and Rainwater 1978). General survey data were simply collected whenever a herptile was encountered outside of census periods, mostly within the preserve, but also occasionally from surrounding areas.

Lewis et al. (2000) conducted herptile sampling in the BSCU during 1998 and 1999. Four forest types were sampled to determine herptile assemblages in each. Circular plots were established in each forest type measuring 69 m (226 ft) in radius with a minimum 10 m (33 ft) separation between each plot. Plots were also placed at a minimum of 50 m (164 ft) from the forest boundary and plots were used to sample herpetofauna as well as vegetation and habitat composition (Lewis et al. 2000). Trapping arrays were installed at the center of each plot and consisted of three 10 m (33 ft) black erosion cloth drift fences arranged in a "Y" shape. Each drift fence had four large cloth funnel traps, totaling 12 traps per array. Nine aluminum screen wire funnel traps were also deployed at each array to facilitate capture of smaller animals (Lewis et al. 2000). Sampling efforts also used PVC tube arrays and time-area searches to detect amphibians and reptiles in the plots and on trails used to access the plots. Traps were checked every 2 to 4 days in 1998 from April through June and in September and October. The same checking interval was used in 1999 from March through June (Lewis et al. 2000). Individuals captured were identified and marked by toe or scale clipping to ensure recaptured individuals would not be included more than once for statistical analysis (Lewis et al. 2000). Data analyses were performed to determine herpetofaunal composition and abundance in the four forest types and the respective vertical vegetative strata. Number of individuals and species were totaled by plot (Lewis et al. 2000).

Members of the Dallas-Fort Worth Herpetological Society (DFWHS) collected data on herptile sightings within the preserve units and in the immediate vicinity (DFWHS 2010). Data were in spreadsheet form and included species, date, time, location by latitude and longitude, county, landmark, temperature, details on condition of individual sighted, and notations on the status of the individuals (i.e., dead on road or alive on road).

More recently, the GULN Vital Signs Monitoring Program (Segura et al. 2010) has conducted trial amphibian and reptile surveys in the BSCU and TCU using three methods, including cover-board arrays, PVC-pipes on trees, and visual encounter surveys.

Crump (2008-2010) sought to document the composition and abundance, and to inventory herptile species within the TCU of BITH; the effort was later expanded to other units of BITH. Between 18 October 2008 and 14 June 2010, Crump (2008-2010) collected field data regarding observed reptiles and amphibians in the TCU, CU, NBU, and JGBU. Data were collected by primary and co-investigators, and volunteers from the Houston Zoo and Eastfield College students. Methods of collection included both passive and active forms of survey, collection, and documentation of herpetofauna. Passive survey methods included cover board arrays, PVC pipe arrays, drift fence and pit fall trap arrays, and minnow and crab baited hoop nets. Active detection methods included visual encounter surveys (VES), both on foot, in a canoe, and in a vehicle, and dip netting. Pertinent morphological measurements (i.e., total length, snout-vent length, and weight) were taken for captured individuals and a small subset of amphibians were swabbed for amphibian chytrid fungus. Crump (2008-2010) also targeted monitoring specifically for turtle populations. Captured turtles were marked using passive integrated transponder (PIT) tags while collecting observation data on herpetofauna in the preserve. PIT tagging uses an electronic microchip encased in biocompatible glass that is injected using a 12-gauge needle or inserted surgically under the animal's skin into muscle or the body cavity (Gibbons and Andrews 2004). The PIT tag serves as a permanent coded marker used to identify individuals (Gibbons and Andrews 2004).

Since 2010, staff members from USGS have conducted an extensive amphibian and reptile monitoring program to investigate impacts of salt-water intrusion on amphibians above and below the permanent saltwater barrier on the Neches River (Waddle 2014). The objective of this longer term study is to use site occupancy analysis to model effect of salinity and habitat on distribution and abundance of reptile and amphibian species at Lower Cypress Tract (Waddle 2014).

The NPS Certified Species List (NPS 2015) provides a record of species that have either been directly observed in the preserve or have overlapping geographic ranges with suitable habitat, making the presence of a species likely.

Due to the ever-changing taxonomy of many herptile species, especially evident in recent years, the taxonomy presented in the many tables and figures of the current condition and trend section below represents how the species were identified in the source literature. This was done to provide readers with a sense of how taxonomy has changed since the time of original publications. In-text references to Latin names were updated to the most recently accepted name whenever possible. Taxonomy included in Appendix I represents the most recently accepted taxonomy of all species included in NPS (2015); for species included in Appendix I, but not included in NPS (2015), the most recently accepted Latin name from www.itis.gov was used.

4.9.5 Current Condition and Trend

<u>Species Richness</u>

Systematic censuses conducted by Fisher and Rainwater (1978) resulted in the observation of 52 reptile and amphibian species within the preserve units and two on adjacent lands. Two salamander and one newt, 13 frog and toad, 10 turtle, six lizard and skink, and 19 snake species were recorded between 20 May 1975 and 25 May 1976. One chicken turtle (*Deirochelys reticularia*) observed near, but not within, the BU and one eastern hog-nosed snake (*Heterodon platirhynos*) near the entry to the NBU-JGBU were not included in the species list, but they likely occur within the preserve due to the observation proximity (Fisher and Rainwater 1978; Appendix I). As noted in the appendix, there were two frog species that were counted as the same due to difficulty in identifications; these were the Cope's gray tree frog (*Hyla chrysoscelis*) and the gray tree frog (*Hyla versicolor*).

Lewis et al. (2000) surveyed BSCU and observed 40 species of amphibians and reptiles across four forest types: five salamander species, 13 frog and toad species, one turtle species, six lizard species, and 13 snake species (Appendix I and Appendix J). Though this is a lower number of species than what Fisher and Rainwater (1978) reported, it is likely due to sampling only one preserve unit as well as the lack of any aquatic sampling.

Crump (2008-2010) documented 15 amphibian and 29 reptile species while conducting herptile surveys in BITH between 2008 and 2010 (Appendix I). There were eight frog and toad, and seven salamander and other (i.e., siren, newt) species observed. A total of 11 snake, 11 turtle, and seven lizard and skink species were also observed during the study. Areas surveyed were in Hardin and Tyler counties and within the TCU, CU and the NBU-JGBU only. Included were two individual observations of the state-listed threatened species, the alligator snapping turtle, one in TCU and the other in the NBU-JGBU.

The DFWHS collected herptile sighting data in 2010 within the preserve and areas in the immediate vicinity; Tyler, Polk, Hardin, Chambers and Houston counties were included in this effort. A total of 54 species were observed in the three counties where BITH is located (Figure 48 and Table 45). The observations consisted of 14 amphibian and 40 reptile species. Amphibian species included 14 species of frogs and toads, and reptiles consisted of 24 snakes, eight turtles, and eight lizards and skink species (including one American alligator [*Alligator mississipiensis*]). The ongoing study by the USGS on their 2010 to 2016 study of herptiles above and below a salt water barrier on the Neches River has resulted in the identification of 45 species (Appendix I), including some located in the course of other duties.

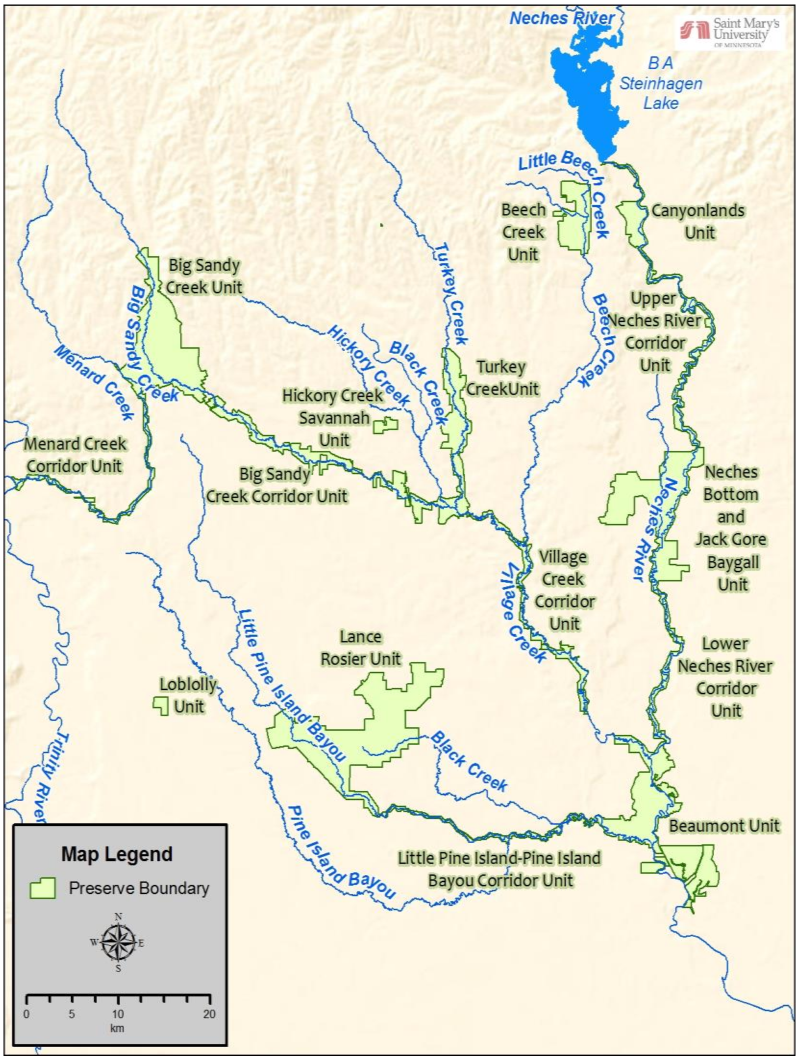

Figure 48. The layout of preserve units and counties where the preserve is located.

Table 45. A compilation of species observed during a field trip conducted by the Dallas-Fort Worth Herpetological Society (2010) and 5 years of ongoing field research being conducted by the USGS within BITH.

Scientific Name	Common Name	Counts Available From 2010 Data
Acris blanchardi	Blanchard's cricket frog	-
Agkistrodon contortrix contortrix	southern copperhead	12
Agkistrodon piscivorus leucostoma	western cottonmouth	8
Alligator mississippiensis	American alligator	-
Anaxyrus fowleri	Fowler's toad	-
Anolis carolinensis	green anole	1
Apalone spinifera	spiny softshell	-
Aspidoscelis sexlineata	six-lined racerunner	-
Chelydra serpentina	common snapping turtle	2
Coluber constrictor etheridgei	tan racer	3
Coluber constrictor etheridgei/anthicus	tan/buttermilk racer intergrade	1
Coluber flagellum	coachwhip	-
Crotalus horridus	timber rattlesnake	1
Eleutherodactylus cystignathoides	Rio Grande chirping frog	-
Farancia abacura	mud snake	2
Gastrophryne carolinensis	eastern narrow-mouthed toad	-
Graptemys sabinensis	Sabine map turtle	-
Haldea striatula	rough earthsnake	-
Heterodon platirhinos	eastern hognose	3
Hyla cinerea	green treefrog	1
Hyla squirella	squirrel treefrog	-
Hyla versicolor / chrysoscelis	gray treefrog	3
Kinosternon subrubrum	eastern mud turtle	-
Lampropeltis calligaster calligaster	prairie kingsnake	2
Lampropeltis gentilis	western milksnake	-
Lampropeltis getula getula	speckled kingsnake	1
Lampropeltis triangulum amaura	Louisiana milksnake	1
Liodytes rigida	glossy swampsnake	-

Table 45 (continued). A compilation of species observed during a field trip conducted by the Dallas-Fort Worth Herpetological Society (2010) and 5 years of ongoing field research being conducted by the USGS within BITH.

Scientific Name	Common Name	Counts Available From 2010 Data
Lithobates catesbeianus -	bullfrog	2
Lithobates clamitans clamitans	bronze frog	1
Lithobates grylio	pig frog	-
Micrurus tener tener	Texas coral snake	1
Nerodia erythrogaster	plain-bellied watersnake	-
Nerodia erythrogaster flavigaster	yellowbelly water snake	8
Nerodia faciata	southern watersnake	-
Nerodia fasciata confluens	broadbanded water snake	2
Nerodia rhombifer rhombifer	diamondback watersnake	1
Ollotis nebulifer	Gulf Coast toad	2
Opheodrys aestivus	rough green snake	1
Ophisaurus attenuatus attenuatus	western slender glass lizard	2
Pantherophis obsoletus	western ratsnake	-
Pantherophis obsoletus lindheimeri	Texas rat snake	4
Plestiodon fasciatus	five-lined skink	3
Plestiodon laticeps	broad-headed skink	-
Pseudacris crucifer	spring peeper	-
Pseudacris fouquettei	Cajun chorus frog	-
Pseudemys concinna	river cooter	-
Rana sphenocephalus	southern leopard frog	-
Regina rigida sinicola	Gulf crayfish snake	1
Sceloporus undulatus consobrinus	n. fence lizard	3
Scincella lateralis	ground skink	4
Sternotherus carinatus	razor-backed musk turtle	-
Storeria dekayi texana	Texas brown snake	4
Thamnophis proximus proximus	western ribbon snake	4
Trachemys scripta	pond slider	-
Trachemys scripta elegans	red-eared slider	1

Currently, 22 amphibians and 39 reptiles are confirmed in BITH by NPS (2015), with an additional 10 amphibians and 18 reptiles being unconfirmed, and one reptile identified as probably present (NPS 2015). NPS (2015) includes all species that have habitat distribution ranges that overlap with the preserve, many of which are not yet confirmed to occur in the preserve.

In total, with all surveys combined, 38 amphibian species and 69 reptile species have been documented, or are considered likely to occur, within the preserve (Appendix I). There have been six amphibian and nine reptile species reported in BITH that are not identified on NPS (2015) during field studies and surveys between the reference period of Fisher and Rainwater (1978) and the DFWHS collections that are ongoing. Documentation of 89 herpetofauna species is now available, with 32 amphibians and 57 reptiles included in this number. It would seem likely that future studies, surveys, and monitoring and inventory efforts at BITH will result in additional species observations.

Species Abundance

Fisher and Rainwater (1978) noted that relative abundances were dependent upon the moisture availability of each habitat type, with greater herptile abundances observed in lower elevations where moisture is more prevalent. During field work, 326 Woodhouse's toads, 216 northern leopard frogs (*Lithobates pipiens*), 186 green frogs (*Lithobates clamitans*), and 159 ground skinks (*Scincella lateralis*) were observed in the preserve. There were also 205 gray or Cope's gray tree frogs observed. In the discussion, Fisher and Rainwater (1978) explain that these two species were recorded as the same species since distinguishing between the two frogs is extremely difficult. These counts are shown in Appendix J.

Lewis et al. (2000) conducted sampling in the BSCU in BITH during the spring and fall of 1998 and 1999 to determine the species of amphibians and reptiles, and general abundances in four different forest types (Appendix J). This survey was limited to one preserve unit, so comparison to the reference condition would not assess the condition of abundance for the entire preserve, or for the BSCU. However, this will be useful to compare abundance data collected in the BSCU in future studies and surveys. There were 462 Woodhouse's toads, 262 ground skinks, 260 southern leopard frogs (*Lithobates sphenocephalus utricularius*), 115 Gulf Coast toads (*Incilius nebulifer*), 97 eastern spadefoots (*Scaphiopus holbrookii*), 93 green anoles (*Anolis carolinensis*), 83 five-lined skinks (*Plestiodon fasciatus*), and 62 copperheads (*Agkistrodon contortrix*) observed in various areas, which are delineated in Appendix J.

Crump (2008-2010) recorded several species in the preserve with a total individual count of 203. The highest number observed of a species was 27 red-eared sliders, with the next most frequently observed species being the dwarf salamander (*Eurycea quadridigitata*) (23 observations), followed by the eastern fence lizard (10 observed), and the marbled salamander (*Ambystoma opacum)* (10 observed). Other species observed were found in numbers less than 10 and are listed in Appendix J.

The DFWHS and the USGS provided an unpublished list of herptiles compiled from 29 April to 2 May 2010 during a 4-day visit to three counties in which preserve units were situated (Table 45). Based on proximity, these species counts are relevant to the preserve units. From greatest to least, individuals observed were copperheads (12), cottonmouths (*Agkistrodon piscivorus*; 8), yellow-bellied water snakes (*Nerodia erythrogaster flavigaster*; 8), Texas rat snakes (*Pantherophis obsoletus lindheimeri*; 4), Dekay's brown snakes (*Storeria dekayi*; 4), and ground skinks (4). Other species were single individuals or lacked a count at all, but were observed in BITH during the ongoing research conducted by USGS. The species that included a count of individual are shown compared with previous studies in Appendix J.

NPS (2015) lists a very simple description of presumed abundance for amphibians and reptiles that inhabit the preserve. It should be noted that this is not the result of an extensive study, but rather an estimate of species abundances based on available studies and reports from the preserve (Appendix J).

Species Distribution

Fisher and Rainwater (1978) conducted reptile and amphibian surveys in all preserve units (Table 46). Although there are two records that were not within the preserve at that time, it is still relevant since there is likelihood that the species also existed within the preserve due to proximity.

Table 46. Species listed with locations by preserve unit (created from Fisher and Rainwater 1978 p. 36-53).

Scientific Name	Common Name	Preserve Unit
Notophthalmus viridescens	central newt	TC
Ambystoma opacum	marbled salamander	BC, JG*
Eurycea quadridigitata	dwarf salamander	BC, BS, JG, LR, NB, TC*
Bufo valliceps	Gulf Coast toad	BC, BS, Bm, JG, LR, NR*
Bufo woodhousii	Woodhouse's toad	BS, Bm, JG, LR, NB, TC, NR*
Acris crepitans	northern cricket frog	BC, BS, JG, LR, MC, NR*
Hyla chrysoscelis/versicolr	gray treefrog	BS, Bm, JG, LR, Lb, NB, TC, MC, NR, PI*
Hyla cinera	green treefrog	BS, JG, LR, NB, MC, NR, PI
Hyla crucifer	spring peeper	TC, BC
Hyla squirella	squirrel treefrog	Bm, JG, LR, NB, TC, NR, PI*
Pseudacris triseriata	upland chorus frog	JG, LR, NB, TC*
Pseudacris triseriata	striped chorus frog	--
Rana areolata	crawfish frog	Bm, Lb
Rana catesbeina	bullfrog	BC, BS, Bm, JG, LR, NB, NR*

*indicates the species was also observed in Lewis et al. (2000) survey of BSCU.

BC=Beech Creek Unit, BS=Big Sandy Creek Unit, Bm=Beaumont Unit, JG=Jack Gore Baygall Unit, LR=Lance Rosier Unit, Lb=Loblolly Unit, NB=Neches Bottom Unit, TC=Turkey Creek Unit, MC=Menard Creek Corridor Unit, NR=Neches River Corridor Unit, PI=Pine Island Bayou Corridor Unit.

Table 46 (continued). Species listed with locations by preserve unit (created from Fisher and Rainwater 1978 p. 36-53).

Scientific Name	Common Name	Preserve Unit
Rana clamitans	bronze frog	BC, BS, Bm, JG, LR, Lb, NB, TC, MC, NR, PI*
Rana pipiens	southern leopard frog	BC, BS, Bm, JG, LR, NB, TC, MC, NR, PI*
Gastrophryne carolinensis	eastern narrow-mouth toad	BC, Bm, JG, LR, NB, NR*
Kinosternon subrubrum	Mississippi mud turtle	Bm, Lb
Sternotherus carinatus	razor-backed musk turtle	Bm, NR
Chelydra serpentina	snapping turtle	NB
Macroclemys temminckii	alligator snapping turtle	NR
Chrysemys floridana	Missouri slider	NB
Chrysemys scripta	red-eared turtle	BS, JG, LR, NB, PI
Deirochelys reticularia	chicken turtle	near Bm (Beaumont Unit)
Graptemys pseudogeographica	false map turtle	Bm, NR
Graptemys kohni	Mississippi map turtle	Bm, NR, PI
Terrapene carolina	three-toed box turtle	Bm, NB*
Terrapene ornata	ornate box turtle	BS
Trionyx muticus	smooth softshell turtle	NR
Trionyx spinifer	spinysoftshell turtle	NR
Anolis carolinensis	green anole	BC, BS, Bm, JG, LR, NB, TC, MC, NR*
Sceloporus undulatus	eastern fence lizard	BS, JG, LR, TC*
Scincella laterale	ground skink	--
Cnemidophrus sexlineatus	six lined racerunner	--
Eumeces laticeps	broad-headed skink	BC, NB*
Plestiodon faciatus	five lined skink	--
Coluber constricter	racer	BC, JG, LR, MC*
Elaphe guttata	Great Plains rat snake	NR
Elaphe obsoleta	Texas rat snake	Bm, JG, LR, NB*
Farancia abacura	mud snake	BS, NR

*indicates the species was also observed in Lewis et al. (2000) survey of BSCU.

BC=Beech Creek Unit, BS=Big Sandy Creek Unit, Bm=Beaumont Unit, JG=Jack Gore Baygall Unit, LR=Lance Rosier Unit, Lb=Loblolly Unit, NB=Neches Bottom Unit, TC=Turkey Creek Unit, MC=Menard Creek Corridor Unit, NR=Neches River Corridor Unit, PI=Pine Island Bayou Corridor Unit.

Table 46 (continued). Species listed with locations by preserve unit (created from Fisher and Rainwater 1978 p. 36-53).

Scientific Name	Common Name	Preserve Unit
Heterodon platirhynos	eastern hog-nosed snake	near entry of Neche Botton and Jack Gore Baygall Units*
Lampropeltis getulus	speckled kingsnake	LR
Masticophis flagellum	eastern coachwhip	BC, JG, NB*
Nerodia erythrogaster	plain-bellied watersnake	--
Natrix erythrogaster	yellow-bellied water snake	BS, JG, LR, NB, TC, NR
Natrix rhombifera	diamondback water snake	BS, JG, NR
Natrix fasciata	broad-banded water snake	BC, BS, Bm, JG, LR, TC, NR, PI
Opheodrys aestivus	rough green snake	NB, TC*
Regina rigida	Gulf glossy water snake	NR
Storeria dekayi	Texas brown snake	BS, Bm, LR, NR*
Storeria occipitomaculata	red-bellied snake	LR
Thamnophis proximus	western ribbon snake	BC, BS, JG, LR, TC, NR*
Thamophis sirtalis	eastern garter snake	LR, Lb
Micrurus fulvis	coral snake	BC, JG*
Agkistrodon contortrix	southern copperhead	BC, BS, LR, NB, TC*
Agkistrodon piscivorus	western cottonmouth	BC, BS, Bm, JG, LR, NB, TC, MC*

*indicates the species was also observed in Lewis et al. (2000) survey of BSCU.

BC=Beech Creek Unit, BS=Big Sandy Creek Unit, Bm=Beaumont Unit, JG=Jack Gore Baygall Unit, LR=Lance Rosier Unit, Lb=Loblolly Unit, NB=Neches Bottom Unit, TC=Turkey Creek Unit, MC=Menard Creek Corridor Unit, NR=Neches River Corridor Unit, PI=Pine Island Bayou Corridor Unit.

Lewis et al. (2000) conducted surveys in the BSCU and found that the assemblage of amphibians and reptiles is distinct from one forest type to the next in BITH. Moisture level appeared to be the determining factor in the distributions, which was also the case with Fisher and Rainwater (1978), and highlights the importance of maintaining the diverse forest types in the preserve units. The species found in the BSCU are listed by forest type (Appendix J). The marbled salamander, upland chorus frog (*Pseudacris feriarum*), common box turtle (*Terrapene carolina)*, broad-headed skink (*Eumeces laticeps)*, racer (*Coluber constricter)*, Texas rat snake, eastern hog nosed snake, eastern coachwhip (*Masticophis flagellum)*, rough green snake (*Opheodrys aestivus)*, and the coral snake (*Micrurus fulvius*) were all observed in BSCU by Lewis et al. (2000), but were not observed there by Fisher and Rainwater (1978). Additionally, there were some species observed in BSCU by Fisher and Rainwater (1978), but not by Lewis et al. (2000). These include the broad-banded water snake (*Nerodia fasciata confluens*), mud snake (*Farancia abacura*), red-eared turtle (*Trachemys scripta elegans*), ornate box turtle (*Terrapene ornata*), yellow-bellied water snake, diamondback water snake

(*Nerodia rhombifer*), and broad-banded water snake. This is likely due to the limited area of sampling, being only in terrestrial habitats and confined to one preserve unit. Further sampling efforts will likely obtain more observations of additional species in the preserve.

Crump (2008-2010) identified 43 species from 203 individual amphibian and reptile observations, and also noted 16 toads (*Bufo* spp.) that were not identified to the species level. These were all within TCU, CU, and the NBU-JGBU of the preserve. Most of these observed individuals (142) occurred in the TCU and included 39 species. Nine species (32 individuals) were observed in the NBU-JGBU, and only one species, two individual southern dusky salamanders, observed in the CU.

DFWHS (2010) recorded herptile sightings and noted the locations of each individual observed by county, preserve unit (when appropriate), or short description of sighting location; for the purpose of this assessment, the list has been modified to only include counties that have BITH units within them (Figure 48 and Table 47)

Table 47. Species observed by county (DFWHS 2010).

Common Name	Hardin	Polk	Tyler
copperhead	x	x	x
western ribbon snake	x	x	x
cottonmouth	x	x	x
northern fence lizard	x	x	-
ground skink	x	x	x
western slender glass lizard	x	x	x
Gulf Coast toad	-	x	-
common snapping turtle	-	-	x
Texas brown snake	-	x	x
eastern hognose	x	-	x
tan racer	x	-	-
mud snake	x	-	x
yellowbelly water snake	x	x	x
broad banded water snake	x	x	-
prairie kingsnake	-	x	-
rough green snake	-	x	-
speckled kingsnake	-	x	-
Texas rat snake	x	x	-

Table 47 (continued). Species observed by county (DFWHS 2010).

Common Name	Hardin	Polk	Tyler
Louisiana milksnake	-	x	-
diamondback watersnake	-	x	-
timber rattlesnake	x	-	-
Texas coral snake	x	-	-
red-eared slider	-	x	-
gray treefrog	-	x	x
green treefrog	-	x	-
bullfrog	-	-	x
bronze frog	-	x	-
5-lined skink	x	-	x
Gulf crayfish snake	x	-	-
tan-buttermilk racer intergrade	-	x	-

Threats and Stressors Factors

The preserve management lists several factors that may be a threat or stressors to herpetofauna species in the preserve. These include habitat loss and fragmentation, drought, saltwater intrusion, altered fire regimes and fire-dependent habitats, road crossing impacts, invasive plants, fire ants, feral hogs, increased visitor use of park trails and waterways including the use of motorized boats and PWC, urban expansion, climate change, and poaching. Although some are unavoidable, monitoring impacts of these factors will help managers and researchers understand how these things can alter the landscape and how this affects native flora, fauna, and general biological health of the preserve over time.

Habitat Loss/Fragmentation

The basic layout of the preserve, as directed by Congress, includes a number of highly scattered land units (in seven Texas counties) interconnected by narrow water units. This in no way is ideal compared to large contiguous blocks of land, but was a political solution to preserving as much of the unique habitats as possible within a 9,065 km^2 (3,500 mi^2) area. Currently, the preserve has over 974 km (605 mi) of perimeter, and this fragmentation results in the habitats of many of the species occurring in the midst of human activities and urban sprawl. The preserve also does not include the entirety of any of the waterways that course through it, as upstream portions of these waterways occur outside the management realm of the NPS. Additionally, the loss of most of the flood pulses on the Neches River due to two upstream dams has had detrimental impacts on the amphibian populations in the area. These flood pulses were important in the formation of the bottomland hardwood forests and backwater areas that provide highly important habitat areas for most of the herptile species. According to Stuart et al. (2004), amphibians are declining substantially more than other terrestrial vertebrates and these worldwide declines have been due largely to habitat loss.

Numerous pipeline and utility corridors also cross the preserve leaving open areas that may or may not benefit the different herptile species.

Roadway Mortality
Reptiles and amphibians are affected by roadways in a variety of ways, the most common being direct mortality by vehicles (Ehmann and Cogger 1985, Klinn and Swann 1998, Seigel and Pilgrim 2002, Jochimsen et al. 2004) and habitat fragmentation (Jochimsen et al. 2004). Forman and Alexander (1998, p. 212) state that "Sometime during the last three decades, roads with vehicles probably overtook hunting as the leading direct human cause of vertebrate mortality on land." The reptiles and amphibians in BITH are secluded, but run in between parallel waterways and in areas where urban development preceded the formation of the preserve. Roadways are encountered on all sides of the preserve units. The roadways, many of which allow vehicles to travel between 65 and 75 mph, are especially detrimental to young frogs and toads moving from aquatic to terrestrial habitats, terrestrial snakes, and to both aquatic and terrestrial turtles moving between habitat areas.

Invasive Species
Feral hogs inhabit the preserve and have had major impacts on the natural resources that are managed there. The hogs are highly adaptable to a wide range of conditions and reproduce at a very high rate (Chavarria 2007). Habitat destruction is a main source of impact to native inhabitants as the hogs are known to uproot and eat so destructively that they out-compete other animals for food and destroy the habitat and vegetation. They are also known to eat just about anything that moves, which includes a majority of the frogs and snakes. Currently, feral hog populations in the preserve are somewhat controlled by recreational hunting programs. Chavarria (2007) studied feral hog impacts in three preserve units that had received numerous reports of hog impacts to assist in reporting the magnitude of damages that are inflicted on the preserve. The study found that the most damage from hogs was inflicted in wetlands and hardwood bottomlands; these are also the habitats where the amphibians and reptiles were most abundant in Lewis et al. (2000) and Fisher and Rainwater (1978). The destruction of habitat and carnivory of herptile species by feral hogs is a major threat to the ecological integrity of the preserve.

Invasive fire ants are found in nearly all of the habitats in the preserve. The fire ant presence poses a considerable threat to native amphibians and reptiles; this is largely due to direct competition for food resources and predation during egg and hatchling stages (Allen et al. 1994). According to Reimer and Okada (2004), the first fire ant introduction initially occurred in the 1930s in Alabama. The fire ant is currently distributed and established throughout the southeastern states, with potential to spread to the west (Figure 49; Reimer and Okada 2004). They are found inhabiting drier mounds and islands in the wetlands of the preserve, and even thrive, using hollow small trees in open wet areas; therefore, they occur in and impact nearly all of the habitat types of the preserve. They have also replaced many of the native ants in the preserve, which were an important food source for many of the amphibians and reptiles. Many herptile species may not be able to feed on fire ants if they are susceptible to the toxic alkaloid venom injected when they sting.

Figure 49. Fire ant distribution in the United States, arrow shows approximate location of BITH (Figure from Reimer and Okada 2004).

Climate Change and Drought

Global climate change (GCC) may be a factor in the more frequent and intense tropical storm and hurricane events that have occurred over the last century. These large storms bring storm surges that push salt waters well inland and then typically flush them out with the storms dropping 12 or more cm (5 in) of precipitation in a very short time period. A limiting factor in amphibian distribution is water availability and the local hydrological regime stability. GCC is rapidly changing the hydrologic patterns and conditions of environments. Walls et al. (2013) states that monitoring efforts should incorporate both aquatic and terrestrial components of amphibian life history stages in order to better understand and manage the effect that GCC is having on their localized ecology. It may also be influencing an earlier breeding period and phenology as winters warm and spring comes earlier. GCC will likely compound the negative effects of habitat fragmentation through drought and deluge. Drought decreases wetland and other ephemeral inundations, which can further increase the distance between aquatic habitats and can shorten the time that ponds are available for successful breeding and development of the young. In turn, deluges can temporarily connect neighboring sites, allowing the introduction of predatory fish and the spread of invasive species, including invasive plants that can quickly choke out open water habitats, into otherwise isolated aquatic environments (Walls et al. 2013).

Saltwater Intrusion

Saltwater intrusion is considered a serious threat to herpetofauna and is associated with human-caused activities like deepening of inland shipping channels and dammed/regulated upstream flows as well as GCC causing a rise in sea level (USGS 1997). Lowland forest and coastal wetland trees and plants are vulnerable to saltwater intrusion and can become partly to entirely decimated following prolonged exposure to elevated salinity, resulting in widespread loss and fragmentation of habitat that is critical to amphibian and reptile species (USGS 1997). BITH is considered vulnerable to the effects of climate change due to the proximity to the Gulf of Mexico and low elevations; areas along the Gulf coast are a high priority to natural resource managers since the ecological services are very important to sustain biodiversity as well as to protect inland areas from tropical storms (USGS 1997). Forthe southern portion of the BU, sea level rise attributed to GCC, regulation of upstream flows of the Neches River at two dams and the saltwater barrier, in conjunction with the deepening of the Sabine-Neches Waterway (a shipping channel to the Port of Beaumont) may exacerbate the impacts of saltwater intrusion on herptiles (Waddle 2014). Coastal wetlands are vulnerable to increased salinization due to coastal wetland loss, global sea level rise, deepening of shipping channels, and storm surge associated with tropical storms and hurricanes (Waddle 2014). Anuran amphibians (frogs and toads) are one important part of coastal ecosystems that may be particularly vulnerable to increased salinity (Waddle 2014). Reptiles may also be affected by salinity, but often have a higher tolerance than amphibians for pulses of salinity that might be expected from storm surges or shorter term droughts.

Visitor Use of Waterways

Balancing the protection of the natural habitats and settings in the preserve, while also providing public use, has been a challenge to managers of all NPS units due to the impacts that visitors can have on those resources and in particular on human-wildlife interactions related to herptiles. The extensive boundary and fragmented layout of the preserve creates additional complexity to managing the wildlife in the units and along the boundaries that abuts private homes and urban developments. Some activities are considered more troublesome than others. According to NPS (2002), the use of personal watercrafts (e.g., jet skis or wet bikes) has been shown to significantly disrupt natural settings by disturbing wildlife. These vehicles, and motorized boats, are a concern for amphibians and water snakes in the Neches River, lower Pine Island Bayou and lower Village Creek drainages both due to direct mortality and to mortality from human-wildlife interactions where the "only good snake is a dead snake" mentality prevails. Two Texas Paddling Trails, the Village Creek and Cooks Lake to Scatterman paddling trails, receive significant use by non-motorized canoes and kayaks which results in additional harassment and possible mortality in these areas. Poaching, collecting, wanton killing, and harassment by visitors in watercraft (motorized and non-motorized) and along the sandbars and banks of the waterways may also affect many of the aquatic turtle and alligator populations in the preserve. An alligator inventory has never occurred within the preserve and is needed to determine where critical habitat (breeding and nesting) areas occur and should be protected for this large and keystone carnivore species (Hyde, written communication, 21 September 2015). Other concerns raised by BITH management include ecologic disturbances from illegal dumping, the host of chemicals (including endocrine disruptors) which could impact herptiles and may be introduced in effluent waters from nearby manufacturing, refinery, and septic treatment plants and discharges of sewage from numerous illegal houseboats on the Neches River (36 C.F.R. 7.85).

Altered Fire Regimes

Fire suppression and extensive logging has altered the habitats in the fire-dependent plant communities like upland pine and sandhill forests of the preserve significantly over time. Restoring a functional fire cycle to small areas of the preserve was first implemented in 1982 (NPS 2004) and has continued to increase in acreage to the present time. The purpose of reintroducing fire to the forests of BITH was to "restore ecosystem balance" (NPS 2004, p. 6) and maintain the historic habitats and herbaceous understories. Amphibian and reptile assemblages in BITH are quite diverse and developed with the natural ecology of the area. While impacts to herptiles from restoring fire occurrence in BITH are not well studied at this time, there is a wealth of literature that documents the need to restore the herbaceous understory in fire-dependent forest lands to provide habitats for the snakes, turtles and tortoises, lizards, and amphibians, along with their food and prey species, that inhabited these areas historically. The Louisiana pine snake is a good example of a species that would benefit from a restored fire regime, healthy longleaf pine forest and herbaceous understory, and a restored gopher population. Previously explored fire impacts on amphibians suggest that mortality amongst amphibian assemblages is minimal, as they are adept at finding refuge and can persist in areas that experience fire regularly (Pilliod et al. 2003). Reptiles are also thought to be quite resistant to direct mortality as a result of fire and are adapted to fire regimes in their home ranges (Renken 2006).

Data Needs/Gaps

There is a significant data gap for the distribution measure and also a lack of consistent abundance data for the preserve. Lewis et al. (2000) is specific to one small preserve unit and is now 15 years old; this is considered too old for assessing the current condition of amphibians and reptiles in the preserve-wide context. Crump (2008-2010) provides some data on the TCU, CU, and NBU-JGBU. The USGS study, which began in 2010 and is ongoing, has focused on areas in the BU and LPI-PIBCU being impacted by the salt water barrier and the Lower Neches Valley Authority water operation. Without a systematic and consistent monitoring and inventory program, it's difficult to assess any trends in abundance or distribution, although there is a good amount of data on species richness. There are plans in place to increase and diversity the herptile sampling efforts as part of the GULN monitoring program that will provide the preserve with resource information needed to effectively manage and assess the condition of the BITH herptile communities. This is projected to begin in early FY2017.

Overall Condition

Species Richness

The project team assigned the *Significance Level* of species richness as a 3. The baseline data for this measure is the Fisher and Rainwater (1978) herptile surveys that were conducted in the preserve units between 1975 and 1976, summer and spring consecutively. The subsequent surveys of herpetofauna have made additions to this list since that time. Additional species continue to be observed, lengthening the list of confirmed herptile species in the preserve. Considering this may continue, this measure has been assigned a *Condition Level* of 0, or no concern.

Species Abundance
The project team assigned the *Significance Level* of species abundance as a 3. Periodic surveys, studies and inventories have been conducted in various areas of the preserve, but they are inconsistent spatially as well as in methodology. Conducting consistent and regularly timed inventory and monitoring in BITH would provide the kind of data required to make an assessment of any trends that may be occurring. Due to the lack of spatially and methodically consistent data for the measure at this time, a *Condition Level* was not assigned.

Species Distribution
The project team assigned the *Significance Level* of species distribution as a 3. Considering that the overall distribution of herptiles was documented over 30 years ago (Fisher and Rainwater 1978) and subsequent data has lacked coverage of the entire preserve area, a *Condition Level* cannot be assigned at this time.

Weighted Condition Score
A WCS was not calculated at this time due to data gaps for two of the three measures.The current condition and trend of BITH's herpetofauna are unknown.

Amphibians and Reptiles			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Species Richness	3	0	
Species Abundance	3	n/a	
Species Distribution	3	n/a	

4.9.6 Sources of Expertise

- Ken Hyde, BITH Chief of Resource Managment

4.9.7 Literature Cited

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4.10 Harvested Mammals

4.10.1 Description

BITH is a unique NPS unit in that it is comprised of several disjointed, but larger, land-based units connected by narrow waterway corridors, within seven Texas counties. BITH is home to a wide variety of mammals due to its diverse habitats. The preserve is comprised of a few open, wetter meadows, various types of wetlands, large expanses of pine and hardwood forests, riparian wetland associated cypress-tupelo forests, and blackwater swamps (NPF 2015). The current certified species list for BITH includes 66 mammal species with seven species labeled as occurring historically and the remainder listed as present or probably present (NPS 2015). Twenty mammal species are identified as harvestable species, and three mammals (white-tailed deer, fox squirrel, and grey squirrel [*Sciurus carolinensis*]) are considered game species by the Texas Parks and Wildlife Department (TPWD). Rabbits (eastern cottontail [*Sylvilagus floridanus*] and swamp [*Sylvilagus aquaticus*]) are identified as nongame animals by the TPWD and are the only nongame animals authorized for hunting, per 36 CFR 7.85 (2)(i). The remaining harvested mammal species that can be taken in the preserve are identified as furbearers by the state. Coyotes (*Canis latrans*) and bobcats (*Lynx rufus*) are classified as nongame animals and can only be taken incidental to trapping for furbearers. The game species that are considered present or probably present in the preserve fall within one of five taxonomic orders: Artiodactyla, Carnivora, Didelphimorphia, Lagomorpha, and Rodentia (NPS 2015).

Photo 16. Nutria (left) and feral hog sow with piglets (right) are exotic species present in BITH (NPS photos).

Most of mammals that are harvested in the preserve are native to the area, with the exception of the nutria and feral hogs (Photo 16). The nutria, a large rodent and member of the Myocastoridae family, was first introduced to North America in 1899, but did not become widespread until the 1930s (Evans 1970). Nutria farms became common in South America in the 1920s when their pelt value was recognized (Feldhamer et al. 2003). Nutria farms were later established in North America in the 1930s. Feral hogs (includes escaped/released domesticated hogs, European wild hogs, and hybrids of the two), on the other hand, were first introduced to Texas as domestic livestock over 300 years ago as a source of both fresh and cured meat for Spanish explorers and settlers (TPWD 2015). The federal and state governments also released feral hogs in Texas as well as several other states in the south (Evans 1970). Feral hog populations became established as the hogs that escaped or were released into the wild were able to successfully breed. Their populations have continued to grow and expand and they are now considered a threat to agriculture and native habitats and wildlife in over 35 U.S. states.

BITH's legislative authority instructs the preserve to conduct a hunting and trapping program. Hunting is allowed in six and trapping is allowed in four of the eight preserve units (Figure 50). Hunting is permitted in BU, BCU, BSCU, JGBU, LRU, and NBU, while trapping is only permitted in BU, JGBU, LRU, and NBU. There are different regulations for hunting and trapping: BITH hunting regulations control weapons and methods used, time of season, and legal game mammals. Weapons that are allowed during hunting season include .17 caliber and .22 caliber rim fire cartridge rifles (small game only), shotguns, muzzle-loading rifles, and bow and arrows (NPS 2014c).

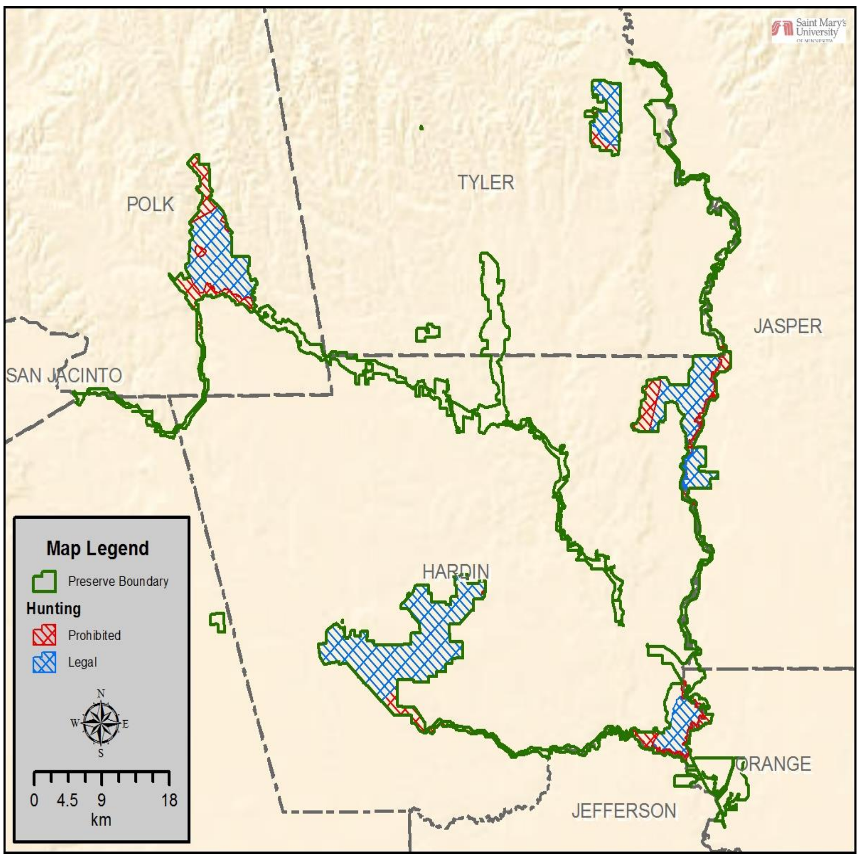

Figure 50. Game units in BITH (NPS). Areas shaded in blue are legal harvestable areas within the preserve units. Areas shaded in red are prohibited areas. Trapping activity is only permitted in Beaumont, Jack Gore Baygall, Lance Rosier, and Neches Bottom Units.

The use of, or possession of dogs (except for waterfowl retrieval), feeding game mammals, and baiting is prohibited during hunting season. There are six mammal species that can be hunted in BITH: white-tailed deer, gray squirrels, red squirrels, eastern cottontail, swamp rabbits, and feral hogs. Feral hogs are not specifically a game species, but because they are destructive exotic species, hunting of feral hogs is allowed during the BITH authorized hunting season and during an extended feral hog only season (Table 48, TPWD 2015).

Table 48. Game mammal species that are legal during hunting season and trapping season in BITH (NPS 2008, 2012, 2014).

Seasons	Scientific Name	Common Name
Legal mammals for hunting	*Odocoileus virginianus*	white-tail deer
	Sciurus carolinensis	grey squirrel
	Sciurus niger	fox squirrel
	Sylvilagus floridanus	eastern cottontail
	Sylvilagus aquaticus	swamp rabbit
	Sus scrofa	feral hog
Legal mammals for trapping	*Bassariscus astutus*	ringtail cat
	Canis latrans	coyote*
	Castor canadensis	American beaver
	Ondatra zibethicus	muskrat
	Didelphis virginiana	Virginia opossum
	Lontra canadensis	river otter
	Lynx rufus	bobcat*
	Mephitis mephitis	striped skunk
	Mustela vison	American mink
	Myocastor coypus	nutria
	Procyon lotor	northern raccoon
	Spilogale putorius	spotted skunk
	Taxidea taxus	American badger
	Urocyon cinereoargenteus	gray fox
	Vulpes vulpes	red fox

* Take of these “nongame” species is only allowed incidental to trapping for furbearers.

The general trapping season occurs from 1 December to 31 January. Legal traps include unmodified steel leghold traps, snares, conibear traps, and live-traps (NPS 2008). Prohibited trapping methods include the use and possession of dogs, bow and arrow, electronic and hand held calls, recording and calling devices, artificial light, and falconry (NPS 2009). It is also illegal to shoot, use explosives and chemicals, and use smoke to flush out or kill game (NPS 2008).

The scattered nature of the preserve, limited access, and the dense vegetation encountered in nearly all the units greatly limits the ability of the preserve staff to monitor and track species population numbers using conventional wildlife monitoring techniques (e.g., spotlight counts, track counts, or walking/helicopter transects). Limited staff time and funding also impacts the ability of the preserve to monitor those species hunted the most (i.e., deer, squirrels, rabbits, and wood ducks).

Population range estimates have been generated by the preserve for deer and squirrels to account for the unique climatic and habitat conditions encountered in southeast Texas. They are used as trigger points in conjunction with the results from the returned harvest cards. Should extreme weather events (e.g., hurricanes, extended droughts), wildlife die-offs (due to disease, overpopulation/starvation), or habitat-changing effects from climate change or exotic species begin to lead a population towards a long-term or plunging downward trend, then management actions or more intensive field research will be undertaken. The number of permits issued per management unit (and thus the number of animals harvested) have and will remain fairly static until a significant or apparent increase or decrease in one or more of the game species populations triggers a need for action. As always, all hunting and trapping activities are recreational opportunities and will be balanced with protecting preserve resources or ecosystems.

4.10.2 Measures

- Annual harvest
- Harvest success

4.10.3 Reference Conditions/Values

The best information available to use as a reference condition for BITH's harvested mammals is the period during which harvest cards have been established. Hunting and trapping harvest cards have been collected and compiled in BITH since 1981. Hunting effort has been summarized each year for each species harvested between 1981 and 2012. Similarly, trapping effort has also been documented for each species harvested every year between 1981 and 2012; trapping data were recorded separately for each trapping unit. Appendix K-Appendix N present both the hunting and trapping effort and harvest success reported by species and preserve unit since 1981. This information is summarized on the following pages to assess the harvested mammal's reference condition.

4.10.4 Data and Methods

NPS (2012a) summarized 30 years of hunter harvest data for six units in BITH between 1981 and 2012. The six units were BU, BCU, BSCU, JGBU, LRU, and NBU. Data records for each unit included hunting acreage, number of permits issued, number of permits returned, number of animals harvested (deer, squirrels, hogs, rabbits), and the total game count. It is important to note that between 2008 and 2012, NPS (2012a) began differentiating squirrel species (gray squirrels, red squirrels) and rabbit species (cottontail, swamp rabbit) in the data.

NPS (2012b) also summarized 30 years of trapping harvest data for four units in BITH between 1983 and 2012. The four units were BU, JGBU, LR, and NBU. Data records for each unit included the number of nights trapped, average number of traps per night, number of animals harvested, and the total game count. Additionally, NPS (2012c) graphically interpreted nearly 30 years of annual trapping harvest data for the same four units in BITH between 1983 and 2012, though the BU and LRU only have annual data between 1985 and 2012. Annual data records included the number of nights trapped, average number of traps per night, number of animals harvested, and the total game count.

NPS (2013) prepared a feral hog management plan and conducted an environmental assessment (EA) which was finalized in early 2014. This management plan was created to determine the impact of feral hogs on the native resources in BITH and to describe how feral hogs will be managed. Management and mitigation methods include a direct trapping program (live-capture), direct shooting program, "Judas hog" tracking and radio-telemetry, use of dogs (support for direct shooting), final disposition of hog carcasses, protective fencing (to protect highly sensitive areas), coordination with adjacent landowners/users, public information and education, and monitoring and research. Feral hog monitoring and research records include identification and tracking number, collection date/time, collection location, collection method, estimated level of hog activity or sign, life stage, physical condition, sex, actual/estimated weight, coat color and pattern, animal appearance, reproductive state for females, any other special markings, number and size of markings, disposition of animal, and description of sample taken. The EA was performed to assess the impacts of two alternatives (no action or implementation of management plan).

NPS (2014a, b) compiled data from hunting and trapping surveys on game mammals in BITH for the 2013–2014 harvest years. Data records included total hunting acreage, percent of surveys returned, and the number and species of mammal harvested.

4.10.5 Current Condition and Trend

<u>Annual Harvest</u>

Hunting Efforts

NPS (2012a) documented 325,763 mammals harvested during the hunting season in BITH between 1981 and 2012. Approximately 93% of the mammals harvested during this period were squirrels (Table 49). On average, only 59% of surveys were returned among the six units in 30 years (Table 49). The most mammals were harvested from the LRU and JGBU, with 138,055 and 81,870 animals, respectively. The totals from BSCU, BU, and NBU were 42,018; 24,036; and 21,227 animals, respectively. The unit with the least amount of recorded harvests was the NBU (Table 49).

Table 49. Summary of hunter harvested mammals for six units in BITH between 1981 and 2012 (NPS 2012a).

Unit	Hunting Acreage	# Permits Issued	# Permits Returned	% Surveys Returned	Deer	Squirrels	Hogs	Rabbits
Beaumont	3,900	4,734	2,816	59	896	22,035	396	709
Beech Creek	3,350	3,873	2,235	58	229	17,571	64	693
Big Sandy Creek	8,850	11,289	7,088	63	1,647	38,918	294	1,159
Jack Gore Baygall	8,000	10,598	6,454	61	1,334	77,430	841	2,265
Lance Rosier	21,000	23,171	14,092	61	1,955	128,305	3,678	4,117
Neches Bottom	2,300	3,751	2,004	53	636	19,835	291	465
Total	**51,300**	**57,416**	**34,689**	**59**	**6,697**	**304,094**	**5,564**	**9,408**

NPS (2012a) differentiated gender of feral hogs and species of squirrels and rabbits in BITH between 2008 and 2012. Similar to Table 49, squirrels (gray squirrels) were the most harvested mammals in BITH. Over 1,000 feral hogs were harvested between 2008 and 2012, and a majority of those hogs were sows (Table 50). Table 50 displays the select game mammals that were differentiated by gender/age or species in BITH between 2008 and 2012.

Table 50. Summary of select mammal harvest during hunting season for six units in BITH between 2008 and 2012 (NPS 2012a).

	Hogs			Squirrels		Rabbits	
Unit Name	Sows	Boars	Piglets	Gray Squirrels	Fox Squirrels	Cottontails	Swamp Rabbits
Beaumont	32	20	20	748	42	28	28
Beech Creek	7	7	0	690	43	24	22
Big Sandy Creek	60	38	17	2,577	220	41	14
Jack Gore Baygall	155	86	49	3,338	277	166	111
Lance Rosier	296	228	57	2,988	170	98	48
Neches Bottom	38	16	10	609	106	11	27
Total	**588**	**395**	**153**	**10,950**	**858**	**368**	**250**

NPS (2014a) recorded 4,043 mammals harvested during the hunting season in BITH between 2013 and 2014. Over half of the mammals harvested throughout BITH were fox and gray squirrels (Table 51). The highest harvests were from the LRU, JGBU, and BSCU with 1,332; 1,209; and 850 animals harvested, respectively. Those were also the largest units (all over 3,237 ha [8,000 ac]). On average, only 59% of surveys were returned among the six units. Table 50 displays the hunter harvest efforts for BITH in 2013 and 2014.

Table 51. Hunter harvest efforts for BITH in 2013 and 2014 (NPS 2014a).

Unit Name	Hunting Acreage	% Surveys Returned	Trips	Deer	Grey Squirrels	Other Squirrels	Hogs	Cottontails	Swamp Rabbits
Beaumont	3,900	58	730	20	219	14	12	4	6
Beech Creek	3,350	52	308	4	108	22	4	8	3
Big Sandy Creek	8,850	64	1,663	49	596	94	76	21	14
Neches Bottom	2,300	64	195	16	148	8	14	2	5
Jack Gore Baygall	8,000	62	2,113	63	935	83	86	16	26
Lance Rosier	21,000	54	2,172	60	942	77	213	15	25
Totals	**47,400**	**59**	**7,181**	**212**	**2,948**	**298**	**440**	**66**	**79**

Trapping Efforts

NPS (2012b) documented 4,219 mammals trapped during the trapping season in BITH between 1983 and 2012. The highest recorded harvests occurred in JGBU; the unit also had a higher number of nights with trapping and average number of traps per night. Raccoons and opossums (*Didelphis virginiana*) were the primary game species trapped over the 30-year period of record. Approximately 72% and 18% of the mammals harvested were raccoons and opossums, respectively (Table 52). The other 13 furbearer species represented 10% of the mammals trapped between 1983 and 2012, collectively.

Table 52. Summary of mammals harvested during trapping season in four BITH units between 1983 and 2012 (NPS 2012b).

Unit Name	Number of Nights Trapped	Average Number of Traps Per Night	Raccoons	Opossum	Gray Fox	Red Fox	Nutria	Coyote	Stripped Skunk	Spotted Skunk	Mink	Muskrat	Ring-tailed Cat	Badger	Beaver	Bobcat	Otter
Beaumont	341	316	218	188	7	1	56	0	1	0	34	1	6	0	16	0	9
Jack Gore Baygall	1,067	621	1,847	304	6	0	18	2	2	2	63	6	0	0	18	21	21
Lance Rosier	428	446	455	83	22	5	2	0	0	0	12	0	0	2	2	2	1
Neches Bottom	351	428	527	184	9	0	8	1	0	2	27	0	0	0	21	3	4
Total	**2,187**	**1,811**	**3,047**	**759**	**44**	**6**	**84**	**3**	**3**	**4**	**136**	**7**	**6**	**2**	**57**	**26**	**35**

NPS (2012c) documented 11 furbearer species trapped in the BU between 1985 and 2012 (Appendix K). This unit had the lowest overall total game count with 537 animals, and there were no spotted skunks (*Spilogale gracilis*), badgers (*Taxidea taxus*), bobcats, or coyotes trapped in this unit. Mammals trapped only once during this time period include red fox (*Vulpes vulpes*), striped skunk, and muskrat in 1996, 1989, and 1986, respectively. The most commonly trapped species were raccoon (218 records) and opossum (188 records). Annual harvest in the BU was highly variable from 1985-2012, and harvest rates were directly related to the number of nights trapped (Figure 51). Peak harvest from trapping in the BU occurred in 1986 (120 individuals on 20 nights trapped; Figure 51). Harvest declined to zero by 1987, however this is due to no nights of trapping being reported. Harvest remained variable from 1989-1997, with trapping harvest still being closely tied to the number of nights trapped (Figure 51). There were no harvests recorded between 1998 and 2005 or between 2007 and 2010; this was also due to no nights being reported. The only trapping activity after 1997 occurred in 2006 and 2011 with total game counts of 43 individuals (eight nights trapped) and 32 individuals (17 nights trapped), respectively.

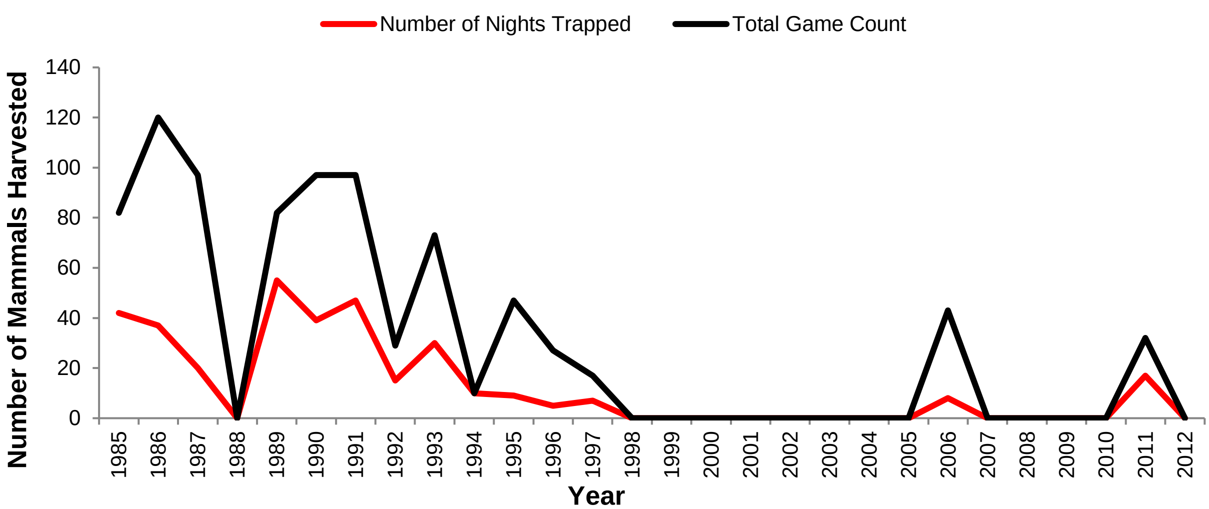

Figure 51. Trapping summary (number of total nights trapped, total game count) for the Beaumont Unit in BITH between 1985 and 2012 (NPS 2012c).

NPS (2012c) documented 12 furbearer species trapped in the JGBU between 1983 and 2012 (Appendix L). This unit had the highest overall total game count with 2,310 records. There were no badgers, ringtails, or red fox trapped in this unit between 1983 and 2012. The only record of coyotes, striped skunks, and spotted skunks being trapped in this unit occurred during 1983, when two individuals of each species were harvested (Appendix L). The most commonly trapped species were raccoon (1,847 records) and opossum (304 records). Annual harvest in the JGBU was highly variable from 1983 to 2012, and harvest rates were directly related to the number of nights trapped (Figure 52). Peak harvest from trapping in the JGBU occurred in 1997 (313 individuals on 97 nights trapped) and 2002 (273 individuals on 44 nights trapped; Figure 52). Harvest declined to zero by 1989 (which was due to no nights of trapping being recorded), and harvest remained low until 1996, with trapping harvest still being closely tied to the number of nights trapped (Figure 52). The highest number of nights trapped occurred in 1983 and 1986 when 136 nights trapped were reported (Figure 52). There was no recorded trapping activity in 1984, 1989, 1994, 1995, 2009, 2010 or 2012.

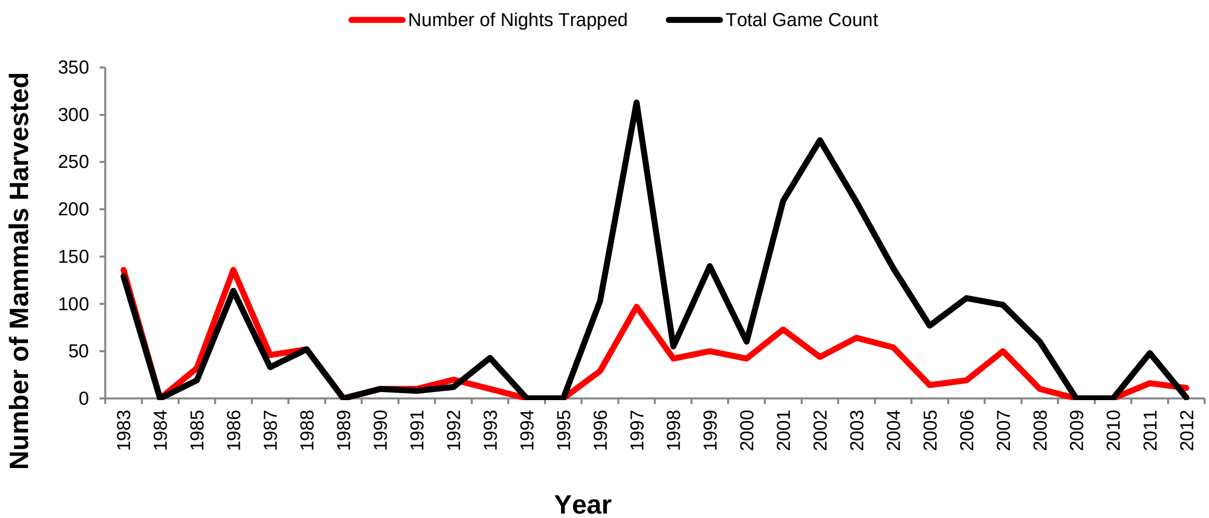

Figure 52. Trapping summary (number of total nights trapped, total game count) for Jack Gore Baygall in BITH between 1983 and 2012 (NPS 2012c).

NPS (2012c) documented 10 furbearer species trapped in the LRU between 1985 and 2012 (Appendix M). There were no coyote, striped skunk, spotted skunk, muskrat, or ring-tail cat recorded between 1985 and 2012. Only one river otter (*Lontra canadensis*) trapping was recorded in 1992. There were only two recorded trappings of nutria (1985), badgers (1988), beavers (1992, 1993), and bobcats (1986, 1997) during this time period. The most commonly trapped species were raccoon (455 records) and opossum (83 records). Annual harvest in the LRU was highly variable from 1985-2012, and harvest rates were directly related to the number of nights trapped (Figure 53). Peak harvest from trapping occurred in 1992 (73 individuals on 37 nights trapped; Figure 53). The most trapping activity occurred between 1991 and 1999. Harvest declined to eight individuals in 2000 and remained below 10 until 2006; however, this is due to no nights of trapping being reported. Harvest increased slightly in 2006 (26 individuals on eight nights trapped) only to decline to zero by 2008. Harvest increased slightly by 2010, but remained low until 2012. There was no harvest recorded in 1989, 1990, 1995, 2004, 2005, 2008, and 2009.

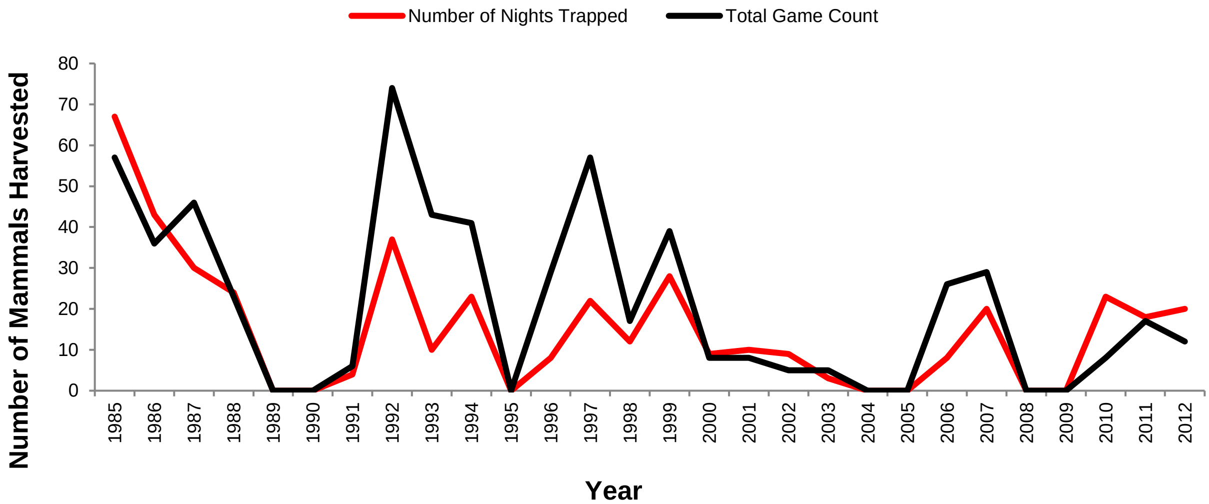

Figure 53. Trapping summary (number of total nights trapped, total game count) for the Lance Rosier Unit in BITH between 1983 and 2012 (NPS 2012c).

NPS (2012c) documented 10 furbearer species trapped in the NBU between 1983 and 2012 (Appendix N). There were no red fox, striped skunk, muskrat, ringtails, or badgers recorded between 1983 and 2012. Only one coyote trapping was recorded in 2001. There were only two recorded trappings of spotted skunks in 1995, three bobcats in 1991, and four river otters recorded in 1989, 1991, and 2006. The most commonly trapped species were raccoon (527 records) and opossum (184 records). Annual harvest in the NBU was highly variable from 1983-2012, and harvest rates were directly related to the number of nights trapped (Figure 54). Peak harvest from trapping in the NBU occurred in 2007 (110 individuals on 10 nights trapped; Figure 54). Harvest first declined to zero in 1984; however, this is due to no nights of trapping being reported. Harvest remained variable from 1985-1992, with trapping harvest still being closely tied to the number of nights trapped (Figure 51, Figure 54). There were no harvests recorded between 1993 and 2000, with the exception of 1995 (17 individuals on 12 nights trapped; Figure 54); this was also due to no nights being reported. Harvest increased and was high in relation to the low number of nights trapped between 2004 and 2008. There was no recorded trapping activity in 1984, 1989, 1993, 1994, 1996-2000, 2003, and 2009–2012.

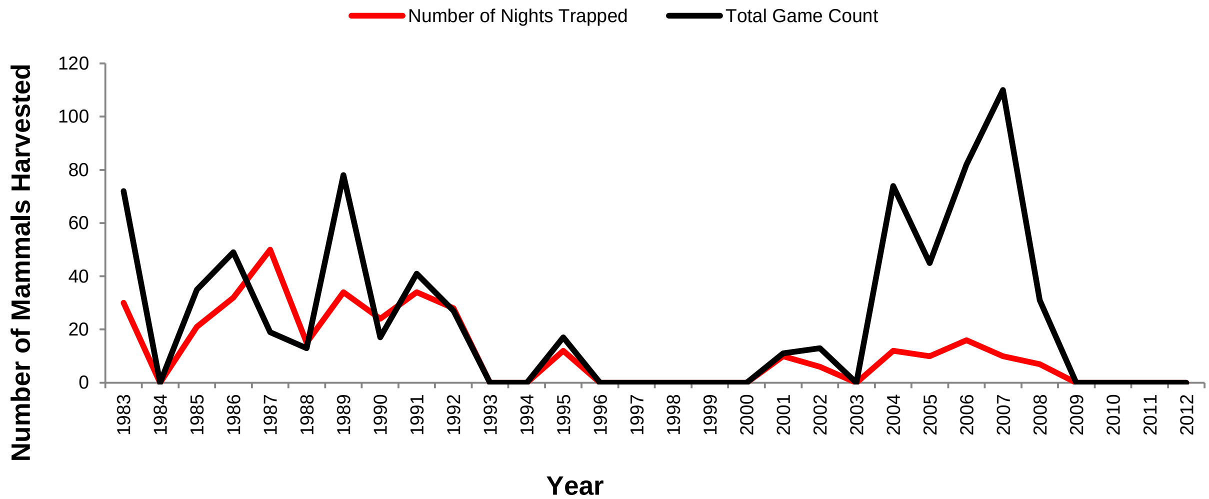

Figure 54. Trapping summary (number of total nights trapped, total game count) for Neches Bottom in BITH between 1983 and 2012 (NPS 2012c).

NPS (2014b) recorded a total of 32 mammals harvested by trapping in BITH between 2013 and 2014. There were no mammals harvested in BU or NBU during this time period. The highest recorded harvests occurred in the JGBU. Only three of the 15 legal furbearer species were harvested (Table 53). Raccoon and opossum were the only game species harvested in the JGBU, with 10 and 16 recorded kills, respectively. Three raccoons and three gray foxes were the only game trapped from the LRU.

Table 53. Summary of trapping records for Beaumont, Jack Gore Baygall, Neches Bottom, and Lance Rosier Units in BITH between 2013 and 2014.

Unit Name	Trapping Acreage	Surveys Returned	Number of Nights Trapped	Average Number of Traps Set	Raccoon	Opossum	Gray Fox
Beaumont	3,900	0	0	0	0	0	0
Jack Gore Baygall	8,000	3	10	12	10	16	0
Neches Bottom	2,300	0	0	0	0	0	0
Lance Rosier	21,000	2	19	10	3	0	3
Total	**35,000**	**3**	**29**	**22**	**13**	**16**	**3**

<u>Threats and Stressors Factors</u>

BITH preserve staff have identified several threats that impact the mammal populations that can be harvested in the preserve. Those threats include illegal take, baiting and hunting pressures along BITH's 966 km (600 mi) of boundary, feral hogs, habitat loss and fragmentation, and road mortality.

Illegal take and legal take along a preserve boundary exceeding 966 km (600 mi) is a threat to the harvested mammal populations in BITH. Illegal take of wildlife within units of the NPS is expressly prohibited under CFR 36 Chapter 1 ~2.2.The current hunting and trapping seasons in BITH have been established to encourage sustainable harvests of all native mammal game species, while also minimizing impacts from non-native invasive mammals. The status of native mammal species at BITH is monitored on an ongoing basis and harvest seasons adjusted accordingly. As this report reveals, much of this monitoring takes the form of interpreting returned hunter and trapper survey cards.

Over 80% of the lands around the preserve boundary are owned/managed by timber management companies who routinely clear-cut harvest their lands and who lease a significant portion of the lands to private hunting leases. During and for the first few years after a timber harvest, there can be a significant movement of deer, hogs and other species to adjacent lands, with preserve lands being an obvious receptacle. Likewise, Texas allows for baiting of game species, which can begin in August and continue well into the new year. This attracts wildlife from preserve lands where baiting is not allowed, especially when mast crops are small or hogs have consumed most of the mast.

The fairly small sizes of the preserve hunting units (except for the LRU) preclude that the entire home ranges of most of the deer are contained entirely within that unit of the preserve. Thus, deer harvest rates for the in-preserve populations of deer may be higher as normal home range movements and baiting result in them being harvested outside the preserve in areas receiving more intensive hunting pressure. Deer harvest trends for nearly all of the hunting units have remained fairly constant over the past 15 years, with little downward movement, indicating that the deer are maintaining their populations in relation to the hunting pressure, both in and out of the preserve (Hyde, personal communication, November 2015).

Feral hogs are a major threat to many natural resources in BITH. Similar to the effects of illegal take mentioned above, native game mammals in the preserve are both directly and indirectly impacted by feral hogs. Direct impacts include competition for food resources and depredation of young mammals (Chavarria 2006). According to NPCA (2005), feral hogs are opportunistic omnivores and have been known to consume a variety of foods including vegetation, nuts and seeds, insects, fruits, herpetofauna, birds, eggs, and the young of several mammal species. Feral hogs indirectly impact other mammals by damaging habitat and transmitting disease (Lowe et al. 2000). According to Lowe et al. (2000), hogs damage or degrade habitat by digging up vegetation, disrupting ecological processes (e.g., fire), and spreading weeds. Degraded habitat may result in the loss or lack of sufficient food or vegetative cover for native wildlife. Feral hogs are also a vector species, and have been known to transmit diseases such as leptospirosis and foot and mouth disease. Diseases could cause stress to individuals and cause declines in native mammal populations in the preserve (Lowe et al. 2000).

Habitat loss and fragmentation is another major threat to mammals inhabiting BITH. Fragmentation sources include oil and gas wells and pipelines, utility corridors, numerous residences along the 966 km (605 mi) boundary, and habitat loss to scattered rural and urban communities and housing developments. Several highways and roads run between each hunting and non-hunting unit (Figure 55) with highways speeds of up to 120 km/h (75 mph). According to Cooper et al. (2004), the close proximity of major cities (e.g., Houston, Beaumont) can cause fragmentation, disturbed lands, contribute to the presence of exotic species, and continued isolation of preserve units. The City of Beaumont is closest to the preserve, and is located adjacent to the BU. Mammals that inhabit the BU may be particularly vulnerable to road mortality, human-wildlife interactions, and habitat loss. Vulnerability may increase as the city continues to develop and expand, especially northward toward the rural communities of Lumberton and Silsbee. Non-authorized use of blinds and baiting, and trespass use of ATVs (all-terrain vehicle)/UTVs (utility task vehicle) for scouting and harvest are additional impacts on the game mammals that are very difficult to track. Limited staff and funding do not typically allow for the resource protection coverage needed.

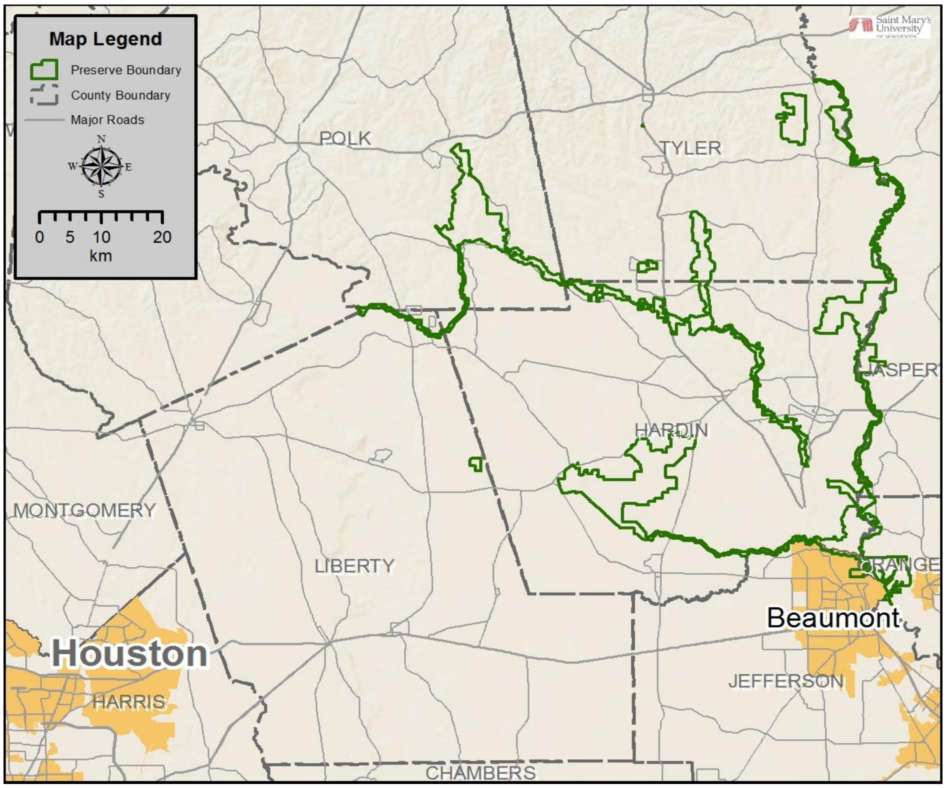

Figure 55. A glance at the large number of roads that run between the BITH Units. Houston and Beaumont are the largest cities in close proximity to the preserve.

<u>Data Needs/Gaps</u>

NPS (2012a) summarized 30 years of hunter harvest efforts between 1981 and 2012. BITH currently monitors the harvested wildlife through yearly reviews of harvest trends while noting if there are apparent or long-term declines in harvest rates for a particular species. An example of two major annual drops in harvest numbers occurred following the hurricanes in 2005 and 2008 when downed trees made it nearly impossible to use the trails or to walk into the woodlands of the preserve to hunt. Harvest numbers then resumed a constant level in the following years (Hyde, personal communication, November 2015). It should be noted that no method of harvest documentation is perfect and the preserve must deal with incomplete and inaccurate reporting. The scattered nature of the preserve and the dense vegetation encountered in nearly all of the units greatly limits the ability of the preserve to monitor and track species population numbers using standard monitoring protocols.

Limited staff time and funding also impacts the ability of the preserve to monitor those species hunted the most.

Continued use and reinforcement of harvest cards may increase the percentage of reports completed and increase accuracy of harvest success data. The current return rate of these harvest cards is approximately 59% (Table 49); while the percentage returned will likely always be less than 100%, a concentrated effort to generate a correction factor that could help estimate the actual harvest for each game species and hunting unit would be helpful for preserve managers.

<u>Overall Condition</u>

Annual Harvest

The project team assigned the *Significance Level* of annual harvest as a 3. Approximately 325,763 mammals were harvested during the hunting season in BITH between 1981 and 2012. Approximately 93% of the mammals harvested during this period were squirrels. Over 1,000 feral hogs were harvested between 2008 and 2012, with a majority of those hogs being sows (Table 50). On average, only 59% of hunter surveys were returned among the six units in 30 years. The most mammals were harvested from the LRU and JGBU, which are two of the larger units. They had 138,055 and 81,870 animals harvested, respectively.

As an example of annual harvest data review, NPS (2014a) documented annual hunter harvest for the 2013–2014 year and recorded approximately 4,043 mammals as harvested during the hunting season in BITH. Over half of the mammals harvested throughout BITH were gray squirrels (2,948). The most mammals were harvested from the LRU, JGBU, and BSCU with 1,332; 1,209; and 850 animals, respectively; these units also represent the largest of the six hunting units.

Historic harvest data indicate that there were over 4,000 mammals harvested during the trapping season in BITH between 1983 and 2012. The highest recorded trap harvests occurred in the JGBU; the unit also had a higher number of nights with trapping and average number of traps per night. Approximately 72% and 18% of the mammals harvested were raccoons and opossums, respectively. The other 13 furbearers collectively represented 10% of the mammals trapped between 1983 and 2012.

The LRU and NBU only had 10 furbearer species trapped at least once over the 30 year period of NPS (2012c). The BU and JGBU had 11 species and 12 species recorded as trapped at least once, respectively. According to BITH trapping harvest data (NPS 2012c), there were 537 furbearers trapped from the BU; 2,310 furbearers trapped from the JGBU; 586 furbearers trapped from the LRU; and 734 furbearers trapped from the NBU. With fewer trapping permits issued, there is a declining trend in number of nights trapped and total game counts at the BU and LRU; however, trapping activity was higher in recent years at JGBU and NBU where most of the current trapping occurs. NPS (2014b) recorded a total of 32 furbearers trapped between 2013 and 2014, with the highest harvests occurring in the JGBU; only three of the 15 legal furbearer species were recorded. There were no mammals harvested in the BU or NBU during the same time period.

After reviewing yearly harvest data including trapping records, and consulting with NPS resource managers, a *Condition Level* of 2 was assigned to this measure. Harvest of mammals by hunting is and has been holding steady over the past 15 years, indicating a balanced and fairly constant harvest. Trapping harvest has declined over the same time period due to low interest and trapping by only a few individuals. Continued monitoring of this resource, through both annual surveys and harvest cards may be warranted to more fully understand and identify potential trends in annual harvest.

Harvest Success

The project team assigned the *Significance Level* of harvest success as a 1. Measures with a *Significance Level* of 1 are not discussed in the body of the text; rather they are briefly summarized in the Overall Condition section. Harvest success information is vital in proper game management as it provides an idea of game mammal population and preferred habitat. Hunters and trappers record the species harvested, where they were harvested, and when they were harvested. Each year's harvest success data plays a role in which game mammals are available for the next year's hunting or trapping season. Harvest success data help managers set game limits to prevent game species populations from being over harvested or from reaching carrying capacity in these isolated units. BITH resource managers rely on the completion and return of harvest cards to calculate harvest success, but they cannot guarantee 100% return rate, which lowers the accuracy of the estimated success rate. An average of 59% of the hunting surveys were returned between 1983 and 2012; this percentage remained the same for the 2013 – 2014 hunting season. Only three surveys were returned for the 2013 – 2014 trapping season, although the number of nights trapped was also low during this time (29 nights trapped). In an effort to increase hunter survey response, hunters cannot receive a hunting permit for BITH unless they complete and return a hunter report for the prior hunting year (NPS 2014c). A *Condition Level* of 1, indicating low concern, was assigned to the harvest success measure.

Weighted Condition Score

A WCS of 0.58 was assigned to the harvested mammals' component, indicating that the resource is currently of moderate concern to preserve managers. A stable trend arrow was assigned to this component, based largely on the professional input from BITH.

Harvested Mammals			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.58**
Annual Harvest	3	2	
Harvest Success	1	1	

4.10.6 Sources of Expertise

- Ken Hyde, BITH Chief of Resources Management\

4.10.7 Literature Cited

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4.11 Freshwater Mussels

4.11.1 Description

Photo 17. A rock pocketbook (*Arcidens confragosus*), a species of mussel found in BITH aquatic habitats (photo by San Antonio River Authority [SARA] 2014).

Freshwater mussels are a type of bivalve mollusk (i.e., naiad, unionid, or clam). They are filter-feeding, benthic invertebrates that are found in freshwater rivers, lakes, and streams. All freshwater mussels have two shells holding the body tissues, connected with a hinge, and exist in a wide variety of sizes and colors, and some can live as long as 100 years (USFWS 2006). Freshwater mussels occur throughout the world, but North America ranks number one in species diversity, with nearly 300 taxa (Williams et al. 1993, USFWS 2014). The rock pocketbook (*Arcidens confragosus*) is one example of a bivalve that is found in the BITH region (Photo 17). It spawns in the summer (bradytictic) and has several fish species (rock bass [*Ambloplites rupestris*], American eel [*Anguilla rostrate*], freshwater drum [*Aplodinotus grunniens*], American gizzard shad [*Dorosoma cepedianum*], channel catfish [*Ictalurus punctatus*], and white crappie [*Pomoxis annularis*]) that can host the larvae of this mussel species (Roe 2002).

The unique life cycle of native freshwater mussels is completely dependent upon a host fish; most species have more than one compatible species. The reproductive cycle begins when the male mussel releases sperm into the water column and it enters a female through the female's siphon and fertilizes her eggs (Figure 56; USFWS 2006). Eggs then develop into larvae, called glochidia, inside the female's marsupia (pouches in her modified gills) (USFWS 2006). The next stage of development occurs once the female mussel has transferred her glochidia to a host. Freshwater mussel females have evolved various methods, some very intricate, of ensuring their glochidia successfully attach to the desired host (USFWS 2006). Some mussel species have modified their mantle tissue into a lure to attract a host; when the fish bites this lure, the female releases the glochidia right into the fish's face or mouth, allowing the glochidia to easily clamp onto the gill tissue or fins (USFWS 2006). The final development of glochidia, which ride attached to the fish's gill tissues or fins, can take anywhere from 3 to 10 days (USFWS 2006). Glochidia transform into juvenile mussels while riding on their host-fish and then fall off and deposit on the river bottom as a free-living mussel.

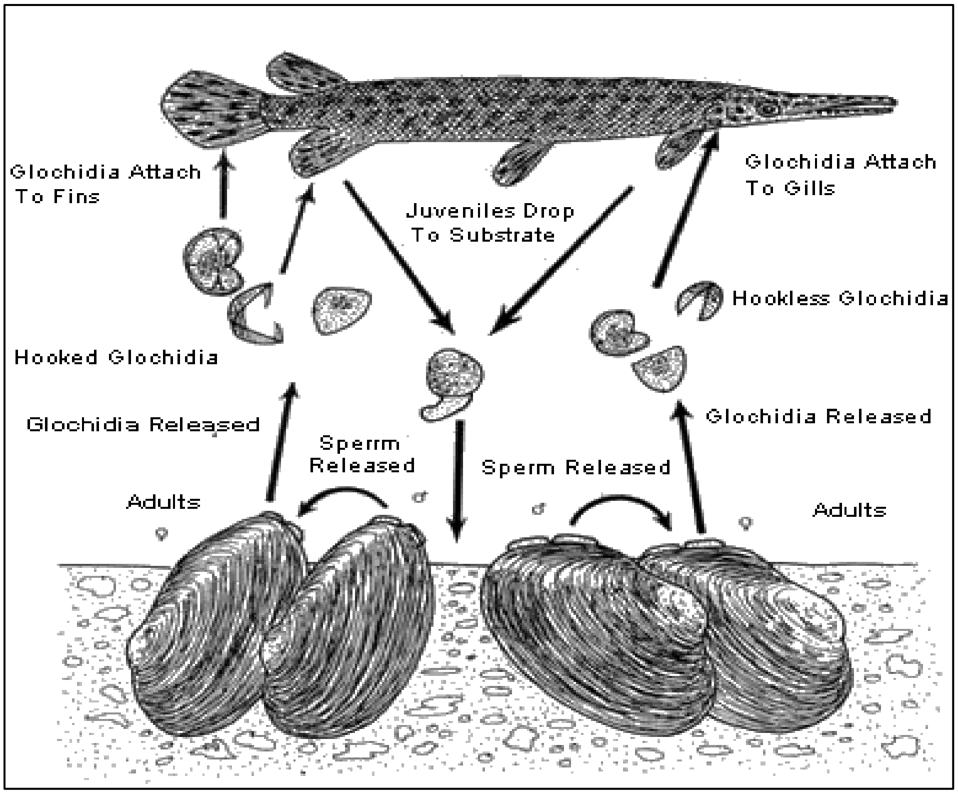


Figure 56. Life cycle of a freshwater mussel (Figure by TPWD 2014).

The freshwater mussel is considered an indicator of environmental condition of aquatic habitats since they are often the first to decline when conditions become unfavorable (Howells 1997). Mussels are sensitive to environmental contaminants, which can accumulate in their tissues and shells (Howells 1997). Importantly, because of this tendency to accumulate contaminants, mussels are an effective biological monitor of current and past water and sediment quality, with the accumulation in the shells acting as a recorded history of the water quality.

According to USFWS (2011, 2014), freshwater mussels are an important component of the aquatic ecosystem as they are a valuable prey item for many other wildlife species in Texas including several species of fish and birds, turtles, muskrats, raccoons, and otters. Mussels also benefit aquatic ecosystems by filtering the water column for food, which helps to purify the aquatic environment. When present in large numbers, freshwater mussels form beds on the bottom of lakes, rivers, and streams. These mussel beds support numerous aquatic species by becoming a living, and quite stable, substrate. Large mussel beds behave much like cobble, which can sustain diverse and abundant communities of macroinvertebrates, aquatic vegetation, and fish (USFWS 2014). The condition of the mussel communities can not only indicate water quality, but also the health of fish populations since they rely on symbiotic relationships with fish to complete their life cycles (USFWS 2014). When there is a decline in freshwater mussels, a decline in other species, such as fish, will often follow (Howells 1997).

4.11.2 Measures

- Abundance
- Richness
- Distribution

4.11.3 Reference Conditions/Values

The reference condition for freshwater mussel abundance, richness, and distribution in BITH is based on Howells (1997). Howells (1997) includes a checklist of species that were observed (by water bodies) within the BITH region (Appendix O). The report does not have any records specific to many of the preserve units; two of the seven rivers and bayous that were included in Howells (1997) are within the boundaries of BITH: the Trinity River and the Neches River, which will be the focus of discussion below. The Neches River runs through five BITH units, and the Trinity River and Menard Creek confluence is within the Menard Creek Corridor Unit on the eastern-most end. The other ten units have no freshwater mussel reports or survey data from this time period and represent a data gap for the reference condition.

Howells (1997) identified 42 freshwater mussel species, with 39 species being found in BITH waters (Neches and Trinity Rivers) and 18 of the 42 mussel species described as abundant (Appendix O). The species abundance and richness values reported for the two rivers (Neches and the Trinity), will serve as the reference condition for the five units that were discussed in Howells (1997) while the remaining 10 units are a data gap.

4.11.4 Data and Methods

Howells (1997) conducted a field survey of bodies of water within the Big Thicket region starting in January of 1992. Sampling methods included casual shoreline and gravel-bar examinations, shallow and deep water qualitative collections, 0.25 m^2 quadrat sampling, transect sampling, skimmer dredge and brails, and some scuba and hookah diving (Howells 1997). Efforts were mostly focused on determining presence or absence of freshwater mussels. Species composition and relative abundance were also recorded. Records of survey results also indicate the general locations of observations which were identified to species whenever possible (Howells 1997).

NPS (2014) lists 33 species of freshwater mussels that are either documented in the preserve or have distributions that overlap with BITH. The NPS (2014) list contained errors in taxonomy which were corrected by SMUMN staff using web and journal queries, as well as an online database of freshwater mussels that occur throughout the world (Graf and Cummings 2013).

Karatayev and Burlakova (2007) sampled select sites in eastern Texas for freshwater mussels. The purpose was deemed highly important due to the widespread decline and level of endangerment that freshwater mussels are now facing. The results are intended to provide managers, researchers, and decision makers with vital information on the condition of local mussel communities to aid in conservation efforts (Karatayev and Burlakova 2007). Methods of mussel sampling and collection were dependent on mussel densities and field conditions; adjustments were made as needed (Karatayev and Burlakova 2007). Random time-searches by wading and snorkeling were used along with density evaluations using 0.25 m^2 quadrats placed in random fashion. Live mussels and empty shell lengths were measured with calipers to the nearest 0.1mm and recorded for each site. Water depth and dominant substrate type, water temperature, dissolved oxygen, pH, total dissolved solids, specific conductivity, and turbidity were recorded for each site and each location's coordinates were recorded with a global positioning system receiver (Magellan Explorist 300) (Karatayev and Burlakova 2007).

Ford (2013) conducted surveys for freshwater mussels in four units of BITH between 3 July and 3 September in 2013: Upper Neches River Corridor Unit (UNRCU), CU, BCU, and NBU and JGBU (Figure 57). A total of 33 surveys were completed; 19 of them were in the Neches River main channel and tributaries, nine in Neches River oxbows, and three in Beech Creek and two small tributaries (Ford 2013). Locations selected by satellite were narrowed down from a boat by habitat featuring cobble or gravel substrate and areas with shells visible on the shoreline (Ford 2013). Timed hand searches were the main method used (this is considered the most effective search method for encountering rare species) (Ford 2013). Searches were conducted in 100-150 meter marked areas for timed increments determined by number of persons searching (e. g. one person=one person/hour or four people=one person/15 minutes) (Ford 2013). In areas with high abundance, increments were increased to optimize assessment of mussel community composition (Ford 2013). Mussels were collected (including shells of dead mussels) and identified, counted, and returned to the water where they were collected. GPS was used to record the location of final survey areas (Ford 2013).

Ford (2014) conducted surveys for freshwater mussels in 11 units of BITH between 24 April and 28 September of 2014, three of which were also surveyed the year previous (indicated by an *) (Ford 2013). Units surveyed during 2014 included VCU, UNRCU*, TCU, MCU, LNRCU*, LPI-PIBCU, LRU, JGBU and NBU*, BSCU, BCU, and the BU of BITH. The data from these surveys will be used in the current condition and trend assessment. Methods were similar to Ford (2013) described above.

4.11.5 Current Condition and Trend

<u>Abundance</u>

Howells (1997) collected 107 individuals within BITH aquatic habitats during the field survey. There were 55 mussels collected in the Neches River and 52 collected in the Trinity River. It should be noted that due to limitations in resources needed for mussel surveys, the samples were collected in areas with a minimum mussel density (1 to 2 mussels per m^2) and this survey extends to areas beyond the boundaries of the BITH units. Species found in abundance were specified in Howells (1997) (Appendix O). None of the species Howells (1997) considered abundant are currently listed as threatened at the state level. However, subsequent data collected by Ford (2013, 2014) did identify seven out of eight state-threatened species of mussels within the preserve during mussel surveys conducted in 2013 and 2014.

Ford (2013, 2014) lists number of individuals found (dead and live) for each species that was documented during the 2013 and 2014 surveys in BITH waters (Table 54). The areas with highest abundance tended to be backwater refugia in the Neches Bottom and Jack Gore Baygall and Canyonlands Units (Ford 2013, 2014).

Table 54. The number of individuals collected during surveys conducted by Ford (2013, 2014).

		Number of Individuals Collected			
		2013		2014	
Scientific Name	**Common Name**	**Live**	**Dead**	**Live**	**Dead**
Amblema plicata	threeridge	48	9	11	1
Arcidens confragosus	rock pocketbook	2	2	-	-
Fusconaia	pigtoe species	-	-	81	8
Fusconaia askewi	Texas pigtoe*	-	-	102	12
Fusconaia lananensis	triangle pigtoe*	-	-	2	-
Toxolasma parvum	lilliput	-	-	51	2
Glebula rotundata	round pearlshell	110	16	-	-
Lampsilis hydiana	Louisiana fatmucket	11	6	30	5
Lampsilis satura	sandbank pocketbook*	4	7	1	1
Lampsilis teres	yellow sandshell	42	119	56	17
Leptodea fragilis	fragile papershell	9	41	16	-
Ligumia subrostrata	pondmussel*	-	1	-	-
Megalonaias nervosa	washboard	44	3	-	-
Obliquaria reflexa	threehorn wartyback	10	3	5	-
Obovaria jacksoniana	southern hickorynut*	-	-	4	1
Plectomerus dombeyanus	bankclimber	65	7	108	1
Pleurobema riddelli	Louisiana pigtoe*	1	1	0	0
Potamilus amphichaenus	Texas heelsplitter*	0	13	0	2
Potamilus purpuratus	bleufer	9	13	2	2
Pyganodon grandis	giant floater	12	0	4	0
Quadrula apiculata	southern mapleleaf	83	6	10	0
Quadrula mortoni	western pimpleback	29	43	55	11
Quadrula nobilis	Gulf mapleleaf	58	7	1	1
Quadrula nodulata	wartyback	2	1	0	0

*Threatened status at the state level in Texas.

Table 54 (continued). The number of individuals collected during surveys conducted by Ford (2013, 2014).

		Number of Individuals Collected			
		2013		2014	
Scientific Name	**Common Name**	**Live**	**Dead**	**Live**	**Dead**
Tritogonia verrucosa	pistolgrip	1	2	3	0
Truncilla donaciformis	fawnsfoot	2	0	0	0
Uniomerus declivis	tapered pondhorn	0	3	0	0
Villosa lienosa	little spectacle case	2	0	13	11
Uniomerus tetralasmus	Pondhorn	0	0	14	0
Strophitus undulatus	creeper	0	0	1	0
Utterbackia imbecillis	paper pondshell	0	0	2	0

*Threatened status at the state level in Texas.

NPS (2014) often lists abundances of fauna and flora, but does not report any abundance levels for freshwater mussel species in the preserve. The most abundant species in the Ford (2014) surveys were bankclimbers (*Plectomerus dombeyanus*), with 108 live mussels of this species collected. Other abundant species were Texas and triangle pigtoes (*Fusconaia lananensis*), lilliputs (*Toxolasma parvum*), and yellow sandshells (*Lampsilis teres*). In 2013, there were 110 live round pearlshell (*Glebula rotundata*) mussels collected, having the largest number collected of all the species observed (Ford 2013). Other species that were found in higher number were the western pimpleback, yellow sandshell, and species in the *Fusconaia* genus, which consist of two pigtoe species in the area, the state-threatened Texas pigtoe and triangle pigtoe.

Richness

There were 39 of the 42 freshwater mussel species listed in Howells (1997) that were actually observed in parts of the preserve. Freshwater mussel species identified were collected in the Neches and Trinity Rivers in BITH (Appendix O).

Karatayev and Burlakova (2007) recorded four species during sampling efforts in Village Creek. Species observed were the Louisiana pigtoe (*Pleurobema riddelli*), western pimpleback (*Quadrula pustulosa mortoni*), triangle pigtoe (*Fusconaia lananensis*), and Texas lilliput (*Toxolasma texasiense*).

Ford (2013, 2014) observed a total of 32 (confirmed) freshwater mussel species during surveys conducted in the preserve, which included 12 units (Appendix O). The Neches River tributaries and oxbows were reported to often have higher species richness than the main channel habitats (Ford 2013). The total number of species found per BITH unit is shown in Table 55. Three units were not included in either survey effort.

Table 55. Data collected during mussel surveys in 2013 and 2014 showing number of species observed by unit (Ford 2014).

	Number of Species Observed	
BITH Unit	**2013**	**2014**
Beaumont	-	17
Beech Creek	-	5
Big Sandy Creek	-	4
Jack Gore Baygall and Neches Bottom	17	7
Lance Rosier	-	2
Little Pine Island-Pine Island Bayou Corridor	-	9
Lower Neches River Corridor	20	7
Menard Creek Corridor	-	3
Turkey Creek	-	8
Upper Neches River Corridor	18	-
Village Creek Corridor	-	19
Canyonlands	10	-
Hickory Creek Savannah	-	-
Loblolly	-	-
Big Sandy Creek Corridor	-	-

Distribution

Howells (1997) states that 42 of the 52 mussel species expected to occur in the state of Texas were reported in or near the Big Thicket area where the preserve is located. The Howells (1997) surveys resulted in collections of freshwater mussels from five rivers and two bayous located in the Big Thicket region of Texas and two of these flow through BITH. The Neches River and the Trinity River have species encountered listed by respective river in Appendix P (Figure 57).

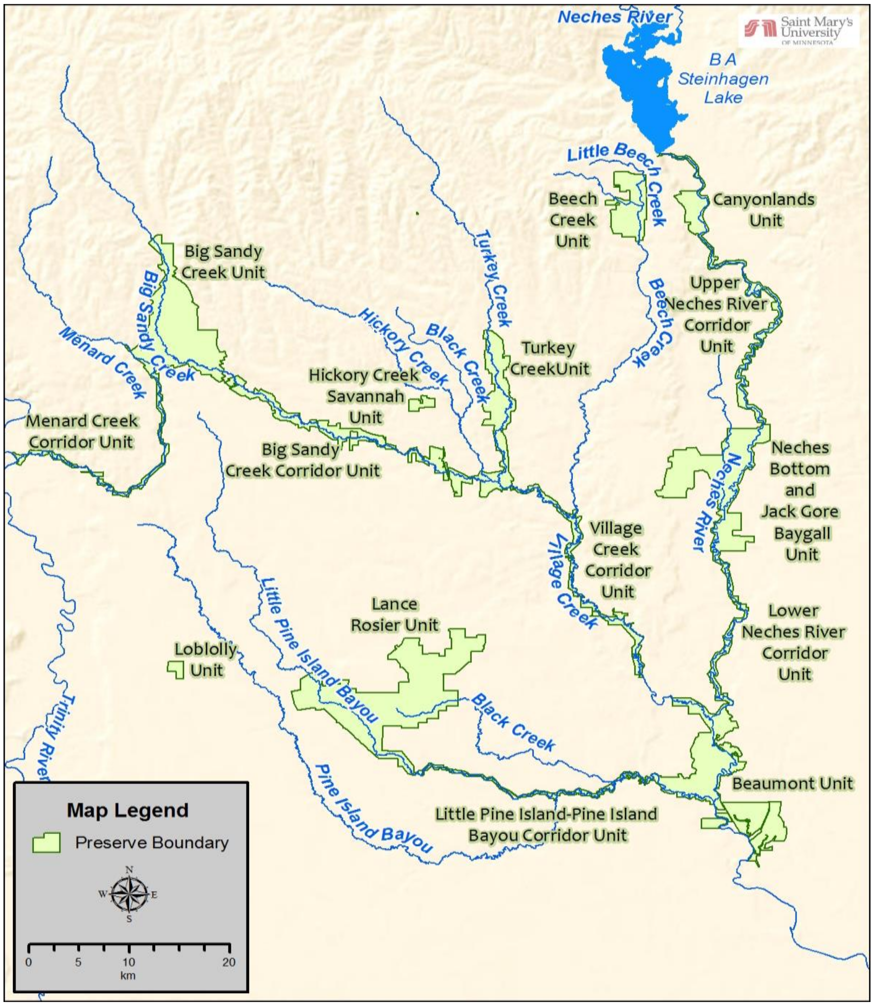


Figure 57. The layout of BITH units with respective rivers and bayous.

There were four species documented in Village Creek in June of 2007 during an east Texas freshwater mussel survey project: Louisiana pigtoe, western pimpleback, triangle pigtoe, and Texas lilliput (Karatayev and Burlakova 2007). The field conditions inhibited survey efforts at that time; Karatayev and Burlakova (2007) recommended that Village Creek be surveyed in subsequent mussel surveys since efforts there were thwarted and a threatened species (triangle pigtoe) was documented there.

Ford (2013, 2014) surveyed for freshwater mussels in BITH to determine species abundance and composition of species in the preserve waters. Species that were encountered are listed in Appendix O. Ford (2013) concluded that mussel distributions were highly variable in abundance and diversity, in particular noting that the B.A. Steinhagen Reservoir is basically a boundary between high abundances above the lake and drastically lower abundances below the lake in the Neches River main channel. This was assumed to be due to high shear stress on the channel following water releases from the lake, which cause significant bank erosion and subsequent aggradation in the Neches River channel (Ford 2013). This type of disturbance is not conducive to mussel survival as they become buried in sand; most mussel species are intolerant of these conditions. At one time there was a large mussel bed just below the lake, but it was buried in sand and is now gone (Ford 2013 citing personnel communication with Howells). There were higher abundances and higher diversities of mussels found in tributaries and oxbows, which are not affected by the water pulses from B.A. Steinhagen, and thus could serve as valuable source populations of mussel species that have been extirpated from other areas (Ford 2013). The CU, NBU, and JGBU have many of these refugia containing high mussel abundance and often high diversity of mussel species and should be a focus in conservation efforts (Ford 2013). In 2014, 11 units were surveyed for mussels and these data were integrated with the data from 2013. Between these two years a total of 32 mussel species were observed throughout the preserve. Individual units varied in compositions; a list indicating the number of species in each unit surveyed is shown in Table 56, and species that were observed are listed in Appendix O.

Table 56. The number of species observed in the units surveyed in 2013 and 2014 (Ford 2013, 2014).

	Number of Species Observed		
BITH Unit	**2013**	**2014**	**Total**
Beaumont	-	17	**17**
Beech Creek	-	5	**5**
Big Sandy Creek	-	4	**4**
Jack Gore Baygall and Neches Bottom	17	7	**18**
Lance Rosier	-	2	**2**
Little Pine Island-Pine Island Bayou Corridor	-	9	**9**
Lower Neches River Corridor	20	7	**20**
Menard Creek Corridor	-	3	**3**
Turkey Creek	-	8	**8**
Upper Neches River Corridor	18	-	**18**
Village Creek Corridor	-	19	**19**
Canyonlands	10	-	**10**
Hickory Creek Savannah	-	-	**-**
Loblolly	-	-	**-**
Big Sandy Creek Corridor	-	-	**-**

The LNRCU had the most species observed (20), and was one of three units that were surveyed 2 years in succession. However, the UNRCU didn't indicate what was observed which is why the number of species observed is not indicated for 2014 in Table 56. The locations of mussel observations are shown in Figure 58 with the cumulative number of species that were observed by preserve unit. The LU seems unlikely to have adequate habitat for mussels to occur, and this may be the case with the HCSU as well. The Big Sandy Creek Corridor Unit (BSCCU) should be surveyed in the near future and would likely result in the observation of more species in that system.

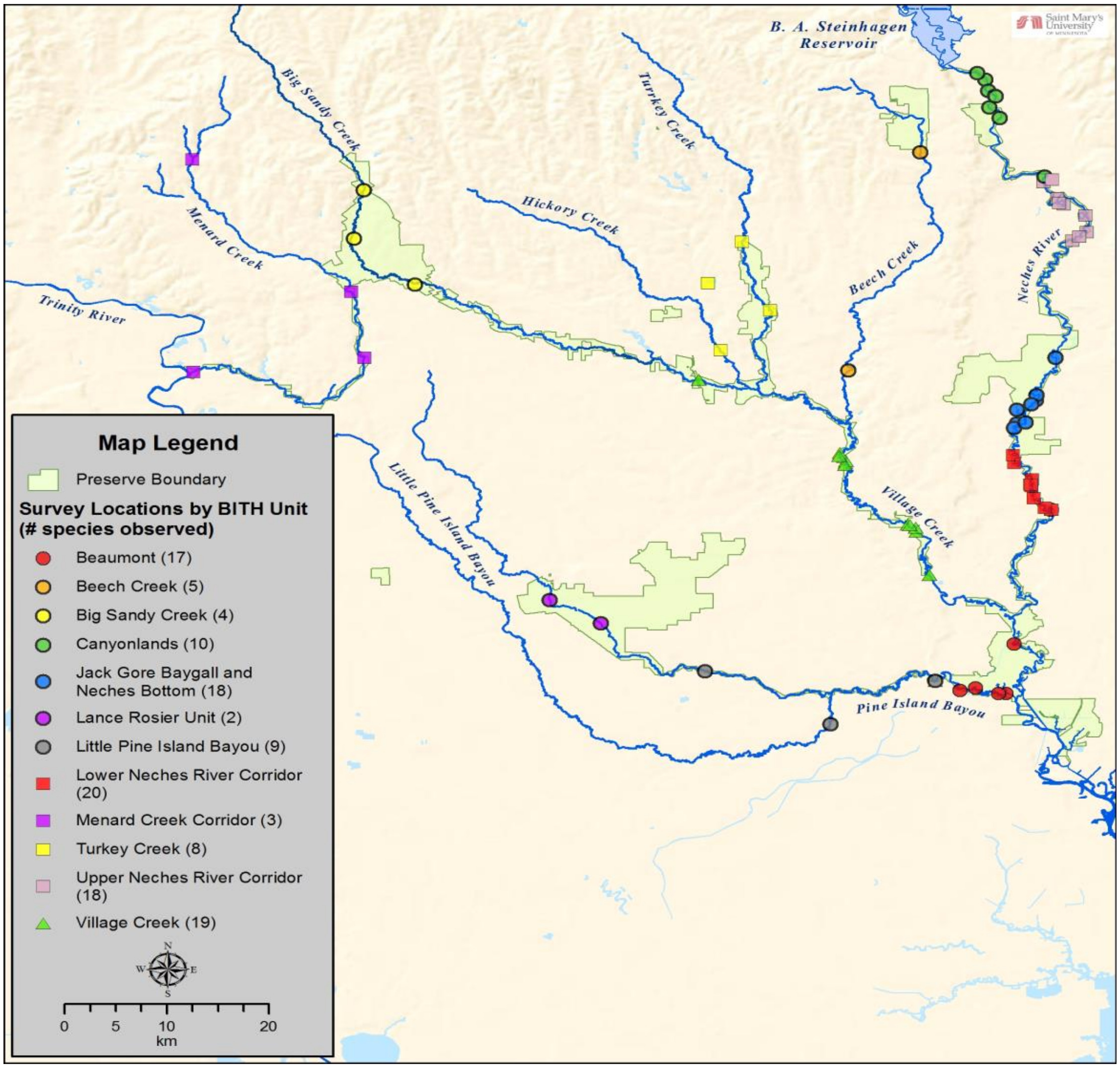


Figure 58. The location sites of survey efforts in 2013 and 2014 and the number of species observed in each unit that was included in the field work (Ford 2013, 2014).

<u>Threats and Stressors Factors</u>

The preserve managers have defined several threats and stressors to the freshwater mussel communities inhabiting the various aquatic habitats found in the preserve units. These include pollution, drought and climate change, and exotic and invasive species; the Asian clam (*Corbicula fluminea*) being the main invasive species threatening the status of freshwater mussels. Overall, freshwater mussels are considered imperiled throughout the United States and Canada and warrant a regular monitoring program at BITH to identify any trends in species richness, distribution, and abundances for all of the preserve waterways (Williams et al. 1993, Ford 2013).

There are a total of 15 state-threatened, native freshwater mussel species in Texas, seven of which are now known to be present in BITH: sandbank pocketbook, smooth pimpleback (*Quadrula houstonesis*), southern hickory nut, Texas fawnsfoot, Texas heelsplitter, Texas pigtoe, triangle pigtoe, and the Louisiana pigtoe (NPS 2014, TPWD 2014). According to the TPWD (2009), these species are known to live in limited habitats with spatially specific distributions and are considered sensitive to poor water quality. According to the USFWS (2011), six of these 15 species are federal listing candidates. The smooth pimpleback, Texas pimpleback, and Texas fawnsfoot are the three that may also occur in BITH (Howells 1997, USFWS 2011, NPS 2014). Ford (2013, 2014) documented seven state-threatened species in the preserve during two years of mussel surveys, which are indicated in Appendix O.

The following sections are divided by body of water to address each river and its level of impairment and the impacts that the conditions may have on the freshwater mussels that may inhabit the area.

Little Pine Island -Pine Island Bayou Corridor Unit

The LPI-PIBCU has signs of water quality degradation ranging from low dissolved oxygen (DO) to elevated *Escherichia coli* (*E. coli*) and chloride concentration (Cummings 2012). The LPI-PIBCU also had elevated ammonium concentrations in the 1990s, which was observed throughout the preserve and was attributed to fertilizer use on the surrounding land surfaces for agriculture (NPS 1995, NPS 2010, Cummings 2012). An increased concentration of ammonium triggers blooms of algae and plankton that are followed by significant drops in DO; this can be harmful to freshwater mussels if low DO conditions persist. Oil and gas activities are a threat to LPI-PIBCU water quality which, like any aquatic ecosystem, is sensitive to spills and leaks of production waste (i.e., oil field brine) and petroleum products (Cummings 2012). Mussels are sensitive to pollution, but also can serve as a record of past contamination events. Surveys for mussels in LPI-PIBCU could be useful in assessing the time frame of suspected contamination events.

Menard Creek

Menard Creek, the main water body of the Menard Creek Corridor Unit (MCCU), is considered in better condition than LPI-PIBCU, but it is considered vulnerable to land use impacts since the preserve only controls a narrow corridor of land. Threats to water quality (and mussels) from adjacent lands outside preserve boundaries include agriculture, septic fields, recreation, and oil and gas pipelines and activity (Cummings 2012). Oil and gas activities can be attributed to elevated chloride concentrations in Menard Creek that have persisted since the 1980s, even though levels have recently dropped below state limits (Cummings 2012). The temperature average of Menard Creek water has occasionally exceeded state maximums and *E. coli* generally meets state standards, but is indicative of non-point bacterial pollution when there is runoff from precipitation (Cummings 2012). These types of water quality degradation threaten mussel communities that may inhabit Menard Creek. It should be noted that there are no data on presence/absence of mussels in Menard Creek.

Turkey Creek

Turkey Creek water conditions are considered fairly stable with periodic elevations of bacteria levels associated with non-point source contamination in the events of runoff from lands outside of the preserve, but within the Turkey Creek watershed (Cummings 2012). Lumber and wood production, oil and gas production, and general land development threaten the Turkey Creek aquatic ecosystem (Cummings 2012). There is also a biomass plant slated for construction at the end of 2014 upstream of the preserve in Woodville, TX (about 20 km [12 mi] from the TCU boundary) which may impact water quality in the TCU. Pollution in the TCU could become a threat to freshwater mussels that may inhabit Turkey Creek (Cummings 2012).

Village Creek

Village Creek has similar bacterial pulses that correlate with rainfall events during which contaminants are washed into the creek from the surrounding land (Cummings 2012). Overall the Village Creek water has been generally good and supports a mussel community (Hall and Bruce 1996, Meiman 2012, Cummings 2012).

Big Sandy Creek

Big Sandy Creek has tended to have low DO on a regular basis, which is attributed mostly to natural conditions of the geomorphology of the land and channel, although low DO can be indicative of excess nutrients (Cummings 2012). There is an oil pipeline that crosses Big Sandy Creek; although this pipeline is outside the preserve boundary, it is upstream of the BSCCU and is a potential threat to freshwater mussels that may inhabit Big Sandy Creek (Meiman 2012). There are not data on presence/absence mussels in Big Sandy Creek.

Neches River

The Neches River runs through five units of BITH and intercepts the Village Creek in the LNRCU. Water quality is considered a high priority for the Neches River because of the reliance on it for municipal drinking water. There is a permanent structural saltwater barrier near Beaumont to prevent saltwater flowing upstream from the Gulf during periods of drought, low flows, or storm surges. The BU spans downstream of the barrier and will experience saltwater intrusion from time to time (Cummings 2012). Overall, the Neches River is in the best condition in comparison to the other BITH unit waterways (Cummings 2012). However, the Neches River is at high risk of becoming polluted. There are many threats to water quality in the river itself and watershed overall including oil and gas well and pipeline activity, septic fields, agricultural landuse, paper mill effluent, oil refinery discharge, and discharge from municipal sewage treatment plants (NPS 2010, Cummings 2012). All the factors that threaten water quality are potential threats to freshwater mussels along with the channel maintenance for shipping purposes (i.e., dredging) which can destroy mussel habitat. There are areas of the Neches River sediments that are high in contaminants that are toxic to sensitive mussels and other invertebrates. The sources of contamination vary. Paper mill effluent is one possible source of dioxin contaminants in the Neches River, and other compounds are also found in fish tissue samples from various industrial activities along the Neches River and its tributaries (Cummings 2012). Mussels are known to be present in the Neches River, some in abundances that support commercial mussel harvests. Future monitoring of water quality should involve mussel surveys to update the status of abundances, species richness, and distributions.

Freshwater Mussels in Decline

According to Williams et al. (1993) and Howells (1996), more than half of North America’s 300+ freshwater mussel species and subspecies have become either endangered, extinct, or threatened, with others to soon follow without some kind of management effort to curb this trend. There are 297 native freshwater mussels known in North America and Canada; 213 of them are considered endangered (77), threatened (43), or of special concern (72), 21 are possibly extinct, 31 are considered extant, meaning extirpation has occurred locally, but they still exist in areas where suitable conditions remain (Williams et al. 1993). The rapid decline is largely attributed to habitat destruction. Mussel habitats have been eliminated as a result of channel modification (e.g., dams, dredging), siltation, contaminants and invasive mussel introductions (Williams et al. 1993). Williams et al. (1993) also emphasizes freshwater mussels' dependence upon fish hosts; the health of the fish community affects the health of mussel communities, both playing integral roles in the aquatic environment.

Nonnative Species

The Asian clam is a threat to native mussels in BITH. The invasive Asian clam is currently found on the east and west coasts of North America and inland across the country. Only Alaska, Montana, and the Dakotas are considered clear of this invasive mollusk (TXID 2011). This would suggest that the Asian clam may be in all the preserve units of BITH, although the impact on native mollusks in BITH is not known at this time. One characteristic of the Asian clam that may negatively affect native mussels is their tendency to cluster in high densities, out competing native mussels for space (Williams et al. 1993). Texas water managers are also on the watch for invasions by zebra (*Dreissena polymorpha*) or quagga mussels (*D. bugensis*). These non-native and highly invasive mussels from the Black Sea region can quickly invade new waters and overwhelm native freshwater mussels by attaching to their shells and filtering all nutrients from the surrounding waters. They are not known to have invaded the Big Thicket region (TPWD 2015).

Climate Change

Stream temperatures have been bordering the maximum limits for freshwater mussels in all the preserve unit creeks and rivers; at times these creeks and rivers are exceeding the maximum recommended temperature (Meiman 2012). The streams and rivers in the preserve are naturally low in alkalinity. This means that the water is susceptible to changes in pH from pulses of acidic or basic pollutants such as oil and gas production, lumber activities, and textile byproducts that have been known to contaminate the water in the BITH area in the past (Cummings 2012, Meiman 2012). Mussels are sensitive to prolonged periods of low DO conditions, which is commonly the result of higher water temperatures. Warmer water has less capacity to hold DO than colder water. Other climate change-related impacts could come from additional saltwater intrusion as sea levels rise and more frequent or prolonged droughts affecting flows or causing some streams to become ephemeral.

Data Needs/Gaps

The reference condition and main data source (Howells 1997) lacks data for over half of the preserve units: BSCU, HCSU, LRU, VCU, TCU, BCU, and LPI-PIBCU of the preserve. This is a significant data gap both spatially and temporally in regard to the reference condition. However, Ford (2013, 2014) provided much more coverage and surveyed 12 of the 15 units over two years of study. Considering there are seven state-level threatened freshwater mussel species occurring in the aquatic habitats of BITH, monitoring and inventories should be implemented on a repeating and regular schedule to determine the full spectrum of mussel species that occur in the preserve.

Overall Condition

Abundance

The project team defined the *Significance Level* of species abundance as a 3. The abundances of certain mussel species mentioned in Howells (1997) are outdated. The most recent survey of mussels lists abundances for each species that was observed in the Neches River and suggests that prior to the construction of the dam above B.A. Steinhagen, abundances were much higher (Ford 2013). The surveys conducted by Karatayev and Burlakova (2007) and Ford (2013 and 2014) indicate that there have been major declines in mussel abundance in the Neches River while other, more isolated, areas (e.g., back channels, smaller tributary creeks) appear to still have relatively abundant mussel populations. Due to these most recent assessments indicating signs of spatially isolated degradation, the *Condition Level* has been assigned a 1, which is of a lower concern, but merits the need for continued monitoring and inventories.

Species Richness

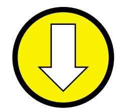
The project team defined the *Significance Level* of species richness as a 3. Species richness data for the reference condition is isolated to the Neches River and the Trinity River and lacked coverage of the other, numerous rivers and creeks in the preserve. The most recent data from Ford (2013, 2014) surveyed aquatic habitat in 12 of the 15 units for mussels. Overall there were 42 species recorded in BITH in 1997 (Howells 1997) and the most recent data available found a total of 32 mussel species (Ford 2013, 2014). The consistency in locations isn’t adequate to determine that this equates to a declining trend in species richness. However, since there have been fewer species observed recently when compared to the reference data, this may indicate a decline in richness. Considering this observation, the *Condition Level* was assigned a 2 or of moderate concern.

Distribution

The project team defined the *Significance Level* of species distribution as a 3. The distribution of mussels in BITH is the largest current data gap. Many of the rivers, creeks, and bayou and backwater areas have not been surveyed to assess mussel distribution within BITH. The Neches River was the most comprehensively discussed water body in the preserve units by Howells (1997), along with the Trinity River which passes through a small section of the MCCU. The latest distribution data indicated a decline in the Neches River mussel beds and species distributions are becoming more isolated to the tributaries and backwaters that have fewer disturbances impacting mussels. There is a high likelihood that mussel communities exist throughout BITH tributaries and backwaters that are in need of assessment in the remaining preserve units to ensure their conservation and management, particularly since they likely serve as a population source for the other larger waterways. The recent studies indicate that distributions are declining due to human-caused disturbance (e.g., degraded water quality, impoundment) and drought conditions likely extirpated species from Beech Creek and its tributaries. Due to the reduction in distribution indicated by the decline in species richness and evidence of past mussel presence in now devoid areas (BCU), a *Condition Level* of 2 has been assigned for this measure.

Weighted Condition Score

The WCS is 0.56 for freshwater mussels at BITH since there is evidence of a decline in species richness and distributions. There are still areas with high species richness and some species were still found in abundance, although overall the freshwater mussels of eastern Texas are in severe decline. The presence of mussels in BITH warrants the need for continued efforts to monitor the composition and abundance of species as well as an expansion of survey areas to determine the condition of mussel communities in the other preserve units where surveys have not been conducted.

Freshwater Mussels			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.56**
Abundance	3	1	
Richness	3	2	
Distribution	3	2	

4.11.6 Sources of Expertise

- Ken Hyde, BITH Chief of Resources Management
- Joe Meiman, GULN Hydrologist

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4.12 Freshwater Fish

4.12.1 Description

In addition to six waterway preserve units, a 129 km (80 mi) stretch of the Neches River, and numerous smaller water courses (totaling 402 km [250 mi] of waterways), there are also many small ponds and lakes, bayous, oxbow lakes, and ephemeral streams included within BITH. Within these water bodies are diverse communities of freshwater native fish as well as a few "marine invader" species (e.g., striped mullet [*Mugil cephalus*]) and euryhaline species (e.g., mosquitofish [*Gambusia affinis*] and freshwater drum) (Figure 59; NPS 2015). The NPS Certified Fish Species List (NPS (2015) contains 106 species, 90 of which are identified as "present," while four species are listed as "probably present," and 12 species are listed as "unconfirmed" in the preserve (Appendix R). These diverse fish communities tend to be dominated by minnows and sunfish, with an inverse relationship between channel size and species richness (i.e., the smaller the channel the greater the number of species) (Moring 2003). The blue sucker (*Cycleptus elongates*) and the creek chubsucker (*Erimyzon oblongus*) occupy aquatic habitats within BITH and are both listed as state threatened species in Texas (Harcombe 1997, Moring 2003, TPWD 2015a). The paddlefish is a Texas state endangered species and is additionally listed as a Federal Species of Concern (Harcombe 1997, Cooper et al. 2004). A number of sightings of paddlefish occurred in the Neches River in and around the confluence with Pine Island Bayou during the 1980s and 1990s (Pitman 1991), however they are considered very rare or extirpated since.

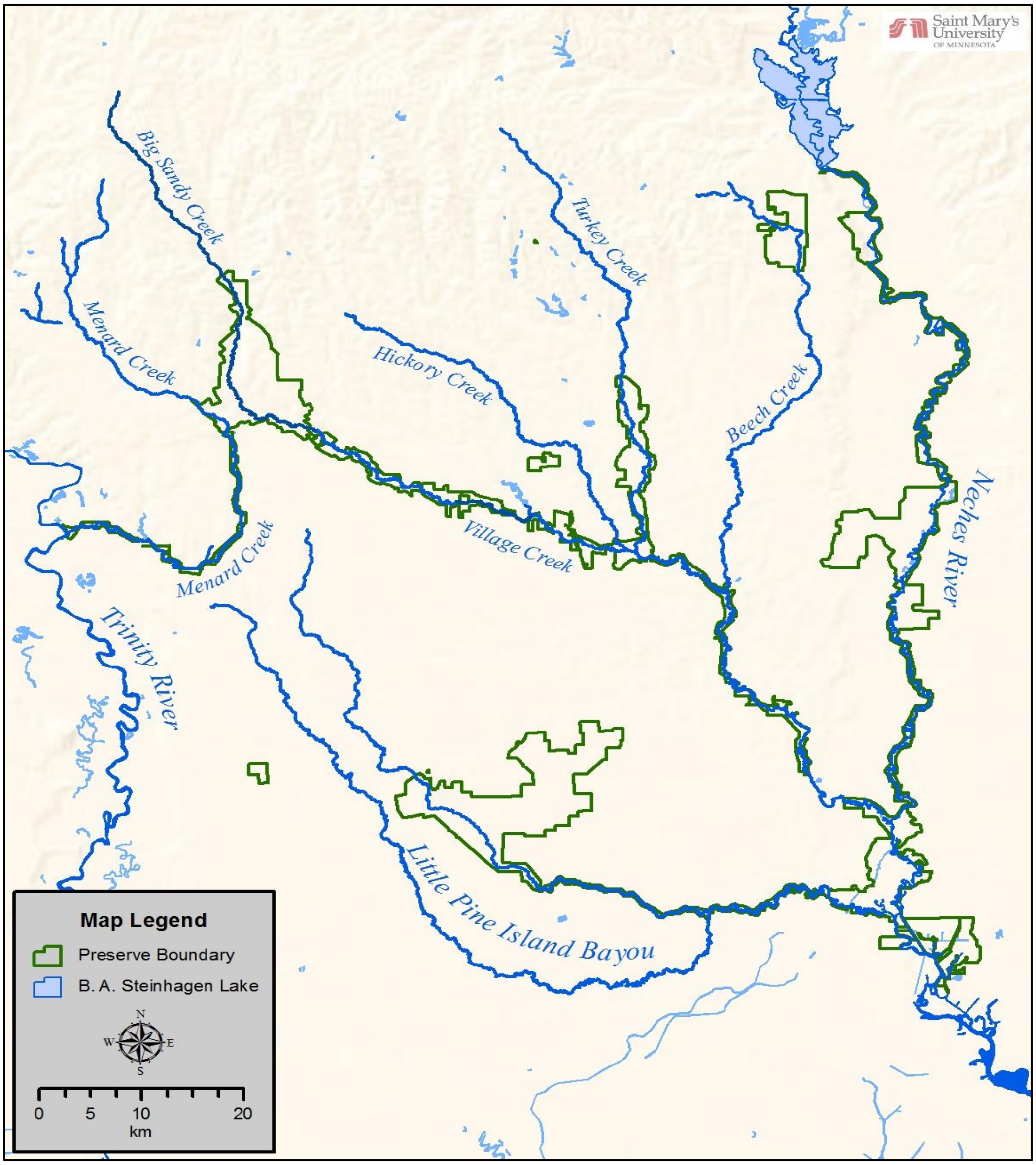

Figure 59. The location of the many creeks, rivers, and bayous in the BITH region.

4.12.2 Measures

- Species abundance
- Species richness
- Distribution

4.12.3 Reference Conditions/Values

Suttkus and Clemmer (1979) was selected by BITH staff as the reference condition for all three measures since it is the earliest available source of preserve-specific fish species richness, abundance, and distribution data. This study reports the results from 15 separate survey trips that obtained fish collections in several BITH waterways over a 3-year period from June 1977 through March 1979.

During the surveys, Suttkus and Clemmer (1979) observed 70 species of freshwater fish. Among these species, the most abundant, based on the number observed, were red shiners (*Cyprinella lutrensis*), bullhead minnows (*Pimephales vigilax*), blacktail shiners (*Cyprinella venusta*), and Sabine shiners (*Notropis sabinae*). These small fish were found in the tens of thousands. Other abundant species were western mosquitofish (*Gambusia affinis*), mimic shiners (*Notropis volucellus*), ribbon shiners (*Lythrurus fumeus*), scaly sand darters (*Ammocrypta vivax*), bluegills (*Lepomis macrochirus*), weed shiners (*Notropis texanus*), and longear sunfish (*Lepomis megalotis*) (Suttkus and Clemmer 1979). Distribution of many species include all major rivers and creeks associated with BITH units, with nearly all species associated with the Neches River drainage that included several tributary creeks and backwater areas. Suttkus and Clemmer (1979) documented all 70 observed freshwater fish species in the Neches River and 37 in Beech Creek, 33 in Turkey Creek, 34 in Hickory Creek, 39 in Big Sandy Creek, 28 in Menard Creek, 47 in Village Creek, and 56 in Little Pine Island Bayou (Appendix Q, Appendix R, Appendix S).

4.12.4 Data and Methods

For all data sets included in this assessment, SMUMN GSS omitted records of saltwater fish species, as this assessment focuses on the freshwater species of the preserve. Instances where datasets could not be adjusted to include only freshwater species are documented to draw attention to this discrepancy in the data.

Suttkus and Clemmer (1979) include all data from 15 fish surveys conducted in BITH between June 1977 and March 1979. This initial survey effort was part of an ongoing project intended to create a complete list of the fish species found within the preserve as well as their distributions. The survey method used a 3 m (10ft) by 1.8 m (6 ft) nylon seine to collect fish. The fish collected were preserved using formaldehyde and then stored in isopropanol alcohol solution with high grade parchment paper labels for each fish specimen (Suttkus and Clemmer 1979). Individual specimens were grouped as collections based on the location where they were obtained. These were stored in the Tulane University Museum of Natural History.

Moriarty and Winemiller (1997) studied fish assemblages in a 3.3 km (2.1 mi) reach of Village Creek from the summer of 1993 to the spring of 1994. Sampling times coincided with the seasons (i.e., summer, fall, winter, and spring) to determine shifts in the fish assemblages between seasons (Moriarty and Winemiller 1997). Site selection was determined by a set of mesohabitat categories with relatively homogenous features (i.e., pools, riffles, and runs), and for each season between seven and 11 sites were sampled (Moriarty and Winemiller 1997). Water temperature, depth, width, discharge, current velocity, pH, salinity, dissolved oxygen (DO), and conductivity for each site where fish were sampled were recorded. Fish were sampled with a variety of methods fitted for each mesohabitat to optimize efforts towards achieving a representative sample of the fish assemblage at each site, as well as an estimate of relative abundances and population size (Moriarty and Winemiller 1997). Sandbanks, sand riffles, and backwater areas were sampled with seines measuring 3 m by 1.9 m, 3mm-mesh, (9.8 ft by 6.2 ft, 0.12 in-mesh) and 6.2 m by 1.8 m, 9.5 mm-mesh (20.3 ft by 5.9 ft, 0.40 in-mesh) (Moriarty and Winemiller 1997). The leaf litter and woody debris at the edges of Village Creek were sampled with dip nets and a 3 m (9.8 ft) seine (Moriarty and Winemiller 1997).

The deep areas (exceeding 1.5 m [5 ft]) were sampled from a boat using a hand-held electroshocking unit or monofilament gillnet measuring 45.7 m by 2 m (150 ft by 5 ft) with three distinct panels with mesh sizes of 2.5 cm (1 in), 5 cm (2 in), and 7.5 cm (3 in) (Moriarty and Winemiller 1997). In addition, the length of each study reach was intensively electroshocked once each study season (Moriarty and Winemiller 1997).

Moring (2003) collected fish, habitat, and macroinvertebrate data at 15 stream sites in BITH units. The collections were conducted from 1999 through 2001 in order to obtain baseline assessment data and compare community composition of the many aquatic habitats within the preserve. Fish collecting occurred at 15 sites in 1999 and eight sites in 2001 (Figure 60; Moring 2003). Site selection was based on existing water-quality monitoring sites in the preserve and measures were taken to ensure upstream to downstream pairing within each corridor unit (Moring 2003).

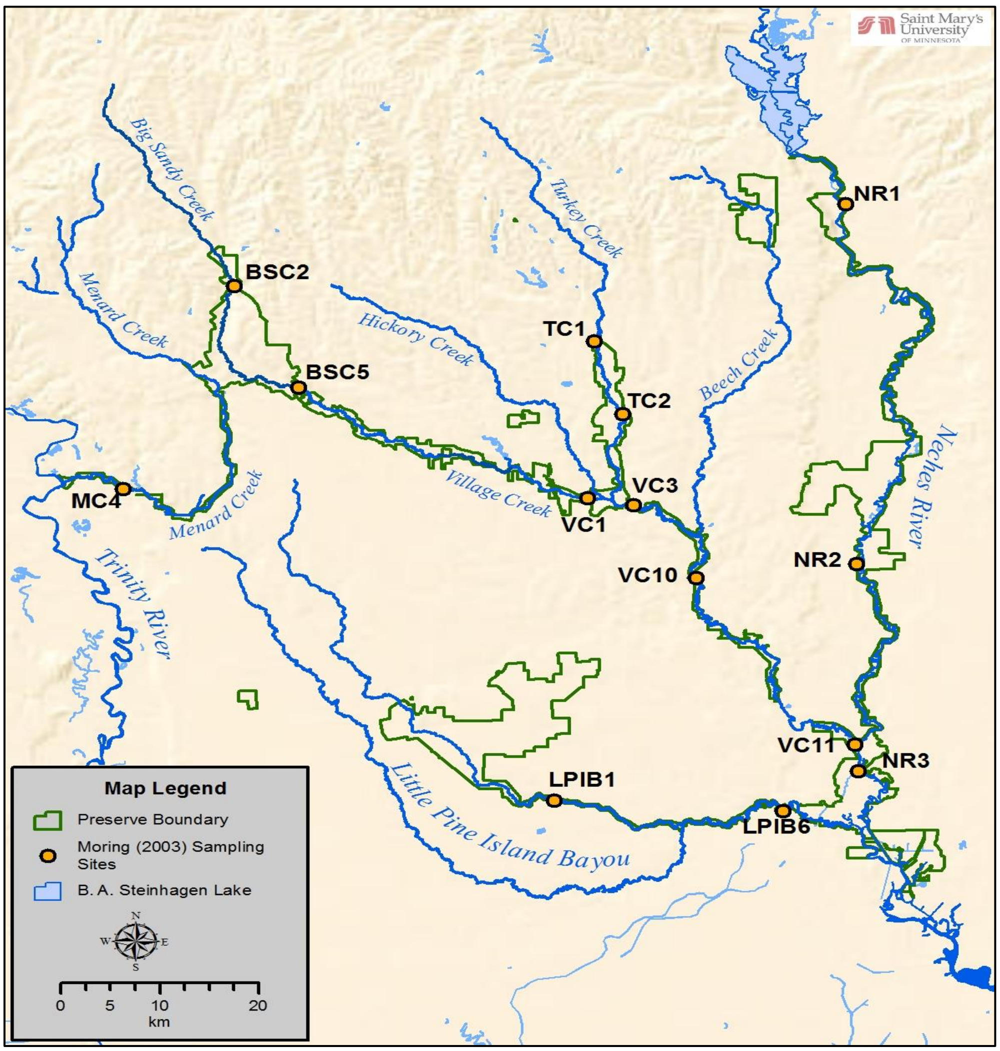

Figure 60. Sampling sites in BITH used by Moring (2003). BSC = Big Sandy Creek; MC = Menard Creek; TC = Turkey Creek; LPIB = Little Pine Island Bayou; VC = Village Creek; NR = Neches River.

The collection of fish was done with barge electrofishing equipment and a supplemental 7.5 m (24.6 ft) by 3 m (9.8 ft) seine (Moring 2003). Fish collected were identified to species and lengths and weights of each individual were recorded (Moring 2003). In the event of fish that were difficult to identify or required verification, specimens were preserved in formalin and sent to the Memorial Museum located at the University of Texas to be identified and then permanently stored.

Winemiller et al. (2014) conducted several field surveys in the southern portion of the BU in 2011 and 2012. The surveys included fish sampling with gill nets and seines, along with water quality assessments (Winemiller et al. 2014). The purpose of the field surveys were to assess the condition and evaluate the flow needs of the aquatic habitat within a recently acquired tract of Neches River wetland that became part of the BU in 2009 (Winemiller et al. 2014). Sites where fish were sampled were within the southern portion of the BU's sloughs and the adjacent main channel of the Neches River below the Lower Neches Valley Authorities (LNVA) saltwater barrier. This permanent structure located at rivermile 29 on the Neches was finished in 2006 and allows LNVA to stop any saltwater intrusion from moving further upstream from the Gulf. Site selection for fish sampling was based on ease of sampling (Winemiller et al. 2014). Sampling for fish occurred in October, November, and December of 2011, and May through August of 2012. Species assemblage structure was analyzed by assessing species richness, abundance of individual species catch-per-unit-effort (CPUE), and relative abundance (i.e., % of total number of individuals) (Winemiller et al. 2014). Calculations of these values were done separately for gillnets and seines (Winemiller et al. 2014).

4.12.5 Current Condition and Trend

<u>Species Abundance</u>

Suttkuss and Clemmer (1979) collected 151,983 individuals which consisted of 70 freshwater fish species (Table 57). The total number of fish specimens collected by Suttkus and Clemmer (1979) (separated by species) is shown in Appendix Q alongside two subsequent fish studies which also recorded specimen counts by species. Moriarty and Winemiller (1997) recorded the number of individuals in Village Creek and are also included in Appendix Q. Most abundant was the blacktail shiner (1,148 individuals collected) followed by 583 bullhead minnows, 327 ribbon shiners, and 194 Sabine shiners (Moriarty and Winemiller 1997). Moring (2003), which collected 4,818 fish specimens in 1999 and 2001 from the preserve, found that individuals collected most were similar to the two previous surveys, with blacktail shiners and bullhead minnows being abundant, but also longear sunfish, bluegills, and shad species in large numbers (Moring 2003).

Table 57. The freshwater fish species with the highest abundance for each study from 1979 to 2003 (Suttkus and Clemmer 1979, Moriarty and Winemiller 1997, and Moring 2003).

1979	Count	1997	Count	2003	Count
red shiner	37,075	blacktail shiner	1,148	longear sunfish	761
bullhead minnow	31,671	bullhead minnow	583	blacktail shiner	644
blacktail shiner	27,100	ribbon shiner	327	bullhead minnow	462
sabine shiner	12,237	western mosquitofish	263	bluegill	404
western mosquitofish	6,348	sabine shiner	194	gizzard shad	297
mimic shiner	4,073	weed shiner	153	threadfin shad	284
ribbon shiner	2,860	blackspotted topminnow	137	spotted bass	179
scaly sand darter	2,465	scaly sand darter	118	red shiner	156
bluegill	2,200	brook silverside	98	largemouth bass	150
weed shiner	2,039	flier	64	blackstripe topminnow	148
longear sunfish	1,998	bluegill	61	freshwater drum	111
blackspotted topminnow	1,739	longear sunfish	45	longnose gar	93
ghost shiner	1,553	mimic shiner	45	mimic shiner	86
threadfin shad	1,471	spotted bass	31	white crappie	83
speckled chub	1,293	pallid chub, pallid shiner	30	smallmouth buffalo	78
redfin shiner	1,261	banded pygmy sunfish	22	spotted gar	76
brook silverside	1,218	white crappie	21	blacktail redhorse	62
pallid chub, pallid shiner	1,171	cypress darter	21	pirate perch	53
dusky darter	1,032	pirate perch	19	striped mullet	51
white crappie	991	Mississippi silvery minnow	18	dusky darter	39

Similar to Suttkus and Clemmer (1979), Moring (2003) found that the Cyprinidae family (minnows) was by far the most frequently collected group of fish, particularly in the preserve's smaller streams and creeks. Species of minnow that were found in notably higher abundance than other fish in Suttkus and Clemmer (1979) were the blacktail shiner, red shiner, and the Sabine shiner. The most frequently collected fish species by site frequency and number of individuals in Moriarty and Winemiller (1997) was the blacktail shiner, although this study was restricted to one creek. Moring (2003) also found the blacktail shiner was the most frequently collected minnow species during sampling; however, there were more longear sunfish specimens than any other species (Appendix Q). Moring (2003) includes relative abundance by family and by site sampled (Figure 60, Figure 61).

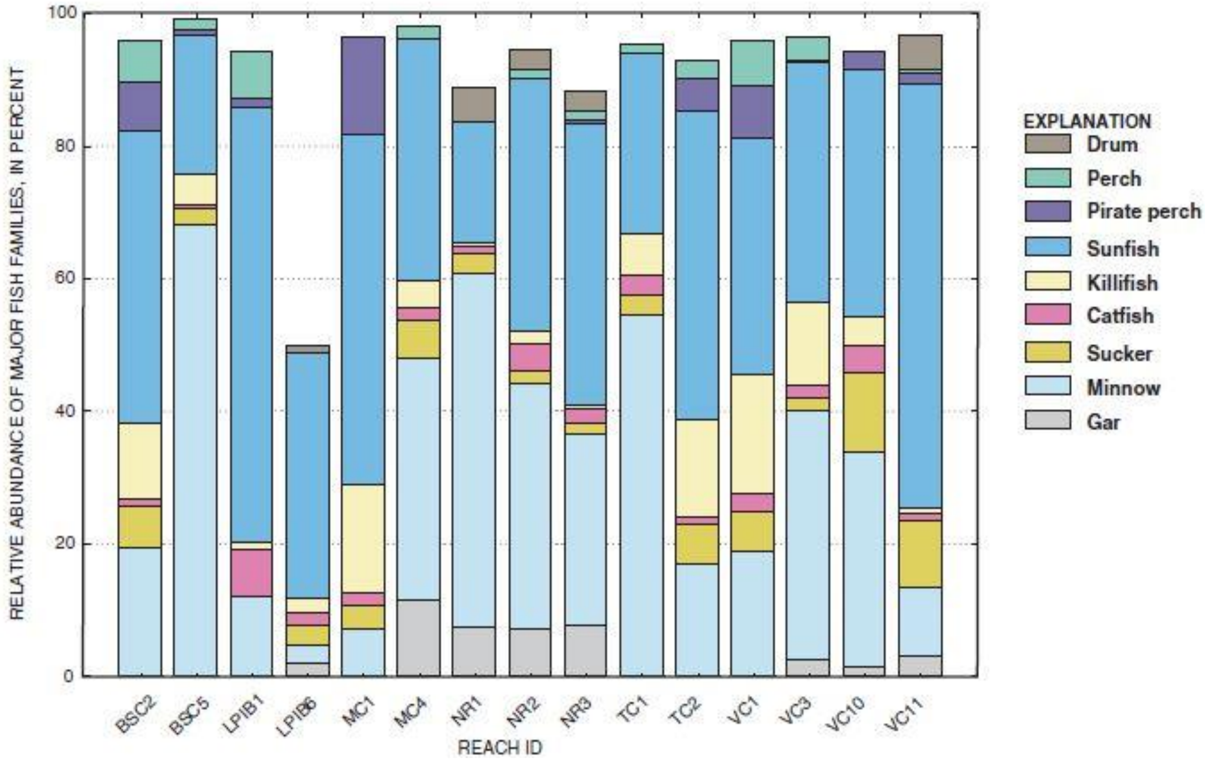

Figure 61. The relative abundance of fish by family and location (reproduced from Moring 2003).

Winemiller et al. (2014) sampled fish in the southern portion of the Beaumont Unit below the saltwater barrier and identified a total of 28,501 specimens, although many were saltwater species and were excluded to focus on freshwater species only. The dominant species (most abundant in samples) in Winemiller et al. (2014) were sheepshead minnows (*Cyprinondon variegatus*) and the inland silverside (*Menidia beryllina*), which were both the most abundant in seining efforts. The dominant species in gillnets were gars, catfish, and shad (*Dorosoma* spp.) (Winemiller et al. 2014).

Species Richness

The NPS Certified Fish Species List (NPS 2015) contains 106 species, 90 (85%) of which are identified as "present," while four species (3.8%) are listed as "probably present," and 12 species (11%) are listed as "unconfirmed" in the preserve (Appendix R). This list, however, does not allow for a specific analysis of species richness, as no data are collected other than the presence (or historic presence) of the identified species.

Suttkus and Clemmer (1979) collected and documented 70 species of fish during surveys from June 1977 to March 1979. Moriarty and Winemiller (1997) sampled fish in a 4.3 km (2.7 mi) stretch of Village Creek during four seasonal trips. The survey trips began in summer of 1993 and continued through spring of 1994 (Moriarty and Winemiller 1997). A total of 44 species were observed during the surveys in Village Creek (Moriarty and Winemiller 1997). Moring (2003) documented a total of 66 freshwater fish species during surveys conducted from 1999 to 2001. There are, as mentioned above, several species that are listed as either unconfirmed or probably present in the preserve

(Appendix R). The three available sources of data that delineate the number of species observed in the preserve waters are outdated. The most recent preserve-wide survey results concluded in 2001, and when compared to the previous study that includes a similar research area, published in 1979, Moring (2003) had fewer total species (Appendix R). This is probably misleading as Suttkus and Clemmer (1979) not only used records from previous collections, but also surveyed more intensively both spatially and in frequency compared to Moring (2003). However, both studies provide a baseline of species richness by waterway and overall species richness found in the preserve. There were two species of fish, the threadfin shad (*Dorosoma petenense*) and the blackspot shiner (*Notropis atrocaudalis*), that Moriarty and Winemiller (1997) observed in Village Creek which had not been observed there previously or following the survey period. This further suggests that more surveys may reveal species of fish that have not yet been documented in the preserve.

Moring (2003) used the Menhinick's index to assess species richness by fish community and included a short discussion on the results. Menhinick's index (*D*) is a measure of the number of species found in a sample and is calculated by taking the number of species (*s*) divided by the square root of the number (*N*) of individuals in a sample, since the larger the sample the more species are likely to be found: $D = s \div \sqrt{N}$. The lowest Menhinick's species richness value was 1.016 in Little Pine Island Bayou at site LPIB6, the highest value was 2.097 observed in Village Creek at site VC10 (Figure 60, Figure 62; Moring 2003).

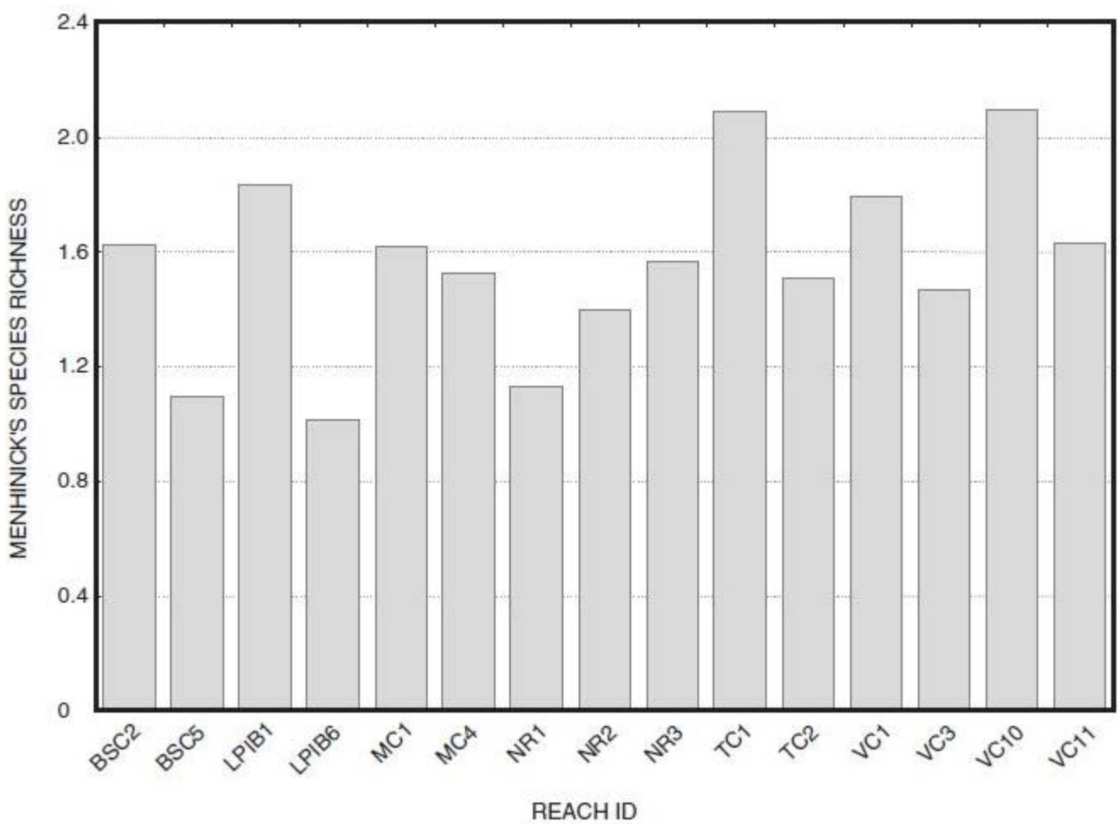

Figure 62. The Menhinick's index was used to assess species richness in BITH (reproduced from Moring 2003)

Winemiller et al. (2014) observed 51 species of freshwater fish and is the most recent available fish data. Though it is isolated to the Neches River only, it is a portion that was not surveyed by the above mentioned studies because it was not acquired until 2009. This study found additional species that are now included the NPS (2015) species list. There were 11 freshwater species observed in the Neches River within the BU that had not been previously listed on the preserve species list (Winemiller et al. 2014, NPS 2015). These species included skipjack shad (*Alosa chrysochloris*), shoal chub (*Macrhybopsis hyostoma*), sheepshead minnow, least killifish (*Heterandria formosa*), Gulf killifish (*Fundulus grandis*), sailfin molly (*Poecilia latipinna*), fat sleeper (*Dormitator maculatus*), darter goby (*Ctenogobius boleosoma*), opossom pipefish (*Microphis brachyurus*), freshwater goby (*Ctenogobius shufeldti*), and redspotted sunfish (*Lepomis miniatus*). There were also additional species observed that were previously listed in NPS (2015) as probably present or unconfirmed; these species were ribbon shiner, bay anchovy (*Anchoa mitchilli*), and yellow bass (*Morone mississippiensis*) (Appendix R; Winemiller et al. 2014). In fact, the ribbon shiner was observed in BITH by Suttkus and Clemmer (1979) and Moriarty and Winemiller (2003) as well. NPS (2015) didn't previously list three species that have been documented in the preserve by this study: the western sand darter (*Etheostoma clarum*), black bullhead (*Ameiurus melas*), and yellow bullhead (*Ameiurus natalis*) (Appendix R).

Distribution

The preserve falls within two large river drainages: the Neches and Trinity River drainages, with a bulk of the waterways being in the Neches watershed. The majority of the creeks and bayous surveyed for fish in the preserve were within the Neches River drainage. Menard Creek was also surveyed and is the only tributary within the preserve that is in the Trinity River drainage (Suttkuss and Clemmer 1979, Moring 2003). Winemiller et al. (2014) sampled fish below the saltwater barrier in and adjacent to the southern portion of the BU, an area that was not included in the previous studies.

A complete list of documented fish species was compiled from Suttkus and Clemmer (1979), Moriarty and Winemiller (1997), Moring (2003), and Winemiller et al. (2014) (Appendix S). Some species of fish were widely distributed and found throughout the preserve's sampled creeks. Species of fish that were documented in every creek/river sampled during Suttkus and Clemmer (1979), Moriarty and Winemiller (1997), Moring (2003), and Winemiller et al. (2014) are presented in Table 58.

Table 58. Fish species documented in all surveyed BITH creeks and rivers and reported in Suttkus and Clemmer (1979), Moriarty and Winemiller (1997), Moring (2003), and/or Winemiller et al. (2014).

Scientific Name	Common Name	Neches River			Beech Creek*	Turkey Creek		Hickory Creek	Big Sandy Creek		Menard Creek		Village Creek			Little Pine Island Bayou	
Year of Report		1979	2003	2014	1979	1979	2003	1979	1979	2003	1979	2003	1979	1997	2003	1979	2003
Minytrema melanops	spotted sucker	x	-	-	x	x	x	x	x	-	x	-	x	x	x	x	-
Cyprinella venusta	blacktail shiner	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Notropis volucellus	mimic shiner	x	x	x	x	x	x	x	x	x	x	-	x	x	x	x	x
Opsopoeodus emiliae	pugnose minnow	x	x	x	x	x	-	x	x	-	x	-	x	x	x	x	x
Pimephales vigilax	bullhead minnow	x	x	x	x	-	x	x	x	x	x	-	x	x	x	x	x
Fundulus olivaceus	blackspotted topminnow	x	-	-	x	x	x	x	x	x	x	x	x	x	x	x	-
Gambusia affinis	western mosquitofish	x	x	x	x	x	x	x	x	x	x	x	x	x	-	x	x
Esox americanus	redfin or grass pickerel	x	-	-	x	x	x	x	x	-	-	x	x	x	x	x	x
Chaenobryttus gulosus	warmouth	x	x	x	x	x	x	x	x	x	x	-	x	x	x	x	x
Lepomis macrochirus	bluegill	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Lepomis megalotis	longear sunfish	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Lepomis punctatus	spotted sunfish	x	x	-	x	x	x	x	x	x	x	x	x	x	x	x	x
Ammocrypta vivax	scaly sand darter	x	x	-	x	x	x	x	x	x	x	-	x	x	x	x	-
Etheostoma chlorosomum	bluntnose darter	x	-	x	x	x	-	x	x	-	x	-	x	x	-	x	x
Percina sciera	dusky darter	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Aphredoderus sayanus	pirate perch	x	x	-	x	x	x	x	x	x	-	x	x	x	x	x	x

*Creek only surveyed in Suttkus and Clemmer (1979).

Table 58 (continued). Fish species documented in all surveyed BITH creeks and rivers and reported in Suttkus and Clemmer (1979), Moriarty and Winemiller (1997), Moring (2003), and/or Winemiller et al. (2014).

Scientific Name	Common Name	Neches River			Beech Creek*	Turkey Creek		Hickory Creek	Big Sandy Creek		Menard Creek		Village Creek			Little Pine Island Bayou	
Year of Report		**1979**	**2003**	**2014**	**1979**	**1979**	**2003**	**1979**	**1979**	**2003**	**1979**	**2003**	**1979**	**1997**	**2003**	**1979**	**2003**
Noturus gyrinus	tadpole madtom	x	-	-	x	x	x	x	x	-	x	x	-	-	x	x	-
Noturus nocturnus	freckled madtom	x	-	-	x	x	x	x	x	x	x	-	x	x	-	x	x

*Creek only surveyed in Suttkus and Clemmer (1979).

Species distributions varied between the surveyed streams and rivers during both Suttkuss and Clemmer (1979) and Moring (2003). Suttkuss and Clemmer (1979) observed an average of 42.4 species at each survey site (Figure 63). The highest species richness values in Suttkuss and Clemmer (1979) were observed in the Neches River (70 species), which was well over the average number of species observed/site (42.2 species/site). The lowest number of species observed during the same study occurred at the Menard Creek site, where just 28 species were observed (Figure 63). Other survey sites in Suttkuss and Clemmer (1979) ranged from 33-56 species/site (Figure 63). Moriarty and Winemiller (1997) surveyed Village Creek and observed 44 species of fish. Although this was the lowest number of species observed at Village Creek, there were two species observed for the first time as mentioned above in the species richness discussion. Additional fish species not previously reported were also observed by Winemiller et al. (2014); the samples were only from the Neches River, specifically below the saltwater barrier in the southern portion of the BU (Appendix R). These species can be reviewed in Appendix R and are mentioned in the species richness section as well.

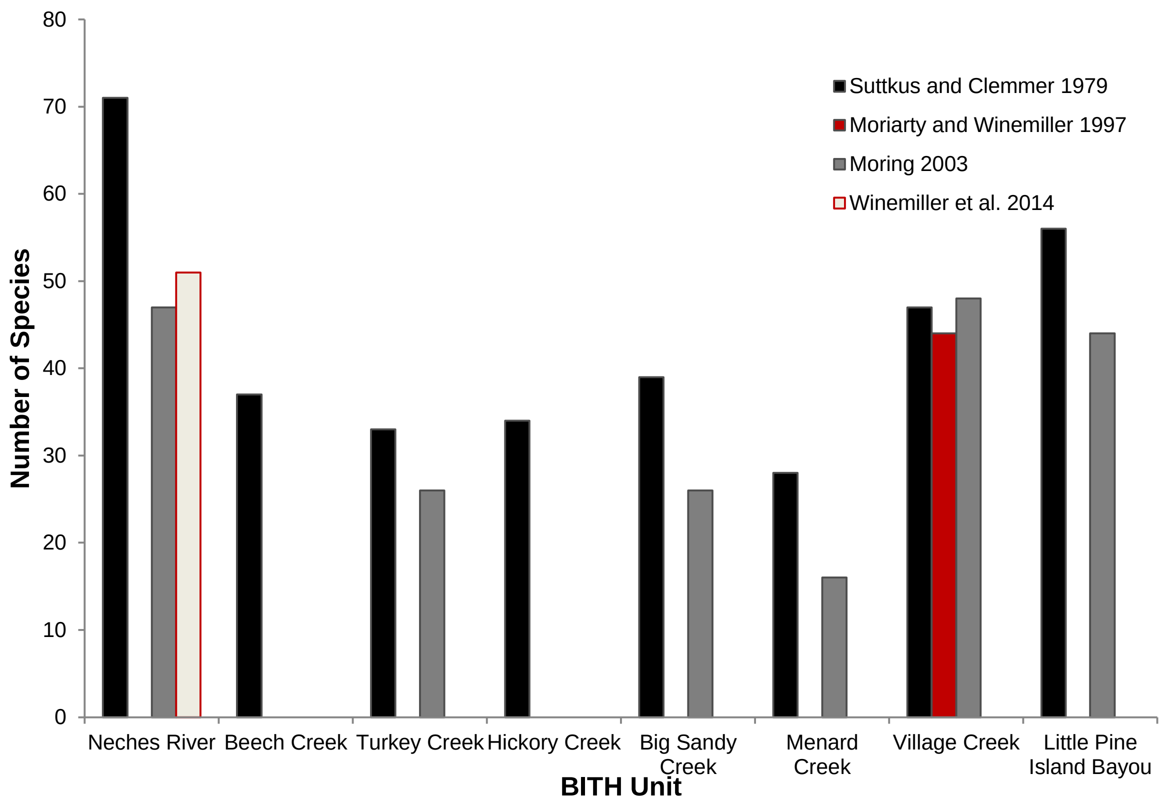

Figure 63. Number of species by water body to indicate species distributions (Suttkus and Clemmer 1979, Moriarty and Winemiller 1997, Moring 2003, Winemiller et al. 2014).

Moring (2003) also observed variable species composition across the study sites in BITH. The average number of species observed at each site in Moring (2003) was 34.5 (Figure 63). Peak species richness values were observed at Village Creek (48 species), and the lowest number of species observed was in Menard Creek (16 species; Figure 63). As has been previously mentioned, comparisons between the two fish surveys may be inaccurate, due to differences in survey methodology and intensity. However, general comparisons between the two studies reveals that similar species were reported in Suttkuss and Clemmer (1979), and sites with the highest and lowest composition of species were similar between the two studies (Neches River had the highest number of species in both studies, and Menard Creek had the lowest). With the additional survey data from Winemiller et al. (2014), the Neches River has a total of 94 species that are now documented, several of which were not previously observed by other fish studies in BITH.

Two creeks, Beech Creek and Hickory Creek, were not surveyed by Moring (2003). There are likely more species of fish in these creeks than what was reported in Suttkus and Clemmer (1979), considering that Moring (2003) found additional species in each creek and river that was sampled, and not necessarily all the species identified in the 1979 report (Appendix S). Additionally, a paddlefish study was conducted following a reintroduction effort in the Neches River where paddlefish were gill-netted and tracked using telemetry to determine their distribution and movements (Wilde 2000). Results from Pitman (1991) record fish being harvested in the 1980s-1990s and Wilde (2000) indicated that paddlefish were captured and tracked within a stretch of the Neches River below the Steinhagen dam (includes several BITH units).

The cumulative total number of species for the Neches River is now 94. The other areas and the respective number of species documented in them are shown in Table 59.

Table 59. The total number of freshwater fish species in each water system included in all surveys (Suttkus and Clemmer 1979, Moriarty and Winemiller 1997, Moring 2003, and Winemiller 2014).

Waterway	Total Number of Species
Neches River	**94**
Village Creek	**71**
Little Pine Island Bayou	**62**
Big Sandy Creek	**44**
Turkey Creek	**41**
Beech Creek	**37**
Hickory Creek	**34**
Menard Creek	**33**

Threats and Stressors Factors

Suttkus and Clemmer (1979) discussed the suspected impacts on fish abundances and distributions following the development of the Town Bluff Dam in 1951 and the Sam Rayburn Dam in 1965. The dams impound sections of the river channel blocking fish, specifically the silvery minnow (*Hybognathus nuchalis*) and the paddlefish, from traveling up and downstream to spawn. The river's capacity to carry suspended silt was also reduced by the construction of dams, which reduce discharge rates, and was suspected to have buried newly spawned eggs (Suttkus and Clemmer 1979). These dams also limit the highwater flood pulse events on the Neches River that historically provided new nutrient-rich sediments, flushed out the backwater areas while importing new fish and their genetics into the backwater areas, recharged or created new oxbow lakes, and that could facilitate the dilution or removal of accumulated toxins.

To date, invasive aquatic plant species have been of most concern in the Neches River Watershed and may be impacting fresh water fish habitat in some areas. These include species such as water hyacinth, giant and common salvinia, hydrilla (*Hydrilla verticillata*), and alligatorweed (*Alternanthera philoxeroides*). The aquatic invasive zebra mussel has not been found in the watershed. As noted at the beginning of this discussion, a few marine invader fish species (e.g., striped mullet) and euryhaline species (e.g., mosquitofish and freshwater drum) have been found within the watershed. No studies specific to their possible impacts on native freshwater species have been conducted.

The widespread decline of paddlefish populations throughout the large rivers in North America has been blamed on a combination of over-harvest, pollution and depleted water quality, and an alteration of river channels for navigation and flood control (Jennings and Zigler 2000). This large planktivore is/was a native inhabitant of several Texas rivers, including the Neches River (Wilde 2000).

Pollution from industrial effluent discharges was studied and discussed in Barclay and Harrel (1985). Water quality parameters were sampled in Mill Creek, Village Creek, and a tributary of Mill Creek downstream of sewage and sawmill effluents (Barclay and Harrel 1985). The study concluded that poor water quality was indeed presenting a problem in the two creeks that were sampled (Barclay and Harrel 1985). The Neches River below the saltwater barrier receives effluent discharges from a paper mill in Evadale, TX and a host of oil refinery and manufacturing plant wastewater treatment systems. Resampling to detect current levels for comparison to this study would reveal if any changes in water quality have occurred. Waterways in portions of BITH are currently under Fish Consumption Advisories by the Texas Department of State Health Services (Texas DSHS 2014) and the TPWD (2015b). These include:

- Neches River and all contiguous waters from State Highway 7 bridge west of Lufkin downstream to the US 96 bridge near Evadale, including B.A. Steinhagen and Sam Rayburn reservoirs. The chemicals of concern include dioxins and mercury for smallmouth buffalo (*Ictiobus bubalus*), flathead catfish (*Pylodictis olivaris*), gar, blue catfish (*Ictalurus furcatus*), largemouth bass (*Micropterus salmoides*), and spotted bass (*M. punctulatus*).

- Village Creek upstream of Neches River in Hardin County. The chemical of concern is mercury and the advisory includes crappie, gar, and largemouth bass.

Saltwater intrusion occurs in the Neches River in the southernmost BITH unit, the BU. There is likely going to be increased saltwater intrusion in the lower Neches within the southern portion of the BU (Winemiller et al. 2014) before the saltwater barrier. This is due, in part, to the effects of climate change which has resulted in periods of severe drought, particularly in 2011 and 2012 when subsistence flow levels of freshwater being released through the salt water barrier were not met (Winemiller et al. 2014). The ongoing maintenance of a shipping channel to the Port of Beaumont and pending project to deepen said channel will also continue to facilitate salt water intrusion up the Neches and into the BU below the salt water barrier. When subsistence flows are reduced and salt water intrusion is facilitated, it is a threat to the native fish and other aquatic communities because it allows higher concentrations of pollutants and salt water to accumulate, especially in the backwaters and sloughs (Winemiller et al. 2014). Sea level is also projected to rise as a result of climate change as well as the frequency and intensity of hurricanes and their storm surges coming out of the Gulf of Mexico, all of which are likely to increase saltwater intrusion in the Neches River (Winemiller et al. 2014). Increased salinity from intrusion and drought are associated with a reduction in species of freshwater fish that are considered indicators of aquatic health (Winemiller et al. 2014). In contrast, these factors may lead to an increase in the number of salt water adapted species below the salt water barrier. Reports of blue crabs (*Callinectes sapidus*) and red drum (*Sciaenops ocellatus*) being caught just below the salt water barrier on the Neches during the drought of 2011 and 2012 were plentiful, and could be an early indication of a complete ecosystem change from a freshwater cypress-tupelo wetland to a saltwater river section and marsh over time. The USGS is currently conducting a series of research studies related to this possibility. The 2011-2012 drought was the driest year on record for the State of Texas and also the hottest summer for any state in United States history.

<u>Data Needs/Gaps</u>
The data that are available are outdated, as Moring (2003) is now over 10 years old. Winemiller et al. (2014) is more recent, but sampled only a limited portion of the preserve and included several salt water species in their data. Species richness, abundance, and distributions are included in the Suttkus and Clemmer (1979) report and serve as a baseline. Moring (2003) also includes this information, but did not survey two of the creeks surveyed by the 1979 report; those being Beech Creek and Hickory Creek. An annual or even periodic fish survey throughout the streams and rivers of the preserve would contribute greatly to assessing the current condition and any trends in the fish communities that inhabit BITH waterways. Winemiller et al. (2014) lacks coverage of the preserve in its entirety; however, it has now created baseline data to assess future trends below the saltwater barrier.

<u>Overall Condition</u>

Species Abundance
The species abundance measure was assigned a *Significance Level* of 3 by the project team. Many of the fish surveys conducted in the preserve are now outdated, and methodologies, timing, and duration of these surveys differ which makes comparisons potentially misleading. While existing surveys provide a baseline of general abundances of certain species, the differences in spatial context and

methodology makes assessment of trends difficult. Results from these surveys appear to suggest that the BITH area supports a robust and diverse freshwater fish community, but trends in abundance are not apparent and comparable at this time. Due to this, a *Condition Level* has not been assigned at this time.

Species Richness
The *Significance Level* for the species richness measure was assigned a 3. The most recent preserve-wide survey of fish is from Moring (2003) which is over 10 years old. Though it is discussed above and compared with the reference condition from Suttkus and Clemmer (1979), it is still too dated to assess any recent trends or the current condition of fish species richness. While Winemiller et al. (2014) documented additional species that occur in the Neches River, this particular reach of the preserve lacks a baseline. For future assessments of condition, the Winemiller et al. (2014) results could be used as a baseline for comparison for this reach of the river/unit of the preserve. A *Condition Level* has not been assigned for this measure at this time.

Distribution
The distribution measure was assigned a *Significance Level* of 3. This measure was also discussed above, comparing the reference condition of Suttkus and Clemmer (1979) with available data included in Moring (2003). These two reports are a useful baseline for several creeks and rivers in the preserve, but are too outdated to determine whether the distributions have been in recent decline or expanded. Winemiller et al. (2014) represents the most recent data collected on BITH freshwater fish, but was conducted at a location that has not been previously surveyed for fish, so there are no data to compare it to. Because of this data gap of over 10 years, a *Condition Level* was not assigned at this time.

Weighted Condition Score
The WCS relies upon the *Condition Levels* assigned to each measure. When there are Condition Levels that cannot be assigned due to data gaps, a WCS cannot be calculated, which is the case with this component. There are excellent baseline data that can be used to compare to subsequent survey findings to assess any trends in fish species richness, abundance, and distributions in the future.

Freshwater Fish			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Species Abundance	3	n/a	
Richness	3	n/a	
Distribution	3	n/a	

4.12.6 Sources of Expertise

- Ken Hyde, BITH Chief of Resources Management

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4.13 Water Quality

4.13.1 Description

Water quality affects species abundance and distribution for both terrestrial and aquatic species, as well as the overall health of the natural ecosystem. Surface water and water quality are at the core of BITH, and represent an integral resource in the preserve. According to NPS (2014, p. 11):

> *Big Thicket National Preserve has an extensive, dynamic system of hydrologic processes and associated dependent systems important to maintain the diverse yet specific ecological make-up of the Big Thicket. These include contiguous riverine and wetland systems. The Preserve provides examples of blackwater systems, which are not typically found outside of the Amazon Basin and southeastern United States, and of rare baygall wetlands that exemplify the original and seemingly impenetrable Big Thicket.*

The overall health of BITH's freshwater resources is integral to the character of the preserve (Meiman 2012). BITH is a multi-unit preserve and includes over 386 km (240 mi) of creek/stream corridors (Meiman 2012). The boundaries of BITH encompass parts of Bear Creek, Big Sandy Creek, Turkey Creek, Menard Creek, Village Creek, Little Pine Island Bayou, Pine Island Bayou, Little Beech Creek, Beech Creek, Massey Lake Slough, and the Neches River (Figure 64). With the exception of Menard Creek, which is in the Trinity River basin, all of these waters drain into the Lower Neches River that runs through the rolling, sandy terrain of Southeast Texas (Meiman 2012).

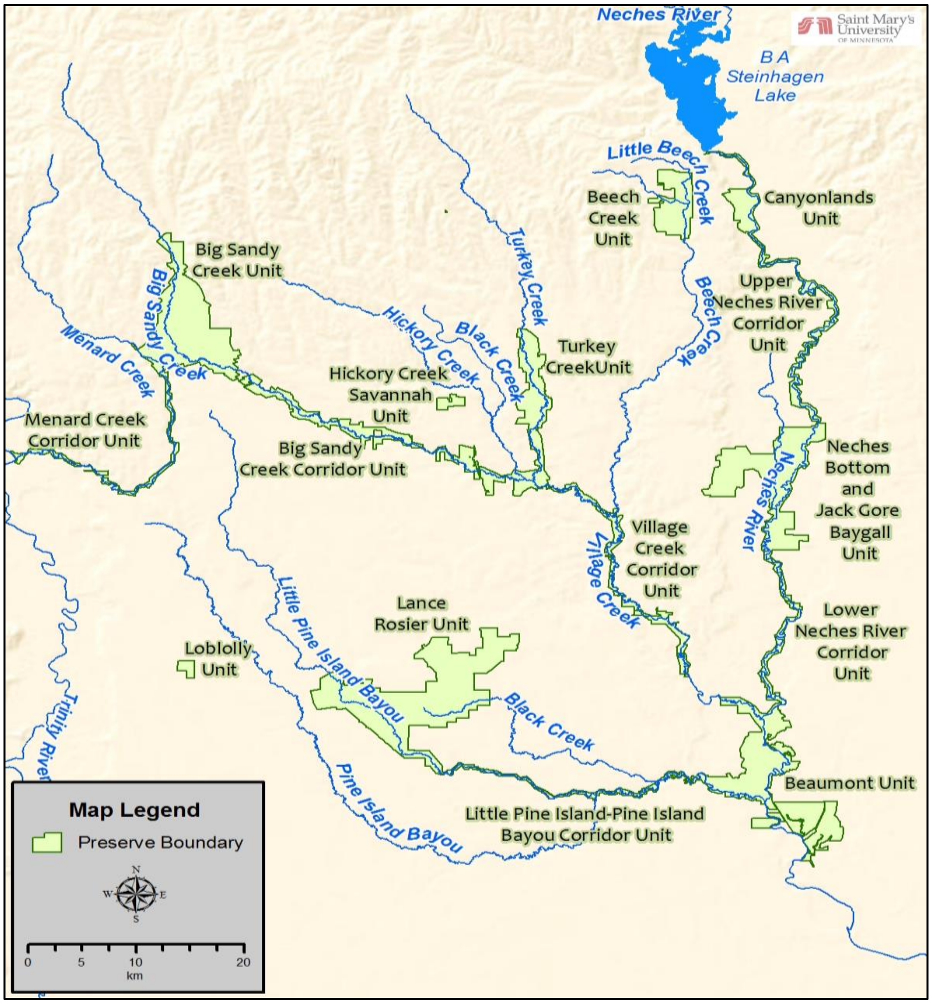

Figure 64. The locations and names of the many creeks, rivers, and bayous in BITH.

The larger rivers in the BITH region (e.g., Neches River) frequently carry elevated amounts of suspended solids, have high conductivity, and are turbid with a color that could be described as "chocolate-brown" (Harcombe et al. 1996). These rivers are frequently referred to as alluvial or brown-water rivers. The smaller creeks and streams in the BITH region that drain predominantly areas with sandy, acidic soils are referred to as "black-water" streams due to their combination of low turbidity and high organic acid concentrations (Harcombe et al. 1996). Each of the waterways in the BITH region exhibits some characteristics of black-water streams (Harcombe et al. 1996).

Several BITH units are comprised of narrow 'water' corridors that closely follow stream channels, and often include only the riparian area surrounding a particular water body. The predominantly narrow widths of these corridor units and stream channels can accentuate impacts from surrounding land uses. Impacts to the water quality within BITH that are directly influenced by surrounding land uses include increased runoff from deforestation, the introduction of pesticides and herbicides, leaks from oil and gas operations (e.g., hydrocarbons, produced waters, chemicals, solvents, and fuels), increased sedimentation, and nutrient enrichment from fertilizers (Sobczak et al. 2010).

Water chemistry has been identified as a Vital Sign for parks in the GULN, including BITH (Segura et al. 2007). Water temperature, conductivity (i.e., specific conductance [SpC]), pH, total suspended solids (TSS), dissolved oxygen (DO), *Escherichia coli* (*E. coli*), nutrients (as measured by phosphate/nitrogen concentrations), turbidity, carbonate chemistry, and impacts on aquatic insects are all core water quality parameters of concern identified by the preserve.

4.13.2 Measures

- Dissolved oxygen
- Temperature
- pH
- Conductivity
- Turbidity
- Nutrients (phosphates, nitrates)
- *E. coli*
- Carbonate chemistry (Total hardness)
- Total suspended solids (TSS)
- Impacts on aquatic insects

Dissolved Oxygen

Dissolved oxygen is critical for organisms that live in water. Fish and zooplankton filter out or "breathe" dissolved oxygen from the water to survive (USGS 2014). Oxygen enters water from the air when atmospheric oxygen mixes with water at turbulent, shallow riffles in a waterway, or when released by aquatic plants as a byproduct of photosynthesis. As the amount of DO drops, it becomes more difficult for aquatic organisms to survive (USGS 2014). The concentration of DO in a water body is closely related to water temperature (cold water holds more DO than does warm water), altitude, salinity, and steam structure (turbulent, rapid waterways integrate more DO than slow-moving, stagnant waterways) (Allan 1995). Thus, DO concentrations are subject to seasonal fluctuations as low temperatures in the winter and spring allow water to hold more oxygen, and warmer temperatures in the summer and fall cause water to hold less oxygen (USGS 2014).

Temperature

Water temperature greatly influences water chemistry and can strongly affect aquatic organisms. Not only can temperature affect the ability of water to hold oxygen, but water temperature also affects biological activity within water systems (Allan 1995). All aquatic organisms, from fish to insects to zoo- and phytoplankton, have a preferred or ideal temperature range (Allan 1995). As temperature increases or decreases too far past this range, the number of individuals and species able to live there eventually decreases. In addition, higher temperatures allow some compounds or pollutants to dissolve more easily in water and can be more toxic to aquatic life (USGS 2014).

pH

pH is a measure of the level of acidity or alkalinity of water and is measured on a scale from 0 to 14. A value of 7 indicates a neutral pH. A pH value less than 7.0 indicates acidity, whereas a pH greater than 7.0 indicates alkalinity (USGS 2014). Aquatic organisms have a preferred pH range that is ideal for growth and survival (USGS 2014). Chemicals in water can change the pH and harm animals and plants living in the water; thus, monitoring pH can be useful for detecting natural and human-caused changes in water chemistry (USGS 2014).

Conductivity

Specific conductance is a measure of the ability of water to conduct electrical current, which depends largely on the amount of dissolved ions in the water (Allan 1995). Water with low amounts of dissolved ions (such as purified or distilled water) will have a low SpC, while water with high amounts of dissolved solids (such as salty sea water) will have a higher SpC (Allan 1995). SpC is an important water quality parameter to monitor because high levels can indicate that water is unsuitable for drinking or aquatic life (USGS 2014). SpC can also quickly and reliably estimate dissolved solids in water (Meiman 2012).

Turbidity

Turbidity assesses the amount of fine particle matter (such as clay, silt, plankton, microscopic organisms, or finely divided organic or inorganic matter) that is suspended in water by measuring the scattering effect they have on light that passes through water (USGS 2014); the more light that is scattered, the higher the turbidity measurement. Turbidity often increases following rainstorms, when sediments are washed into the water from adjacent lands and stream velocity increases (USGS 2014). High turbidity decreases light penetration, which can reduce the productivity of aquatic plants and other organisms (USGS 2015a).

Nutrients

Nutrients, such as nitrogen and phosphorus, are crucial in supporting healthy aquatic environments. However, elevated concentrations of these nutrients can negatively impact water quality and threaten the ability of plants and aquatic organisms to thrive (USGS 2013a). Nitrogen occurs naturally in the atmosphere and in soils and is deposited into surface waters through precipitation and runoff; nitrogen deposition is increased by human inputs such as sewage, fertilizers, and livestock waste (USGS 2013b). Nitrates can cause a host of water quality-related problems when present in high concentrations including, but not limited to, excessive plant and algae growth, eutrophication, and depleted dissolved oxygen available to aquatic organisms (USGS 2013b). Nitrate in drinking water can be harmful to humans, particularly young children, and livestock (USGS 2013b). Phosphorus is commonly found in agricultural fertilizers, manure, organic wastes in sewage, and sometimes industrial effluent (USGS 2013b). Excessive phosphorus in water systems can increase the rate of eutrophication, encourage overgrowth of aquatic plants, deplete dissolved oxygen, and threaten fish and macroinvertebrate populations (USGS 2013b). Soil erosion is the primary contributor of phosphorus input into surface waters, in which enriched soils are deposited into waterways through runoff during heavy precipitation events (USGS 2013b).

E. coli

Bacteria are a common natural component of surface waterways and are mostly harmless to humans. However, certain bacteria, specifically those found in the intestinal tracts and feces of warm-blooded animals, can cause illness in humans (USGS 2011). Fecal coliform bacteria are a subgroup of coliform bacteria that, when used in monitoring water quality, can indicate if fecal contamination has occurred in a specific waterway. *Escherichia coli* (*E. coli*) is a specific species of bacteria that belongs to the larger group of coliform bacteria and is characterized by its ability to break down urease (an enzyme that breaks down urea into carbon dioxide and ammonia) (USGS 2011). *E. coli* is a preferred indicator for determining if potential pathogens are present in freshwater resources. It is tested by counting colonies that grow on micron filters placed in an incubator for 22-24 hours. High concentrations of *E. coli* can cause serious illness in humans (USGS 2011).

Carbonate Chemistry

Carbonate chemistry will be determined by a hardness measurement. Total hardness is a measure (expressed as mg/l $CaCO_3$) of magnesium and calcium (Meiman 2012). In general, an inverse relationship exists between metal toxicity and hardness; the higher the hardness, the lower the toxicity (Meiman 2012).

Total Suspended Solids

As defined by Meiman (2012, p. 21), total suspended solids (TSS) are a "direct gravimetric measurement of particles normally suspended in water and expressed as mg/l." Total suspended solids contribute to turbidity, with higher TSS values often representing high turbidity levels (Meiman 2012). Using turbidity as an estimation of TSS, however, has linear regression limitations as it is affected by particle size, shape and color, unlike the dry weight method of measuring TSS (Joe Meiman, NPS Hydrologist, written communication, 14 October 2014).

Impacts on Aquatic Insects

The presence or absence of some species of aquatic insects may be indicative of water quality. For example, the Ephemeroptera-Plecoptera-Trichoptera (EPT) index is often used to estimate water quality degradation (Moring 2003). This particular index was used to analyze water quality within BITH in a 1999 – 2001 study by Moring (2003). The EPT index is the sum of the proportion of each of the three orders of insects and is expressed as a percentage of the total identified taxa (Moring 2003). Theoretically, the higher the EPT index score, the healthier the stream.

4.13.3 Reference Conditions/Values

The reference conditions for water quality in BITH are the Texas Commission on Environmental Quality (TCEQ) water quality criteria considered to be protective of aquatic life and human recreation and bathing. Table 60 shows the standards for various surface water quality parameters set by the TCEQ. For some measures (e.g., nutrients), neither TCEQ nor the Environmental Protection Agency (EPA) have set applicable standards. The TCEQ has published "screening levels," or levels of concern, indicating that if these levels are exceeded a concern for water quality is warranted (TCEQ 2010). Table 61 identifies the streams in and around BITH that are listed in the Texas 303(d) (impaired) waters list (TCEQ 2012).

Table 60. Water quality criteria for parameters measured in BITH; water quality standards tied to specific stream segments are noted (Meiman 2012, 2014).

Parameter	Water Quality Criteria
Alkalinity	no state standard
Ammonia as N	no state standard (screening <0.33 mg/l)
Chloride	<150 mg/l (Village Creek), <50 mg/l (Neches River)
Specific conductance	no state standard
Dissolved oxygen	>3.0 mg/l (instantaneous value), >5.0 mg/l (24-hour average) Spring season: >4.5 mg/l (instantaneous value), >5.5 mg/l (24-hour average)
E. coli	<394 MPN/100 ml, single sample
Flow	no state standard
Hardness, total	no state standard
Nitrate+Nitrite as N	no state standard (screening <1.95 mg/l)
pH	between 6.0 and 8.5 SU
Phosphorus, total	no state standard (screening <0.69 mg/l)
Sulfate	<75 mg/l (Village Cr), <50 mg/l (Neches Riv, Pine Island Bayou)
TDS	<300 mg/l (Village Creek), <200 mg/l (Neches River)
TSS	no state standard
Water temperature	<32.2 °C (Village Creek), <32.8 °C (Neches River)
Turbidity	no state standard

Table 61. Section 303(d) (2010) listing for water body impairment in and around BITH (reproduced from Meiman 2012, based on TCEQ 2012).

Stream	Segment	Problem	Category[a]	First Listed[b]
Neches River	Between Saltwater Barrier and B.A. Steinhagen Reservoir and all tributaries	Mercury (Hg) in fish	5c	2010
Neches River	From confluence with Sabine Lake to the Saltwater Barrier	PCBs in fish	5c	2012
Pine Island Bayou	Mouth to mile 12.1	Low dissolved oxygen (DO)	5b	2000
Pine Island Bayou	Mile 12.1 to mile 35.4	Bacteria	5c	2008
Little Pine Island Bayou	Lower 25 miles	Low DO	5b	2000
Village Creek	FM 418 to Lake Kimball	Hg in fish	5c	2010
Beech Creek	Lower 20 miles	Bacteria	5c	2006
Big Sandy Creek	Lower 30 miles downstream from US 190	Bacteria	5b	2000
Turkey Creek	Lower 25 miles	Bacteria	5c	2000

[a] Category denotes administrative status. 5b indicates that a review of water quality standards will be conducted before a total maximum daily loads (TMDL) is scheduled, and 5c indicates that additional data will be collected before a TMDL is scheduled.

[b] Refers to the first year in which the water body was identified on the 303(d) list as having a possible water quality concern.

4.13.4 Data and Methods

This assessment will focus on the most recent water quality monitoring efforts in BITH, as summarized by Meiman (2012). The estimates provided in this document will most accurately represent the approximate current condition of this resource in the preserve. Additional historic data sources are briefly summarized below so as to not discount their utility at the various stages of the preserve's history. Current condition will not be estimated using these earlier sources, but instead they are presented below for documentation purposes.

In an effort to preserve and protect the water resources of BITH, water quality monitoring was put into place in the preserve as early as 1967 (Sobczak et al. 2010). Some of the earliest water quality monitoring in the preserve was conducted by Lamar University's Dr. Richard Harrel et al. (Harrel 1977, Harrel and Darville 1978, Harrel and Bass 1979, Harrel and Commander 1980, Harrel and Newberry 1981). Some of these early water quality monitoring reports documented elevated SpC and chlorides primarily due to oilfield brine seeping into Little Pine Island Bayou and Menard Creek (Harrel and Darville 1978, Harrel and Commander 1980). While many of these concerns have since been mitigated, other concerns raised in these publications, such as depressed DO, still exist in many waterways of BITH.

The USGS summarized water quality trends using data collected in BITH in 1985 (Wells and Bourdon 1985). These data were collected from three sites: the Neches River (at Evadale), Village Creek (Farm to Market Road 418 [FM 418]), and Pine Island Bayou (upstream of the confluence with Little Pine Island Bayou). The results of Wells and Bourdon (1985) indicated a primary concern regarding DO levels in the Neches River and its tributaries.

NPS (1995) characterized water quality within BITH using data that span more than 35 years (1950s–1990s). All data presented in NPS (1995) were collected from publicly accessible sources, such as: Storage and Retrieval System (STORET), Industrial Facilities Discharge (IFD), Drinking Water Supplies (DRINKS), Water Gages (GAGES), Water Impoundments (DAMS), and River Reach File version 3 (RF3). Additionally, NPS (1995) summarized the number of observations that exceeded EPA and NPS water quality criteria for a variety of water quality parameters. NPS (1995) indicated that the most frequent water quality-related issues in BITH were low dissolved oxygen and pH levels.

Rizzo et al. (2000) monitored surface water quality at 19 locations within BITH between 1996 and 1999. Samples were collected and analyzed for temperature, DO, pH, conductivity, light attenuation, ortho-phosphate, nitrate, and nitrite. Moring (2003) collected fish and benthic macroinvertebrate data from 15 streams and reaches in BITH between 1999 and 2001. Moring (2003) provided detailed baseline data concerning aquatic biota and determined the land uses in the drainage areas upstream from each sampling location. The biological data collected from 15 site locations within BITH was then compared to the land use data and changes in land use were briefly addressed.

Meiman (2012)

Since the early 2000s, the LNVA has sampled up to 31 stations outside of BITH as part of the Texas Clear Rivers Program (CRP), with several sites occurring directly upstream of the preserve boundaries. The LNVA monitoring stations are monitored quarterly and include a variety of field and laboratory sampling measures. Meiman (2012) represents the beginning of a GULN long-term water quality monitoring project for BITH, which initiated data collection in October 2007 and is ongoing at present. Sampling sites in Meiman (2012) coincided with existing LNVA sites, and were sampled quarterly using the same schedule, parameters, and protocols as LNVA monitoring. The water quality parameters identified for monitoring in Meiman (2012) include: alkalinity, ammonia, chloride, specific conductance, dissolved oxygen, *E. coli*, flow, hardness, nitrate + nitrite (as N), pH, phosphorus, secchi depth, sulfate, total dissolved solids (TDS), TSS, water temperature, and turbidity. Datasets in Meiman (2012) were generally small ($n \leq 100$) and it was possible that nearly every sample (out of a period of 12 site visits) was taken during base flow. Other samples occurred at periods of high flow; it will take many years of data in order for a clear assessment of water quality trends to occur at BITH, as neither base flow nor high flow are necessarily representative of the actual water quality in the preserve. It should be noted that beginning in October 2014, the GULN has, at least temporarily, sampled BITH sites on a monthly basis. After a sufficient amount of data is collected the optimum sampling frequency will be determined.

Figure 65 shows the sampling sites in BITH monitored by Meiman (2012); sites that have irregular borders and letter codes are sampled by the GULN through a contract with the LNVA. Sites with regular borders and numeric codes are sampled by the LNVA under the TCEQ CRP. Periodic reports are produced by the LNVA on their findings with the 2013 Basin Highlights Report summarizing the most recent findings (LNVA 013).

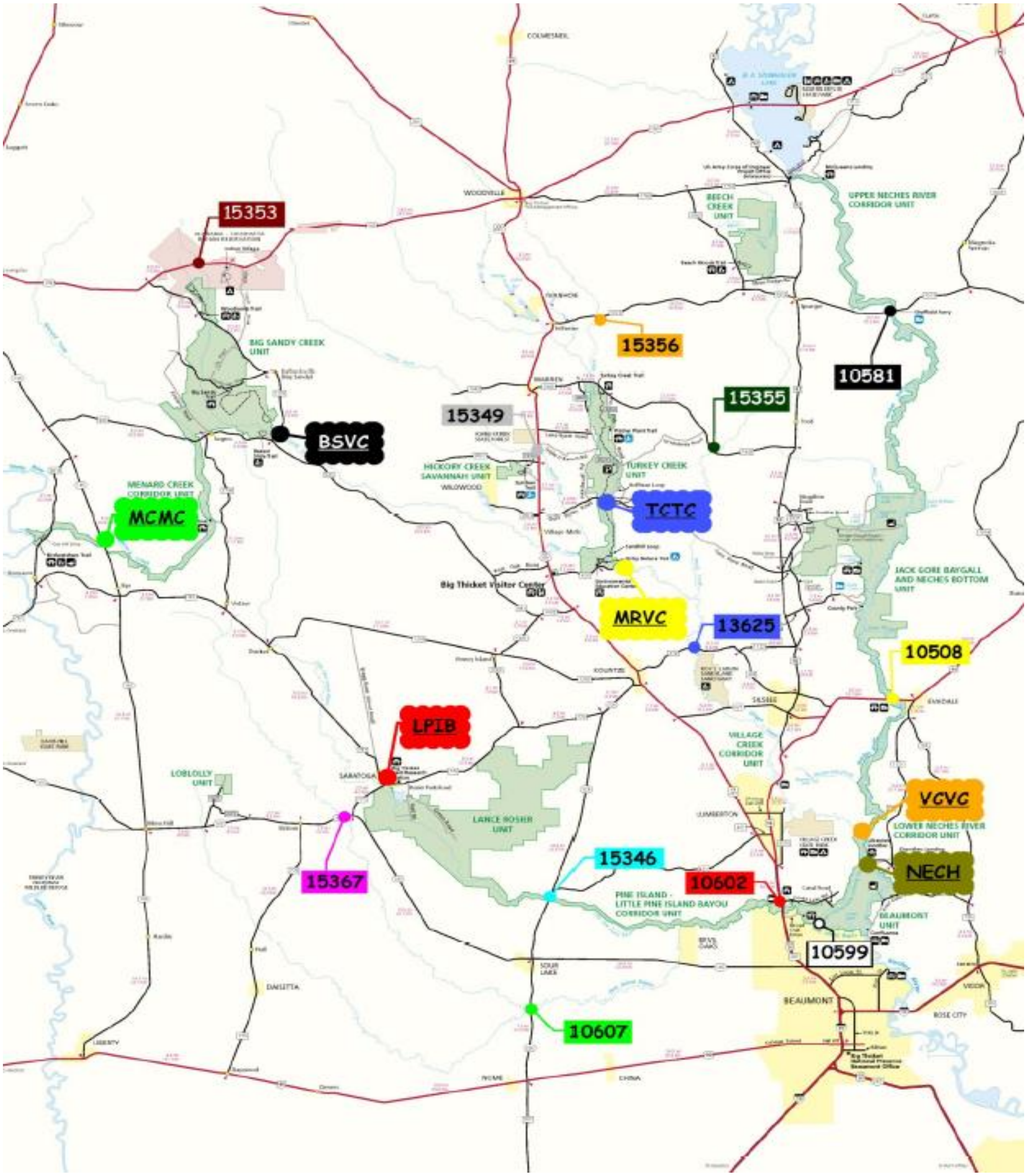

Figure 65. Location of water quality sampling sites in the BITH area. Sample sites labeled with alphabetic abbreviations and irregular borders represent sites that are sampled by the GULN through a contract with the LNVA. Sites with regular borders and numeric codes are sampled by the LNVA under the TCEQ CRP (reproduced from Meiman 2012).

The seven GULN-monitored sampled sites are summarized (with photos) below; these summaries were taken directly from Meiman (2012, p. 13-16).

Menard Creek (MCMC)
Menard Creek is the only stream in the preserve that does not contribute flow to the Neches, but instead flows into the Trinity River. It is sampled at the crossing of Texas State Highway 146 (SH 146) (Photo 18). The NPS controls a narrow corridor of the lower half of this stream. The upper portion of the Menard Creek Corridor Unit connects to the Big Sandy Creek Unit. Access to the sampling site is gained via unpaved roadway adjacent to the northwestern approach to the SH 146 bridge over Menard Creek. This station is co-located with the USGS (08066300) real-time monitoring station (stage and discharge).

Photo 18. Menard Creek sampling site, facing upstream. USGS reported mean daily flow of 83 cfs. The 12-year mean daily flow is approximately 70 cfs for this date. Discharge was 19 cfs at the time of the photograph (photo taken by Joe Meiman, GULN, on 12 April 2007).

Big Sandy Creek (BSVC)
This stream, which changes names to Village Creek downstream of this point, is sampled at its crossing under the FM 1276 bridge, at the downstream end of the Big Sandy Creek Unit (Photo 19). This site represents a headwater site within the Village Creek watershed. Two additional sites are sampled at the approximate mid- and end-points of Village Creek. Upstream of the Big Sandy Creek is the Alabama-Coushatta Indian Reservation (location of a TCEQ CRP sampling site). Access is gained from the approach to the FM 1276 bridge.

Photo 19. Big Sandy Creek from the FM 1276 bridge, facing downstream. An oil pipeline crosses the stream in the foreground and is visible during low flows. A pole-mounted electrical transformer was found in the creek during this visit (photo taken by Joe Meiman, GULN, on 22 August 2006).

Village Creek at McNeely Road Bridge (MRVC)

Near its mid-point, Village Creek is sampled at the McNeely Road Bridge a few kilometers east of the BITH Visitor Center (Photo 20). This site is downstream of the confluence of Hickory and Turkey Creeks, the former a significant tributary to Village Creek but without much federally managed land. This is a popular recreational site for fishing, swimming, and canoeing.

Photo 20. Village Creek at McNeely Road Bridge, facing upstream (photo taken by Joe Meiman, GULN, 19 May 2010).

Turkey Creek (TCTC)

Turkey Creek, another significant tributary to Village Creek, is sampled at the Gore Store Road Bridge (Photo 21). Unlike the adjacent Hickory Creek, the preserve manages a considerable part of the lower portion of this watershed, the Turkey Creek Unit. The headwaters of this basin are privately owned and contain several small reservoirs near Ivanhoe.

Photo 21. Turkey Creek at Gore Store Road Bridge, facing downstream. Flow is above normal due to recent rains at time of photo (photo taken by Joe Meiman, GULN, 18 May 2009).

Little Pine Island Bayou (LPIB)

Little Pine Island Bayou is a wide, low-gradient stream entering the preserve at the upstream end of the Lance Rosier Unit (Photo 22). The NPS does not own any of the watershed upstream of this site. Little Pine Island Bayou is sampled at the FM 770 bridge as it flows into the Lance Rosier Unit of the preserve. Flow typically diminishes to a trickle during the drier summer months, with isolated pools left during drought.

Photo 22. Little Pine Island Bayou, facing upstream during normal flow conditions (photo taken by Joe Meiman, GULN, 18 May 2009).

Village Creek at Neches River (VCVC)

This site represents the third and most-downstream sampling location along Village Creek (Photo 23). At this point, Village Creek has grown from the shallow headwater streams of Big Sandy, Hickory, Turkey, and Beech Creeks to a navigable waterway. The site is accessed by boat via the Neches River. This site was abandoned in May 2014 and replaced by a site downstream on Little Pine Island Bayou in the Lance Rosier Unit.

Photo 23. Mouth of Village Creek during above-normal flow. The turbid waters (right) of the Neches River mix with the tannin-stained waters of Village Creek (left) (photo taken by Joe Meiman, GULN, 23 August 2006).

Neches River at Lakeview (NECH)

This location has been included in the routine LNVA sampling effort since 1997 (LNVA site 15353). This site is an integrator of the Neches River as related to the preserve, with the exception of Pine Island Bayou, which enters the Neches River just above the Saltwater Barrier (Photo 24). The GULN program does not monitor this site. This site was abandoned in August 2014 and replaced by a site upstream at Village Creek State Park.

Photo 24. The Neches River at Lakeview, facing downstream. This section of the river, and Lakeview in particular, is heavily used for full-contact recreation during warmer months (photo by Joe Meiman, GULN, 23 August 2006).

4.13.5 Current Condition and Trend

Dissolved Oxygen

Dissolved oxygen levels within BITH were generally above state criteria (Table 62, Figure 66; Meiman 2012). The only exceptions observed by Meiman (2012) were low DO concentrations recorded at Little Pine Island Bayou and Big Sandy Creek (Figure 66). These low DO concentrations were most likely attributed to natural processes such as decaying vegetation, water temperature, low gradients, and reduced summertime flows, although time of day when sampled could also influence DO levels (Meiman 2012). While low DO levels in BITH are likely the result of natural processes, continued monitoring is necessary as low DO can also be an indication of eutrophication (Meiman 2012). DO levels below state standards (normal >3.0 mg/l, and spring season >4.5 mg/l [instantaneous values]) are not unusual at Little Pine Island Bayou or Big Sandy Creek and have been documented historically (Figure 67, Figure 68).

Table 62. Dissolved oxygen summary of quarterly sample results (Sept. 2007 - August 2010) (reproduced from Meiman 2012).

Parameter	Units	Count	< Detectable limits	Min	Max	Mean	Median	Std. Dev
DO	mg/l	108	0	0.54	12.7	6.91	7.19	2.8

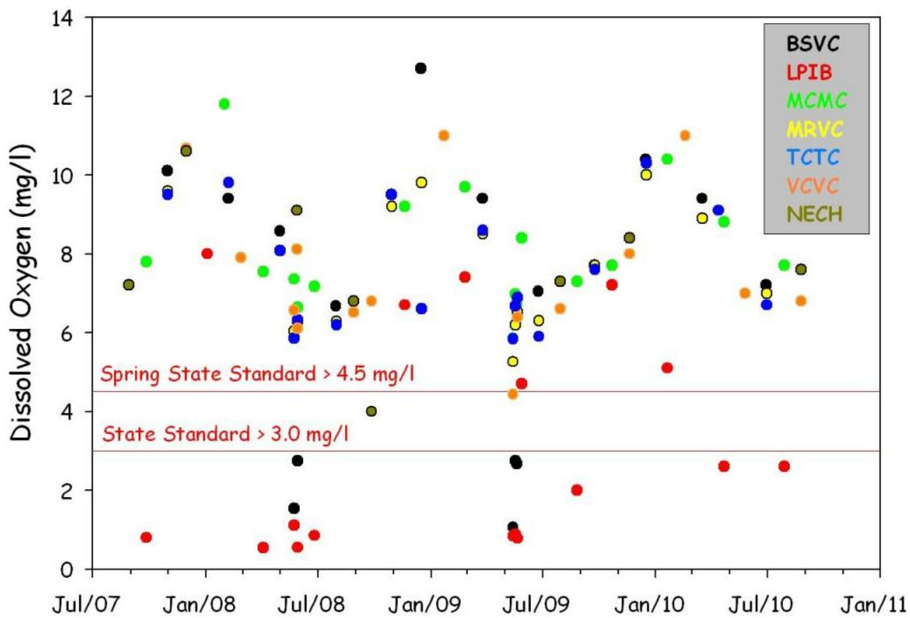

Figure 66. Dissolved oxygen monitoring results for BITH, reported by station (reproduced from Meiman 2012). Sampling locations are shown in Figure 65.

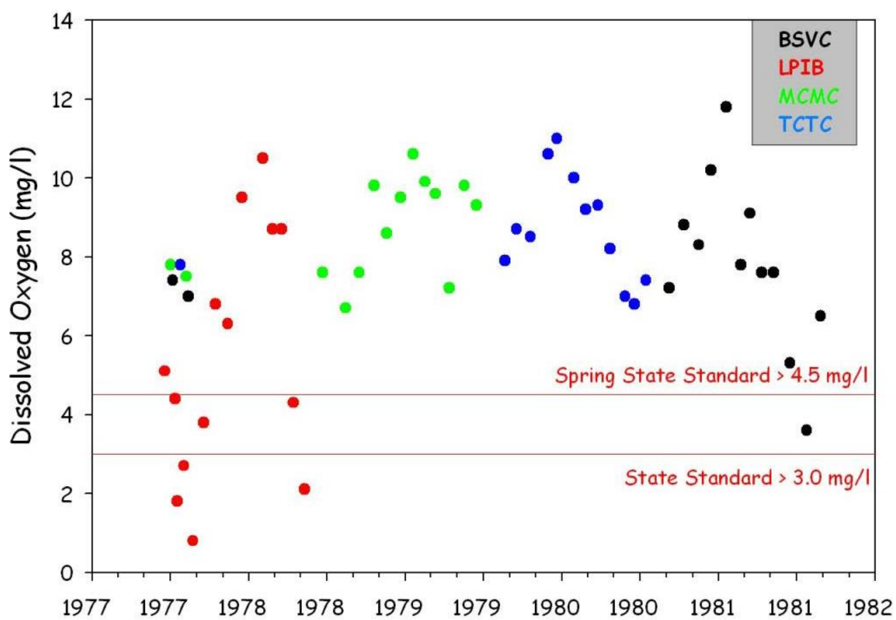

Figure 67. Historic DO levels in the BITH region; data sources used to create this graphic include: Harrel 1977, Harrel and Darville 1978, Harrel and Bass 1979, Harrel and Commander 1980, and Harrel and Newberry 1981 (n=55) (reproduced from Meiman 2012).

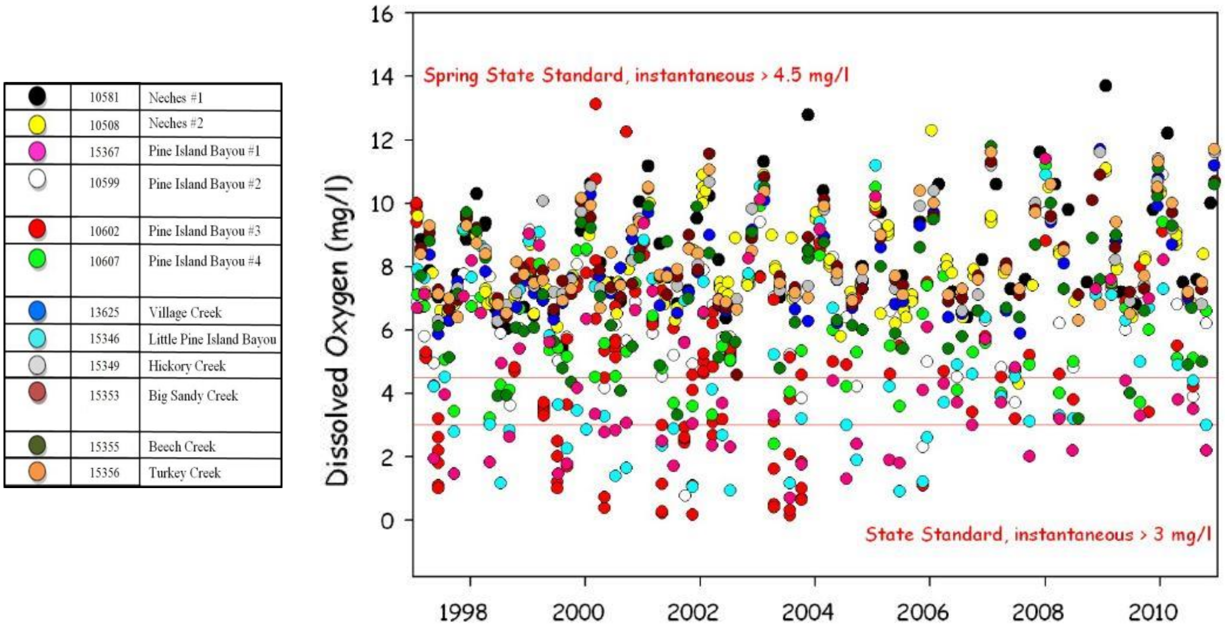

Figure 68. Dissolved oxygen measurements obtained by the TCEQ's Clean Rivers Program (reproduced from Meiman 2012).

<u>Temperature</u>

The various creeks, tributaries, and rivers in BITH generally have different temperature limits, as determined by the State of Texas. Examples of these temperature limits include: Pine Island Bayou (<35°C [95°F]), Neches River (<32.8°C [91°F]), and Village Creek (<32.2°C [90°F]) (Meiman 2012). Water temperatures in BITH traditionally follow closely with the seasonal air temperatures and can have ranges spanning 25°C (45°F) during a calendar year. The range of water temperatures observed in the BITH region from 2007-2010 varied from 5.6°C (42.1°F) to 31.5°C (88.7°F), with an average temperature of 21.1°C (70°F) (Table 63) .Very few violations of water temperature standards have occurred in the BITH region since 1997, with no violations observed at the GULN monitoring stations (Figure 69), and only three known exceptions during TCEQ CRP monitoring on the Neches River where samples exceeded the reference condition of 32.8°C (91°F) (Figure 70) (Meiman 2012).

Table 63. Temperature measurement summary of quarterly sample results (Sept. 2007 - August 2010) (reproduced from Meiman 2012).

Parameter	Units	Count	< Detectable limits	Min	Max	Mean	Median	Std. Dev
Temperature	°C	108	0	5.6	31.5	21.1	22.3	6.2

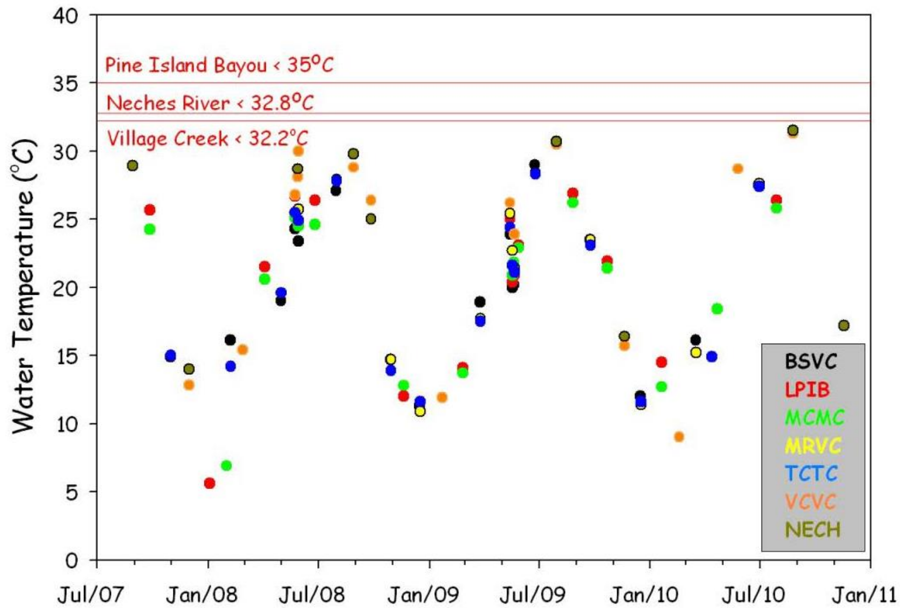

Figure 69. Individual temperature samples for BITH, reported by station (reproduced from Meiman 2012). Sampling locations and abbreviations are shown in Figure 65.

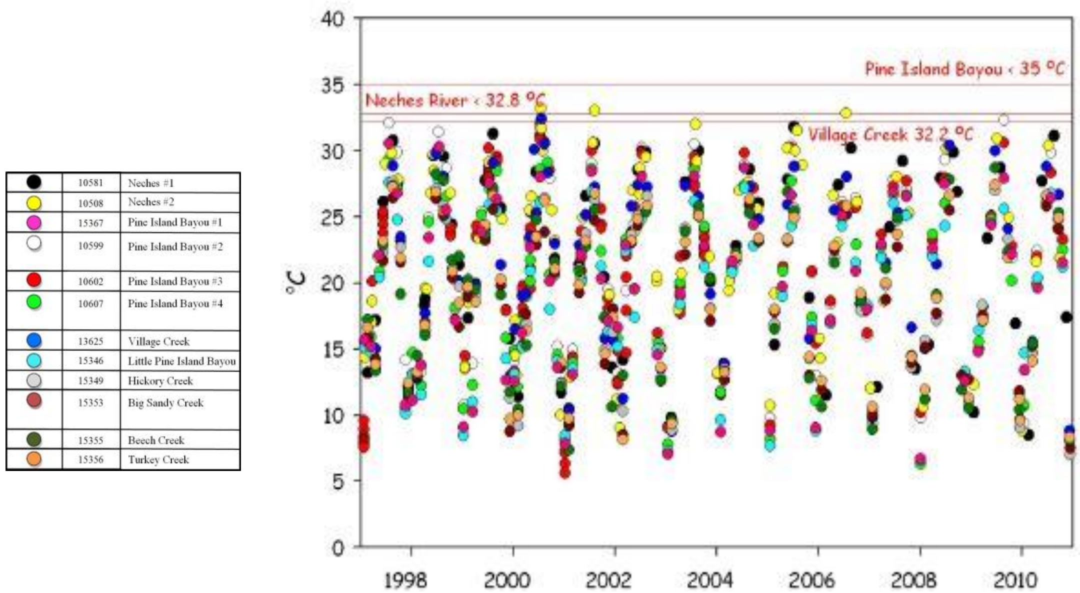

Figure 70. Temperature measurements in the BITH region as recorded by the TCEQ CRP monitoring (reproduced from Meiman 2012).

<u>pH</u>

Low pH levels are common historically in the many waterways of BITH (NPS 1995, Rizzo et al. 2000, Meiman 2012), primarily due to high amounts of carbonic acid (CO_2) and tannic acid (found in leaves, plant parts, and bark) in the water systems, and low alkalinity in these systems (which limits buffering capacity) (Meiman 2012). pH samples in BITH from 2007-2010 have ranged from 5.05-8.1, with an average value of 6.55 (Table 64). Little Pine Island Bayou and Big Sandy Creek exhibited very low pH at several GULN-monitored stations in BITH, with values falling below 6.0 on several occasions (Figure 71; Meiman 2012). These results are consistent with historic findings from Harrel and Newberry (1981). TCEQ CRP monitoring at sites proximate to BITH have also indicated several instances of low pH, with sites 15355 (Beech Creek) and 15346 (Little Pine Island Bayou) recording consistently low pH values over 10 years (Figure 72).

Table 64. pH measurement summary of quarterly sample results (Sept. 2007-August 2010) (reproduced from Meiman 2012).

Parameter	Units	Count	< Detectable limits	Min	Max	Mean	Median	Std. Dev
pH	SU	108	0	5.05	8.1	6.55	6.60	0.64

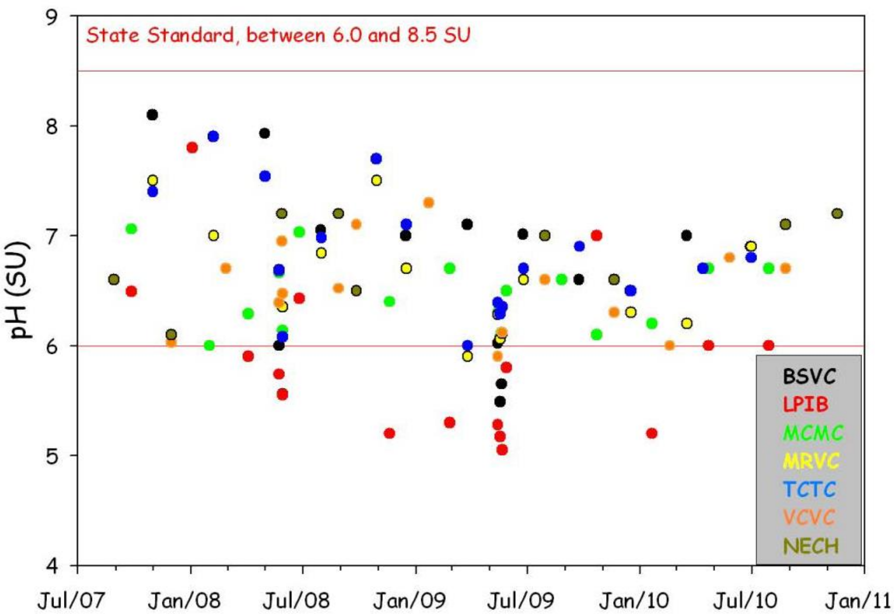

Figure 71. Individual pH measurements for BITH, reported by monitoring station (reproduced from Meiman 2012). Sampling locations are shown in Figure 65.

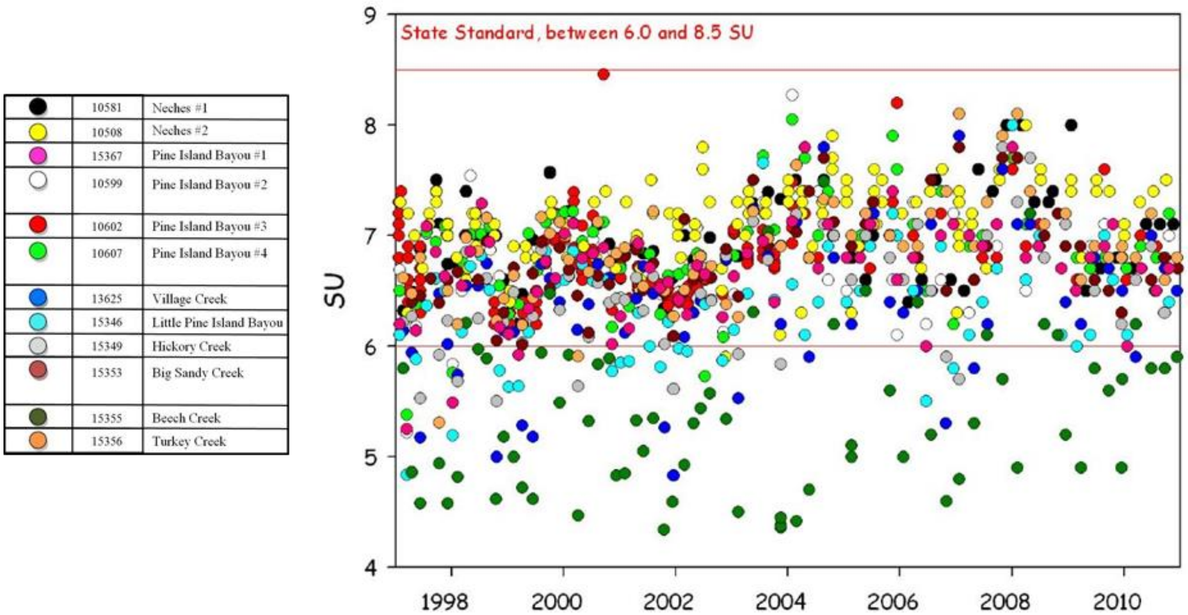

Figure 72. pH readings from the TCEQ's CRP (reproduced from Meiman 2012).

<u>Conductivity</u>

Although SpC does not have established state standards for comparison, historic SpC data indicated relatively high values in the BITH area during the late 1970s and early 1980s (Harrel 1977, Harrel and Darville 1978, Harrel and Bass 1979, Harrel and Commander 1980, Harrel and Newberry 1981). SpC values observed during this period at Little Pine Island Bayou were typically in the vicinity of 1,000 µS/cm, and sometimes approached 3,500 µS/cm. These elevated SpC observations were likely related to oilfield brines being released into the environment at the time (Harrel and Darville 1978, Meiman 2012).

Specific conductance was generally low and stable across streams in BITH during GULN monitoring (Meiman 2012). SpC values ranged from 49.5 to 234 µS/cm at GULN-monitored stations, with an average SpC value across all sample sites of 91 µS/cm (Table 65). Pine Island Bayou and Little Pine Island Bayou continued to show elevated SpC values, but did not approach historic values (Figure 73). SpC values observed at Little Pine Island Bayou did not exceed 250 µS/cm for the duration of Meiman (2012) (Figure 73), although occasional high levels of SpC were observed during TCEQ CRP monitoring at the Pine Island Bayou routine monitoring site (10602, Figure 74). High values observed at Little Pine Island Bayou are the highest among the streams monitored and are cause for concern; however, they are still magnitudes below levels observed at these sites just 30 years ago (Meiman 2012).

Table 65. SpC measurement summary of quarterly sample results (Sept. 2007 - August 2010) (reproduced from Meiman 2012).

Parameter	Units	Count	< Detectable limits	Min	Max	Mean	Median	Std. Dev
SpC	µS/cm	108	0	49.5	234	91	82.5	33

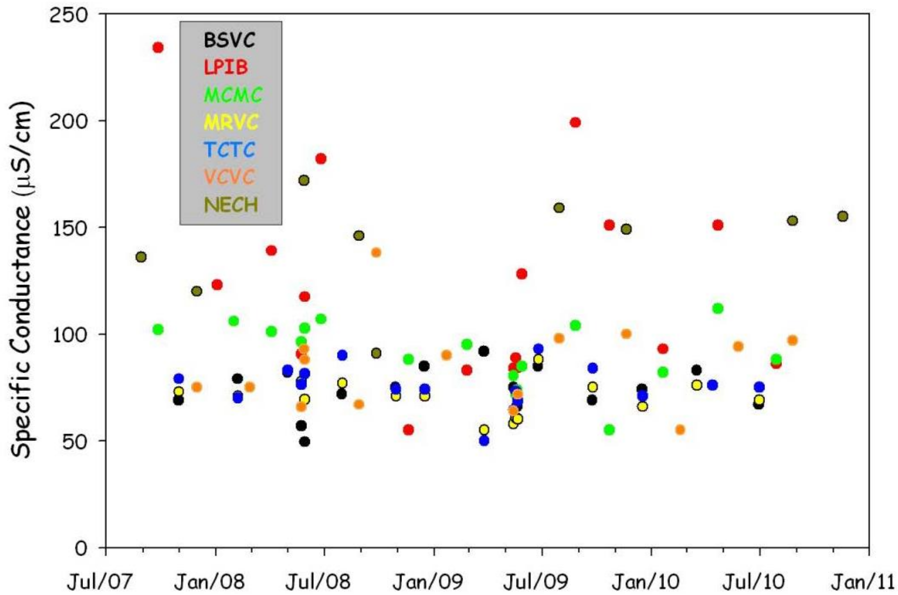

Figure 73. Individual SpC samples by station from BITH (reproduced from Meiman 2012). Sampling locations are depicted in Figure 65.

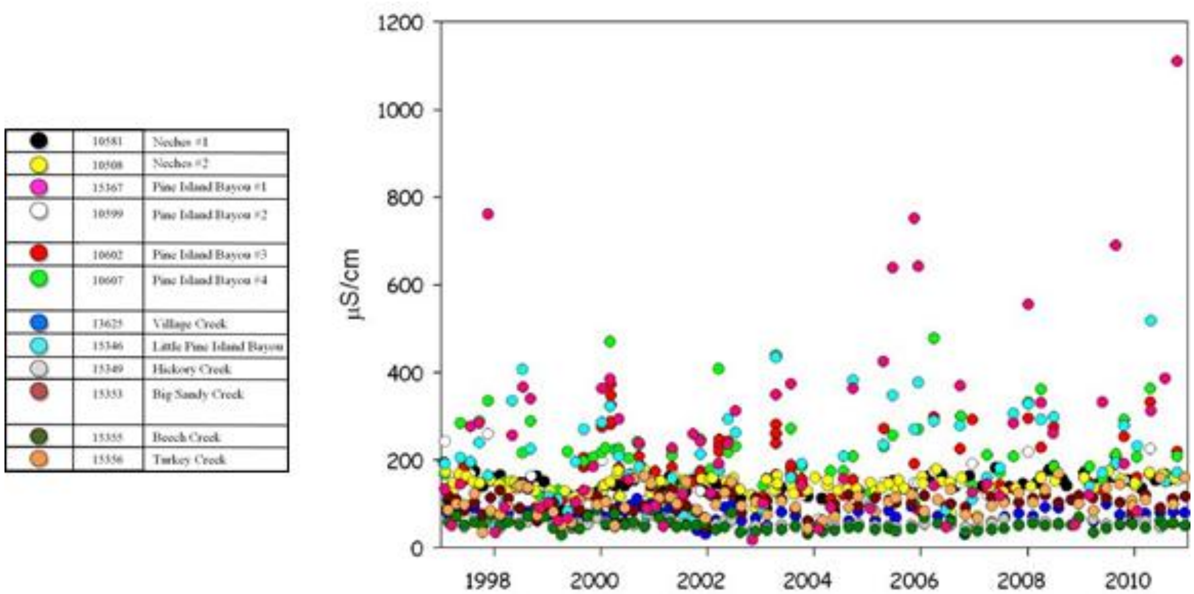

Figure 74. Historic SpC readings from the TCEQ's CRP (reproduced from Meiman 2012).

Turbidity

Similar to SpC, turbidity does not have established state standards. While the waters of BITH are often dark and appear turbid, the darker colors are tannins from localized organic input (e.g., leaves and bark) (Meiman 2012). Turbidity within BITH is generally considered low, with turbidity values ranging from 6.9-237 nephelometric turbidity units (NTU) and averaging 21.0 NTU between 2007 and 2010 (Table 66). Turbidity values recorded during GULN monitoring typically fell below 50 NTU, with a median value of 17 NTU (Table 66). Elevated turbidity values in Figure 75 generally corresponded to a period of high flow at a sample site, with the value recorded on 22 October 2009 representing an outlier at 237 NTU (Meiman 2012). This phenomenon is also evident in the phosphorous and TSS discussions below.

Table 66. Turbidity measurement summary of quarterly sample results (Sept. 2007 - August 2010) (reproduced from Meiman 2012).

Parameter	Units	Count	< Detectable limits	Min	Max	Mean	Median	Std. Dev
Turbidity	NTU	96	0	6.9	237	21	17	23

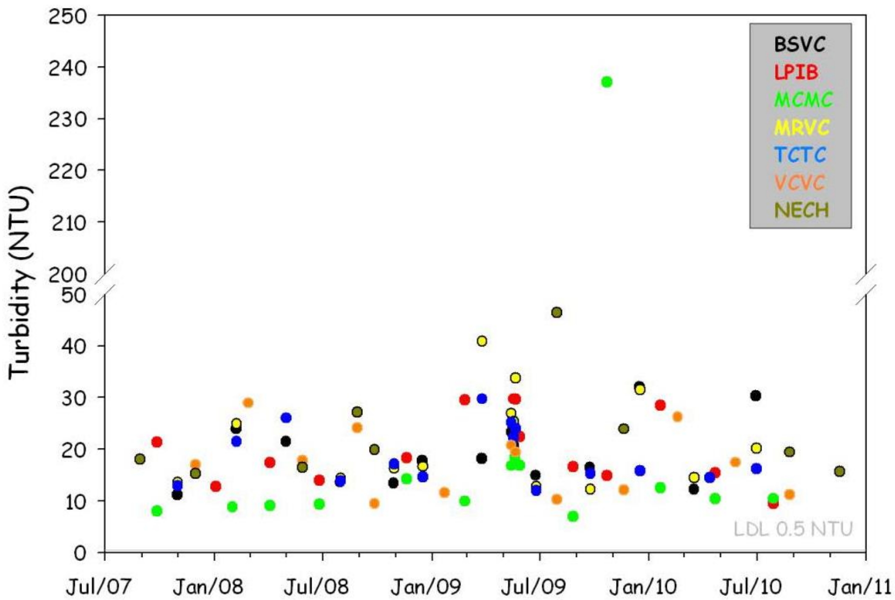

Figure 75. Individual turbidity samples for BITH, reported by station (reproduced from Meiman 2012). Note the shift in NTU values after the break in the Y-axis. Sampling locations are depicted in Figure 65.

Nutrients (phosphates, nitrate-nitrite)

Total nutrient load in a water body can be monitored a number of ways; this assessment will focus on the total phosphorous and nitrate-nitrite levels. Orthophosphates are a biologically, readily available form of phosphorus found in many water sources. Anthropogenic sources of orthophosphates can include manure, fertilizer, and organic wastes that run off into streams, lakes, and rivers (USGS 2015b). While there is no state standard for total phosphorous, the EPA recommends that total phosphorous levels be less than 0.05 mg/l in any stream at the point of entry to a lake or reservoir (EPA 1986). This level is intended to reduce or limit the potential growth of nuisance aquatic plant species or algae. Surface waters that have total phosphorous levels between 0.01 and 0.03 mg/l tend to experience minimal algal blooms (EPA 1986).

Total phosphate levels vary greatly between water bodies in BITH. Values exceeding the lower detection limit (LDL) of 0.06 mg/l are more common, although still variable, in Turkey Creek, Little Pine Island Bayou, and the Neches River (Figure 76). Meiman (2012) recognized that, while these three sites are the only sites to have regular observations exceeding the LDL, there are not enough data to indicate a trend or cause concern. Other sites in the preserve, such as Village Creek and Big Sandy Creek, rarely, if ever, exceeded the LDL for total phosphorous.

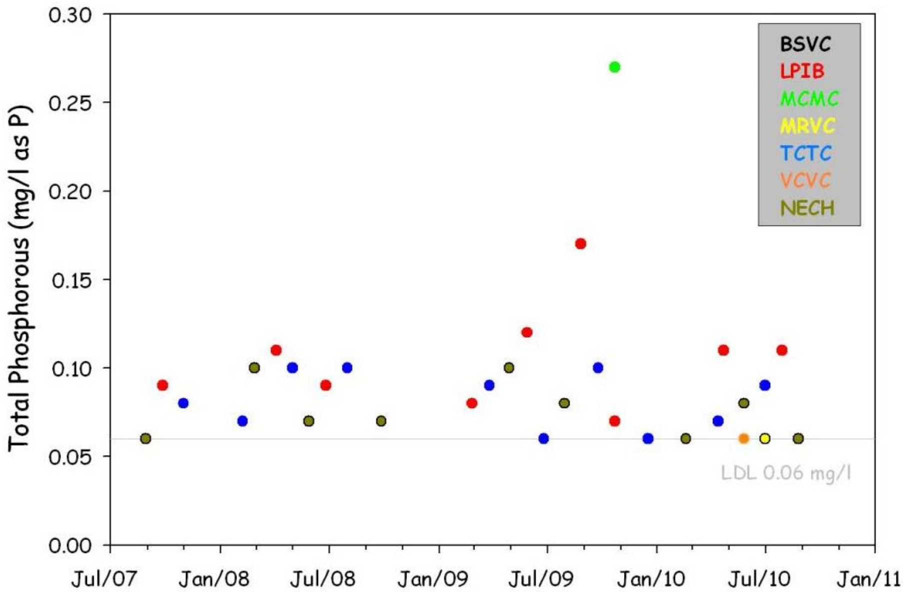

Figure 76. Total phosphorus values by monitoring station in BITH from 2007-2010 (reproduced from Meiman 2012). Sampling locations are depicted in Figure 65.

The measure of total nitrogen (N) includes ammonia and nitrate-nitrite (combined into a single value in BITH). Nitrogen is a nutrient in high demand in many ecosystems, and has a cycle that relies upon many bacterial species that are able to convert atmospheric nitrogen into forms that are readily usable by plants and animals. Nitrogen is typically consumed quickly by plants when it is available, and sources of nitrogen input in the BITH area include agricultural sources (e.g., animal waste and commercial fertilizers running off into water sources) and municipal wastewater discharge (Meiman 2012).

Presently, Texas has no regulatory criterion to limit nitrate-nitrite levels. However, Texas does have a state screening level of 1.95 mg/l for nitrate. Total nitrogen measurements from the GULN monitoring in BITH have been low, with total nitrogen levels well below the state screening level (Figure 77). Similar results have been observed during the TCEQ CRP monitoring in waters adjacent to the preserve (Figure 78).

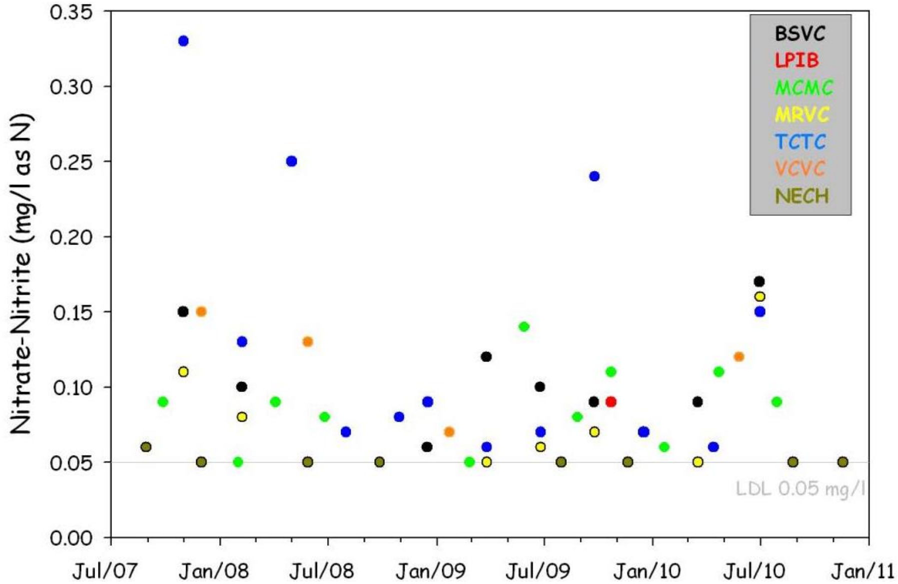

Figure 77. Nitrate-nitrite monitoring results for BITH from 2007-2010, reported by station (reproduced from Meiman 2012).

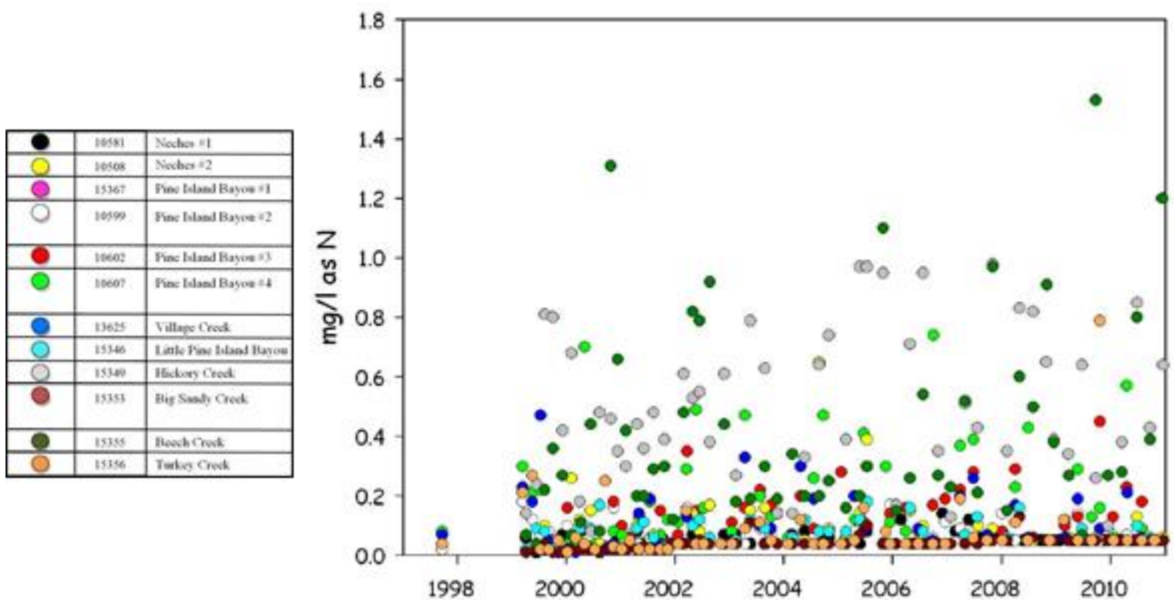

Figure 78. Nitrate-nitrite monitoring results from the TCEQ's CRP (reproduced from Meiman 2012).

<u>*E. coli*</u>

E. coli levels in BITH have traditionally been reported as most probable number (MPN)/100 ml, where MPN represents a statistical derivation of a bacterial count in the sampled water (Meiman 2012). These *E. coli* values are then compared to the Texas single-sample, full recreational contact standard of 394 MPN/100 ml to determine any exceedances. In BITH, specifically, Meiman (2012) has noted that elevated *E. coli* levels have typically coincided with discharge events. High *E. coli* counts are generally tied to high discharges; this relationship may indicate that non-point sources of bacteria are responsible for these elevated levels when they are washed into streams and rivers during heavy rainfall events (Meiman 2012).

E. coli samples collected by GULN monitoring in BITH have generally fallen below the state standard, with an average *E. coli* estimate of 197 MPN/100 ml (Meiman 2012) (Table 67). However, there have been multiple instances where *E. coli* values have exceeded the single sample standard (Figure 79). In each of these instances, the exceedance correlated with a period of high flow (Figure 80). The only exception to this pattern occurred in Little Pine Island Bayou where high *E. coli* readings corresponded to low flow (Meiman 2012). The cause of this reading has not been determined due to the small size of the data set but may suggest a point source rather than non-point source pollution.

Table 67. *E. coli* measurements as summarized by quarterly sample results (Sept. 2007-August 2010) (reproduced from Meiman 2012).

Parameter	Units	Count	< Detectable limits	Min	Max	Mean	Median	Std. Dev
E. coli	MPN/100 ml	79	0	2	2,419	197	50	529

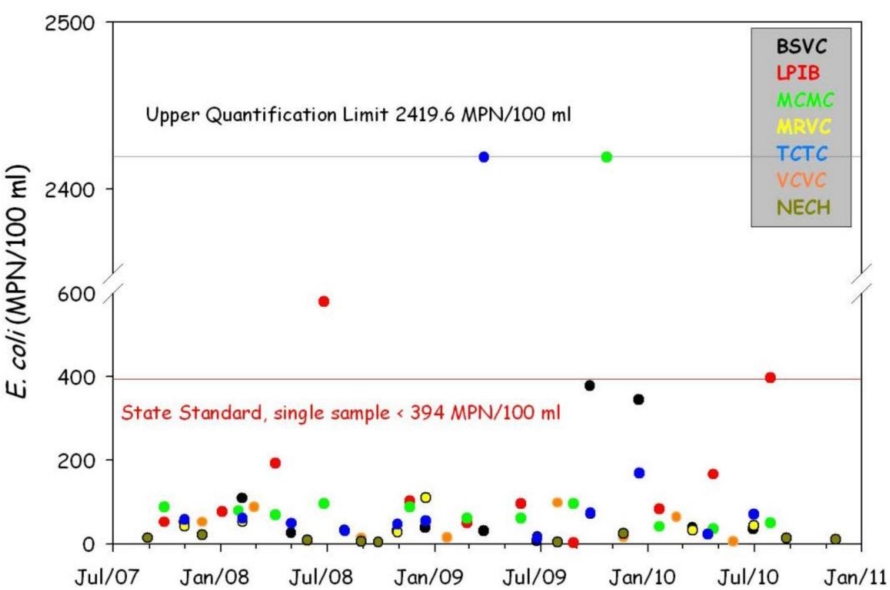

Figure 79. *E. coli* monitoring results for BITH from 2007-2010, reported by station in BITH (reproduced from Meiman 2012).

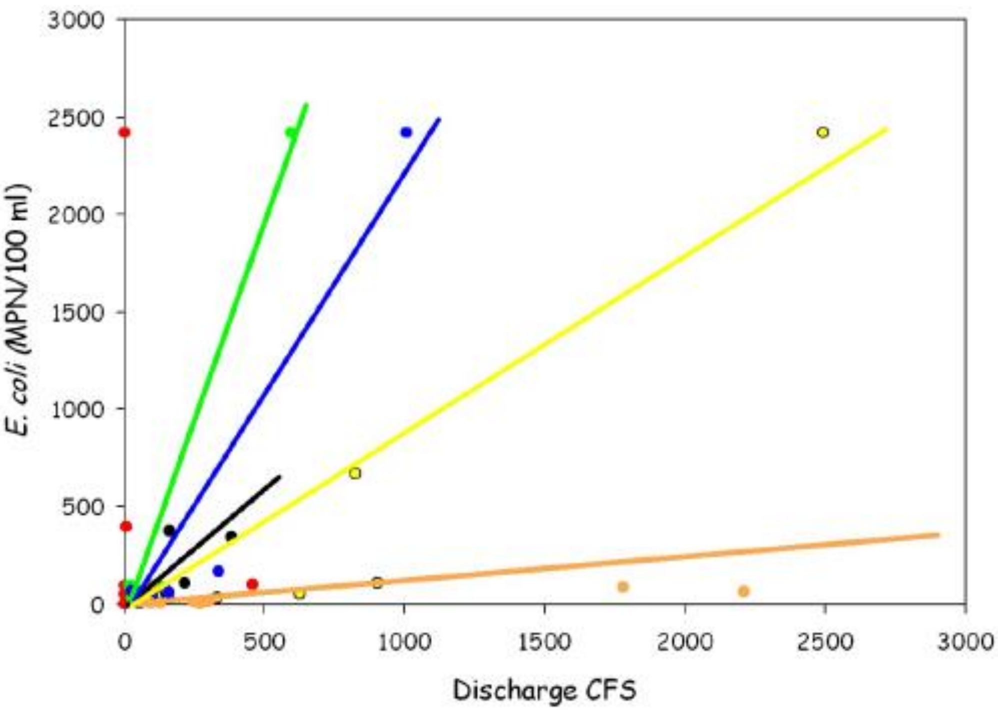

Figure 80. *E.coli* compared to discharge values during GULN monitoring in BITH (2007-2010) (reproduced from Meiman 2012). Note: colors in this figure correspond to the colors used to identify locations in Figure 79.

Carbonate Chemistry (Total Hardness)

Carbonate chemistry will be evaluated using the total hardness measure, expressed as mg/l $CaCO_3$; there is not a state standard for total hardness. In general, total hardness in a watershed that is dominated by carbonate strata will provide an approximation of the relative bicarbonate concentration (i.e., alkalinity) (Meiman 2012). For the majority of the GULN sample sites in BITH, it appeared that total hardness and alkalinity showed comparable patterns, which may suggest limited availability of carbonates. An exception to this trend was observed at Little Pine Island Bayou, where occasional high total hardness values suggest another source of calcium and/or magnesium may have been present (Figure 81; Meiman 2012).

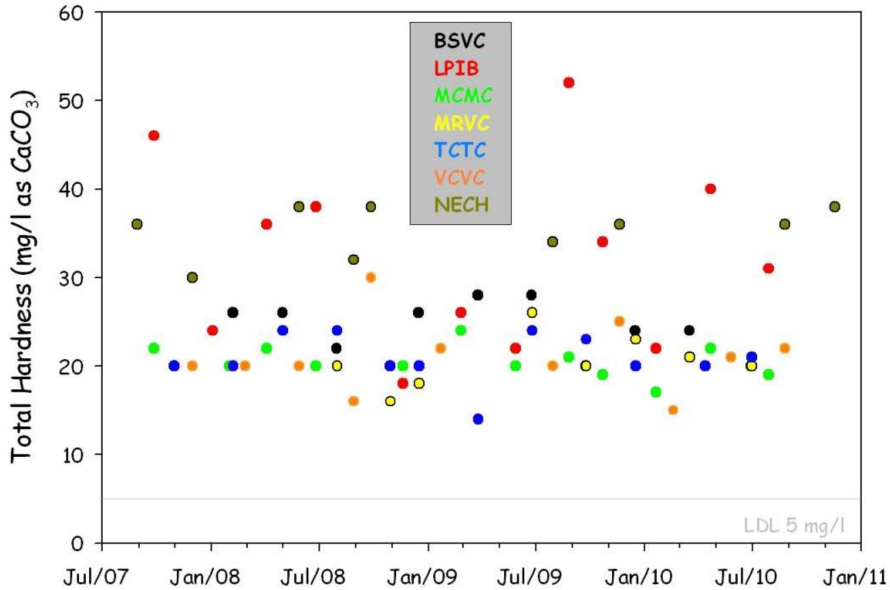

Figure 81. Total hardness (mg/l $CaCO_3$) monitoring results for BITH, reported by station (2007-2010) (reproduced from Meiman 2012). Sampling locations are shown in Figure 65.

<u>Total Suspended Solids</u>

Total suspended solids typically increase during periods of high flow and rainfall events, as more particles become suspended in the water column (Meiman 2012). The highest observed TSS measurement observed in BITH during GULN monitoring was in 2009 (80 mg/l), and corresponded to the highest observed flow at Menard Creek. The TSS measurements in BITH ranged from 4 mg/l to 80 mg/l, and averaged 12 mg/l from 2007-2010 (Table 68; Figure 82). There is no state standard for the TSS measure.

Table 68. Total suspended solids measurement summary of quarterly sample results (Sept. 2007 - August 2010) (reproduced from Meiman 2012).

Parameter	Units	Count	< Detectable limits	Min	Max	Mean	Median	Std. Dev
TSS	mg/l	79	0	4	80	12	9	12

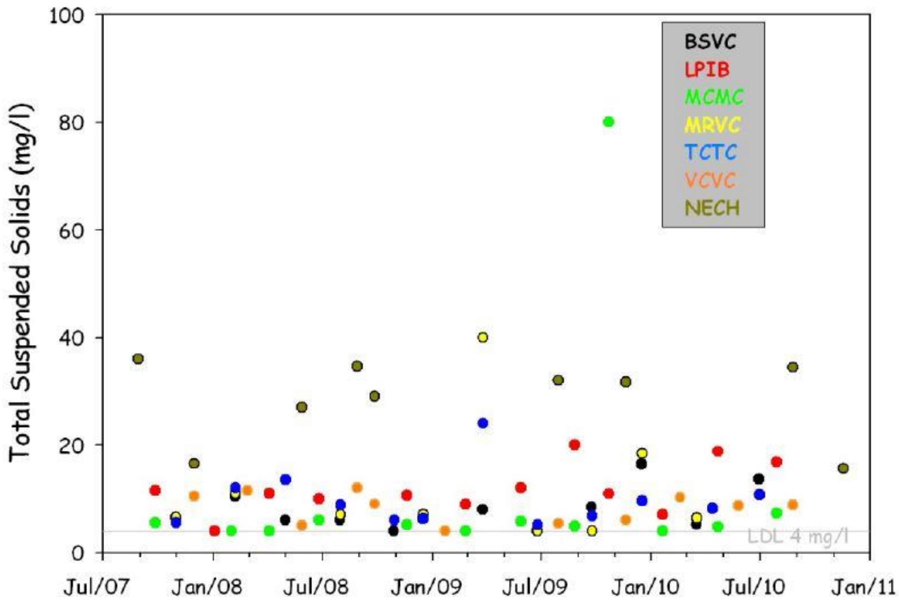

Figure 82. Total suspended solids (mg/l) monitoring results for BITH, reported by station (2007-2010) (reproduced from Meiman 2012).

<u>Impacts on Aquatic Insects</u>

The impact of water quality on aquatic insects is of specific interest to BITH management. BITH is considered a "biological crossroads" of North America (Sobczak et al. 2010). Because of the ecological diversity of the preserve, many individual aquatic insect/macroinvertebrate inventories have been conducted on the various streams of BITH.

Using aquatic insects and macroinvertebrates as indicators of water quality is a common practice. EPA (1997) lists aquatic insects and other macroinvertebrates as good indicators of water quality due to a number of factors:

- They are affected by the physical, chemical, and biological conditions of the stream and often can't escape the pollution input.
- They show the effects of short- and long term pollution events and can also show the cumulative impacts of pollution.
- They may show the impacts from habitat loss not detected by traditional water quality assessments.
- They are a critical part of the stream's food web and their presence or absence can have ramifications throughout the entire food web.
- Some are very intolerant of pollution as well as being relatively easy to sample and identify.

Sobczak et al. (2010) listed a number of studies that examined various aquatic invertebrate communities at BITH. A majority of these reports found a high diversity of insects/macroinvertebrates within BITH waters, although some studies reported a moderately stressed benthic community (Sobczak et al. 2010). Moring (2003) collected samples of benthic macroinvertebrates from 1999 – 2001 at 14 locations (Figure 83). The samples collected were comprised of 242 aquatic insect taxa and 59 non-insect taxa. Within the preserve, Moring (2003) identified Village Creek as supporting the most insect taxa and the Neches River just below the Town Bluff Dam as the least diverse, using Menhinick's species richness algorithm (Figure 84). Moring (2003) identified riffle beetles (*Elmidae* spp.) as the most common insect captured at sample points.

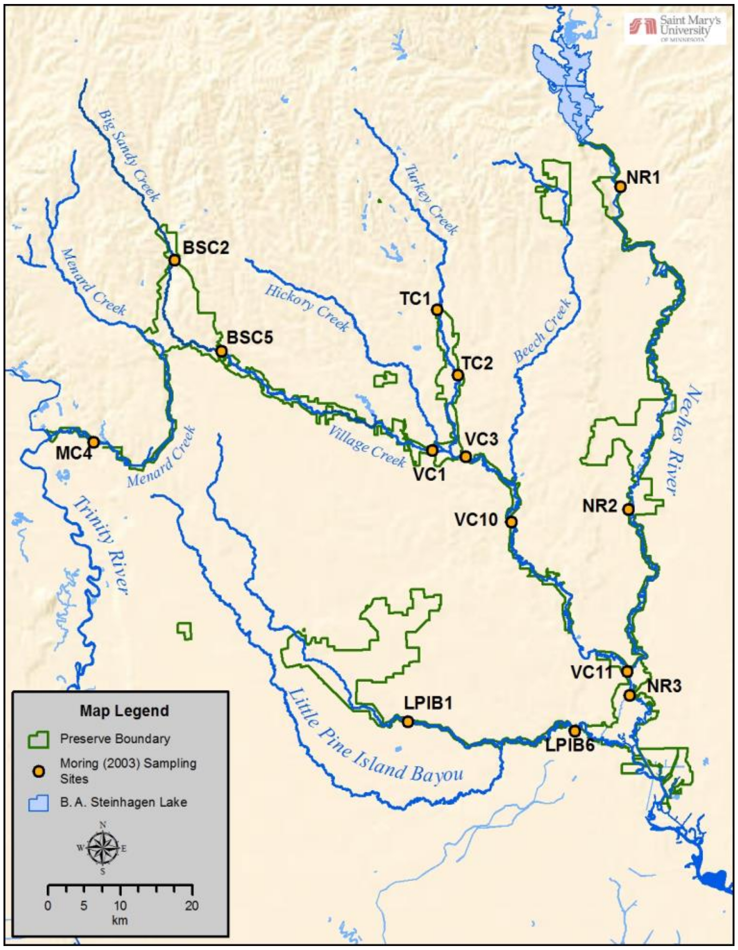

Figure 83. Sampling sites in BITH used by Moring (2003). BSC = Big Sandy Creek; MC = Menard Creek; TC = Turkey Creek; LPIB = Little Pine Island Bayou; VC = Village Creek; NR = Neches River.

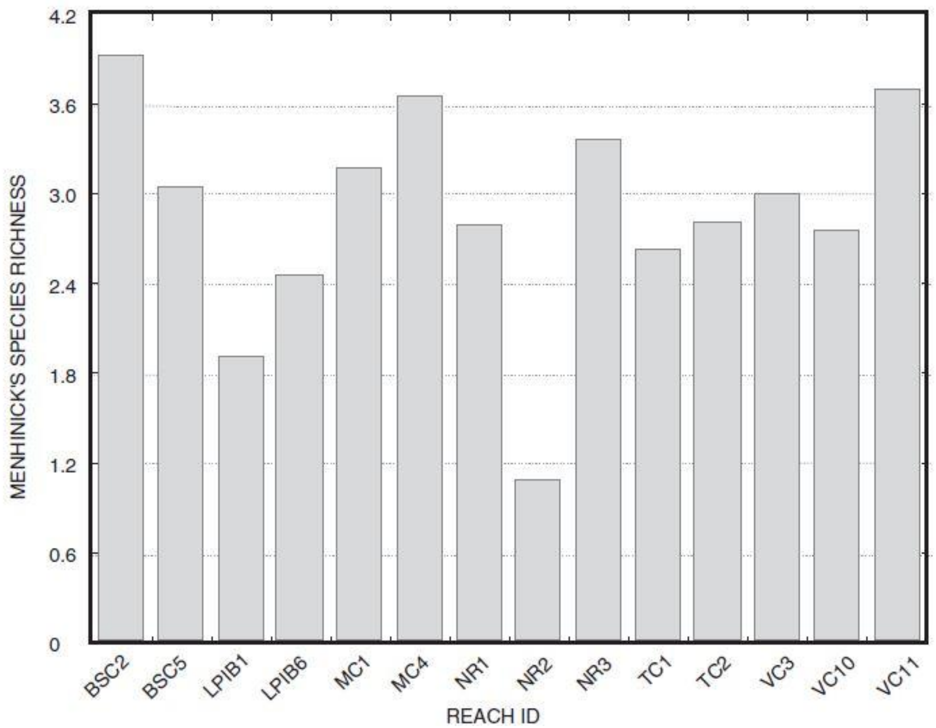

Figure 84. Menhinick's insect species richness chart for BITH water bodies (reproduced from Moring 2003).

Moring (2003) used the Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) (EPT) index to assess the health of the BITH streams. The larger the EPT index score, theoretically the healthier the stream. EPT index values were highest for the Neches River reach NR1 (below the Town Bluff Dam) and lowest in the Little Pine Island Bayou reach LPIB6 (Figure 85), which is also listed on the state's 303(d) impaired waters list (Table 61).

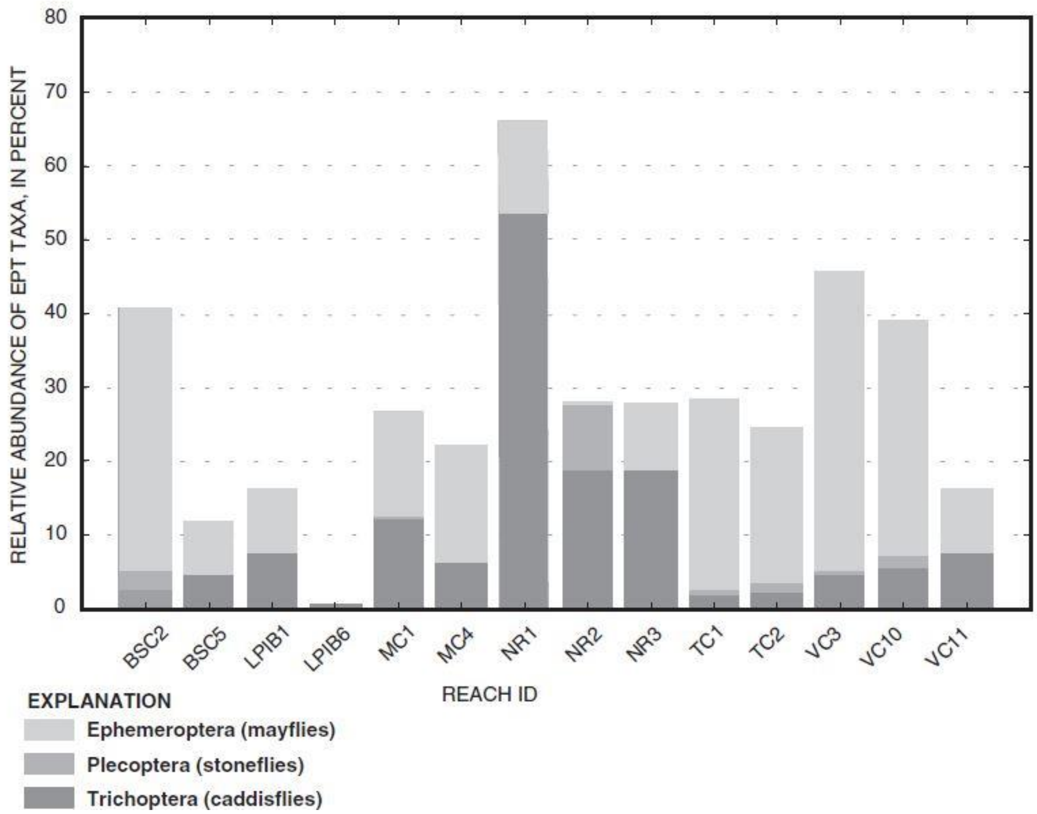

Figure 85. EPT index graph for sampled BITH streams (reproduced from Moring 2003).

<u>Threats and Stressors Factors</u>

Much of BITH is comprised of a series of narrow corridors of NPS-controlled land alongside stream/creek channels. This narrow geography means the majority of the adjacent land use practices are beyond the influence and jurisdiction of the preserve. Those land uses are of critical importance to BITH, as they introduce point and non-point source pollutants into preserve waters.

Agriculture and silviculture are prominent throughout the Neches watershed and represent potential threats to water quality (Meiman 2012). Runoff from the surrounding landscape can deliver excessive nutrients (phosphorus and nitrogen) from agricultural fertilizers as well as persistent organic pollutants (POPs) from pesticides and other farm chemicals. An increase in *E. coli* bacteria is seen during rain events and is likely attributable to runoff from pastured livestock (Meiman 2012). Waste and droppings from feral hogs and waterfowl feeding near the waterways may also contribute to this influx. POPs, such as chlorophenoxy-acetic herbicides (2,4-D, 2,4,5-T) and dieldrin (pesticide) have been found in and around BITH (Gallaher et al. 2005). Other contaminants, including PCBs, dioxins, and DDT derivatives (some of which are known endocrine disruptors in herptiles) are also of concern and are showing up in recent fish advisory studies and reports.

Fifteen industrial dischargers are listed in NPS (1995) as being within the study area around BITH and are capable of contributing point-source pollution impacting the preserve (Figure 86, Meiman 2012). These point sources include municipalities, oil and gas operations, and paper mills (NPS

1995). Other point source pollution threats come from failing septic systems, inadequate wastewater treatment facilities, and confined livestock operations (Meiman 2012).

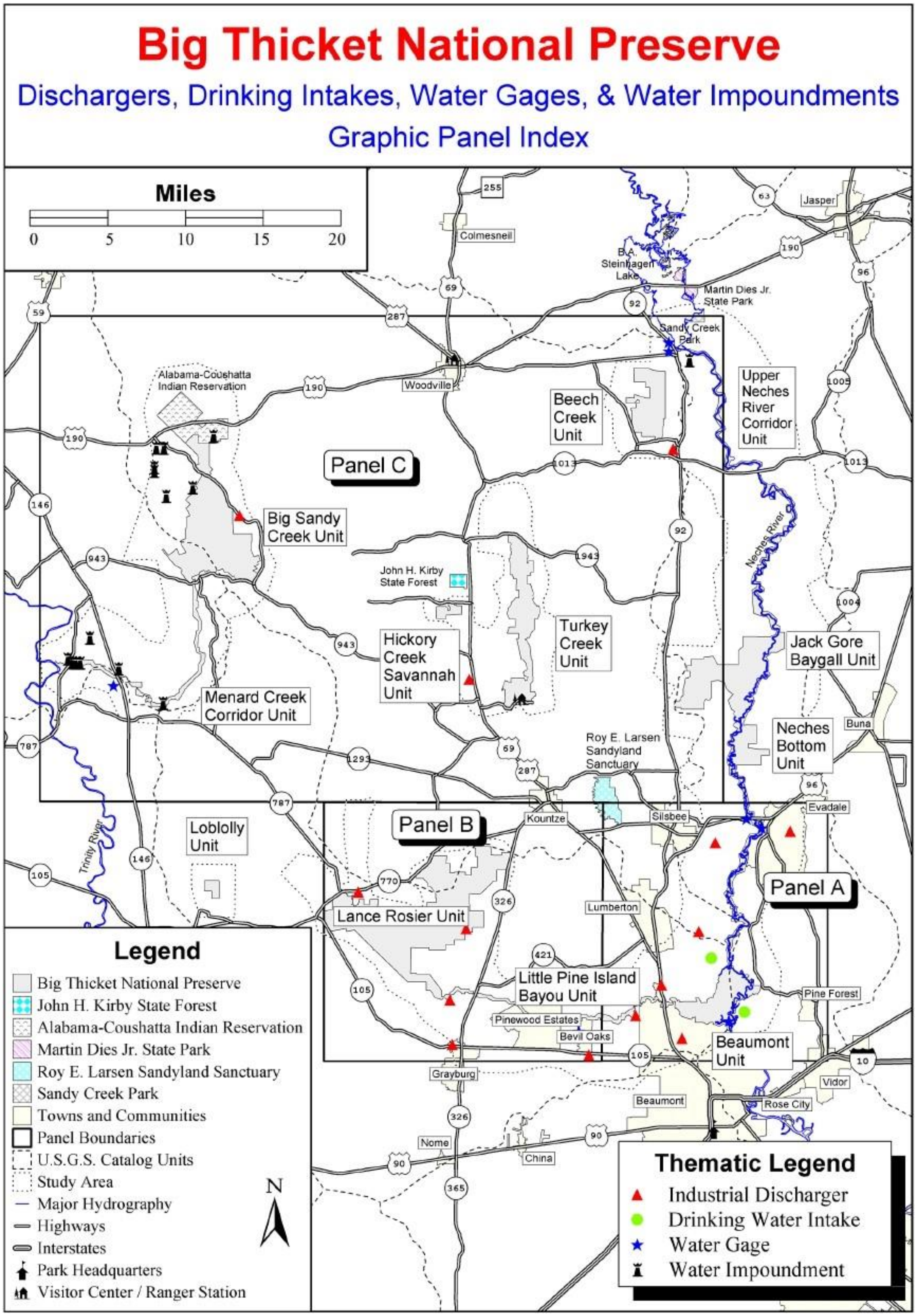

Figure 86. Location of industrial dischargers (in red) in and around BITH (reproduced from NPS 1995).

Saltwater intrusion is another threat to BITH water quality. The highly altered nature (i.e., dredging of a shipping channel, dikes and levees, placement of temporary and now a permanent salt water barrier, regulation of flows by upstream dams, etc.) of the Neches River up and downstream of Beaumont, Texas has allowed the encroachment of saltwater into the historically freshwater portions of the Neches River (TTWP 1998). The saltwater intrusions are of concern for BITH managers because of the many potential impacts of saltwater mixing with BITH's freshwater resources (Meiman 2012). Freshwater has a surface salinity of 0, while seawater averages 35 ppt (USGS 2015c). During a drought in November 2011, the salinity level in the Neches River just below the permanent saltwater barrier at Beaumont ranged from 13.3-15.8 ppt (Winemiller et al. 2014). Climate change related sea level rise and the possibility of more frequent/intense hurricanes with their associated storm surges may also contribute to this threat.

Atmospheric deposition of mercury (Hg) is considered a threat to BITH waters. In 2010, a fish consumption advisory was issued for all BITH waters based on elevated Hg levels in flathead catfish, freshwater drum, gar, largemouth bass, spotted bass, and white bass (*Morone chrysops*) (Meiman 2012). Gallaher et al. (2005) reported that Hg was present in 29% of the 633 BITH samples analyzed between the early 1970s and late 1990s. Concentrations of Hg in sediment ranged from 0.006 to 10 mg/kg (average = 0.51; n =32) and frequently exceeded the 0.2 mg/kg guideline for sediment quality. Two fish samples taken during this time contained Hg concentrations exceeding the safe consumption limit of 0.5 mg/kg (Gallaher et al. 2005). The fish consumption advisory has been updated in 2012 and 2015 to include additional contaminants of concern (including some endocrine disrupters) for waterways within the preserve which are discussed in the Freshwater Fish section of this document.

Low flow conditions regularly occur in some areas of BITH and exacerbate many of the existing threats to water quality (Meiman 2012). Threats intensified by low flow include salt water intrusion in the Neches River (as in 2011), decreased DO levels, and increased water temperatures. While low DO levels and pH values may be the result of natural processes (e.g., in Pine Island/Little Pine Island Bayou), continued monitoring is necessary as low DO can also be an indication of eutrophication (Meiman 2012). State water quality violations within BITH during 2014 are summarized in Table 69.

Table 69. BITH water quality violations from the calendar year 2014 (reproduced from Meiman 2014).

Site	*E. coli*	pH	DO	NO_3	NH_3	Turbidity
Menard Creek	2	1	0	1	1	0
Little Pine Island Bayou	1	5	3	0	2	1
Little Pine, Lance Rosier	2	2	4	1	0	0
Big Sandy Creek	2	1	0	1	0	3
Village Cr, McNeely Br.	2	1	0	1	0	0
Turkey Creek	0	1	0	1	0	1

Table 69 (continued). BITH water quality violations from the calendar year 2014 (reproduced from Meiman 2014).

Site	*E. coli*	pH	DO	NO_3	NH_3	Turbidity
Mouth of Village Cr.	0	1	0	0	0	0
Village Creek State Park	0	1	0	1	0	0

Data Needs/Gaps

Meiman (2012), combined with the various publications of Dr. Harrel regarding BITH, provides a strong baseline for water quality parameters in BITH. Continued regular monitoring in the preserve's many waterways is needed to ensure that the water quality is clearly understood. Continuation of the GULN monitoring (Meiman 2012), particularly in regards to increasing sample frequency, will help managers identify any trends in or threats to BITH's water quality. Additionally, the overall health and integrity of the diverse aquatic invertebrate community should not be overlooked, and preserve managers should view these resources in concert with each other, rather than separately.

With the threat of endocrine disruptors such as dioxin and polychlorinated biphenyls (PCBs) in many waterways, additional monitoring and research are needed in the BITH region. Other endocrine disruptors, such as birth control residues in treated wastewater releases, also threaten not only the waterways of BITH, but also the amphibian and reptile communities (Hoffmann and Kloas 2012). These potential threats have received little research, and are of particular importance as amphibian populations continue to decline.

Overall Condition

Dissolved Oxygen

The project team defined the *Significance Level* for dissolved oxygen as a 3. The TCEQ standard is a DO value ≥3.0 mg/l (instantaneous value). With the exception of Pine Island and Little Pine Island Bayou, and occasionally Big Sandy Creek, the DO levels observed by Meiman (2012) were all above the minimum level identified by the state standard. The non-compliant DO levels identified in Little Pine Island Bayou and Big Sandy Creek are likely due to natural conditions including low flow, high water temperatures, decaying vegetation, and low gradient (Meiman 2012). The Pine Island Bayou system has had chronically low DO conditions, which have worsened over time. While DO levels are above the state standards in all but two streams, the chronic low measurements in the Pine Island Bayou system are cause for concern. Because of this, DO is currently of moderate concern (*Condition Level* = 2).

Water Temperature

Water temperature was also identified as having a *Significance Level* of 3. Because water temperatures at BITH closely follow the seasonal air temperatures, they can span a range of 25°C (45°F) annually. Very few violations of water temperature standards have occurred in and around BITH, with only three known exceptions on the Neches River since 1997 (Meiman 2012). Continued monitoring of this measure is needed, however, as climate change may potentially influence global temperatures in the future. Increases in air temperature would likely influence the temperatures of the preserve's waters, potentially pushing them closer to, or above, state standards. Currently, water temperature is of low concern (*Condition Level* = 1).

pH

The *Significance Level* for pH was defined as a 3. Lower pH levels are not uncommon in BITH; naturally high amounts of carbonic acid (CO_2) and tannic acid (found in leaves, plant parts, and bark) contribute to low pH levels (Meiman 2012). While most pH measurements are within the state standard of 6.0-8.5 SU, Little Pine Island Bayou, Big Sandy Creek, and on rare occasions Menard Creek and Village Creek, all have recent pH measurements below the minimum. The general trend in pH appears to be heading downwards, as is supported by the longest continuous record of pH at a site proximate to BITH (NPS 2014).Therefore, pH is of moderate concern (*Condition Level* = 2).

Conductivity

The *Significance Level* for conductivity (measured as SpC) was also defined as a 3. Historic data indicate high values for SpC in the late 1970s (Harrel 1977, Harrel and Darville 1978). These elevated levels are attributed to oil field brines being released into the environment at the time (Harrel and Darville 1978, Meiman 2012). Pine Island Bayou and Little Pine Island Bayou continue to show increased SpC, but levels are lower than during the time period when oilfield brines were being released (Meiman 2012). However, a sample taken at Menard Creek in October 2015 had elevated chloride and SpC levels, reminiscent of oil brines (Joe Meiman, GULN Hydrologist, written communication, November 2015). During recent monitoring, SpC has been generally low and stable across most of the streams at BITH (Meiman 2012). Because of the continual threat of contamination by brines, conductivity is of moderate concern (*Condition Level* = 2).

Turbidity

The project team defined the *Significance Level* for turbidity as a 3. Turbidity within BITH is generally considered low (Meiman 2012). The waters of BITH are often dark and may appear turbid but the darker colors are often tannins from localized organic input (i.e., leaves and bark). However, during periods of high flow in the many streams/rivers of BITH, levels of turbidity typically will elevate. Because of the generally low readings, turbidity is of low concern (*Condition Level* = 1).

Nutrients

The project team defined the *Significance Level* for nutrients as a 3. Using phosphorus and nitrate-nitrite as an indicator of nutrient levels, most measurements were well below acceptable guidelines. At present, Texas has no regulatory criteria to limit either phosphate or nitrate-nitrite levels. While no state criteria exist for the regulation of phosphates in Texas waters, the EPA recommends total phosphate levels below 0.05 mg/l in any stream where the stream enters a lake or reservoir (EPA 1986). Meiman (2012) reported that all phosphate measurements from the BITH area were at or above this threshold. The combined nitrate-nitrite values from BITH were well below the standard expected to be implemented by the State of Texas (Meiman 2012). Therefore, nutrients are of low concern (*Condition Level* = 1).

E.coli

E. coli was given a *Significance Level* of 3 by the BITH project team. Water samples from Meiman (2012) were generally below the state single-sample full recreational contact standard of 394 MPN/100ml. *E. coli* levels at BITH correspond closely to discharge and typically increase as rain waters wash the bacteria into streams (Meiman 2012). Heavy rainfall and high flow events typically bring in *E. coli* from sources in the watershed that are beyond NPS control. Historic *E. coli* measurements indicate a moderate number of exceedances of the state criteria. For the majority of the GULN-sampled streams, *E. coli* is considered to be of low concern. However, there are a few streams where exceedances of state standards have been noted (Little Pine Island Bayou, Turkey Creek, and Menard Creek), and portions of four streams are listed under Section 303(d)(TCEQ 2012) as impaired due to bacterial levels (Table 61). For these reasons, the *E. coli* measure was assigned a *Condition Level* of 2, indicating moderate concern.

Carbonate Chemistry

A *Significance Level* of 3 was assigned to carbonate chemistry. BITH's carbonate chemistry was evaluated using total hardness. With the exception of Little Pine Island Bayou, the total hardness in BITH waters follows the trend that is to be expected in the BITH region (Meiman 2012). Little Pine Island Bayou's elevated (compared to other waters in BITH) hardness values suggest an alternative source of calcium/magnesium, possibly stemming from historic residual oil field brines (Meiman 2012). The potential threat from historic oilfield contamination has not been studied or confirmed. Due to the generally low hardness values found within BITH, this measure is considered to be of low concern (*Condition Level* = 1).

Total Suspended Solids

TSS was also assigned a *Significance Level* of 3. Elevated TSS readings in BITH corresponded with high flows and rainfall events (Meiman 2012). The unexplained exception to this trend was Little Pine Island Bayou. Although the dataset for this measure in Meiman (2012) was considered small (n=32), the current patterns observed concerning TSS and high flow or rainfall events in the preserve indicate that this measure is of no concern at present (*Condition Level* = 0).

Impacts on Aquatic Insects

The project team defined the *Significance Level* for this measure as a 3. Moring (2003) found that the EPT index was the lowest for Little Pine Island Bayou, but that the trophic structure of the majority of the 14 reaches sampled in BITH were consistent with the river continuum concept. Based on this limited information, the impacts on aquatic insects are considered to be of low concern (*Condition Level* = 1).

Weighted Condition Score

The WCS for water quality in BITH is 0.43, indicating moderate concern. While results from Meiman (2012) appear to indicate stability for the majority of the measures selected, small sample sizes and samples that are now over 5 years old make it difficult to assign a trend arrow for this component. A medium confidence border was assigned to this measure.

Water Quality			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.43**
Dissolved Oxygen	3	2	
Temperature	3	1	
pH	3	2	
Conductivity	3	2	
Turbidity	3	1	
Nutrients	3	1	
E. coli	3	2	
Carbonate Chemistry	3	1	
Total Suspended Solids	3	0	
Impact on Aquatic Insects	3	1	

4.13.6 Sources of Expertise

- Joe Meiman, GULN Hydrologist

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4.14 Air Quality

4.14.1 Description

Air pollution can significantly affect natural resources and their associated ecological processes. Consequently, air quality in parks and wilderness areas is protected and regulated through the 1916 Organic Act, the Clean Air Act of 1977 (CAA) and the CAA's subsequent amendments. The CAA defines two distinct categories of protection for natural areas, Class I and Class II airsheds. Class I airsheds receive the highest level of air quality protection as offered through the CAA; only a small amount of additional air pollution is permitted in the airshed above baseline levels (EPA 2013a). For Class II airsheds, the increment ceilings for additional air pollution above baseline levels are slightly greater than for Class I areas and allow for moderate development (EPA 2013a). BITH is designated as a Class II airshed.

Photo 25. Smoke from a prescribed fire in BITH (NPS photo).

Parks and preserves designated as Class I and II airsheds typically use the EPA's National Ambient Air Quality Standards (NAAQS) for criteria air pollutants as the ceiling standards for allowable levels of air pollution. The EPA believes these standards, if not exceeded, protect human health and the health of natural resources (EPA 2013a). The CAA also establishes that current visibility impairment in these areas must be remedied and future impairment prevented (EPA 2013a). However, the EPA acknowledges that the current NAAQS are not necessarily protective of ecosystems and is currently developing secondary NAAQS for ozone, nitrogen, and sulfur compounds to protect sensitive plants, lakes, streams, and soils (EPA 2010, EPA 2011). To comply with CAA and NPS Organic Act mandates, the NPS established a monitoring program that measures air quality trends in many park and preserve units for key air quality indicators, including atmospheric deposition, ozone, and visibility (NPS 2008).

4.14.2 Measures

- Nitrogen deposition
- Sulfate deposition
- Mercury deposition/concentration
- Ozone concentration
- Particulate matter ($PM_{2.5}$)
- Visibility

Atmospheric Deposition of Nitrogen and Sulfur

Nitrogen and sulfur oxides are emitted into the atmosphere primarily through the burning of fossil fuels, industrial processes, and agricultural activities (EPA 2012a). While in the atmosphere, these emissions form compounds that may be transported long distances and settle out of the atmosphere in the form of pollutants such as particulate matter (e.g., sulfates, nitrates, ammonium) or gases (e.g., nitrogen dioxide, sulfur dioxide, nitric acid, ammonia) (EPA 2012a, NPS 2008). Atmospheric deposition can be in wet (i.e., pollutants dissolved in atmospheric moisture and deposited in rain, snow, low clouds, or fog) or dry (i.e., particles or gases that settle on dry surfaces as with windblown dusts) form (EPA 2012a). Deposition of sulfur and nitrogen can have significant effects on ecosystems, including acidification of water and soils, excess fertilization or increased eutrophication, changes in the chemical and physical characteristics of water and soils, and accumulation of toxins in soils, water, and vegetation (NPS 2008, reviewed in Sullivan et al. 2011a and 2011b). The wetland and riparian corridor communities in BITH are considered sensitive to excess nitrogen and acidic deposition (Sullivan et al. 2011c, 2011d).

Mercury Concentration

Sources of atmospheric mercury include fuel combustion and evaporation (especially coal-fired power plants), waste disposal, mining, industrial sources, and natural sources such as volcanoes and evaporation from mercury-enriched soils, wetlands, and oceans (EPA 2008). Mercury deposited into rivers, lakes, and oceans can accumulate in various aquatic species, resulting in exposure to wildlife and humans that consume them (EPA 2008). BITH preserve units are connected through a network of freshwater riparian corridors that are important habitat for a variety of wildlife, especially migratory and resident waterbirds, and could be vulnerable to mercury contamination.

Ozone

Ozone occurs naturally in the earth's atmosphere where, in the upper atmosphere, it protects the earth's surface against ultraviolet radiation (EPA 2012a). However, it also occurs at the ground level (i.e., ground-level ozone) where it is created by a chemical reaction between nitrogen oxides and volatile organic compounds (VOCs) in the presence of heat and sunlight (NPS 2008). Ozone is also one of the most widespread pollutants affecting vegetation and human health in the U.S. (NPS 2008). Considered phytotoxic, ozone can cause significant foliar injury and growth effects for sensitive plants in natural ecosystems (EPA 2012c, NPS 2008). Specific effects include reduced photosynthesis, premature leaf loss, and reduced biomass, and prolonged exposure can increase vulnerability to insects and diseases or other environmental stressors (NPS 2008). At high concentrations, ozone can aggravate respiratory and cardiovascular diseases in humans, reduce lung function, cause acute respiratory problems, and increase susceptibility to respiratory infections (EPA 2012a, EPA 2012d, EPA 2013b); this could be a concern for visitors and staff engaging in aerobic activities in the preserve, such as walking the trails.

Particulate Matter (PM) and Visibility

Particulate matter (PM) is a complex mixture of extremely small particles and liquid droplets suspended in the atmosphere. Fine particles ($PM_{2.5}$) are those smaller than 2.5 micrometers in diameter (EPA 2014a). Particulate matter largely consists of acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles (EPA 2013c, EPA 2014a). Fine particles are a major cause of reduced visibility (haze) in many national parks and wildernesses (EPA 2012a). $PM_{2.5}$ can be directly emitted from sources such as forest fires, or they can form when gases emitted from power plants, industries, and/or vehicles react with air (EPA 2012a, EPA 2014a). Particulate matter either absorbs or scatters light. As a result, the clarity, color, and distance that humans can see decreases. Water in the atmosphere causes particles like nitrates and sulfates to expand, increasing their light-scattering efficiency (EPA 2012a, EPA 2013c). $PM_{2.5}$ is also a concern for human health as these particles can easily pass through the throat and nose and enter the lungs (EPA 2012a, EPA 2013c, EPA 2014a). Short-term exposure to these particles can cause shortness of breath, fatigue, and lung irritation (EPA 2012a, EPA 2013c, EPA 2014a).

4.14.3 Reference Conditions/Values

The NPS Air Resources Division (ARD) developed an approach for rating air quality conditions in national parks, based on the current NAAQS, ecosystem thresholds, and visibility improvement goals (Table 70) (NPS 2011). Assessment of current condition of nitrogen and sulfur atmospheric deposition is based on wet (rain and snow) deposition. Ozone condition is based on the NAAQS standard of 75 parts per billion (ppb) (an annual fourth-highest daily maximum 8-hr concentration, averaged over 3 years). The NAAQS standard for $PM_{2.5}$ is a weighted annual mean of 15.0 $\mu g/m^3$ or 35 $\mu g/m^3$ in a 24-hour period over an average of 3 years (EPA 2011). Visibility conditions are assessed in terms of a Haze Index, a measure of visibility (termed deciviews) that is derived from calculated light extinction and represents the minimal perceptible change in visibility to the human eye (NPS 2011). Finally, NPS ARD recommends the following values for determining air quality condition (Table 70). The "good condition" metrics may be considered the reference condition for BITH.

Table 70. National Park Service Air Resources Division air quality index values (NPS 2011).

Condition	Ozone Concentratio (ppb)	Wet Deposition of N or S (kg/ha/yr)	Visibility (dv*)
Significant Concern	≥76	>3	>8
Moderate Condition	61-75	1-3	2-8
Good Condition	≤60	<1	<2

*a unit of visibility proportional to the logarithm of the atmospheric extinction (TCEQ 2012); one deciview represents the minimal perceptible change in visibility to the human eye.

4.14.4 Data and Methods

Monitoring in the Preserve

There is no active on-site monitoring of air quality parameters at BITH (Segura et al. 2007).

NPS Data Resources

Although data on air quality parameters are not actively collected within preserve boundaries, data collected at several regional monitoring stations for various parameters can be used to estimate air quality conditions in BITH. NPS ARD provides estimates of ozone, wet deposition of nitrogen and sulfur, and visibility that are based on data interpolations from all air quality monitoring stations operated by the NPS, the U.S. EPA, various states and other entities, averaged over the most recent five years (e.g., 2008-2012). These estimates are available from the Explore Air website (NPS 2014) and are used to evaluate air quality conditions. On-site or nearby data are needed for a statistically valid trends analysis, while a 5-year average interpolated estimate is preferred for the condition assessment. NPS (2010) describes air quality conditions and trends in an annual report for over 200 park and preserve units, including BITH.

Other Air Quality Data Resources

The EPA Air Trends Database provides annual average summary data for ozone concentrations near BITH. Ozone concentrations are collected at a monitor in Beaumont, TX (site ID 48-245-0009), located near the BU but approximately 88 km (55 mi) from the northernmost areas of the preserve. The site is operated by the TCEQ and has collected data from January 1990 through March 2014 (EPA 2014b). Since 2014 data were not complete at the time of assessment, data through December 2013 are used for assessment. The nearest monitor collecting data on particulate matter concentrations ($PM_{2.5}$) is located in Mauriceville, TX (site ID 48-361-1100), approximately 20 km (12 mi) northeast of the BU. Data were collected at this monitor from April 2001 through August 2005; the monitor is no longer active in data collection. There are no active monitors in the region for particulate matter concentrations. While results from monitors located within 16 km (10 mi) of parks are generally considered to be representative of park conditions, data recorded at monitors beyond this distance may represent regional conditions, but may not be representative of actual park conditions (Ellen Porter, NPS Air Resources Division Air Quality Specialist, phone communication, 25 October 2012).

The National Atmospheric Deposition Program–National Trends Network (NADP) database provides annual average summary data for nitrogen and sulfur concentration and deposition, as well as estimates for mercury deposition and concentration across Texas. The nearest NADP monitoring sites are located at Atwater Prairie Chicken National Wildlife Refuge (site ID TX10) in Colorado County, Texas (approximately 209 km [130 mi] southwest of BITH) and Longview (site ID TX21) in Gregg County, Texas (approximately 269 km [167 mi] north of BITH). The proximity of these monitors to BITH, as well as access to the monitor data summaries, is viewable on the NPS Air Atlas – Estimated Atmospheric Deposition website (NPS 2013b). TX10 has collected data since 1984 and is currently active in monitoring; TX21 has collected data since 1982 and is still an active monitor (NADP 2014). However, their distances from BITH make it difficult to accurately extrapolate conditions at the preserve; thus, data from these monitoring stations were not considered in this assessment. Thus, only the most recent interpolated averages (in map form) calculated by the NADP are used for this assessment.

The Clean Air Status and Trends Network (CASTNet) provides summaries of the composition of nitrogen and sulfur deposition in various regions around the U.S. Similarly, the Interagency Monitoring of Protected Visual Environments Program (IMPROVE) actively monitors visibility conditions in Class I airsheds across the U.S. The nearest IMPROVE monitoring site is located in Sikes, Louisiana, approximately 257 km (160 mi) northeast of BITH and the nearest CASTNet monitoring site is located in Caddo Valley, Arkansas, approximately 450 km (280 mi) north of the preserve. This distance and the variations in terrain make it difficult to extrapolate data accurately; thus, data from these monitoring stations were not considered in this assessment.

Special Air Quality Studies

Sullivan et al. (2011a) assessed the relative sensitivity of national parks to the potential effects of acidification caused by acidic atmospheric deposition from nitrogen and sulfur compounds. The relative risk for each park was assessed by examining three variables: the level of exposure to emissions and deposition of nitrogen and sulfur; inherent sensitivity of park ecosystems to acidifying compounds (N and/or S) from deposition; and level of mandated park protection against air pollution degradation (i.e., wilderness and Class I). The outcome was an overall risk assessment that estimates the relative risk of acidification impacts to park resources from atmospheric deposition of nitrogen and sulfur (Sullivan et al. 2011a). Using the same approach, Sullivan et al. (2011b) assessed the sensitivity of national parks to the effects of nutrient enrichment by atmospheric deposition of nitrogen. The outcome was an overall risk assessment that estimates the relative risk to park resources of nutrient enrichment from increased nitrogen deposition.

4.14.5 Current Condition and Trend

Atmospheric Deposition of Nitrogen and Sulfur

Five-year interpolated averages of total nitrogen (from nitrate and ammonium) wet deposition and total sulfur (from sulfate) wet deposition are used to estimate condition for deposition; using a 5-year average smooths out annual variations in precipitation, such as heavy precipitation one year versus drought conditions in another. The current 5-year average (2008-2012) estimates total wet deposition of nitrogen in BITH at 4.9 kg/ha/yr, while total wet deposition of sulfur is 4.4 kg/ha/yr (NPS 2014). Relative to the NPS ratings for air quality conditions (see Table 70 for ratings values), atmospheric deposition of both nitrogen and sulfur falls into the *Significant Concern* category.

Relative risk of acidification and nutrient enrichment of ecosystems was assessed by examining exposure to nitrogen deposition and acidification, inherent sensitivity of park or preserve ecosystems, and mandates for park protection. Sullivan et al. (2011c) ranked BITH as having high exposure to acidifying (nitrogen and sulfur) pollutants, low ecosystem sensitivity to acidification, and moderate park protection due to its Class II airshed status. The ranking of overall risk from acidification due to acid deposition was moderate relative to other parks (Sullivan et al. 2011c). In a separate examination, Sullivan et al. (2011d) used the same approach to assess the sensitivity of national parks to nutrient enrichment effects from atmospheric nitrogen deposition relative to other parks. BITH was ranked as having high risk for nitrogen pollutant exposure, moderate ecosystem sensitivity, and moderate park protection mandates (Class II airshed). The ranking of overall risk of effects from nutrient enrichment from atmospheric nitrogen deposition was high relative to other parks (Sullivan et al. 2011d).

Atmospheric Concentration of Mercury

Estimates from 2011 NADP isopleth maps indicate the annual average mercury concentration in the BITH region is approximately 10-14 ng/L (Figure 87). To date, no monitoring data are available for mercury concentration directly within BITH, and the nearest monitoring station is located in Gregg County, TX, approximately 269 km (167 mi) north of the preserve (NADP 2014). Thus, the estimates available may not accurately reflect conditions in the BITH region.

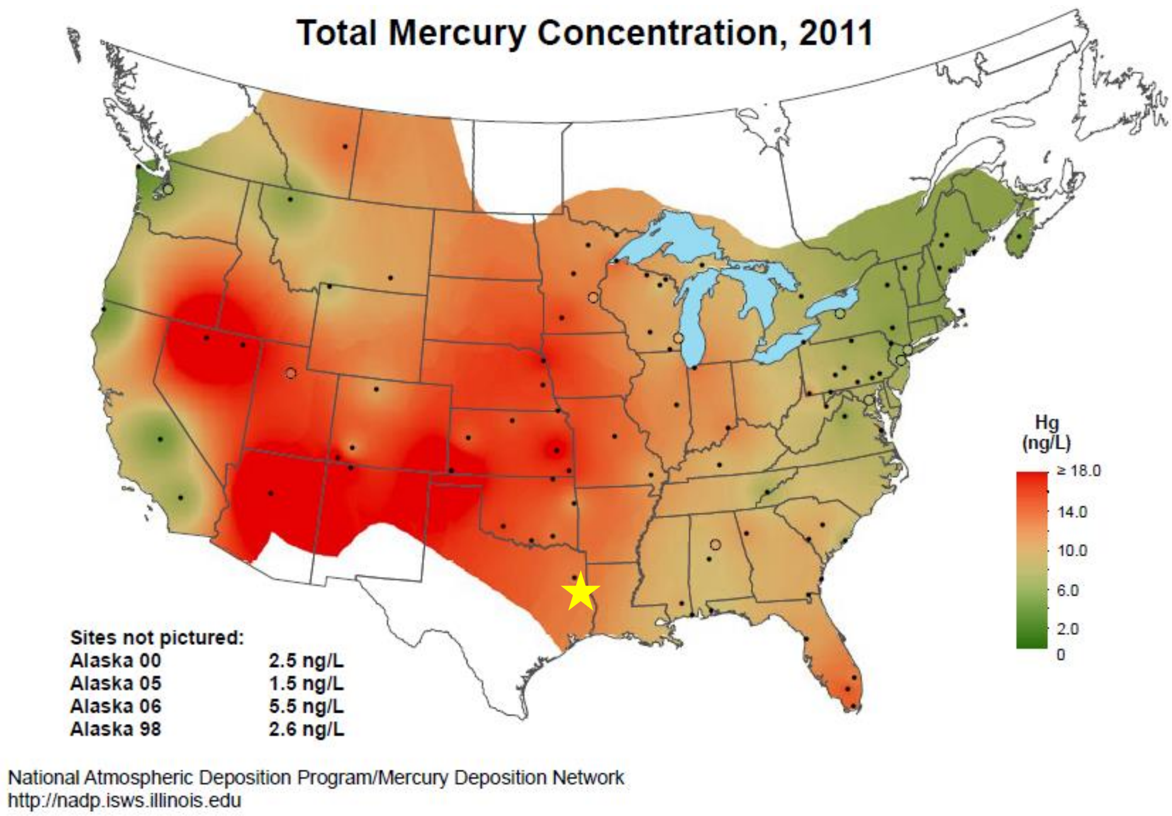

Figure 87. Mercury concentration in the U.S. based on 2011 data. The yellow star marks the approximate location of BITH on the east Texas state boundary. Mercury concentrations featured in this map are estimates calculated through interpolation (Source: NADP 2014).

Ozone Concentration

In 2004, the EPA designated the Beaumont-Port-Arthur, TX area as a marginal nonattainment area under the 1997 8-hour NAAQS (80 ppb) (TCEQ 2008). Under this designation, the Beaumont-Port Arthur area was given a period of time (until June 2007) to attain the standard or face reclassification to a more serious nonattainment class (TCEQ 2008). The area did not monitor or meet attainment by the deadline, and as a result, was reclassified to moderate nonattainment for 8-hour ozone as of 18 April 2008. TCEQ sought redesignation of the area since monitoring showed the area had attained the 1997 standards (TCEQ 2008). Air quality monitoring data from 2006-2010 showed 1997 ozone standards had been attained consistently (EPA 2010). Thus, the EPA approved the request for redesignation to an 8-hour ozone area of attainment (EPA 2010).

The NAAQS standard for ground-level ozone is the benchmark for assessing current ozone conditions within park units. In 2008, the standard was strengthened from 80 ppb to 75 ppb, based on the annual fourth highest daily maximum 8-hour concentration, averaged over 3 years (EPA 2012b). The condition of ozone in NPS units is determined by calculating the 5-year average of the fourth-highest daily maximum of 8-hour average ozone concentrations measured at each monitor within an area over each year (NPS 2011). The current 5-year average (from 2008 - 2012) for BITH indicates an average ground-level ozone concentration of 73.8 ppb (NPS 2014), which falls under the *Moderate Condition* category based on NPS guidelines (NPS 2013a).

Long-term data that characterize ozone concentrations within the preserve do not exist. However, ozone concentrations are monitored daily by TCEQ at the Beaumont, TX monitoring site, near the BU. Results from this monitor may not be representative of ozone concentrations throughout BITH, but they represent concentrations in the portion of the preserve closest to an urban area and a general level for the remainder of the preserve. Figure 88 illustrates the trend in annual fourth-highest daily maximum 8-hour values from 1990 to 2013; these are presented with both the old and revised national standards to provide perspective on acceptable versus potentially harmful ozone conditions in the region. Historically, measurements since 1991 have exceeded the national standard protective of human health, and in the last six years, ozone concentrations have measured at or below the revised NAAQS standard. Despite fluctuations across some years, the general trend of ozone concentrations measured at Beaumont, TX appears to be decreasing overall.

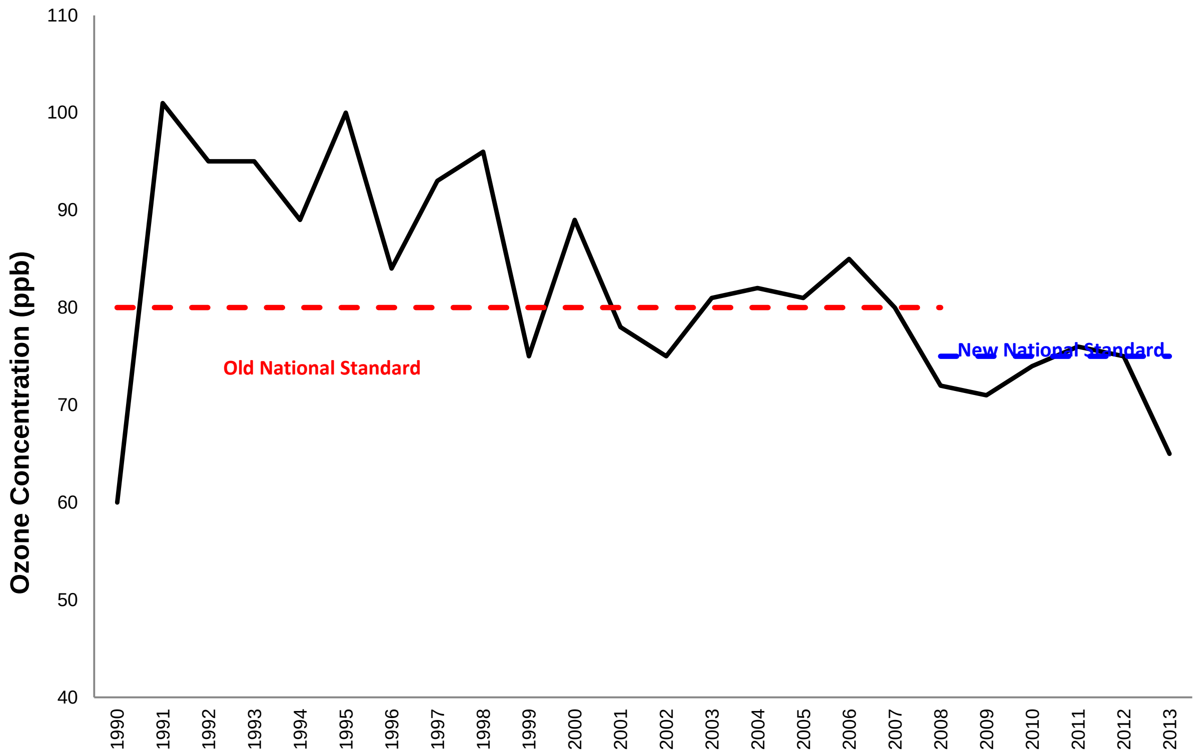

Figure 88. Annual 4th highest 8-hour maximum ozone (O_3) concentrations (ppb) in the BITH region, 1990-2013 (Source: EPA 2014b). Note: Beaumont, TX monitoring site 48-245-0009 is located approximately 56 km (35 mi) from all BITH units. Prior to 2008, the NAAQS ozone standard was 0.08 ppm (80 ppb) (shown in red); in March 2008, the standard was amended to 0.075 ppm (75 ppb) (shown in blue).

Kohut (2004) assessed ozone concentrations in GULN and the risk of injury to plant species that are sensitive to sustained ozone exposure. Estimations by kriging indicate that, from 1995-1999, ambient ozone concentrations around BITH frequently exceeded 60 ppb and 80 ppb. Concentrations exceeded 100 ppb intermittently, although one year catalogued 62 hours above this threshold; at these levels, it is possible for vegetation to sustain injury. Sensitive plant species begin to experience foliar injury when exposed to ozone concentrations of 80-120 ppb/hour for extended periods of time (8 hours or more), and dryer soil conditions can decrease the ability of plants to absorb ozone; this increases ambient ozone concentrations but reduces the likelihood of foliar injury (Kohut 2004). Overall, the risk of foliar injury from ozone is high due to frequent exposures to ozone concentrations greater than 80 ppb and occasionally 100 ppb (Kohut 2004). White ash (*Fraxinus americana*), black cherry (*Prunus serotina*), American elder (*Sambucus canadensis*), American sycamore (*Platanus occidentalis*), and redbud (*Cercis canadensis*) are identified as plant species in BITH that are sensitive to elevated ozone levels, and which may be used as indicator species for foliar ozone injury from elevated ozone concentrations (Kohut 2004).

Particulate Matter ($PM_{2.5}$)

The NAAQS standard for $PM_{2.5}$ is a weighted annual mean of 15.0 µg/m^3 or 35 µg/m^3 in a 24-hour period over an average of 3 years (EPA 2012b). Particulate matter concentrations collected at the

Mauriceville, Texas monitoring site are available from 2001 through 2005. Weighted annual average $PM_{2.5}$ concentrations in the BITH region during the time of data collection appeared to be relatively stable from 2001 through 2005 (Figure 89). All measurements were well within the EPA standards for levels that are protective of human health at the time of active data collection. However, these data are outdated and likely are not indicative of more recent trends or current $PM_{2.5}$ conditions around the preserve. There are currently no active monitors collecting data on $PM_{2.5}$ concentrations in the area surrounding BITH.

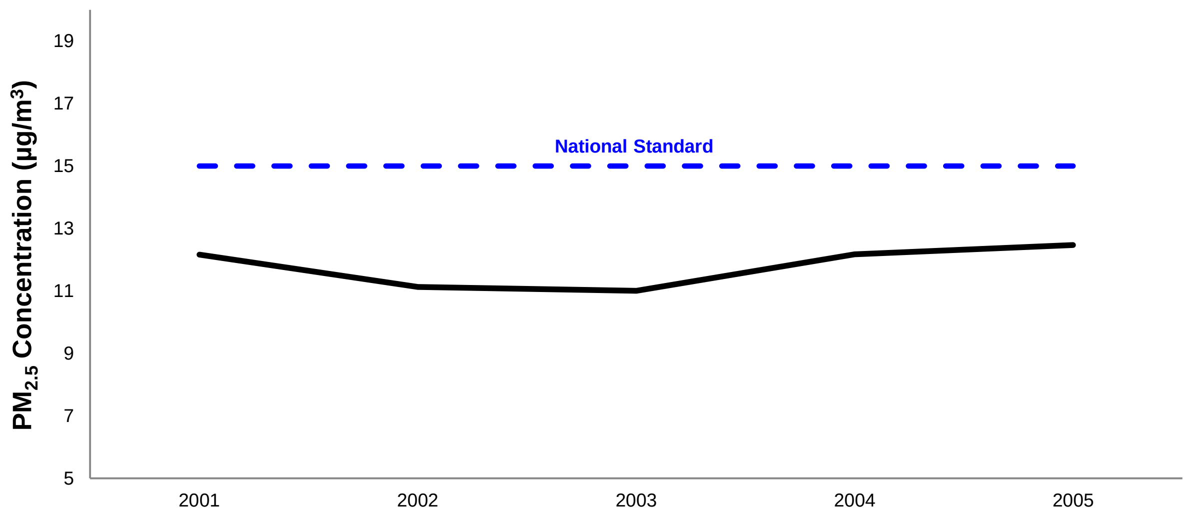

Figure 89. Annual particulate matter ($PM_{2.5}$) concentrations (weighted annual mean) near BITH, 2001-2005 (EPA 2014b). Note: The Mauriceville, TX monitoring site (ID 48-361-1100) is located approximately 56 km (40 mi) east of BITH.

Visibility

Visibility impairment occurs when airborne particles and gases scatter and absorb light; the net effect is called "light extinction," which is a reduction in the amount of light from a view that is returned to an observer (EPA 2003). In response to the mandates of the CAA of 1977, federal and regional organizations established IMPROVE in 1985 to aid in monitoring of visibility conditions in Class I airsheds. The goals of the program are to 1) establish current visibility conditions in Class I airsheds; 2) identify pollutants and emission sources causing the existing visibility problems; and 3) document long-term trends in visibility (NPS 2010, NPS 2011, NPS 2013a).

The most current 5-year average (2008-2012) estimates average visibility in BITH to be 10.4 dv above average natural visibility conditions (NPS 2013a, NPS 2014). This falls into the *Significant Concern* category for NPS air quality condition assessment (NPS 2013a).

The clearest and haziest 20% of days each year are also examined for parks (NPS 2014), as these are the measures used by states and the EPA to assess progress towards meeting the national visibility goal. Conditions measured near 0 dv are clear and provide excellent visibility, and as dv measurements increase, visibility conditions become hazier. The most current 5-year average (2008-

2012) estimates visibility at BITH at 11.6 dv on the 20% clearest days and 23.2 dv on the 20% haziest days (NPS 2014). Both estimates fall into the *Significant Concern* category.

Threats and Stressors Factors

BITH contains a number of habitats classified as “highly fire-dependent,” in that the plant communities in these systems, and animal species dependent upon them, require periodic fire to support their ecological integrity and renewal (NPS 2012). BITH uses prescribed fire for habitat maintenance and hazard fuel reduction. During particularly dry years, periods of drought, or following hurricanes when there is substantially more downed woody debris, wildfire conditions can become severe (NPS 2012). Smoke from burning wildfires, either prescribed or natural-caused, can impact air quality, in particular visibility. The preserve works with the TCEQ to ensure compliance with smoke management regulations before and during any prescribed burns (Hyde, written communication, June 2015).

Nitrogen deposition results from nitrogen oxides in vehicle emissions, power plants, and other combustion sources, and ammonia from agricultural activities and fires. In many terrestrial ecosystems, and in some aquatic ecosystems (characteristic of BITH), the growth of plants and/or algae typically is limited by nitrogen. If increasing amounts of N are added to these ecosystems from atmospheric deposition, growth rates can increase (Sullivan 2011b). However, increased nitrogen deposition can also alter plant communities and reduce diversity, in that higher nitrogen levels favor certain plant species, like fast-growing, opportunistic non-native or invasive species, at the expense of native forbs and shrubs (Sullivan 2011b). Sulfur emissions and particulate matter often originate from such sources as oil and gas drilling operations, petroleum refining, and chemical processing operations, many of which are located in eastern Texas and southern Louisiana. The Beaumont-Port Arthur and Houston-Galveston, TX urban centers are major hubs of development, industrial activity (contributing emissions), oil and gas refining, and shipping. These urban centers produce emissions that likely make their way into the BITH airshed frequently, depending on predominant wind patterns (Sobczak et al. 2010).

Data Needs/Gaps

The nearest NADP monitoring sites are located at Atwater Prairie Chicken National Wildlife Refuge (site ID TX10) in Colorado County, Texas (approximately 209 km [130 mi] southwest of BITH) and Longview (site ID TX21) in Gregg County, Texas (approximately 269 km [167 mi] north of BITH). Though these monitors offer an estimate of the much wider regional conditions regarding nitrogen and sulfur deposition and concentration, the distance of these monitors from BITH preserve units makes it difficult to extrapolate data to understand preserve conditions accurately. The nearest CASTNet site, monitoring acid deposition, is located in Caddo Valley, Arkansas (450 km [280 miles] north of BITH) and the nearest IMPROVE site, monitoring visibility, is located in Sikes, Louisiana (257 km [160 mi] northeast of BITH). There are no active particulate matter ($PM_{2.5}$) monitors in the region. In-preserve monitoring of nitrogen and sulfur deposition and visibility would help managers better understand the local air quality conditions in and around BITH.

Overall Condition

Nitrogen Deposition

The *Significance Level* for atmospheric deposition of nitrogen was defined as a 3. Current NPS interpolated averages for nitrogen deposition are considered to be of significant concern (NPS 2014) based on NPS criteria for rating air quality when factoring in the sensitivity of the ecosystem. Likewise, Sullivan et al. (2011b, 2011d) rate BITH as having high risk for pollutant exposure and moderate ecosystem sensitivity, with an overall high risk of nutrient enrichment relative to other parks. Deposition of nitrogen is of significant concern in BITH (*Condition Level* = 3).

Sulfate Deposition

The *Significance Level* for atmospheric deposition of sulfate was defined as a 3. Current NPS interpolated averages for sulfate deposition are considered to be of significant concern (NPS 2014) based on NPS criteria for rating air quality when factoring in the sensitivity of the ecosystem. Sullivan et al. (2011a, 2011c) rate BITH as having high exposure to acidifying pollutants, low ecosystem sensitivity to acidification, and moderate preserve protection against pollution. The overall risk due to acid deposition was categorized as moderate relative to other parks. Deposition of sulfate is of significant concern in BITH (*Condition Level* = 3).

Deposition/concentration of Mercury

The project team defined the *Significance Level* for mercury concentration as a 3. NADP estimates annual average mercury concentration, based on interpolated data from regional monitors, to be in a rage of 10-14 ng/L. There are no active mercury monitors within 161 km (100 mi) of BITH, and thus, the interpolated averages may not accurately represent in-preserve conditions. Due to lack of data specific to BITH, a *Condition Level* could not be determined.

Ozone Concentration

The *Significance Level* for ozone concentration was defined as a 3. Current average ground-level ozone concentrations fall into the moderate condition category based on NPS criteria for rating air quality condition. Annual 4th highest 8-hour maximum concentrations (1990 through 2013) indicate a declining trend since 1991, with year-to-year fluctuations in concentration. All measurements since 2008 are at or below EPA standards protective of human health. Kohut (2004) suggests the risk of foliar injury from ozone is high for the preserve. Therefore, the *Condition Level* for ozone concentration is a 3, of significant concern.

Particulate Matter Concentration ($PM_{2.5}$)

The *Significance Level* for concentration of fine particulate matter ($PM_{2.5}$) was defined as a 3. There are no active monitors recording $PM_{2.5}$ concentrations near BITH and most recent data dates back to 2006. Due to lack of data, a *Condition Level* could not be assigned.

Visibility

The *Significance Level* for visibility was defined as a 3. Current interpolated average visibility estimates for BITH fall into the significant concern category based on NPS criteria. However, no data are collected at the preserve, and the nearest visibility monitor is over 257 km (160 miles) northeast of the preserve; this makes it difficult to determine average conditions or trends in visibility conditions in BITH. The *Condition Level* for visibility could not be determined at this time.

Weighted Condition Score

The WCS for the air quality component is 1.0, indicating the condition warrants significant concern. Air quality is considered a vital sign for BITH and, although it is not monitored directly in the preserve, air quality information is interpolated from regional air monitors and basic parameters are estimated for BITH on a yearly basis. While there is a lack of long-term trend data for the region and preserve, recent observations regarding the focal measures in this assessment indicate that conditions are likely to decline before they improve.

Air Quality			
Measures	**Significance Level**	**Condition Level**	**WCS = 1.0**
Nitrogen Deposition	3	3	
Sulfate Deposition	3	3	
Mercury Concentration	3	n/a	
Ozone Concentration	3	3	
Particulate Matter	3	n/a	
Visibility	3	n/a	

4.14.6 Sources of Expertise

- Ellen Porter, Biologist, NPS Air Resources Division
- Ken Hyde, BITH Chief of Resource Management

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4.15 Hydrology

4.15.1 Description

Located in the East Texas Pineywoods region, BITH was established in 1974 to "assure the preservation, conservation, and protection of the natural, scenic, and recreational values of a significant portion of the Big Thicket area in the State of Texas and to provide for the enhancement and public enjoyment thereof…" (8~ Stat. 1254; P.L. 93-439). Water has served as a central force in shaping the ecology and diversity of the area known as the Big Thicket (Sobczak et al. 2010). Fluvial features and processes, such as channel migration, erosion, and flooding dominate the landscape of the preserve (Sobczak et al. 2010). In particular, river corridors have been highlighted for their ecological and historical role in "the thicket" (Sobczak et al. 2010). Stream channel migration processes can cause the rivers and larger creeks to meander in and out of the preserves boundaries (Sobczak et al. 2010). This is especially true for the Neches River (Sobczak et al. 2010). Channel migration and stream bank erosion can threaten preserve resources and infrastructure (Sobczak et al. 2010). Flooding, particularly the combination of timing, extent, and duration, is an important factor in shaping and preserving the vegetation communities that exist within the floodplain (Sobczak et al. 2010).

Rivers on the coastal plains of the Southeastern U.S. are characterized by strong annual cycles (Harcombe et al. 1996, Sobczak et al. 2010) in spite of fairly even monthly precipitation patterns (Table 71). They exhibit low flows in the summer and fall when vegetation cover in the watershed evapotranspires much of the precipitation, and high flows in the winter and spring when evapotranspiration is low (Harcombe et al. 1996, Sobczak et al. 2010). Flood events or 'pulses' can occur along with this seasonal cycle, triggered by high regional rainfall during the hurricane or tropical storm season (Harcombe et al. 1996), typically running from June to November. The larger rivers, whose headwaters are in the continental interior, frequently carry large amounts of suspended solids, are turbid with a chocolate-brown color, and have high conductivity (Harcombe et al. 1996). These rivers, such as the Neches River within BITH, are commonly referred to as "alluvial" or "brown-water" rivers (Harcombe et al. 1996).

Table 71. 1981-2010 normal average monthly precipitation (cm) for Kountze, Texas (U.S. Climate Data 2015).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Monthly Precipitation (cm)	11.5	11.5	10.8	10.2	10.8	15.6	10.7	10.2	9.3	15.1	15.3	14.6

The smaller streams in this region that originate on the coastal plain also exhibit fluctuating flows, but these flows are more closely associated with local precipitation events (Harcombe et al. 1996). These small streams that drain predominately areas with sandy, acidic soils are referred to as "black-water" streams due to a combination of low turbidity and high concentrations of organic acids (Harcombe et al. 1996). Blackwater streams are rarely found outside the southeastern U.S. or the Amazon River Basin (Sobczak et al. 2010). Each of the waterways within BITH exhibits some characteristics of a black-water stream, with Village Creek being most nearly typical of black-water streams (Harcombe et al. 1996).

The combination of the topography, soils, and climate of the region produce the unique flood regime of Southeast Texas (Sobczak et al. 2010). Most notable of these factors is the proximity of the preserve to the Gulf of Mexico moisture source and the effects of tropical storms (Patton and Baker 1977). Intense storms in the region result in large magnitude runoff events; however, the flood peaks are diminished to some degree by the region's broad, flat valleys, resulting in slow-moving floodwaters that persist for long durations (Sobczak et al. 2010). In areas like the southern portion of the preserve, where the land is nearly level and slopes are generally less than 1%, the high clay and silt content of the soils are another factor in flooding (Sobczak et al. 2010). Surface water accumulates from these poorly drained soils and contributes to the high, slow-moving, long-term flood flows.

BITH protects this extensive and dynamic system of hydrologic processes and associated dependent systems that are important to maintaining the diverse, and yet specific ecological composition of the Big Thicket (Sobczak et al. 2010). This area is often referred to as a biological crossroads (DESCO 2006). It is a transition zone between the swamps of the southeast, eastern deciduous forests, the central plains, pine savannas, and dry sandhills (DESCO 2006). Approximately 50% of the preserve is comprised of floodplains (Sobczak et al. 2010), and these floodplains contain the majority of the wetlands found within the preserve (Sobczak et al. 2010). Eight of the 15 units that currently make up the preserve are considered river, creek, or bayou corridors (Sobczak et al. 2010). These corridors contain 386 km (240 mi) of riparian waterways, comprised mainly of floodplain forests (Harcombe and Callaway 1997a, b; Sobczak et al. 2010).

With the exception of the MCCU, the units of BITH are located within the Neches River basin (Figure 90). The MCCU is located along Menard Creek which drains into the Trinity River. The Neches River originates in Van Zandt County, Texas and flows to the southeast for approximately 669.5 km (416 mi) to the Gulf of Mexico near Port Neches, Texas (Sobczak et al. 2010). The Neches River drains approximately 25,928 km^2 (10,011 mi^2) (Sobczak et al. 2010). With the exception of the MCCU, the remaining management units in BITH are located within the Big Sandy/Village Creek, Pine Island Bayou, or the Lower Neches River watersheds within the Neches River basin (Figure 90) (Sobczak et al. 2010). The Trinity River originates in the extreme northern portion of Texas and flows southeasterly for 1,142.6 km (710 mi) before entering Trinity Bay, part of Galveston Bay on the Gulf of Mexico near Anahuac, Texas (Figure 90) (Sobczak et al. 2010). The Trinity River drains an area of approximately 46,620 km^2 (18,000 mi^2) (Sobczak et al. 2010). The Menard Creek watershed is part of the Trinity River basin.

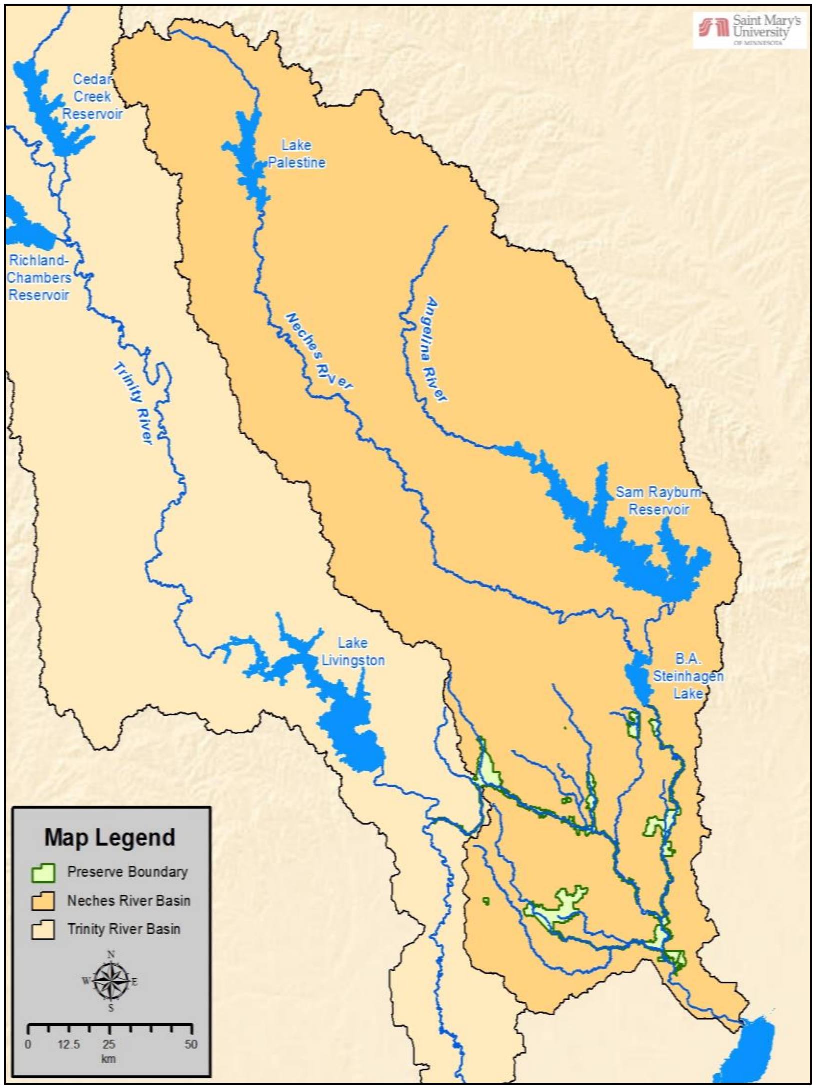

Figure 90. Location of BITH units within the Neches River and Trinity River basins

Menard Creek, Village/Turkey/Big Sandy Creek, Little Pine Island/Pine Island Bayou, and the Neches River comprise the four primary water corridors associated with the preserve (Figure 91) (Harcombe et al. 1996). Other streams associated with the management units are Beech Creek, Hickory Creek, and Savanna Creek. These are tributaries of Village/Big Sandy Creek (Figure 91).

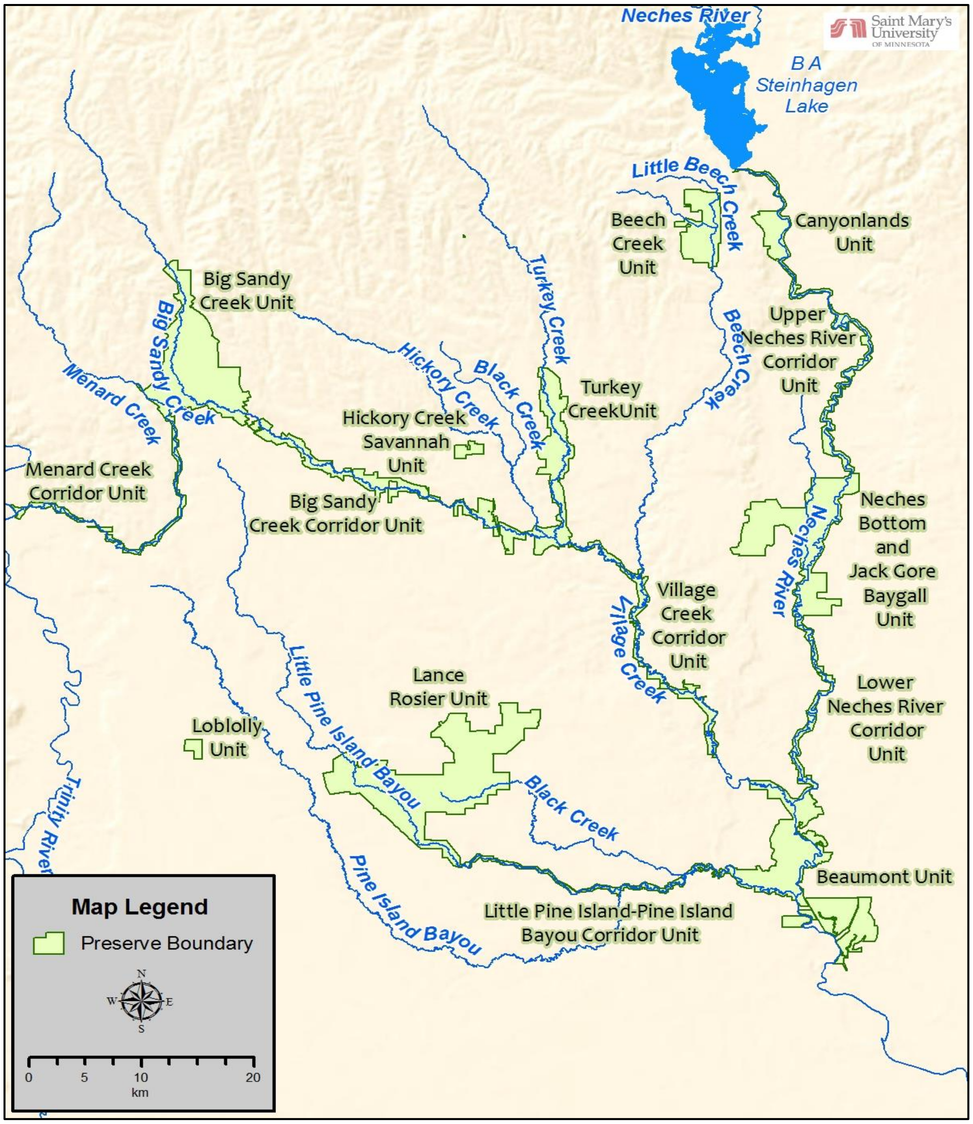

Figure 91. The various streams and rivers associated with the management units that make up BITH.

Black Creek starts in the LRU and ends in the LPI-PIBCU. Only the LU and HCSU have no apparent surface water within the units themselves (Harcombe et al. 1996). The other management units in BITH are closely associated with these streams and rivers. The eight units along the primary water corridors preserve critical aquatic habitat and aquatic resources (e.g., snags, stream banks, or floodplain forests) and provide a linkage between the surrounding floodplain forests to preserve connectivity (Harcombe and Callaway 1997b). The units also provide important wildlife travel corridors, although some at a limited capacity due to their narrow widths (Harcombe and Callaway 1997b), gaps in NPS ownership, and crossings by major roads, pipelines, and utility corridors. The streams within the preserve are also used by the public for recreation, primarily canoeing/kayaking, boating, and fishing (Harcombe and Callaway 1997b). At lower water levels, many groups travel to and use the exposed sand bars along Village Creek and the Neches River for day trips and overnight camping.

The individual units of the preserve are geographically connected by these waterways, yet the enabling legislation does not contain any reference to hydrologic terminology or include any water-related language other than the use of "stream banks" and "stream corridors" as references in delineating unit boundaries (Sobczak et al. 2010). Despite the minor references in the enabling legislation, water is a dominant and unifying theme of the preserve (Sobczak et al. 2010). The management units and their associated stream (or river) are shown in Table 72.

Table 72. BITH management units and their associated waterways.

Waterway	Management Unit
Menard Creek	Menard Creek Corridor Unit
Neches River	Upper Neches River Corridor Unit
	Neches Bottom and Jack Gore Baygall Unit
	Lower Neches River Corridor Unit
	Beaumont Unit
	Canyonlands Unit
Pine Island Bayou	-
Big Sandy Creek	Big Sandy Creek Corridor Unit
	Big Sandy Creek Unit
Village Creek	Village Creek Corridor Unit
Beech Creek	Beech Creek Unit
Un-named tributaries of Hickory and Village Creek	Hickory Creek Savannah Unit
Turkey Creek	Turkey Creek Unit
Little Pine Island Bayou and Black Creek	Lance Rosier Unit
No apparent surface water	Loblolly Unit

The Neches River in the BITH area of Texas has a broad floodplain with a main channel and a number of anastomosing sloughs, small oxbows, and cutoffs forming a large braided channel system (Hall 1993). The Neches River has important characteristics of a brown-water river, such as high turbidity and a high ratio of dissolved inorganics to organics, but it also has a high total organic carbon load, that is more typical of a black-water river (Sobczak et al. 2010). There are a number of impoundments upstream from BITH. The two closest are Sam Rayburn Reservoir on the Angelina River, and B.A. Steinhagen Reservoir on the Neches River (Figure 92). The portion of the Neches River associated with the preserve begins below the Town Bluff Dam (or Dam B) and continues approximately 137 river kilometers (85 river miles) to the saltwater barrier (SWB) near Beaumont, Texas (Figure 91) (Sobczak et al. 2010). With recent NPS land acquisitions, portions of another approximately 16 km (10 mi) of the Neches River adjoin the land in the southern BU nearly to the Interstate 10 bridge. The vegetation within the floodplain area of this section is largely bottomland forest, while the upland areas contain primarily pine and pine-hardwood forests (Harcombe et al. 1996).

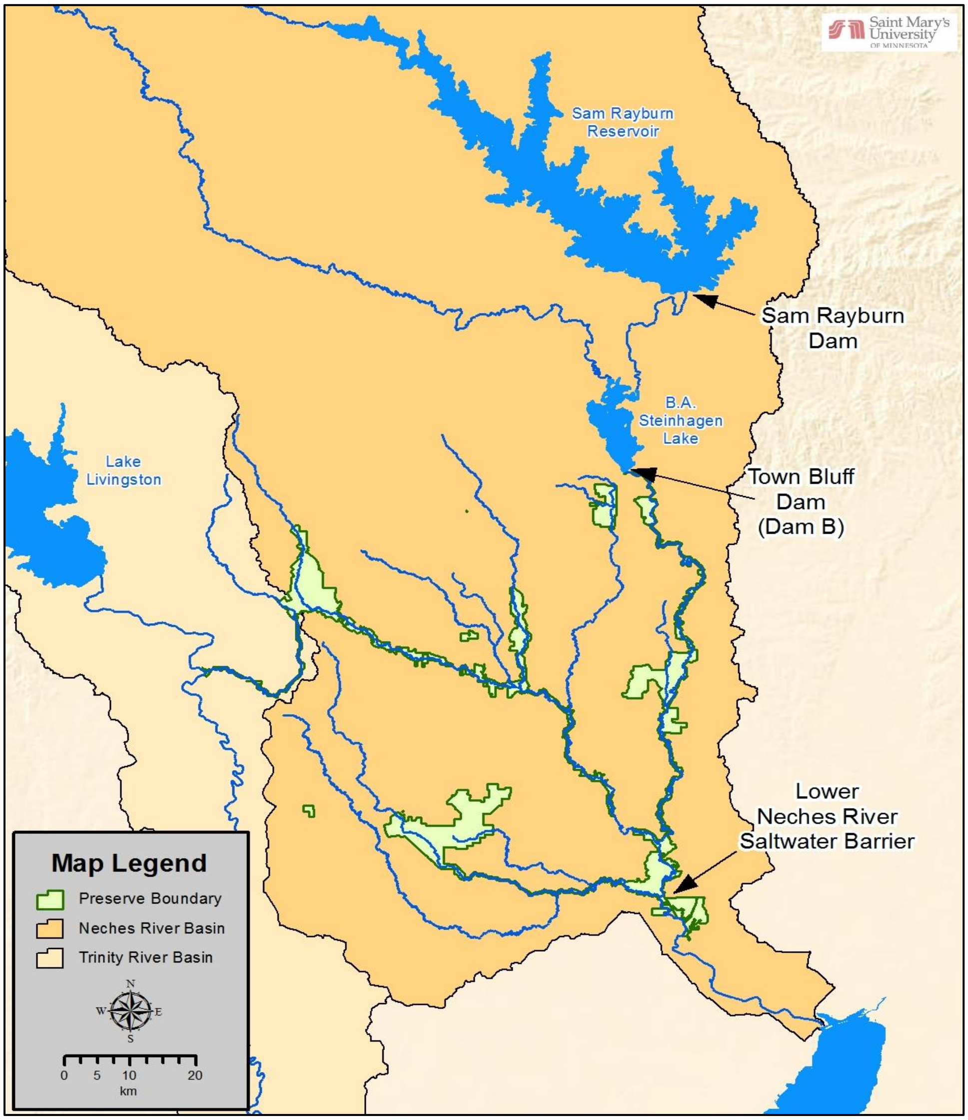

Figure 92. Locations of current dams and saltwater barriers in or adjacent to BITH.

This stretch of the Neches River is a slow moving, meandering river with dark-colored water flowing through swamps, sloughs, and bayous (Ward and Burgess 2011a, b). Within this stretch there is a mixture of wide, open waterways and dark stagnant pools and oxbows (Ward and Burgess 2011a, b). The open waterways are more evident in the northern portion of the river, and the pools and oxbows are more evident in the southern portion of this stretch of river (Ward and Burgess 2011a, b). The stretch of the river below the saltwater barrier in the BU does have some tidal influence that exposes and then re-covers many sandbars at given times during the day (Ward and Burgess 2011a, b).

Menard Creek is a spring-fed black-water stream with a surface flow that is not very turbid (Fulton and Burgess 2012b). Menard Creek is the only stream within BITH that is not part of the Neches

River drainage. It flows approximately 27.4 km (17 mi) through the preserve before it eventually joins the Trinity River near Romayor, Texas (Figure 91). Menard Creek is associated with BITH's distinct upland pine forests as it maintains the area's floodplain riparian area and associated flood pulse, as do all the waterways in the preserve (Cummings 2011). Water stage and flow, along with the creek's sediment load, flooding duration, and seasonal timing, play an important role in maintaining the structure and function of the MCCU's riparian corridor (Sobczak et al. 2010).

Big Sandy Creek originates to the north of BITH and a section of the creek (approximately 46.7 km [29 mi]) runs through the BSCU and BSCCU (Figure 91) (Fulton and Burgess 2012a). Big Sandy Creek is fed by both springs and runoff and a number of smaller order tributaries including Bear and Priest Creek in the BSCU (Fulton and Burgess 2012a). As the creek travels through these two units it acts as a free-flowing, alluvial stream (Fulton and Burgess 2012a). Big Sandy Creek also is associated with the preserve's upland pine forests, due to its unobstructed floodplain (Fulton and Burgess 2012a). The waters of Big Sandy Creek have a dark-stained appearance due to heavy litter on the floor of the surrounding forests. Its streambed is composed of clay and sand, and can hold moisture during drought conditions, providing some relief to aquatic macroinvertebrates and a few of the surrounding benthic communities (Fulton and Burgess 2012a). It eventually flows into Village Creek.

Turkey Creek is another alluvial, black-water tributary of Village Creek (Ward 2011, Cummings 2012b), that originates approximately 24 km (15 mi) to the north of BITH (Figure 91) (Ward 2011). Turkey Creek flows through upland pine forests with beech and hickory deposits (Ward 2011). The waters are stained dark from the detritus and heavy litter of the surrounding forest floor (Ward 2011). Similar to Big Sandy Creek, the stream bed is composed of clays and sand that hold water during dry periods (Ward 2011), and it too flows into Village Creek.

Village Creek is an alluvial black-water stream formed by the confluence of Big Sandy Creek and Kimble Creek near the BSCCU (Figure 91) (Cummings 2012c). It is one of the main water sources in the area, and is a popular destination for locals and visitors during the summer months (Ward and Burgess 2011d). The diversity of plant and animal life contributes to its aesthetic quality and is an important aspect of Village Creek (Ward and Burgess 2011d). The creek has an abundance of sandbars along its edge that provide resting points for visitors and access points for mammals and birds (Ward and Burgess 2011d). American alligators use the stream as a travel corridor and have been observed sunning themselves on the sandbars of the lower portion of the creek where fewer visitors are encountered (Hyde, personal communication, 21 January 2016).

Pine Island Bayou is a slow-moving creek with black, heavy water (Ward and Burgess 2011c). While technically a creek, the Pine Island Bayou is known as a bayou due to the thickness and density of the surrounding vegetation (Ward and Burgess 2011c). Pine Island Bayou begins in eastern Polk and Liberty counties and flows for 93km (58 mi) to the Neches River just north of Beaumont(Figure 91) (Ward and Burgess 2011c). Little Pine Island Bayou is the major tributary of Pine Island Bayou and it flows for 74 km (46 mi) (Ward and Burgess 2011c) including in portions of the LRU. The habitats along these corridors are a combination of flatland hardwood forests, low shrubs, cypress sloughs, and open water (Ward and Burgess 2011c). Pine Island Bayou and Little Pine Island Corridor closely resemble the Ten Mile Bayou oxbow on the lower Neches River (Ward and Burgess 2011c), as it contains similar types of trees, plants, and animals, and the wider open river section is similar in flow and diversity (Ward and Burgess 2011c). Some water is diverted from Pine Island Bayou by the LNVA before it enters the Neches River and is used for municipal and industrial purposes. It is also included in water quality monitoring conducted by the LNVA (LNVA 2013).

4.15.2 Measures

- Flooding frequency and duration
- Drought frequency and duration

4.15.3 Reference Conditions/Values

Natural resource managers at BITH identified the flow regimes of the Neches River, and its tributaries that are associated with the preserve, prior to the construction of the dam and reservoir projects as the reference condition for this assessment. Congress authorized five dam and reservoir projects in the Neches River basin, but to date only three have been built. The Town Bluff Dam (Dam B) creating B.A. Steinhagen Lake was completed in 1953, the Sam Rayburn Dam and Reservoir was completed in 1965, and the Neches River Saltwater Barrier was completed in 2003 (Sobczak et al. 2010). Prior to construction of these dams (c. 1950), flow in the Neches River typically peaked at 283–340 cms (10,000-12,000 cfs) in late winter/early spring (Sobczak et al. 2010). Following this peak, flows dropped to a low-water base flow of 14 cms (500 cfs) during the summer and early fall (Sobczak et al. 2010). Additionally, aperiodic high flow events, with short-term flows exceeding 1,416 cms (50,000 cfs) occurred at a frequency of once every 5 years prior to construction of the dams (Sobczak et al. 2010), and were associated with tropical storms, hurricanes, and other heavy precipitation storms.

4.15.4 Data and Methods

The information for this assessment was gathered primarily from hydrologic information included in several water quality and hydrology studies of the Neches River and the water corridors within BITH. This included a number of unpublished ecological notes and free flowing condition reports compiled by GULN and BITH staff (e.g., Cummings 2011, Ward 2011, Cummings 2012b, Fulton and Burgess 2012a). Other hydrologic studies reviewed for this assessment included a literature review of the limnological and hydrological studies conducted at BITH (Harrel and Newberry 1981), and a research study to reconstruct the flooding history of a river floodplain site within BITH (Hall 1993). The majority of the information and data used in this assessment were derived from a few very thorough water corridor assessment reports (Harcombe et al. 1996, Harcombe and Callaway 1997a, b), a research project that estimated the environmental flow needs for the Lower Neches River (Winemiller et al. 2014), and the natural resource foundation report for BITH (Sobczak et al. 2010).

The USGS maintains several monitoring stations on the Neches River and the waterways within the management units that comprise BITH (Table 73). Stream discharge for these stations can be obtained from the USGS Water Information System website (http://waterdata.usgs.gov/nwis/inventory/). Additionally, the GULN also monitors discharge at several sites within BITH on a quarterly basis (Table 74). Data for these sites can be downloaded

from the NPSTORET Web Interface
(http://science.nature.nps.gov/im/units/guln/npstoret/DefaultNP.aspx).

Table 73. USGS monitoring gauge stations for the waterways of BITH (Sobczak et al. 2010)

Station ID Number	Location	Waterway
08040600	Town Bluff	Neches River
08041000	Evadale	Neches River
08041780	Beaumont	Neches River (SWB)
08041500	Kountze	Village Creek
08041749	Beaumont	Pine Island Bayou
08041700	Sour Lake	Pine Island Bayou
08066300	Rye	Menard Creek

Table 74. GULN I&M Network monitoring sites for the waterways of BITH

Station ID Number	Location
BITH_MCMC	Menard Creek at Hwy 146 Bridge
BITH_BSVC	Big Sandy Creek 20m Upstream of FM 1276 Bridge
BITH_MRVC	Village Creek at McNeely Road
BITH_TCTC	Turkey Creek at Gore Store Road Bridge
BITH_LPIB	Little Pine Island Bayou at Saratoga
BITH_VCVC	Village Creek at Neches River Confluence
BITH_NRLNVA	Neches River at Lower Neches Valley Authority Station

4.15.5 Current Condition and Trend

Flood Frequency and Duration

Floodplains are defined as "areas that are periodically inundated by the lateral overflow of rivers or lakes, and/or by direct precipitation or groundwater; the resulting physicochemical environment causes the biota to respond by morphological, anatomical, physiological, phenological and/or ethological adaptations, and produce characteristic community structures" (Junk et al. 1989). This definition acknowledges that flooding causes a noticeable impact on the biota of these riparian systems, and that the biota displays a defined reaction to the flooding (Junk et al. 1989). The definition also implies that the impact of water level pulse on this system is not dependent on the source of the pulse (Junk et al. 1989). Simply restated, floodplain ecology is dependent on the quantity, timing, and duration of various stages of flood pulses (Sobczak et al. 2010). This riparian flood pulse is a fundamental hydrologic process to BITH (Sobczak et al. 2010). The floodplain/riparian areas and the associated flood pulses that sustain them are one of the most defining characteristics of BITH (Sobczak et al. 2010). Like all floodplain systems, the riparian systems in BITH respond to the annual rise and fall in water stage and the amplitude, duration, frequency, and regularity of the pulses (Junk et al. 1989). This rise and fall of flood waters occurs along all the waterways in the preserve, but it is most pronounced and occurs at a larger scale along the Neches River (Sobczak et al. 2010). Flooding duration and timing, water stage and flow, and the sediment load in the water column all play significant roles in maintaining the function and structure of the floodplain/riparian corridors of BITH (Sobczak et al. 2010).

Stream flow within the preserve is dependent on rainfall (Sobczak et al. 2010). Flows tend to be variable and depend on season, drought conditions, and precipitation patterns. Precipitation in the region is evenly spread throughout the year (Figure 93) (NPS 2010). This causes an annual trend where the flow in the region's rivers and streams rises to a peak in winter and recedes during the summer to settle into a baseflow in the fall (Figure 93) (Sobczak et al. 2010). Despite slightly higher precipitation in the summer and fall, this seasonal trend reflects the significant role that evapotranspiration plays within this region of the country (Sobczak et al. 2010). The most defining process and characteristic of the preserve is this annual flood pulse and the associated floodplain/riparian vegetation (Cummings 2012a). This flood pulse delivers the necessary nutrients to the floodplain and riparian corridor vegetation (Sobczak et al. 2010).

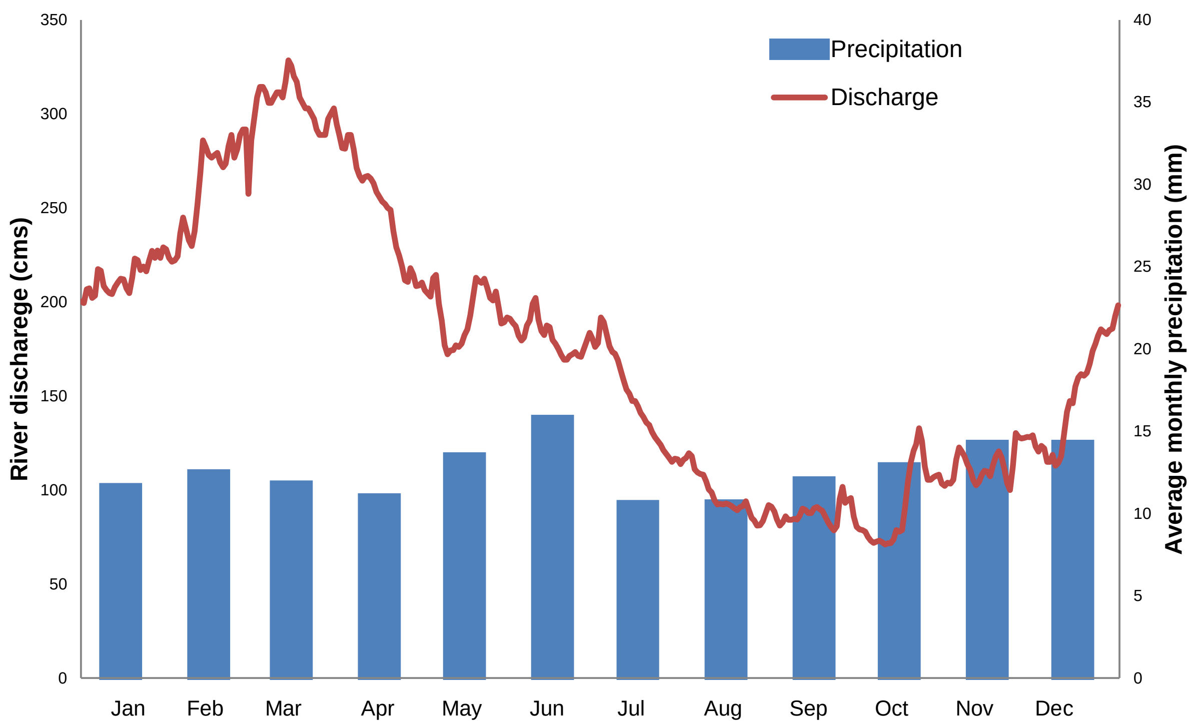

Figure 93. Comparison of average weekly discharge for the Neches River (USGS 08040600) and average monthly rainfall at Town Bluff, Texas (1980-2010). Discharge data is from USGS Station 08040600 and precipitation data is for NOAA Coop Station 00419101 (Menne et al. 2012, USGS 2015).

The flow in the waterways within the boundaries of BITH are influenced and impacted by events and structures outside the control of BITH resource managers. The timing and amount of flow in the waterways of the preserve is dependent on climatic conditions in the upper reaches of the Neches River basin and associated smaller watersheds of each tributary, and the Trinity River basin for Menard Creek (Sobczak et al. 2010). The amount and timing of flow in the Neches River is also dependent on the structural controls on the river that are outside the preserve boundaries and also pre-date the preserve (Sobczak et al. 2010).

In an effort to determine what effect the dams on the Neches River had on the frequency and duration of floods at BITH, Hall (1993) analyzed median and maximum annual discharge for the USGS gauging station at Evadale, Texas (Station ID #08041000). Hall (1993) compared discharge for three time periods, before dam construction (1922-1950), after construction of Dam B (1951-1964), and after construction of Rayburn Dam (1965-1990). Median and maximum annual discharge for this period for the USGS gauging station at Evadale, Texas (Station ID # 08041000) is shown in Figure 94. Based on statistical analysis of the discharge data, Hall (1993) concluded that dam construction has significantly reduced annual peak flows, but also has significantly increased median daily flow Figure 94). Variability in flow has been reduced, as the incidence of high flows has decreased (Hall 1993). The net effect of the dams has been to redistribute flows through the decrease of peak flow and the increase of base flow (Hall 1993). Hall (1993) also concluded that the expected frequency of large floods has been dramatically reduced by dam construction. Flood frequency declined from a regime of once every 2 years to once every 2-5 years. Hall (1993) also calculated and compared the duration of flood events both prior to and after dam construction (Table 75). These results showed the duration of flood events also decreased since the construction of the dams (Hall 1993). With both a decrease in the frequency and duration of flooding since dam construction, there is a corresponding increase in the number of flood-free years. Frequency of years without flooding has more than doubled since the construction of the dams (Table 75, Hall 1993).

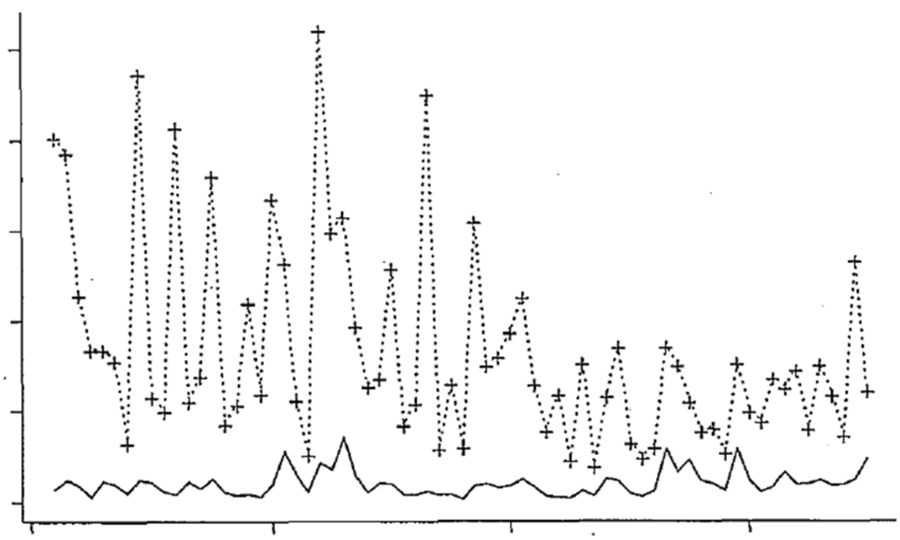

Figure 94. Maximum and median daily discharge by year for the Neches River at Evadale, Texas for the period of 1920-1990 (from Hall 1993).

Table 75. Expected Neches River flows for a 100, 50, 25, 10, 5, and 2-year flood event, for the period 1920-1990, and the periods before and after the beginning of dam operations (reproduced from Hall 1993).

Return Period (years)	Flow Prior to 1965 (cms)	Flow After 1965 (cms)	Flow for period 1920-1990* (cms)
100	5482.45	920.87	3175.05
50	4068.14	913.25	2613.79
25	2980.13	898.80	2114.86
10	1920.32	859.90	1535.95
5	1330.77	797.25	1148.86
2	740.53	602.69	676.29
Total	**47**	**26**	**73**

*Hall (1993) analyzed the flows for the period of 1920-1990

Table 76. Comparison of the median and maximum number of consecutive days with flooding, total number of days flooded, and the frequency of years with no flooding for four levels of flooding along the Neches River before and after dam construction. Frequency of flooding is expressed as a percentage (reproduced from Hall 1993).

	Median Number of Days Flooded per Year		Median Number of Days in Biggest Flood		Frequency of Years with No Flooding	
Level	Prior to 1965	After 1965*	Prior to 1965	After 1965*	Prior to 1965	After 1965*
Bankfull	42.0	23.5	21.0	14.0	8.3%	32.0%
Depressions flooded	24.0	8.5	17.0	6.0	14.6%	44.0%
Flats flooded	14.0	1.0	10.0	1.0	25.2%	52.0%
All flooded	12.0	0.0	7.0	0.0	27.1%	60.0%

* Hall (1993) analyzed the flows for the period of 1920-1990

Currently the flow in the Neches River in the BITH region is controlled through a coordinated effort by the Sam Rayburn Dam, the Town Bluff Dam, and the Lower Neches Saltwater Barrier (Figure 92) (Sobczak et al. 2010). These structures maintain a carefully calibrated water flow and stage regime for the Neches River (Sobczak et al. 2010). In-stream flows are managed by the State of Texas through Senate Bill 3 (SB3) – Texas in-stream flow process (Winemiller et al. 2014). SB3, passed in 2007, provided a new regulatory approach to protect environmental flows through the use of environmental flow standards developed through a stakeholder process culminating in TCEQ rule making (Winemiller et al. 2014). This environmental flow regime is defined as a “schedule of flow quantities that reflect the seasonal and yearly fluctuations that typically would vary geographically by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats” (Winemiller et al. 2014, p. 20). The SB3 schedule did not allow for the development of multi-year, site-specific in-stream flow studies, and instead relied on predicting the flow standards using the best science and data available (Winemiller et al. 2014). The recommended flow regime for the five gauges in the Neches River basin was a two-per-season, and one-per-season flow pulses during each of four seasons (Appendix T) (Winemiller et al. 2014). An additional study recommended including a one-per-year high flow pulse with these flows, to ensure that sufficient riparian inundation, lateral connectivity, and channel maintenance flows would be provided (Appendix U) (Winemiller et al. 2014). In setting the environmental flow standards, the TCEQ only protected two of the two-per-season flow pulses for spring and fall, and only one one-per-season flow pulse for winter and summer (Roach and Winemiller 2011). Currently, the high flow pulses protected under the state's environmental flow standards are unlikely to maintain the current vegetation communities of the study area within the BU of BITH (Winemiller et al. 2014).

Drought Frequency and Duration

A unique combination of topography, soils, and climate are responsible for the characteristic vegetation of the Big Thicket (Sobczak et al. 2010). The seasonal pattern of abundant rainfall combined with extended dry periods and unpredictable and heavy rains in association with the region's high temperatures and humidity produce the rapid growth and decay of the Big Thicket's dense floodplain vegetation (Sobczak et al. 2010). These factors also impact the flow in the region's rivers and streams. The presence and rate of flowing water within the preserve can be most simply explained as a balance between precipitation and evapotranspiration (Sobczak et al. 2010). Drought conditions can interrupt this seasonal balance (Sobczak et al. 2010). Prolonged absence of summer rains can reduce stream flows, expose wetland flats, and negatively impact vegetation (Sobczak et al. 2010).

The hydrologic regime of a river reflects the climate of its upstream watershed area (Junk et al. 1989). Low order streams exhibit an irregular flood pattern with numerous peaks, as they are more strongly influenced by localized precipitation (Junk et al. 1989). This local influence usually diminishes as the size of the watershed increases (Junk et al. 1989). The streams and rivers of BITH and the surrounding region have a unique relationship between precipitation and flow (Sobczak et al. 2010). BITH receives abundant rainfall, approximately 153.5 cm (60.4 in) annually (NOAA 2015b). Rainfall is spread fairly consistently throughout all seasons (Sobczak et al. 2010). Heavy and intense rainstorms in the summer can cause localized flooding due to the poor drainage of the soils in the region, but this is offset somewhat by high evapotranspiration rates in the summer (Sobczak et al. 2010). Winter rains and the associated low evapotranspiration rates generally caused the preserve's creeks and rivers to have their peak flows during this season (Sobczak et al. 2010). Prolonged periods of below normal rainfall or droughts can lead to diminished base flow, or in the case of the Neches River, lower upstream reservoir releases (Sobczak et al. 2010).

The most recent drought period (between October 2010 and September 2011) resulted in the driest 12-month period in Texas history (Winemiller et al. 2014), with statewide precipitation averaging approximately 29 cm (11.4 in) during the drought (Winemiller et al. 2014). This lack of precipitation was reflected in the flow pattern of the Neches River, which experienced low, mostly consistent flow with a few large flow pulses (Figure 95) (Winemiller et al. 2014). Flow remained at this level until larger and more frequent rainfall events occurred near the end of November 2011 (Winemiller et al. 2014). Drought conditions lessened from January 2012 until May 2012 and the Neches River experienced more frequent high pulse flows (Winemiller et al. 2014). Discharge was relatively stable during the summer of 2012, with a single large flow pulse during July (Figure 95) (Winemiller et al. 2014). Average discharge during this period was 97.0 cms (3,425 cfs) (Winemiller et al. 2014).

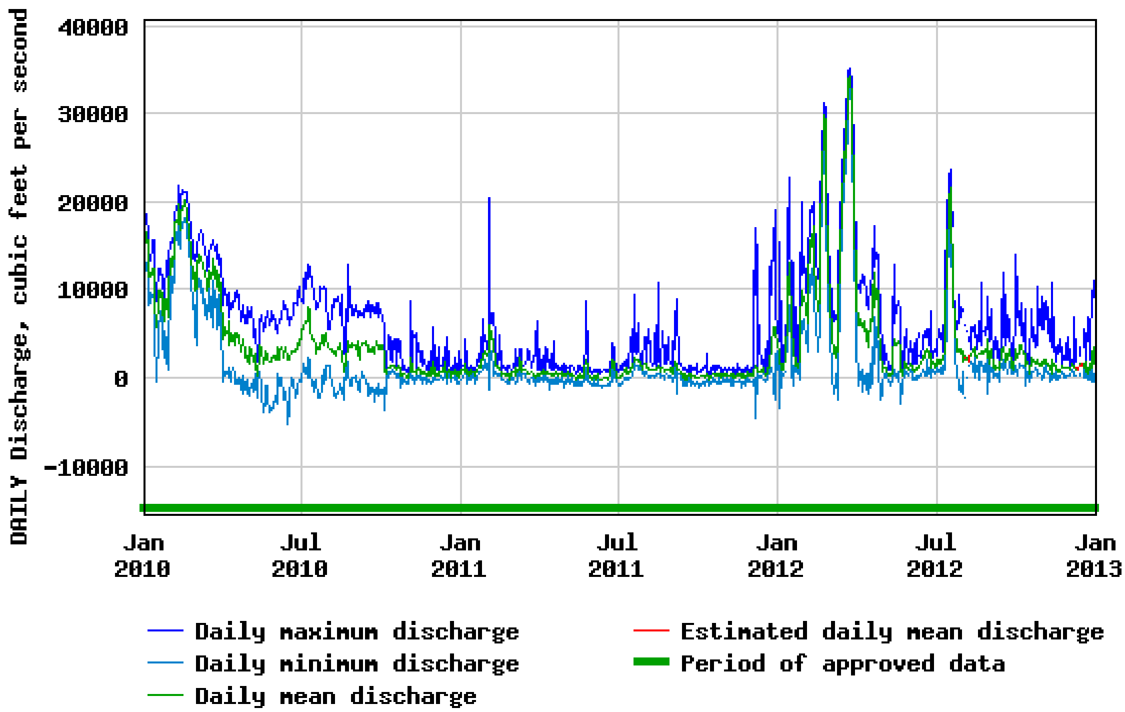

Figure 95. Daily maximum, minimum, and mean discharge rates (cfs) for the Neches River at the saltwater barrier near Beaumont, Texas from January 2010 to January 2013. 10,000 cfs equals 283 cms. (Graph produced by USGS Web Interface for station 08041780).

The Palmer Drought Severity Index (PDSI) can be used to show the duration and intensity of long-term drought-inducing circulation patterns (NCDC 2015). This index also responds fairly quickly as meteorological patterns change from one regime to another (NCDC 2015). The PDSI assesses the relative amount of water that is available in the soil based on precipitation, evaporation, temperature, and soil type (Nielsen-Gammon 2011). The PDSI uses 0 as normal condition, and drought conditions are shown as negative numbers (Palmer 1965). An index of -4 indicates extreme drought conditions, -3 indicates severe drought conditions, -2 indicates moderate drought conditions, and -1 indicates mild drought conditions (Palmer 1965); wet conditions are the positive counterpart of these designations (Palmer 1965). Figure 96 shows the PDSI for the East Texas Climate Division since 1895. This climate division was chosen as the majority of the Neches River basin is located within this division. As can be seen in Figure 96, drought is a recurring theme in East Texas, and this area has experienced long and extreme droughts in the past (SCCC 2013).

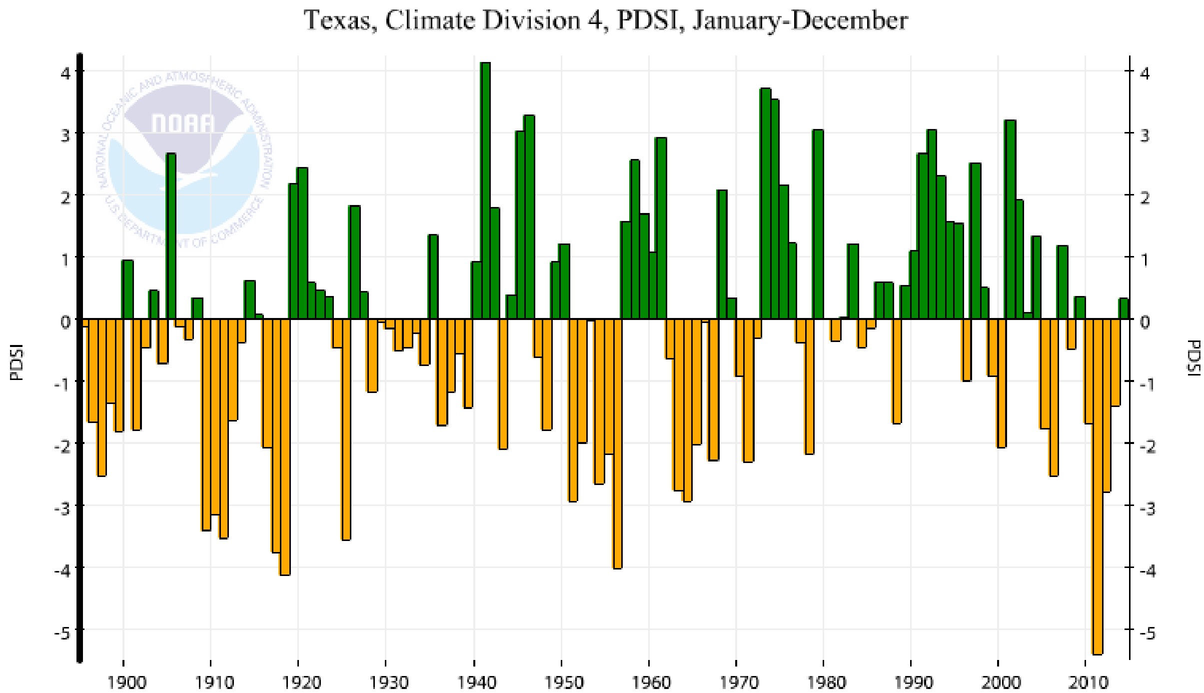

Figure 96. Annual PDSI for East Texas (Climate Division 4) for the period of record (1895-2014). Graph was created and downloaded from time series data from the National Climatic Data Center (NCDC 2015).

Droughts in the BITH region tend to have a longer duration due to the influences on local weather patterns by El Niño/La Niña (Nielsen-Gammon 2011). Climate records and atmospheric models indicate that long-term precipitation patterns in Texas are primarily controlled by the sea surface pattern known as the Pacific Decadal Oscillation (PDO) (Nielsen-Gammon 2011). Observational and modeling data also suggest that the Atlantic Multidecadal Oscillation (AMO) has some effect on precipitation in Texas (Nielsen-Gammon 2011). The warm phase of the PDO is associated with relatively dry weather in Texas (Nielsen-Gammon 2011). This is also true for the warm phase of the AMO (Nielsen-Gammon 2011). Texas has experienced some of its more pronounced periods of drought during periods when both these patterns were in unfavorable states (Nielsen-Gammon 2011). This condition occurred most recently during a drought which began in 2010 (Nielsen-Gammon 2012). The only other recent times when both patterns were in this unfavorable state was from the mid-1940s to the early 1960s (Nielsen-Gammon 2012). During this period, Texas experienced some of its more extreme drought periods (Nielsen-Gammon 2012). Historically, the droughts in East Texas have been of long durations. The duration of some of the more significant droughts in East Texas is given in Table 77.

Table 77. Duration and the PDSI values for several droughts affecting East Texas. Reproduced from Nielsen-Gammon (2012).

Time Period	Months with PDSI less than -1	Months with PDSI less than -4	Lowest PDSI Value
May 1896 – August 1902	48 (of 88 months)	-	-3.82
December 1915 – September 1918	27 (of 35 months)	10 consecutive	-5.99
November 1950 – February 1957	49 (of 76 months)	8 (6 consecutive)	-4.54
December 1962 – May 1972	77 (of 114 months)	-	-3.78
May 2010 – December 2012*	29 (of 29 months)	11 consecutive	-6.5

* Cited author had data available only through 2012; data to complete the analysis were not available to SMUMN GSS.

It is unknown exactly how long these unfavorable conditions for both the PDO and AMO will last (Nielsen-Gammon 2011). Recent research suggests that these patterns may change to conditions more favorable to rainfall in Texas (Nielsen-Gammon 2011). Current observations for the PDO show that it is currently in a cool phase, which normally leads to wetter conditions in Texas (Nielsen-Gammon 2011, NOAA 2015a). This cool phase of the PDO is reflected by the positive PDSI value for 2014 in Figure 96.

Climate change will also have an impact on the timing and duration of droughts in this region (Nielsen-Gammon 2012). Climate change models project relatively small changes in precipitation compared to past natural precipitation patterns (Nielsen-Gammon 2011), so it is unlikely that climate change will lead to a substantial decrease in precipitation in East Texas by 2050 (Nielsen-Gammon 2012). As may be presently occurring, it is likely that the natural variations in the PDO and AMO over the next couple of decades will evolve from the recent dry phase into another wet phase, although this may be temporary (Nielsen-Gammon 2012). Climate researchers are also unsure whether climate change will cause La Niña to become more or less frequent (Nielsen-Gammon 2012).

While the climate models predict only small increases in precipitation as compared to historical averages, temperature is projected to have a larger increase over the past decade-scale temperature variations for Texas (Nielsen-Gammon 2012). This warming trend is predicted by all the models, and it is likely that average temperatures will increase by several degrees Celsius by mid-century (Nielsen-Gammon 2012). The increase in temperature coupled with even a small increase in precipitation will result in higher evapotranspiration rates (Nielsen-Gammon 2012). In the future, evapotranspiration will have an increasingly larger impact on water quantity throughout Texas (Nielsen-Gammon 2012). As a result, future droughts will be warmer than in the past, and will tend to be more severe, even with the increase in precipitation (Nielsen-Gammon 2012).

Threats and Stressors Factors

The waters and aquatic resources of BITH are subject to basin-wide and watershed-specific threats and stressors (Sobczak et al. 2010). Additionally, many of these threats and stressors originate outside of the jurisdiction of the preserve's riparian buffers and corridors (Sobczak et al. 2010). BITH natural resource staff identified several specific issues which currently are, or could become, potential threats and stressors to the hydrologic resources of the preserve. The following paragraphs assess the impact or potential impact of these threats and stressors.

Prolonged absence of rain or periods of drought interrupt the seasonal balance between evapotranspiration and rainfall (Sobczak et al. 2010). This results in increased evapotranspiration, causing the desiccation of vegetation, exposure of wetland flats, parched floodplains, and reduced stream flows (Sobczak et al. 2010). The reduced riparian flows reflect base flow conditions or in the case of the Neches River, upstream reservoir releases (Sobczak et al. 2010). These periods of deeper and prolonged decreases in flow are not uncommon in the region, either due to low rainfall years or multi-year cycles of drought (Sobczak et al. 2010).

The control and utilization of water is an issue of state-wide importance in Texas (Sobczak et al. 2010). The unpredictable and flashy nature of precipitation results in a cycle of periodic flooding and droughts in all areas of the state (Sobczak et al. 2010). This is magnified by the uneven distribution of water in Texas, which is often least abundant in the areas where population, commercial, and industrial needs are the greatest (Sobczak et al. 2010). Flow within the Neches River has been altered by the construction of a number of dam/reservoir projects (Figure 97) (Sobczak et al. 2010). A total of five projects have been authorized by Congress, only three of which have been built (Sobczak et al. 2010). The Sam Rayburn Reservoir is located on the Angelina River, just above the confluence of the Angelina and Neches River and Dam B/Lake B.A. Steinhagen is on the Neches River, just upstream of BITH. The Nechessaltwater barrier, located some 137 km (85 mi) downriver from Dam B and operated by the LNVA, is the third structure involved in regulating the flow of the Neches River through the preserve (Harcombe and Callaway 1997a, Sobczak et al. 2010). These structures, acting in concert, maintain a calibrated water flow and stage regime in the Neches River and prevent saltwater intrusion from the dredged Sabine Lake estuary (Sobczak et al. 2010). An additional dam and reservoir (Blackburn Crossing Dam and Palestine Lake) is located over 241 km (150 mi) north of Dam B in the upper reaches of the Neches River Basin (Sobczak et al. 2010).

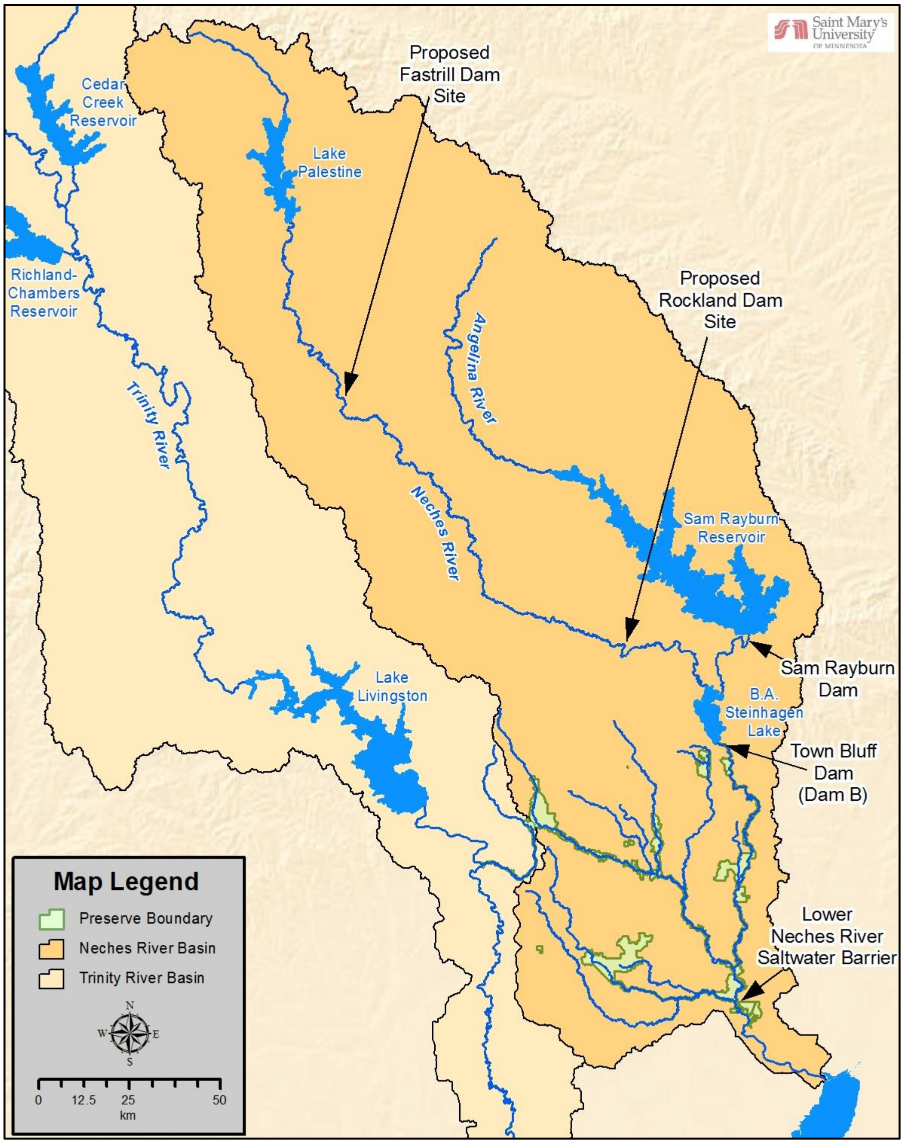

Figure 97. Existing and proposed dams and reservoirs on the Neches and Angelina Rivers.

The Sam Rayburn Dam/Reservoir (completed in 1965) is managed and operated in accordance with a multi-use mission (Sobczak et al. 2010). During periods of potential flooding, the dam stores incoming flow from the Angelina River watershed in its flood pool (Sobczak et al. 2010). Once the threat of downstream flooding is reduced, the flood pool is lowered through water releases by the dam (Sobczak et al. 2010). This creates a condition of higher flows downstream, but below flood stage, until the levels in Sam Rayburn Reservoir are reduced (Sobczak et al. 2010).

The purpose of Dam B/B.A. Steinhagen Lake (completed in 1953) is to re-regulate the intermittent releases from Sam Rayburn Dam, and also to provide storage for hydroelectric power and diversion into a water supply canal (Sobczak et al. 2010). It also provides some floodwater storage (Sobczak et al. 2010). Water releases from this dam are also utilized by the LNVA in Beaumont, Texas, for rice culture, salinity control, pollution abatement, municipal, and industrial uses (Sobczak et al. 2010).

The LNVA is authorized to withdraw water from Dam B at any time directly from the tainter gates (Sobczak et al. 2010). If the pool capacity above Dam B is not sufficient to satisfy the requirements over an extended period of time, Sam Rayburn Dam can release water into B.A. Steinhagen Lake to supplement the LNVA demand (Sobczak et al. 2010).

The intended hydrologic effect of dam construction was to reduce the frequency, duration, and depth of flooding (Hall 1993). Since there is no significant withdrawal of water from the reservoirs for use or export from the watershed, approximately the same amount of water is available to flow as was before dam construction (Hall 1993). The overall effect of the dams in terms of flow has been to redistribute them through decreasing peak flows and increasing base flow (Hall 1993). While annual flow volumes have remained relatively unchanged, the timing and magnitude of spring peak flows, summer base flows, and aperiodic flushing events has been altered (Hall 1993). The management of these dams has resulted in lessening the magnitude of seasonal and extreme flood events within the Neches River system (Hall 1993). These changes may impact river water quality, sediment load, and riparian/floodplain habitats to varying degrees (Hall 1993).

According to LNVA (2016):

> *Sam Rayburn and Steinhagen Reservoirs are owned by the U.S. Government and operated by the USACE, Fort Worth District. Local financial sponsorship is provided by the LNVA. Water stored in Sam Rayburn for use by LNVA is released to Steinhagen (Dam B) Reservoir, from which it flows into the lower Neches River and on to the LNVA freshwater intakes. LNVA has state-approved rights to the use of essentially the entire dependable freshwater yield of Rayburn Reservoir, approximately 820,000 acre-feet (or 267 trillion gallons) a year. This volume not only meets current demands, but is expected to be sufficient to meet the projected needs of the lower Neches Basin far into the 21st century. In releasing freshwater through Rayburn's and Steinhagen's powerhouses, electrical power is generated for use in homes and industries within the area.*
>
> *Delivery of fresh surface water by the distribution system is performed by withdrawal of the water from the lower Neches River and Pine Island Bayou by 21 very large pumps. They can each deliver between 20,000 and 110,000 gallons a minute and can pump a total of over one billion gallons of water a day. The pumps are driven by huge, natural gas-fueled engines in providing the freshwater to eight cities and water districts, 26 industries, and over 100 irrigated farms.*

The building of two new reservoirs, along with the expansion of B.A. Steinhagen Lake, is under consideration for the Neches River (Sobczak et al. 2010). If constructed, these dams would divert water currently flowing through the preserve, and potentially disrupt vegetation communities, affecting wildlife and impacting recreational opportunities (Sobczak et al. 2010). These projects have been periodically discussed by regional planners since the 1940s (Sobczak et al. 2010). The proposed Rockland Dam and reservoir (Figure 97) would be located some 40 km (25 mi) upstream of B.A. Steinhagen Lake (Sobczak et al. 2010). Recently, the LNVA raised the possibility of constructing the Rockland Dam in conjunction with enlarging B.A. Steinhagen Lake as a regional effort to increase water supplies for the state (Sobczak et al. 2010). The current plans call for an enlargement of Steinhagen Reservoir from 5,260 to 8,500 surface ha (13,000 to 21,000 surface ac) and the creation of a large reservoir behind Rockland Dam (Sobczak et al. 2010). While generally discussed in tandem, these would be two separate projects (Sobczak et al. 2010). Combined, the projects would inundate a 4,856 ha (12,000 ac) Texas Park and Wildlife Management Area above Dam B and also submerge most of Martin Dies Jr. State Park, a heavily used recreation area that compliments the recreational river use within the preserve (Sobczak et al. 2010). Opponents of this plan argue that in addition to the inundation of public and private lands, the projects would negatively impact downstream river flows (Sobczak et al. 2010). It is also argued that the 50-year water projections have already been met, and it is speculated that the surplus water would be sold outside the basin (Sobczak et al. 2010).

Since the early 1960s, plans to meet the increased water demands of the Dallas-Fort Worth area have included proposals to build a dam on the upper main stem Neches River (Sobczak et al. 2010). The proposed Fastrill Reservoir would be located about 97 km (60 mi) above Dam B and would inundate an estimated 10,927-12,950 ha (27,000-32,000 ac) of hardwood bottomland habitat (Sobczak et al. 2010), The construction of the Fastrill Dam is also normally discussed in tandem with the proposed Marvin Nicholls Dam located in Northeast Texas (Sobczak et al. 2010). The proposed Marvin Nicholls Dam would flood 40,467 ha (100,000 ac) of land and require nearly 500 km (310 mi) of water pipe (Sobczak et al. 2010). The Fastrill Dam project was dealt a setback with the USFWS initiative to create a 10,117 ha (25,000 ac) national wildlife preserve along 61 km (38 mi) of the Upper Neches River that is within the proposed Fastrill Area (Sobczak et al. 2010).

BITH’s ability to manage its lands and waters along the Neches River requires an understanding of the entire Neches River system, and being able to advocate its interests in the operational, regulatory, and planning aspects of Neches River basin and river management plans (Sobczak et al. 2010). Traditionally, BITH’s efforts have focused on Dam B, as it is the direct source of water coming into the preserve (Sobczak et al. 2010). However, the release and storage of water in the Neches is done in coordination between Dam B, Sam Rayburn Dam, and the Lower Neches River SWB (Sobczak et al. 2010). In reality, BITH needs to advocate its interests to the regulation of the entire system, including these two new reservoir projects should they ever come online (Sobczak et al. 2010).

The Neches River is especially vulnerable to saltwater intrusion during periods of low flow or prolonged drought (Sobczak et al. 2010). This situation has worsened with the dredging of the navigation channel downstream near Port Arthur, Texas (Sobczak et al. 2010). Historically, saltwater intrusion in the Neches River was prevented by flushing the river with freshwater flows from Sam Rayburn Dam, coupled with the seasonal installation of temporary saltwater barriers (Sobczak et al. 2010). The temporary saltwater barriers protected the freshwater diversion points of the LNVA when low water levels in Sam Rayburn Reservoir prevented the release of fresh water to combat the upstream movement of saltwater (Callaway 1995, Harcombe and Callaway 1997a). The prevention of saltwater intrusion into freshwater habitat also has beneficial impacts on wildlife and vegetation in the riparian corridor, as well as the overall water quality in the river (Callaway 1995, Harcombe and Callaway 1997a). From 1940 to 2000, an estimated total of 36 temporary saltwater barriers were installed within BITH boundaries (Sobczak et al. 2010). These barriers were removed when water elevations in Sam Rayburn Reservoir increased, but were typically in place for a period of 3 days up to 11 months (Callaway 1995, Harcombe and Callaway 1997a). In addition to the positive impacts, the temporary barriers also had negative impacts on the shoreline, vegetation, and aesthetic quality of the preserve (Callaway 1995, Harcombe and Callaway 1997a). The temporary structures also disrupted fish migration and impeded boat traffic on the Neches River (Sobczak et al. 2010).

From a water management perspective, the temporary barriers became less effective over time due to a number of factors (Sobczak et al. 2010). The dredging of the Sabine-Neches Waterway to Beaumont for deep draft navigation caused an increase in the surge and frequency of saltwater intrusion in the Neches River (Sobczak et al. 2010). Secondly, seasonal droughts also tended to coincide with the summer growing season when the irrigation, industrial, and municipal demands are at their highest (Sobczak et al. 2010). Lastly, the overdraft of Sam Rayburn Reservoir during periods of drought decreased the amount of water available for salinity control purposes (Sobczak et al. 2010). Over the years, these temporary barriers and their secondary effects generated negative public sentiment and subsequent debate (Callaway 1995). The construction of a long-term solution was needed. The construction of a permanent barrier(s) to replace the temporary ones was authorized under the Water Resources Development Act of 1976. However, the coordinated planning phase between the USACE and LNVA did not occur until the 1990s (Sobczak et al. 2010). A long-term solution to this saltwater intrusion problem was addressed with the proposal by the LNVA for SWBs to be installed in the Neches River between river kilometer 53.9 and 56.3 (river mile 33.5 and 35.0) near Beaumont, Texas and in Pine Island Bayou at or near stream kilometer 4.8 (stream mile 3.0) (Callaway 1995). The proposed SWB in Pine Island Bayou would have been within the boundaries of BITH (Callaway 1995). Only the SWB on the Lower Neches River was built. Construction of the Lower Neches SWB on the river just above the city of Beaumont, Texas began in 2000 and was completed in 2003 (Sobczak et al. 2010). The Lower Neches SWB is operated to maintain the differential in water from upstream to downstream during low flow conditions (Sobczak et al. 2010). This results in a slight slackwater pool on the upstream side of the barrier, but essentially all the water that flows from upstream passes through the barrier, even during times of low flow (Sobczak et al. 2010). In general, it preserves water quality by preventing the intrusion of the saltwater wedge; however, it also reduces the flow of freshwater to the river and the associated freshwater wetlands downstream (Winemiller et al. 2014). Due to this reduced flow, an average minimum discharge of 11.3 cms (400 cfs) passes through the barrier in order to ensure downstream water quality and stream health (Sobczak et al. 2010). However, it should be noted that this structure is operated in concert with upstream river releases and while it is an important part of providing supply allocations to industrial, agricultural, and municipal interests, the newest unit of the preserve is located downstream from, and is not protected by, the permanent barrier (Sobczak et al. 2010).

The Big Thicket historically covered approximately 1,416,402 ha (3.5 million ac). Remnants of this habitat are protected by a variety of state and federal agencies, tribes, and non-profit organizations. Approximately 45,325 ha (112,000 ac) are protected as part of BITH. As the proportion of suitable habitat is reduced, the configuration and suitability of the surrounding habitat become more important (Harcombe et al. 1996). With less than 10% of the historical Big Thicket remaining, habitat fragmentation is a serious concern in BITH (Harcombe et al. 1996). The ecological impact of fragmentation due to pipelines, roads, agriculture, timber harvests, and residential development can vary in severity (Harcombe et al. 1996). In general, habitat fragmentation has two main inter-related consequences (Harcombe et al. 1996). Populations become isolated and the extent of edge effects is related to the size and shape of the fragmented habitat (Harcombe et al. 1996). While the effects of fragmentation within BITH have not been widely studied, conclusions on their impact on wetlands can be drawn (Harcombe et al. 1996). Landscape-scale disturbances, such as flooding and runoff, that are important to the maintenance of wetlands are disrupted in their timing and duration, or may not occur at all (Harcombe et al. 1996). This can lead to loss of biodiversity, change in wetland community structure, or total loss of the wetland through the conversion to other habitat types that are not reliant on seasonal inundation.

Oil and gas extraction and transportation activities have historically been conducted within the Big Thicket area (Harcombe and Callaway 1997a). In fact, these historical uses were recognized in the legislation that authorized creation of BITH (Harcombe and Callaway 1997a). A number of active and abandoned wells and oil and gas pipelines are present within the preserve (Figure 98, Appendix V). Currently, there are 71 oil and gas pipeline segments crossing the various management units of BITH (NPS 2005). Combined with the rights-of-way, this totals 162.5 km (101 mi) and occupies approximately 238 ha (589 ac) (NPS 2005). These pipelines carry saltwater, crude oil, natural gas, liquid petroleum gas, and natural gas liquids within or through the preserve (NPS 2005). These pipelines can pose a significant threat to preserve resources if not managed and maintained properly (NPS 2005). Due to the water-dominated landscape of the preserve, pipeline leaks and spills could inflict considerable damage to water quality, aquatic habitat, aquatic life, and adversely impact public use of the preserve (NPS 2005). Although all the water corridors of the preserve could be affected, due to its size the Neches River may represent the greatest potential flood hazard to oil and gas facilities and be the most susceptible to a pipeline spill or fire catastrophe (Harcombe and Callaway 1997a). Despite the potential for problems, oil and gas industry experts and federal safety officials believe that underground pipelines are the safest form of transport (NPS 2005).

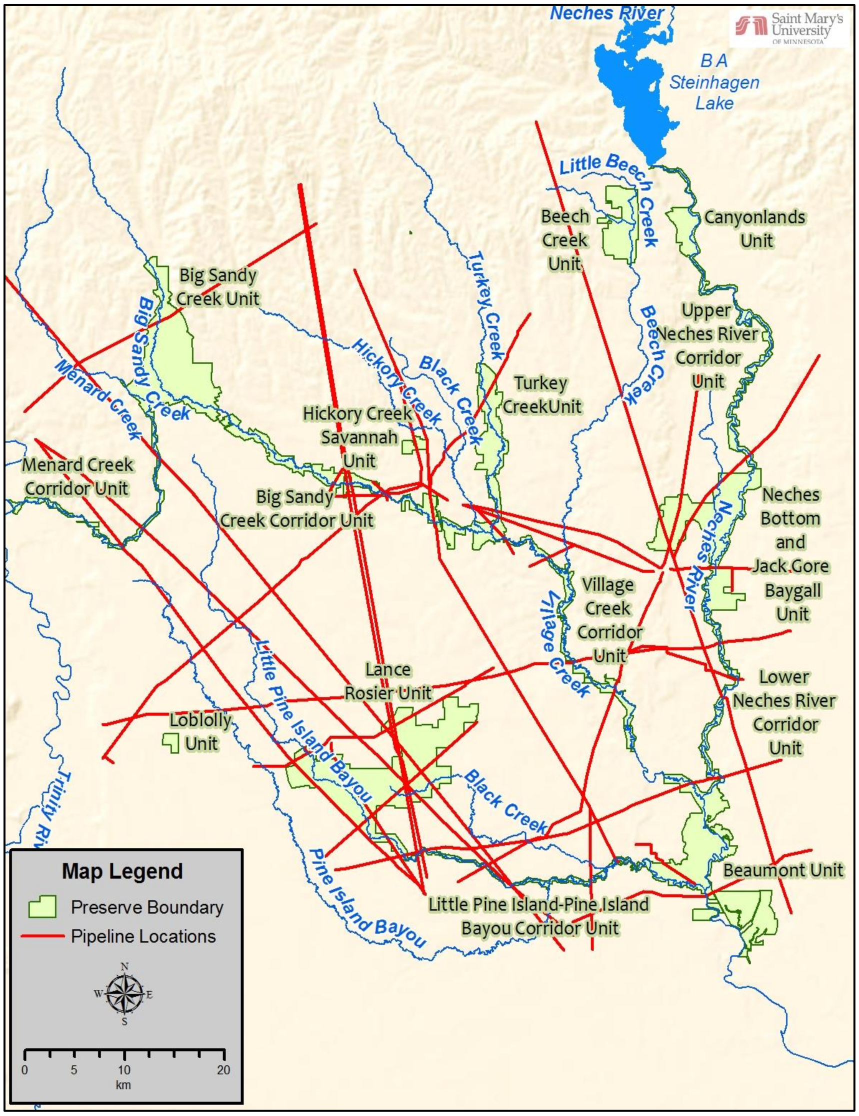

Figure 98. Location of pipeline sections in relation to BITH units.

Pipelines and their associated facilities may also have an impact as agents of habitat fragmentation. Pipeline crossings and their rights-of-ways have the potential to isolate habitats (NPS 2005). Pipeline rights-of-way are also a good example of edge habitats, and BITH's corridor habitats are one long continuous edge zone (NPS 2005). The impact of edge habitat is known to be ecologically significant, yet there is no generally accepted threshold of significance (NPS 2005). Fragmentation of habitat is possibly a greater problem in upland areas than in the water corridors (Harcombe and Callaway 1997a). At least two plugged oil and gas well pipes have been exposed by the natural meandering of the river and plans are underway to remove these navigational and environmental hazards from the Neches River channel.

Natural meanders are occurring in the waterways of BITH (Harcombe and Callaway 1997a). Harcombe and Callaway (1997a) noted that minimal damage to water corridors has been documented as a result of this meandering. Field observations did find specific locations of impacts to stream banks that were the result of modifications of the bank by nearby property owners in an attempt to control erosion (Harcombe and Callaway 1997a). Impact to bank vegetation, or vegetation removal, has an effect on current and the potential for future bank erosion (Harcombe and Callaway 1997a). This erosion, in turn, deposits additional sediment into the streams, impacting water quality (Harcombe and Callaway 1997a).

Groundwater in Texas is governed by the rule of capture which grants landowners the right to capture the water beneath their property (Sobczak et al. 2010). The landowner does not own the water, but has the right to pump and capture whatever water is available, subject to reasonable use clauses, without regard to the effects the pumping has on neighboring wells (Sobczak et al. 2010).

Under Texas law, riparian owners retain the right to use water, as long as they own the land directly adjacent to the water (Sobczak et al. 2010). Texas courts have adopted, and the legislature has not modified, the common law that a landowner has a right to take for use or sale, all the water that they can capture from below their land (Sobczak et al. 2010). The courts have been consistent in ruling on this issue (Sobczak et al. 2010). Recently, it has become increasingly apparent that groundwater is a finite resource, interconnected with streams, and subject to depletion by larger and deeper pumps (Sobczak et al. 2010). There is a growing concern that all Texas waters, not just surface waters, be merged under a common system (Sobczak et al. 2010).

The geology of BITH is characterized by marine and non-marine fluvial and deltaic sedimentary deposits (Sobczak et al. 2010). These geologic deposits are generally composed of alternating layers of clay, silt, sand, and gravel that are hydrologically connected and compose the aquifers in the vicinity of the preserve (Sobczak et al. 2010). As aquifers generally consist of parts of more than one geologic formation, the sedimentary deposits in the area are grouped together and referred to as the Gulf Coast aquifer or Gulf Coast Aquifer System (Sobczak et al. 2010). In this area, the Gulf Coast aquifer is composed of three separate aquifers, two of which underlie the preserve: the Evangeline Aquifer and the Chicot aquifer (Sobczak et al. 2010). The Evangeline Aquifer is the deepest of the three Gulf Coast aquifers, and contains fresh to moderately saline water (Sobczak et al. 2010). Wells in the Evangeline Aquifer supply a portion of the municipal needs of Hardin, Liberty, Newton, Jasper, and Tyler counties (Sobczak et al. 2010). The Chicot Aquifer contains fresh to slightly saline water and is the main source of water for Orange County (Sobczak et al. 2010). The primary uses of groundwater are as a domestic drinking water supply, and industrial and irrigation use (Baker 1964).

Groundwater can be impacted by both natural and anthropogenic causes (Sobczak et al. 2010). Natural contaminants include salt from salt domes, sulfur and associated mineral deposits, naturally radioactive materials, and the chemicals associated with petroleum deposits (Sobczak et al. 2010). Anthropogenic impacts on groundwater include: improper handling, storage, or transport of toxic or hazardous substances, leaching from septic systems, agricultural runoff, and contamination by pathogenic organisms (Sobczak et al. 2010). Over pumping of wells causes the formation of cones of depression and under certain conditions can cause saltwater contamination of wells (Sobczak et al. 2010).

Channelization, levee construction, and other water development factors contribute to an overall reduction in the area available for flooding, and therefore reduce the areas available for habitats and wildlife species that rely on seasonal flood pulses (Harcombe et al. 1996). Channelization has also been shown to increase the amount of saltwater intrusion upstream (Sobczak et al. 2010, Winemiller et al. 2014). Water development of the lower portion of the Neches River, under a partnership between the USACE and the LNVA, dates back to the early part of the twentieth century (Sobczak et al. 2010). It began in response to the area's economic growth with the discovery of oil south of Beaumont, Texas (Sobczak et al. 2010). As oil production expanded, the Neches River was deepened and straightened to accommodate ocean-going vessels from the Gulf of Mexico to reach the refineries in the Beaumont-Port Arthur area (Sobczak et al. 2010). The channel dredging and straightening altered the brackish water balance at the mouth of the Neches River, particularly at times of low flow, allowing saltwater to threaten the region's supply of freshwater (Sobczak et al. 2010). This issue eventually led to the installation of the permanent SWB as described above.

The USACE has plans to deepen and widen the navigational channel from the Port of Beaumont to the Gulf of Mexico from the current depth of 12.2 to 14.6 m (40 to 48 ft) in order to accommodate the large ocean-going vessels (Winemiller et al. 2014). Previous dredging projects in the shipping channels below Beaumont have resulted in significantly greater saltwater intrusion into the lower reaches of the Neches and Sabine Rivers (Winemiller et al. 2014). It is likely that this new dredging project will have the same effect, and that increased freshwater flows, especially during dry seasons, will be necessary to counter the increased salt water intrusion or the construction of new SWBs to upstream movement of saltwater (Winemiller et al. 2014). Installation of a system of improved levees from the Louisiana border to Galveston Island are also being considered after hurricanes in 2005 and 2008 caused widespread damage in southeastern Texas (USACE 2015). These would funnel additional saltwater up the Neches during storm surges and higher tides. Predictions of elevated ocean levels related to climate change will only add to this concern, especially for the portions of BITH's BU acquired since 2009 which are located downriver of the SWB.

Data Needs/Gaps

No major data gaps were found in reviewing the background literature and data that would have affected the analysis. However, including BITH resource managers or the NPS in decisions on the timing and volume of flow releases from the upstream dams is an area that should be investigated. This was previously proposed by Harcombe and Callaway (1997a) in their assessment of the water corridors at BITH. Other research needs identified by Harcombe and Callaway (1997a) involved research into alternative means of bank stabilization and how bank modifications affect habitat for important preserve species. Harcombe and Callaway (1997a) also identified a need for a comprehensive baseline inventory and continued updates of neighboring land uses. These studies are still recommended by this assessment, if not already in progress. In addition, research into the effects of climate change in the BITH region would be helpful, in particular how changes in aridity will impact the availability of water and drought severity.

Overall Condition

Flood Frequency and Duration

The measure of flood frequency and duration was assigned a *Significance Level* of 3. While it appears that flow volumes have remained relatively unchanged when comparing flows before and after dam construction, the timing and magnitude of spring peak flows, summer base flows, and periodic pulse flood events has been altered (Sobczak et al. 2010). Spring peak flows have tended to be repressed in magnitude and low-water base flows have been increased (Sobczak et al. 2010). These changes may impact river water quality, sediment load, and riparian/floodplain habitats to varying degrees (Sobczak et al. 2010).

The changes in the seasonality and peaking of flows on the Neches River have altered the floodplain forest (Hall 1993). This change in flow regime has resulted in increased sapling recruitment and changes in species composition, particularly in the smaller size classes (Hall 1993). The manipulation of the lake water levels to control the growth of nuisance vegetation (such as hydrilla, water hyacinth, and lotus [*Nelumbo lutea*]) may result in negative effects to habitat resources downstream from the dam on the UNRCU (Sobczak et al. 2010). The flushing of this dead vegetation after the lake is refilled may result in impairment of water quality (lower DO levels, odor problems) and a diminished scenic and aesthetic quality downstream on the Neches River (Sobczak et al. 2010).

Furthermore, permanent changes in the overall amounts and timing of stream flows may affect the stream corridors (Sobczak et al. 2010). Direct effects to habitat resources can include changes in channel morphology, meander rate, sedimentation and water quality, and the amount and type of submerged habitat (Sobczak et al. 2010). Secondary effects to natural resources may include changes in growth, mortality, and regeneration of vegetation along the riparian corridor (Hall 1993).

Finally, in setting the environmental flow standards, the TCEQ only protected two of the two-per-season flow pulses for spring and fall, and only one one-per-season flow pulse for winter and summer (Roach and Winemiller 2011). Currently the high flow pulses protected under the state's environmental flow standards are unlikely to maintain the current vegetation communities of the study area within BITH's BU (Winemiller et al. 2014).

While these factors merit the assignment of a *Condition Level* of 3 (significant concern), the ability to affect change to the flow regimes is not within the purview of the NPS. However, the changes from the natural flood regime to one that is based on flood control and water demand does pose a threat to vegetation communities of BITH. Therefore a *Condition Level* of 2, meaning moderate concern is assigned.

Drought Frequency and Duration

The measure of drought frequency and duration was assigned a *Significance Level* of 3. Droughts in East Texas historically have tended to be fairly cyclic in nature and have multi-year durations. Climate change will undoubtably have an effect on the timing, duration and severity of droughts in the future (Nielsen-Gammon 2012). Projections are for increased temperatures, slight increases in precipitation, and increased aridity levels (Nielsen-Gammon 2012). These increases will have an increasingly larger impact on water quantity throughout Texas (Nielsen-Gammon 2012). As a result, future droughts will be warmer than in the past, and will tend to be more severe, even with the increase in precipitation (Nielsen-Gammon 2012). Additionally, climate researchers are unsure whether climate change will cause La Niña events to become more or less frequent and how this will subsequently impact the timing and duration of droughts (Nielsen-Gammon 2012). Due to these factors, a *Condition Level* of 2, meaning moderate concern was assigned.

Weighted Condition Score
The WCS for hydrology at BITH is 0.67, meaning the component warrants significant concern. A downward trend arrow is assigned to this component due to the flow in the Neches River is regulated by the TCEQ, and as currently allotted, will not support the present vegetation communities. Also due to climate change, droughts are likely to increase in duration and frequency, which can exacerbate saltwater intrusion and lead to higher water withdrawals by the larger urban municipalities of the region.

Hydrology			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.67**
Flood Frequency and Duration	3	2	
Drought Frequency and Duration	3	2	

4.15.6 Sources of Expertise

- Joe Meiman, GULN Hydrologist

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Chapter 5 Discussion

Chapter 5 provides an opportunity to summarize assessment findings and discuss the overarching themes or common threads that have emerged for the featured components. The data gaps and needs identified for each component are summarized and the role these play in the designation of current condition is discussed. Also addressed is how condition analysis relates to the overall natural resource management issues of the preserve.

5.1 Component Data Gaps

The identification of key data and information gaps is an important objective of NRCAs. Data gaps or needs are those pieces of information that are currently unavailable, but are needed to help inform the status or overall condition of a key resource component in the preserve. Data gaps exist for most key resource components assessed in this NRCA. Table 78 provides a detailed list of the key data gaps by component. Each data gap or need is discussed in further detail in the individual component assessments (Chapter 4).

Table 78. Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Fire Regime	➢ The effects of fire in mesic communities have been under researched and additional work is needed. ➢ Additional research is needed regarding the response of ground-layer plants to burning, especially in longleaf pine communities. ➢ Information on post-fire vegetation responses (i.e., re-sprouting of non-desirable vegetation like yaupon holly, germination of longleaf and loblolly pine) has been collected, but not analyzed to-date and would be very useful. ➢ Research into the relationships between invasive species and fire in various vegetation communities is needed. ➢ Analyses of collected fire effects data have not been done, and are in order to more accurately assess condition and response.
Pine Uplands	➢ Many of the surveys are outdated and are from the TCU and HCU. Updated surveys preserve -wide are needed that focus on the measures identified in this component. ➢ A compilation of the past 15 years of BITH fire effects monitoring data (2000-2015) would be valuable, along with detailed maps of past efforts to use prescribed fire, physical vegetation treatments, herbicides, and seedling plantings to restore longleaf to historic habitats. Due to staff turnover and the loss of the Fire Ecologist position, this analysis is still pending. ➢ Completion and implementation of a vegetation monitoring protocol by the GULN in 2018 should provide a greater understanding of the overall composition and coverage of pine uplands in BITH. This will be partnered with ongoing fire-effects monitoring.

Table 78 (continued). Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Slope Forest	➢ No data exist regarding age class structure within BITH, and basal area data are outdated and limited in spatial extent. Pre and post-hurricane stand composition would also be useful to monitor and understand stand replacement processes and ensure that invasive species are not becoming established. ➢ A preserve-wide vegetation map does not exist but is scheduled to be completed in 2018.
Arid Sand Hills	➢ This component has not been surveyed specifically for endemic herbaceous plant species ➢ A preserve-wide vegetation map does not exist but is scheduled to be completed in 2018.
Longleaf Pine Wetlands	➢ Most of the available data for this component are outdated ➢ Data related to composition and density of the herbaceous understory in the longleaf pine wetlands are needed. Additional surveys are also needed that focus on the herbaceous midstory in this community ➢ An invasive plant survey could also help determine how much of a threat these species pose to the preserve's longleaf pine wetlands ➢ A preserve-wide vegetation map does not exist but is scheduled to be completed in 2018.
Floodplain Hardwood Forest	➢ Little to no data exist for the selected measures in this component. Size and age class data are out dated and are geographically limited in the preserve. Pre and post-hurricane stand composition would also be useful to monitor and understand stand replacement processes and ensure that invasive species are not becoming established. ➢ An investigation into the spread of invasive Chinese tallow would help to better inform the full impact that invasive species are having in floodplain forests. ➢ A preserve-wide vegetation map does not exist but is scheduled to be completed in 2018.
Estuarine Wetlands	➢ It will be important for BITH to monitor the lower portion of the Beaumont Unit below the salt water barrier to document the conversion of current cypress-tupelo wetlands to estuarine wetlands due to salt water intrusion and climate change impacts, and additional research is needed to determine trends in these wetlands. ➢ There are currently no wetland areas identified within BITH that meet the 'estuarine' classification of Cowardin et al. (1979). These areas are likely to increase as man-made threats and sea level rise continue in the area. ➢ The vegetation dynamics of the lower portion of the Beaumont Unit are in need of additional research, particularly in regards to how it may change due to various threats.
Birds	➢ Continued monitoring in BITH is needed to create a long-term dataset for the preserve. Expansion of existing GULN monitoring to other units of the preserve and other time periods, whether by GULN or other birding partners, would also be beneficial.
Amphibians/Reptiles	➢ A significant data gap exists for the species distribution measure, and there is a lack of consistent abundance data in the preserve. ➢ A routine monitoring/inventory program is needed to update outdated data in the preserve and to monitor for potential invasive herptile species and diseases.

Table 78 (continued). Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Harvested Mammals	➢ Harvest cards are not always returned or completed in high numbers. Continued use and reinforcement of need to return harvest cards should continue to increase the accuracy of the harvest data reported. ➢ Analysis of ongoing harvest data is needed to accurately assess population conditions and to monitor for red flags that may indicate stressors are impacting population levels or reproductive success and more in-depth population surveys are needed..
Freshwater Mussels	➢ Historic data are lacking coverage of the entire preserve (which has continue to expand since inception), and contemporary surveys have expanded the spatial extent of surveys. Systematic survey efforts of priority sampling sites is needed, especially with state-threatened species occurring in preserve waters.
Freshwater Fish	➢ The most recent survey in BITH only sampled a portion of the preserve, and other surveys of the preserve are now outdated. The establishment of annual monitoring efforts for freshwater fish (especially sensitive or T&E listed species) may be needed to assess the current and future condition and trend of this resource. ➢ TPWD does have some recent fish monitoring in place that documents the presence of fish in the area and could be used in the future as a baseline. They also monitor and set the annual daily and bag limits for the waters in BITH.
Water Quality	➢ Continued regular monitoring in the preserve's waterways is needed, and will help to identify trends, threats, or stressors to the resource. ➢ Additional research regarding the potential threat of endocrine disruptors and other emerging contaminants (i.e. neonicotinoids) in the preserve's waterways is needed. ➢ The EPA's 2014 Texas 303(d) List was approved late in the process of completing this NRCA and is not reflected in this component's write up.
Air Quality	➢ In-preserve monitoring of air quality-related parameters is needed, as several of the measures are only monitored by stations that are located at some distance from the preserve. There are no active particulate matter monitors in the region. ➢ BITH is finalizing a permit for an air quality monitoring station primarily looking at hydrocarbons from oak tree respiration in relation to hydrocarbons released from oil & gas processing plants. This may potentially provide data related to some of the metrics in this component in the future.
Hydrology (Surface and Groundwater)	➢ Research into alternative means of bank stabilization and how bank modifications affect habitat for important preserve species is needed. ➢ There is a need for a comprehensive baseline inventory and continued updates of neighboring land uses. ➢ Research into the effects of climate change in the BITH region, in particular how changes in aridity will impact the availability of water and drought severity is needed.

Some of the preserve's data needs involve continuing recently established monitoring programs to accumulate enough data for identifying any trends over time (e.g., birds, water quality). Many of the vegetation community data gaps will be addressed through soon-to-be implemented GULN monitoring efforts, and completion of the preserve-wide vegetation community map.

5.2 Component Condition Designations

Table 79 displays the conditions assigned to each resource component presented in Chapter 4 (definitions of condition graphics are located in Figure 99 following Table 79). It is important to remember that the graphics represented are simple symbols for the overall condition and trend assigned to each component. Because the assigned condition of a component (as represented by the symbols in Table 79) is based on a number of factors and an assessment of multiple literature and data sources, it is strongly recommended that the reader refer back to each specific component assessment in Chapter 4 for a detailed explanation and justification of the assigned condition. Condition designations for some components are supported by existing datasets and monitoring information and/or the expertise of NPS staff, while other components lack historical data, a clear understanding of reference conditions (i.e., what is considered desirable or natural), or even current information. Condition could not be determined for six of the 15 selected components: slope forest, longleaf pine wetlands, floodplain hardwood forest, estuarine wetlands, amphibians/reptiles, and freshwater fish.

For featured components with available data and fewer data gaps, assigned conditions varied. None of the components were considered to be of low concern, while five components (fire regime, birds, harvested mammals, freshwater mussels, and water quality) were of moderate concern. Four components were of high concern: pine uplands, arid sand hills, air quality, and hydrology. The high concern levels for both the hydrology and air quality components are primarily due to the urban land uses and management decisions from areas surrounding the preserve, which are largely beyond NPS control.

Table 79. Summary of current condition and condition trend for featured NRCA components.

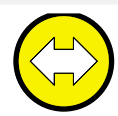
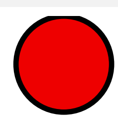
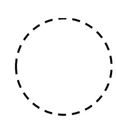
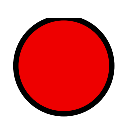
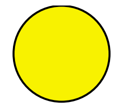
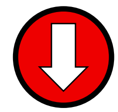
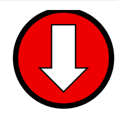
Component		WCS	Condition
Ecosystem Extent and Function			
	Disturbance Regimes		
	Fire Regime	0.64	
Biological Composition			
	Vegetation communities		
	Pine Uplands	0.89	
	Slope Forest	N/A	
	Arid Sand Hills	0.67	

Table 79 (continued). Summary of current condition and condition trend for featured NRCA components.

Component		WCS	Condition
Biological Composition			
	Vegetation communities		
	Longleaf Pine Wetlands	N/A	
	Floodplain Hardwood Forest	N/A	
	Estuarine Wetlands	N/A	
	Birds		
	Birds	0.50	
Ecosystem Extent and Function			
	Herpetofauna		
	Amphibians/Reptiles	N/A	
	Mammals		
	Harvested Mammals	0.58	
	Invertebrates		
	Freshwater Mussels	0.56	
	Aquatics		
	Freshwater Fish	N/A	

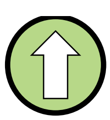
Table 79 (continued). Summary of current condition and condition trend for featured NRCA components.

Component		WCS	Condition
Environmental Quality			
	Aquatics		
	Water quality	0.43	
	Air Quality	1.00	
Physical Characteristics			
	Geologic & Hydrologic		
	Hydrology	0.67	

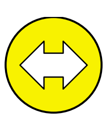
Condition Status		Trend in Condition		Confidence in Assessment	
	Resource is in Good Condition		Condition is Improving		High
	Warrants Moderate Concern		Condition is Unchanging		Medium
	Warrants Significant Concern		Condition is Deteriorating		Low

Figure 99. Description of symbology used for individual component assessments.

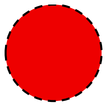
<u>Examples of how the symbols should be interpreted:</u>



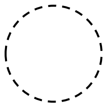
Resource is in good condition, its condition is improving, high confidence in the assessment.



Condition of resource warrants moderate concern; condition is unchanging; medium confidence in the assessment.



Condition of resource warrants significant concern; trend in condition is unknown or not applicable; low confidence in the assessment.



Current condition is unknown or indeterminate due to inadequate data, lack of reference value(s) for comparative purposes, and/or insufficient expert knowledge to reach a more specific condition determination; trend in condition is unknown or not applicable; low confidence in the assessment.

5.3 Park-wide Condition Observations

Despite the disjunct nature of many of BITH's units, many of the resources discussed in this report are interrelated and share similar management concerns (e.g., data gaps, threats from outside the preserve, climate change impacts, etc.).

5.3.1 Vegetation Communities

The vegetation communities of BITH have been heavily influenced by human impacts (repeated logging and fire suppression), with many of the units in the preserve also having some impacts from urban growth. Over a relatively recent history (100-150 years), much of the Big Thicket area has undergone human induced changes to the floral community. The absence of fire due to the past 100 years of fire suppression planting of plantations of non-fire dependent pine species, and other human activities has shifted the open longleaf pine savannas and sandhills from dense and complex herbaceous understories to mixed loblolly pine/hardwood with dense brush understories (McHugh 2004). In more recent years (20-30 years), the BITH prescribed burn and mechanical mastication program has managed to suppress the brush that accumulated and grew to heights exceeding 15 feet during the absence of fire. So far, the removal of brush using prescribed burning and mechanical mastication followed by multiple plantings of nursery-reared longleaf pine seedlings has allowed for the replacement of loblolly pine with longleaf pine seedlings and saplings in small portions of BITH (HCU, TCU, BSCU) (McHugh 2004, Hyde, personal communication, January 2016). More intense management of larger portions of the BSCU are now in progress to restore several hundred acres of longleaf pine habitats in an area where larger, and more oft repeated prescribed burns can occur. This is still a far cry from restoring the 6,070-8,094 ha (15,000 to 20,000 ac) of historic longleaf pine habitats that once existed in the preserve. Hurricanes in 2005 and 2008 also heavily impacted the tree overstories of the bottomland hardwood communities. A high proportion of the large trees in these habitat areas were either blown down or injured leading to resultant rot and disease. This is of particular concern in the beech-magnolia areas and cypress-tupelo swamps, both of which have a number of other factors impeding their health and recruitment abilities (i.e. drought impacts, dense midstory shrubs, saltwater intrusion, etc.).

The protected plant communities and waterways of BITH represent a small proportion of the once vast Big Thicket of Texas, but still provide critical habitat for wildlife and perform crucial ecological functions. Due to a lack of data for several key measures, a current condition could not be determined for four of the six identified vegetation communities in the preserve (Table 79). Many of these information gaps will be addressed by a GULN vegetation mapping and monitoring program scheduled to be initiated 2016.

The two vegetation communities that were assigned a current condition both fell into the significant concern category (pine uplands, arid sandhills). The pine uplands community has seen reductions in longleaf pines primarily due to repeated intense logging historically and the planting of pine loblolly/slash pine plantations and fire suppression in the more recent past. The root sprouting midstory plants in these communities has increased greatly, which plays a significant role in inhibiting longleaf pine recruitment and allowing for the associated complex herbaceous understories. Additionally, limitations in staffing & funding, an extensive boundary, and the ability to use prescribed burns on large areas of a scattered preserve have limited management's ability to restore fire ecology to much of the preserve, which has slowed the restoration of pine upland habitats. In 2015, the preserve completed a parkwide NEPA review that added chemical treatments of the midstory native shrubs as a management tool and should greatly enhance the success of controlling the shrub completion and ladder fuel threat while allowing for better establishment and management of the longleaf pine and herbaceous plants. The arid sand hills community is one of the rarest vegetation communities in BITH and the region and is home to several endemic species that are threatened by a variety of sources. The extent of this community is limited, making it vulnerable to habitat loss. Preserve managers have been actively working on restoring this habitat through the use of prescribed fire, and condition may be improving in these very small areas of the preserve.

5.3.2 Other Biotics

Animals featured as NRCA components were birds, amphibians/reptiles, harvested mammals, freshwater mussels, and freshwater fish. Because of limited or outdated data sources, overall condition could not be determined for amphibians/reptiles or freshwater fish. Birds, harvested mammals, and freshwater mussels were all assigned conditions that fell within the moderate concern category (Table 79). Habitat loss and degradation, water quality impairments, upstream dams and in-park saltwater barrier, and droughts (which may be exacerbated by climate change) have all likely contributed to degradation of the freshwater fish and mussel communities in the BITH region. The current condition of birds in the preserve was based largely on the recent results of GULN monitoring, and also utilized the best professional judgment of BITH managers. The continuation of annual avian monitoring will provide greater confidence in the overall condition of this resource in BITH or initiate more in-depth studies if certain species or guilds are showing impacts locally, nationally, or continent-wide. The harvested mammal data from the returned harvest cards has been analyzed recently (2014) and indicates fairly steady population levels for the past 15 years in the six units that are hunted. The preserve has not yet analyzed and set population trigger levels for each species that might indicate a significant population drop or impact (i.e. major disease outbreak) and need for subsequent population monitoring or research studies.

5.3.3 Environmental Quality

Environmental quality is important in maintaining healthy functioning ecosystems. The health of terrestrial and aquatic organisms can be substantially affected by the condition of air and water quality. Air quality is of high concern at BITH, particularly due to high ozone concentrations and nitrogen deposition levels. All ozone measurements since 2008 are at or below EPA standards protective of human health and Kohut (2004) suggests the risk of foliar injury from ozone is high for the preserve. Likewise, Sullivan et al. (2011a, 2011b) rated BITH as having a high risk for pollutant exposure and moderate ecosystem sensitivity, with an overall high risk of nutrient enrichment relative to other parks.

Water quality is of moderate concern in BITH. The results from Meiman (2012) appear to indicate stability for the majority of the measures selected, although this conclusion comes from small sample sizes and data that are now over 5 years old. Many of the water quality-related impacts originate from areas outside of BITH-managed land. For example, heavy rainfall and high flow events typically bring in *E. coli* from sources in the watershed that are beyond NPS control. Conductivity measurements in the Pine Island Bayou indicate that there may be oilfield brines being released in this area. This area of Texas has several large oil refineries, many other petroleum-based manufacturing plants, andone paper mill which all release chemicals into the air and into their associated wastewaters. Even though many are downstream of the preserve, they release their wastewaters into the Neches River system, and, with salt water intrusion, there is a high likelihood that some of the chemicals are carried upstream at least to the salt water barrier in the BU. Of particular concern, but not studied at all to-date are the endocrine disrupters such as PCB's, dioxins, and DDT. Recent concerns have also added nicotine based pesticides which could impact honey bees and amphibians.

5.3.4 Hydrologic Characteristics

Hydrology in BITH is of significant concern, although a majority of the impacts to the preserve's hydrology are due to forces outside of NPS control. Hydrologic conditions have continued to worsen in the preserve, primarily due to the fact that the flow in the Neches River is regulated within the preserve by the LNVA and upstream and downstream of the preserve by the State of Texas and a number of other government agencies, and as currently allotted, is impacting the health of the current riparian and wetland vegetation communities. Upstream dams severely limit the flushing flows of floodwaters that helped form and recharge the bottomlands of the Neches River. Climate change will likely continue to increase the duration and frequency of droughts and the intensity/frequency of tropical storms and hurricanes in the area with all of their ramifications. Current science predicts significant sea level rise along the coast and up into the BU which can exacerbate saltwater intrusion in conjunction with a number of other human-caused issues, including an ever-growing regional population and expanding industry base needing significantly more fresh water withdrawals from the Neches River.

5.3.5 Park-wide Threats and Stressors

Several threats and stressors influence the condition of multiple resources throughout BITH. These include the presence of non-native invasive species and the effects of urban development (e.g., habitat loss and fragmentation, pollution, hydrologic alterations). Drought and more frequent and intense hurricanes are also a re-occurring threat which may be exacerbated by climate change. Invasive plant species (e.g., Chinese tallow, hardy orange, kudzu, and Japanese climbing fern) are a threat to all the preserve's vegetation communities due to their ability to out-compete native plants.

Several aquatic invasives, including giant salvinia and water hyacinth, are an already present threat that clogs the backwater and inland lake areas of the preserve's waterways. Among non-native animals, feral hogs are the greatest threat. Their destructive rooting and wallowing behaviors, along with a diet that includes nearly all the mast and smaller vertebrates, impact all the preserve vegetation communities as well as native wildlife (herptiles, birds, invertebrates, etc.). Other significant non-native animals include RIFA which are everywhere in the preserve and impact everything from herptiles to ground nesting birds. Feral cats, invading amphibians, and Asiatic clams are also present in varying degrees, all of which impact a number of the ecological communities in BITH.

Many of the preserve's air and water quality concerns are due to its close proximity to several urban locations (e.g., Beaumont, Houston) and the extensive petroleum-based industry of the region. As mentioned previously, these threats and stressors are largely beyond the control of preserve management. Another threat that is outside of preserve control is climate change. Much of Texas has been experiencing drought conditions for several years now (U.S. Drought Monitor 2014). Both extended and more intense droughts negatively impact many preserve resources, from riparian vegetation, amphibians, and fish, to water quality and hydrology. Unfortunately, droughts are likely to increase in frequency and duration in the future as a result of climate change (Twilley et al. 2001, Davey et al. 2007). Winter and spring precipitation are projected to decrease in the BITH region over the next century; combined with warmer temperatures, this will lead to overall drier conditions in the region (Maurer et al. 2007; see Chapter 2). A number of climate models also predict that sea levels will rise and could be a major impact, especially in the BU, by the year 2070. This could lead to the loss of large areas of cypress-tupelo habitats that would be replaced by estuarine wetlands. On the flip side, the frequency and intensity of hurricanes coming out of the Gulf of Mexico have increased over the last century. The high winds and heavy rains associated with these storms has significantly impacted the preserve, including Rita in 2005 and Ike in 2008.

Although BITH has had a wealth of inventories and some early in-depth research and monitoring programs, it also has had a history of fairly high turnover among most of the staffing positions from superintendent down to the staff biologist/ecologist position. This has resulted in data gaps, some misplaced field notes and reports, poor management of the natural resource collections gathered by researchers, and in periodic changes in program directions, priorities, and goals. Acquisition of additional NPS lands has also continued throughout the history of the preserve resulting in many new segments being added in the corridor units and sizeable upland additions in units including the CU and southern portion of the BU. Little research has occurred in these new acquisitions. As a mid-sized park staffed at a small park level, BITH is often seen as a career stepping stone so many come and go as they move up the career ladder. The lack of continuity and noted data gaps result in it being difficult to properly assess "current" conditions for many of the components although sufficient data is available to preserve managers to continue to properly manage nearly all the resources.

5.3.6 Overall Conclusions

The Big Thicket historically covered approximately 1,416,402 ha (3.5 million ac). Remnants of the amazing array of habitats found in this region are protected by a variety of state and federal agencies, tribes, and non-profit organizations and approximately 45,325 ha (112,000 ac) are protected as part of BITH. As the proportion of suitable habitat is reduced, the configuration and suitability of the surrounding habitat becomes more important (Harcombe et al. 1996). With less than 10% of the historical Big Thicket remaining, BITH represents one of the last strongholds of this historic and vital ecological community.

Despite the broad and fractured spatial scale of BITH, the preserve supports a variety of natural resources, includes portions of some of the most unique and pristine habitats, and represents one of the largest and last protected portions of the Texas Big Thicket. Although BITH is impacted and fragmented by adjacent human activities and infrastructure, by protecting portions of the unique habitats and river/creek corridors, the preserve still provides a glimpse into the historic Big Thicket of this region. While no resources analyzed in this report fell into the good condition category, management actions, particularly those aimed at returning a natural fire regime, restoring the longleaf pine overstory to its historic area, and protecting the small microhabitats and water resource, combined with continued land acquisitions will only improve the natural condition and integrity of the priority resources in the preserve. The protected ecosystems of the preserve provide an oasis from the surrounding developed areas for both wildlife and human visitors. Maintaining and/or improving these resources will contribute to the environmental health of the surrounding area and give important opportunities for urban residents, visitors, and the next generation to connect with the natural world.

5.4 Literature Cited

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Appendices

Appendix A. Burn severity data.

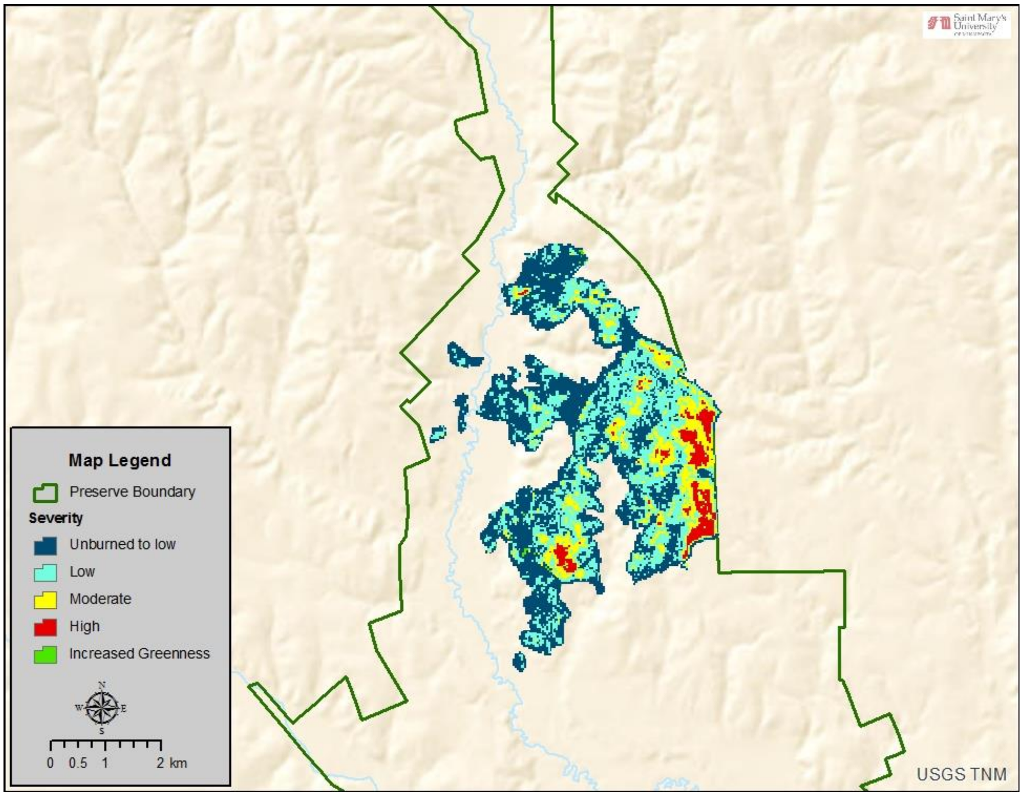

Figure A-1. MTBS burn severity data for a March 1986 prescribed fire in the BSCU (MTBS 2015b).

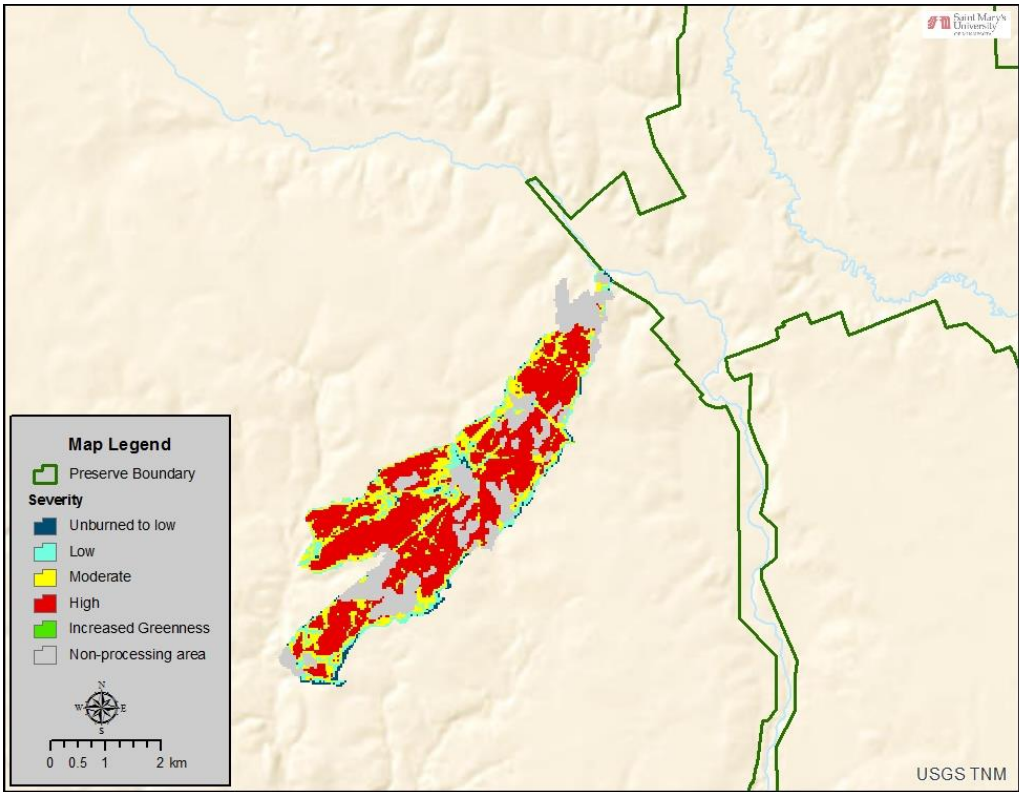

Figure A-2. MTBS burn severity data for an April 1996 wildfire just outside the BSCU (MTBS 2015b).

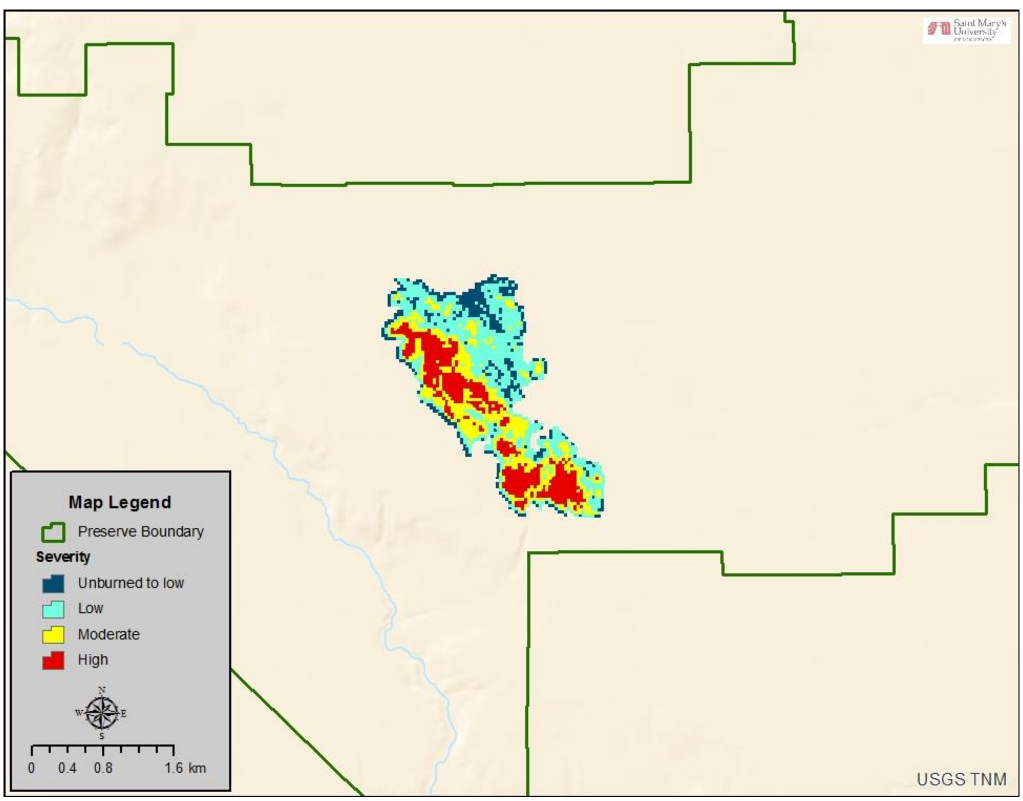

Figure A-3. MTBS burn severity data for a July 1998 wildfire in the Lance Rosier Unit (MTBS 2015b).

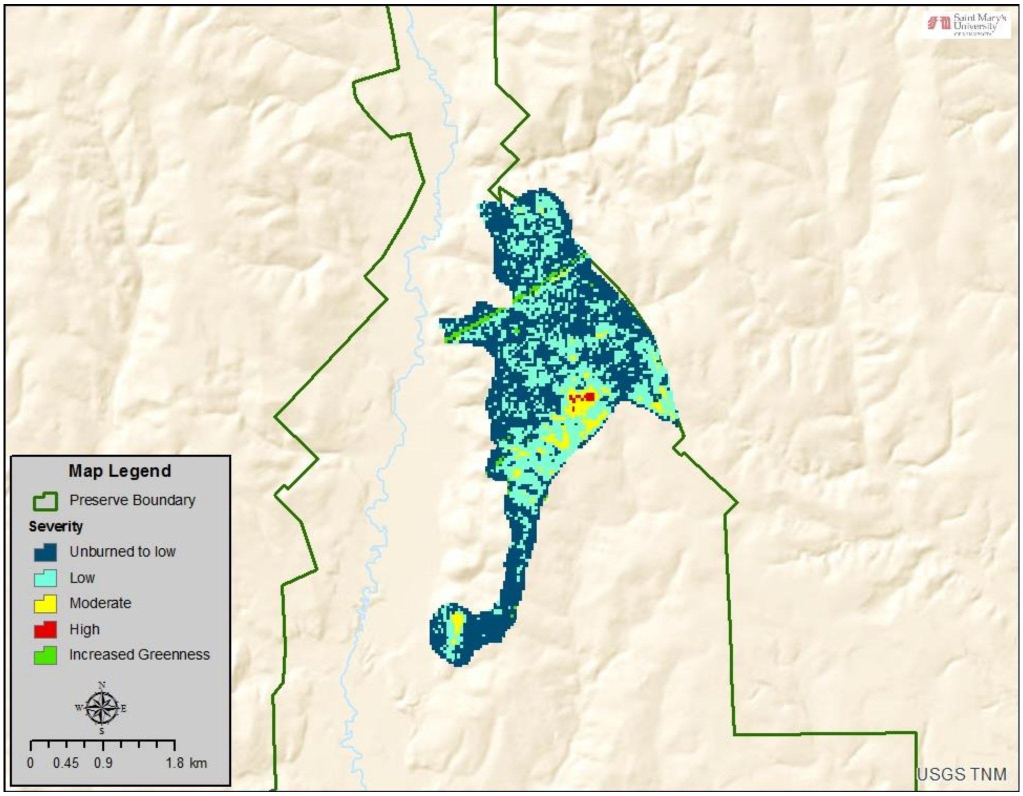

Figure A-4. MTBS burn severity data for a July 2001 prescribed fire in the BSCU (MTBS 2015b).

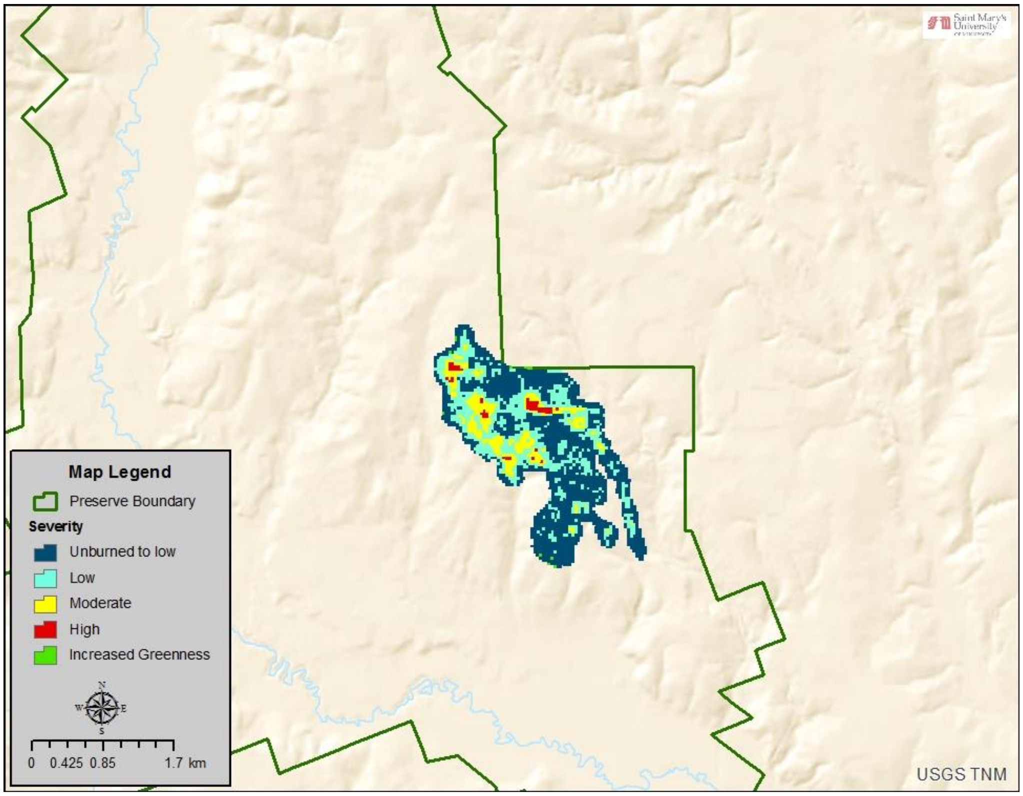

Figure A-5. MTBS burn severity data for an August 2001 prescribed fire in the BSCU (MTBS 2015b).

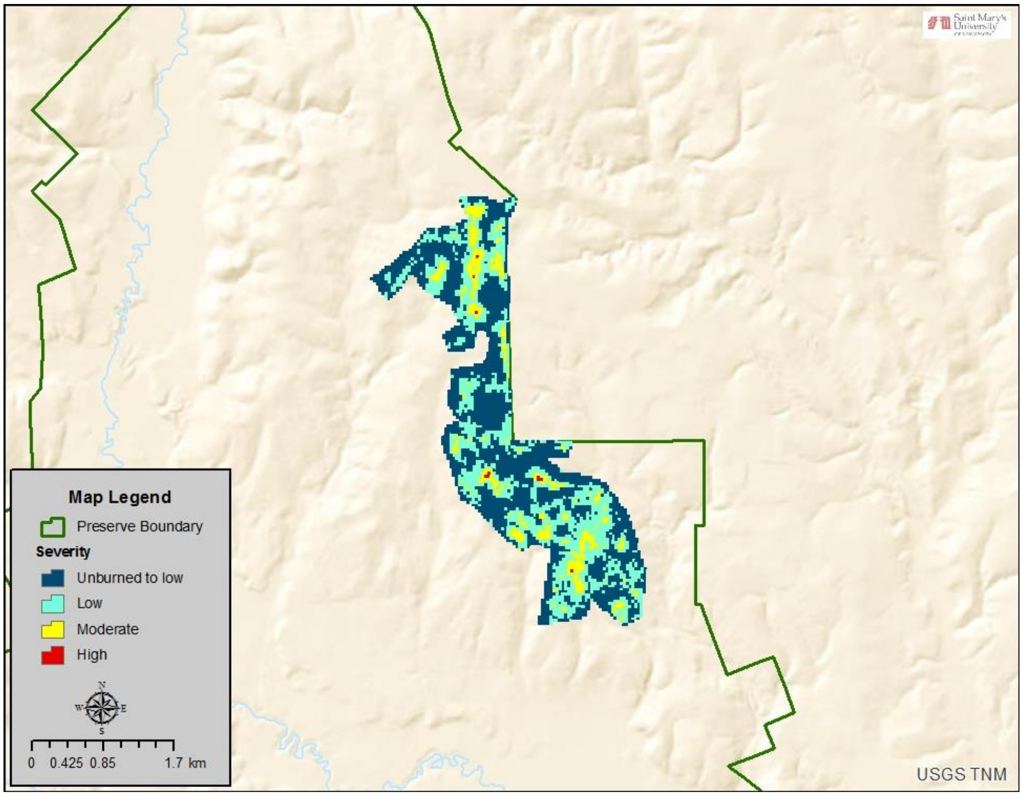

Figure A-6. MTBS burn severity data for a July 2004 prescribed fire in the BSCU (MTBS 2015b).

Appendix B. Prescribed and wildland fire locations.

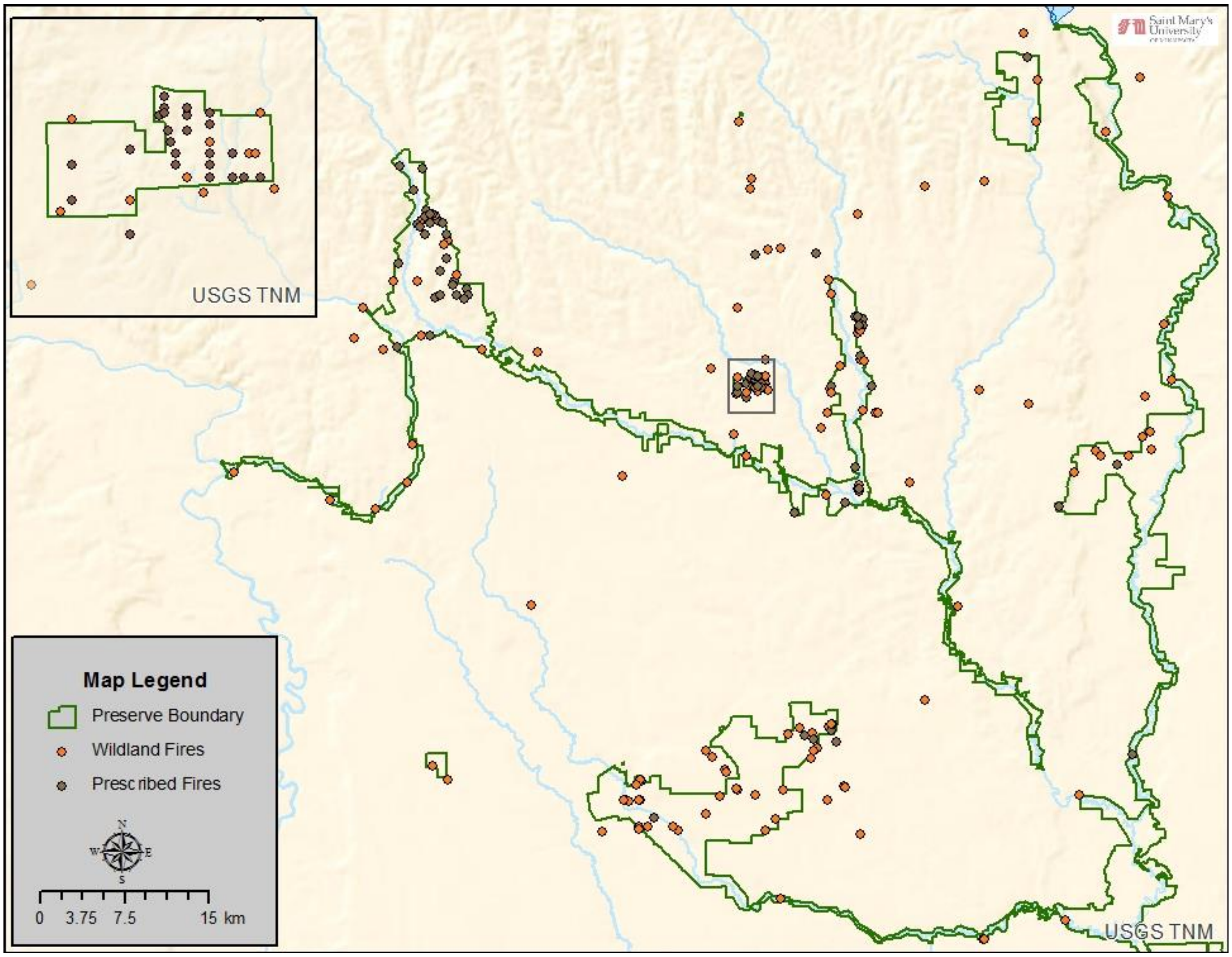

Figure B-1. Prescribed and wildland fire locations in and around BITH, 1976-2002 (Hansen 2004). The upper left map shows a close-up of the Hickory Creek Savanna Unit.

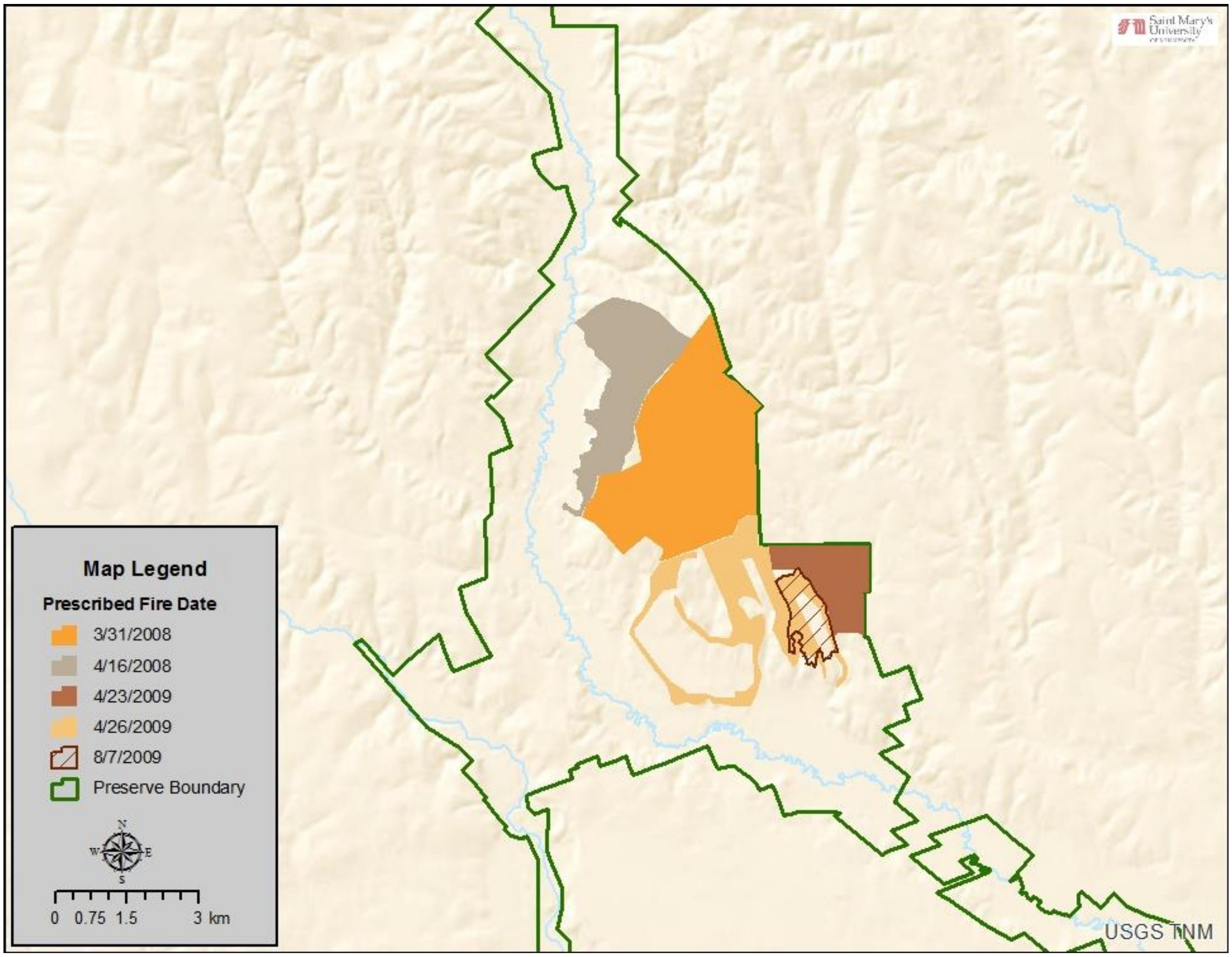

Figure B-2. Prescribed fires in the BSCU, 2008-2009 (NPS 2015a).

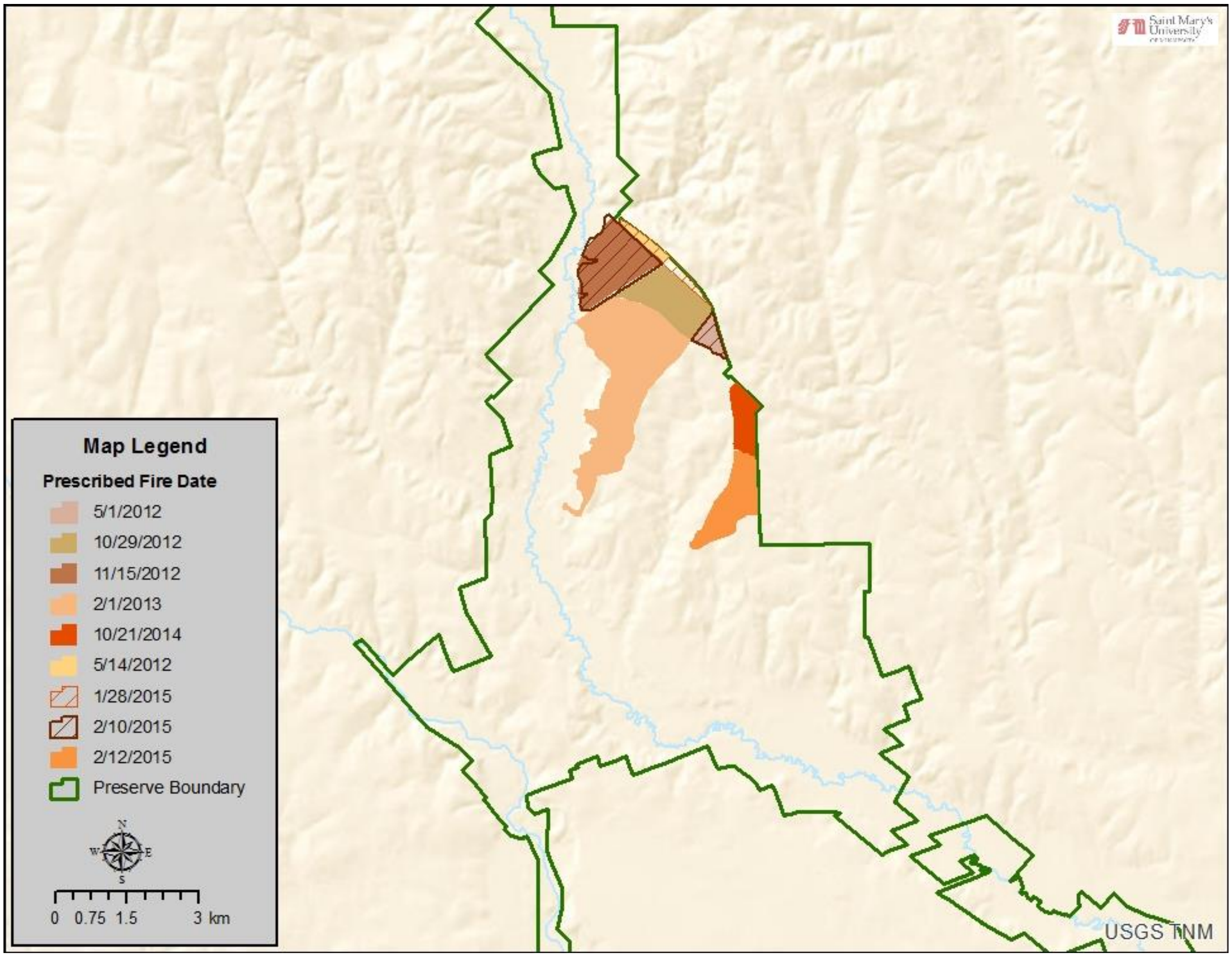

Figure B-3. Prescribed fires in the BSCU, 2010 - February 2015 (NPS 2015a).

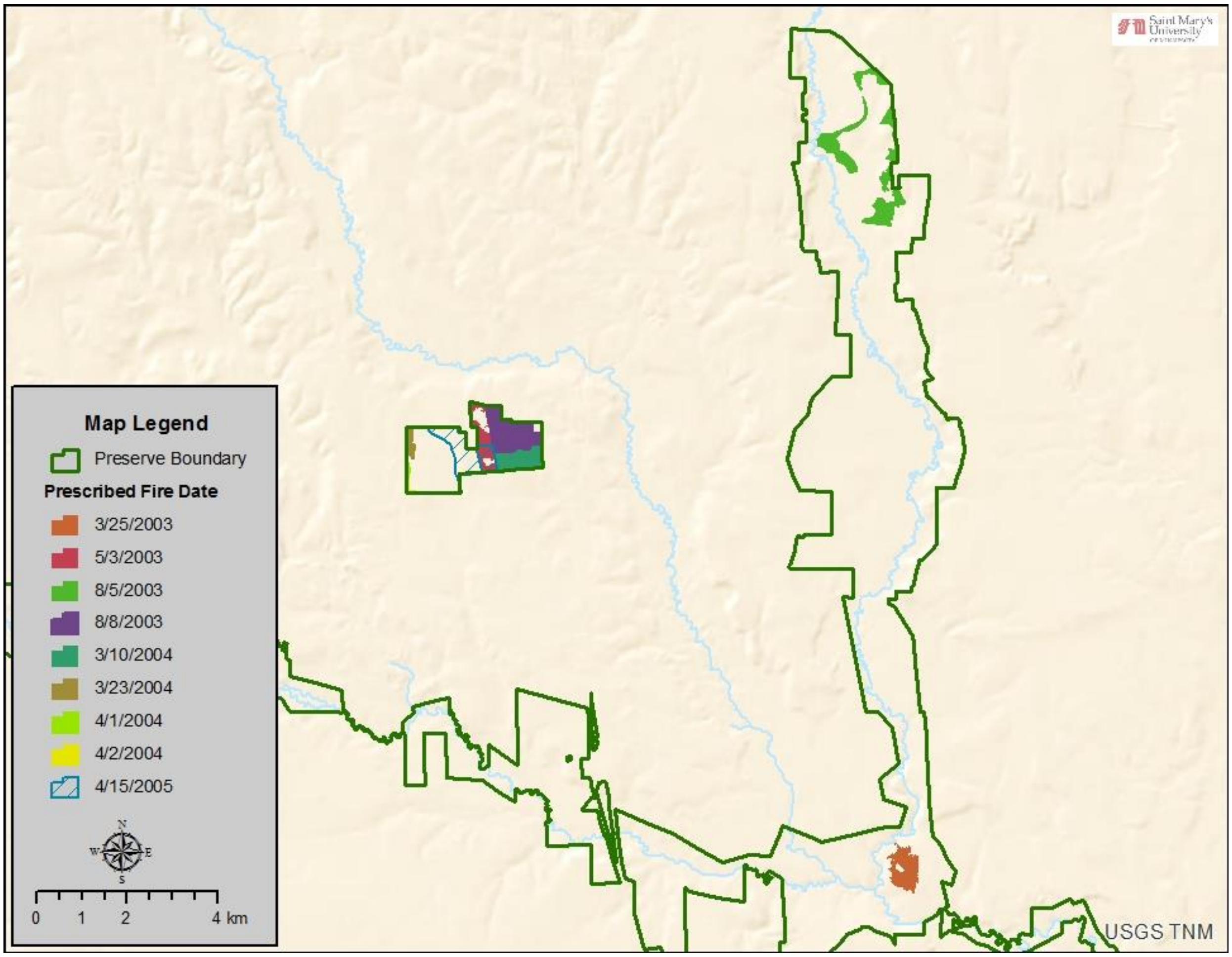

Figure B-4. Prescribed fires in the HSCU (smaller unit) and TCU (larger unit), 2003-2005 (NPS 2015a).

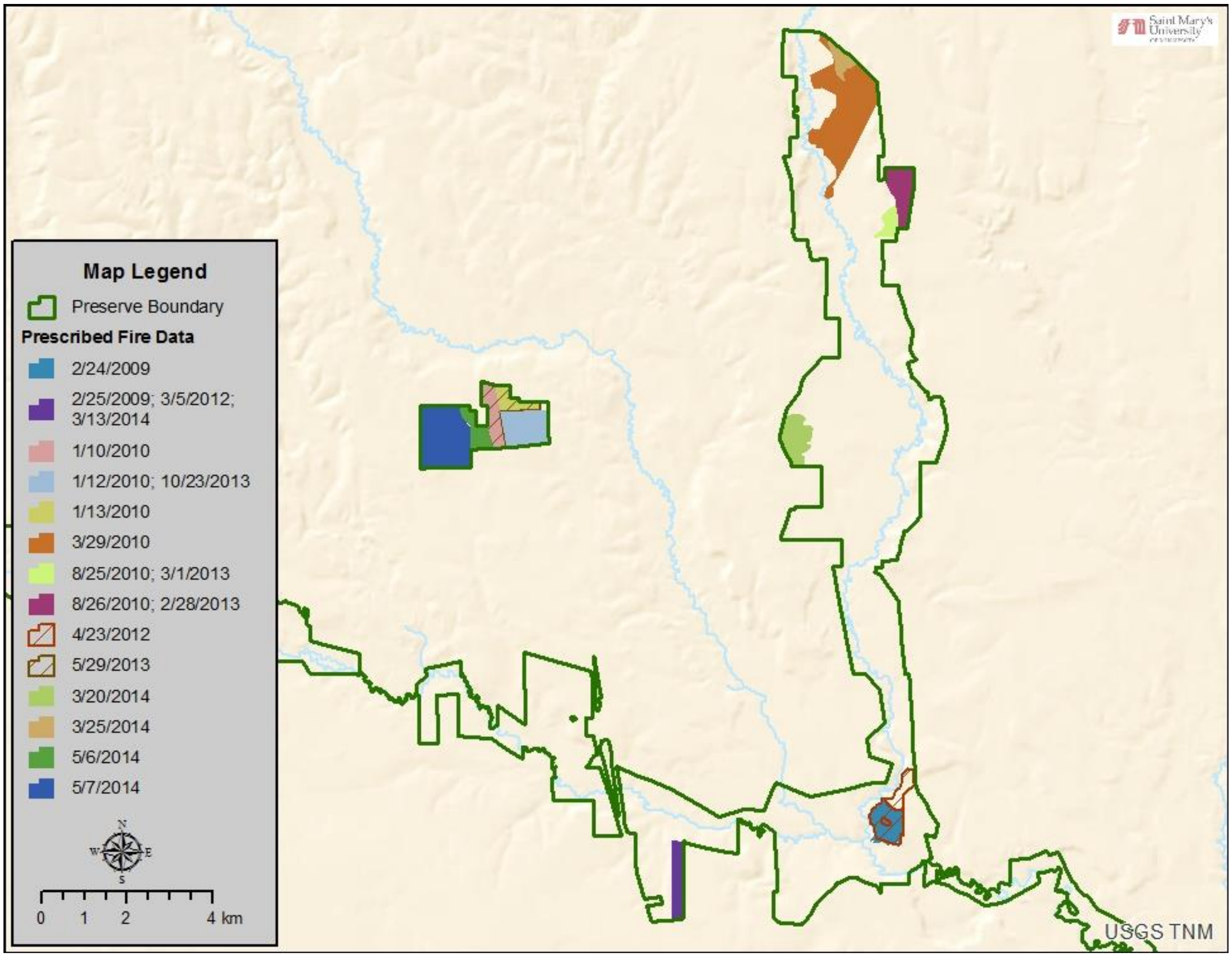

Figure B-5. Prescribed fires in the HSCU and TCU, 2009-2014 (NPS 2015a).

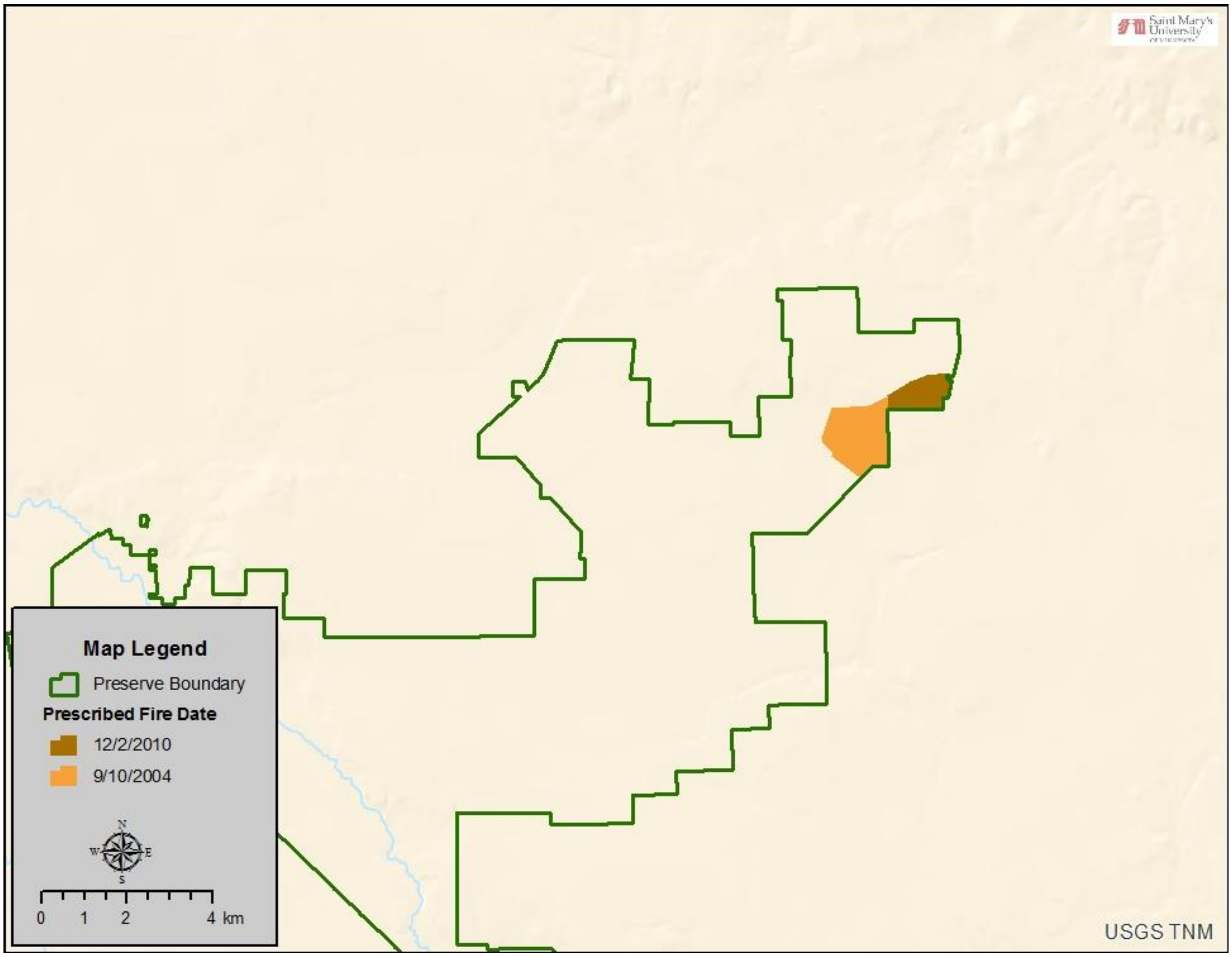

Figure B-6. Prescribed fires in the LRU, 2004-2014.

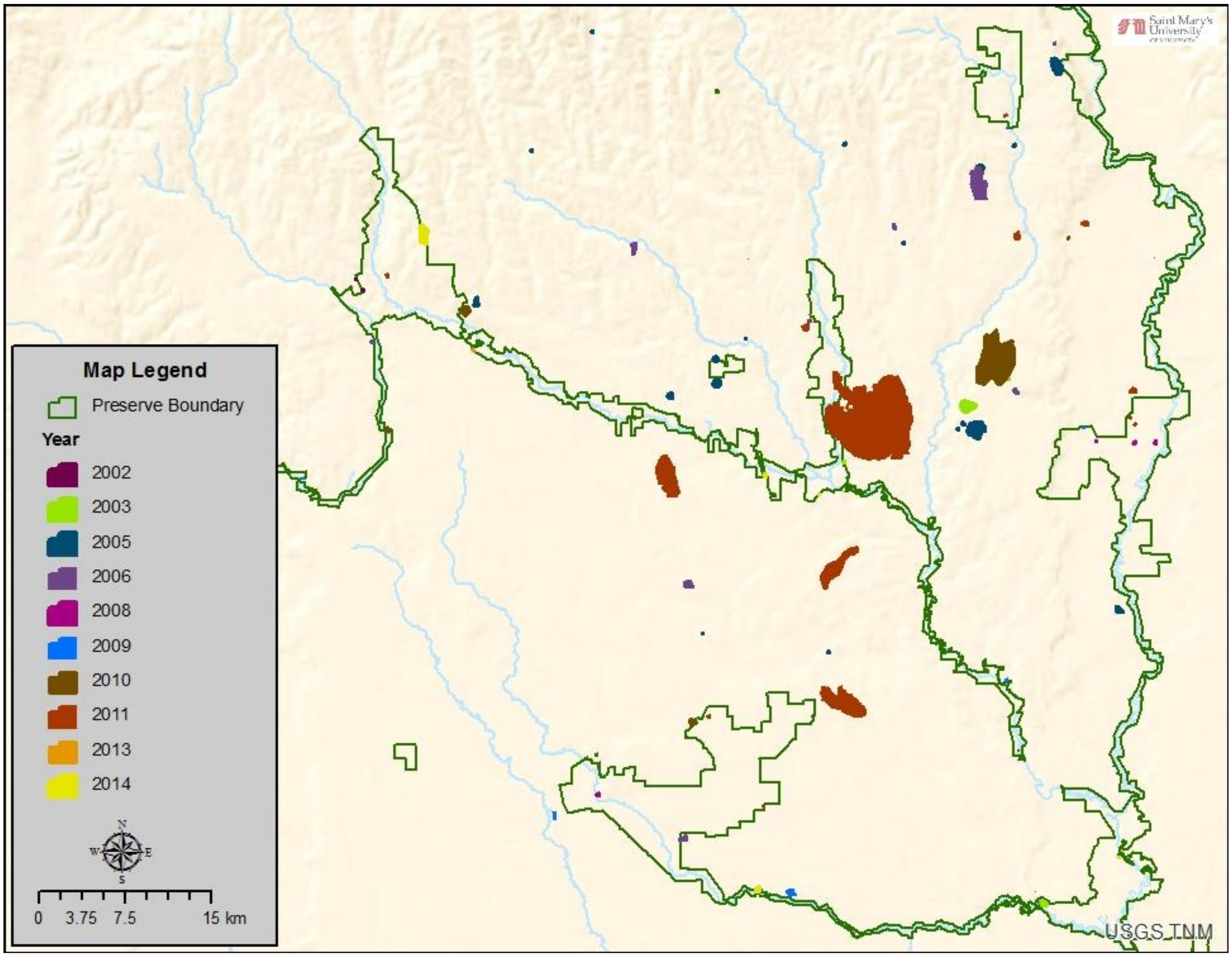

Figure B-7. Locations of wildfires in the BITH area by year, 2002-2014 (NPS 2015b). The size of polygons is not reflective of actual fire size as borders were "thickened" so that small fires would be visible on the map.

Appendix C. Herbaceous species occurring in BITH's pine upland habitats, according to Watson's vegetation classifications, Harcombe and Marks classifications (from Watson 1982), and DESCO (2007 - TCU only). Some scientific and common names were updated to match the USDA PLANTS database (http://plants.usda.gov/java/).

Scientific Name	Common Name	Watson	Harcombe & Marks	DESCO
Buchnera americana	American bluehearts	x	x	
Crotalaria sagittalis	arrowhead rattlebox	x	x	
Viola sagittata	arrowleaf violet	x	x	
Clitoria mariana	Atlantic pigeonwings	x		
Toxicodendron pubescens	Atlantic poison oak	x	x	x
Poa autumnalis	autumn bluegrass			x
Salvia azurea	azure blue sage	x	x	
Symphyotrichum pratense	barrens silky aster	x	x	
Oplismenus hirtellus	basketgrass			x
Agalinis fasciculata	beach false foxglove	x	x	
Bidens aristosa	bearded beggarticks	x	x	
Gymnopogon ambiguus	bearded skeletongrass	x	x	
Andropogon gerardii	big bluestem	x	x	
Eragrostis hirsuta	bigtop lovegrass	x	x	
Viola pedata	birdfoot violet	x	x	
Cardamine sp.	bittercress			x
Rudbeckia hirta	black-eyed susan	x	x	
Dichanthelium boscii	Bosc's panicgrass			x
Andropogon virginicus	broomsedge bluestem	x	x	
Paspalum plientulum	brownseed paspaulm	x	x	
Paspalum boscianum	bull crowngrass	x	x	
Euthamia leptocephala	bushy goldentop	x	x	
Asclepias tuberosa	butterflyweed	x	x	
Eryngium yuccifolium	button eryngo	x	x	
Lathyrus hirsutus	Caley pea	x	x	
Heterotheca subaxillaris	camphorweed	x	x	
Sanicula canadensis	Canadian blacksnakeroot			x
Conyza canadensis	Canadian horseweed	x	x	

* Species not recognized by the USDA PLANTS database (http://plants.usda.gov/java/)

+ Non-native species known to be invasive

Scientific Name	Common Name	Watson	Harcombe & Marks	DESCO
Stylodon carneus	Carolina false vervain	x	x	
Helianthemum carolinianum	Carolina frostweed	x		
Delphinium carolinianum	Carolina larkspur	x		
Lithospermum caroliniense	Carolina puccoon	x		
Ruellia caroliniensis	Carolina wild petunia	x	x	
Asclepias amplexicaulis	clasping milkweed	x	x	
Commelina diffusa	climbing dayflower	x	x	
Oldenlandia uniflora	clustered mille graines	x	x	
Cenchrus spinifex	coastal sandbur	x	x	
Aureolaria pectinata	combleaf yellow false foxglove	x	x	
Hypoxis hirsuta	common goldstar	x	x	
Verbascum thapsus	common mullein	x	x	
Sporobolus compositus	composite dropseed	x	x	
Lespedeza repens	creeping lespedeza	x	x	
Aristida desmantha	curly threeawn	x	x	
Muhlenbergia expansa	cutover muhly	x	x	
Dichanthelium dichotomum	cypress panicgrass			x
Elephantopus tomentosus	devil's grandmother			x
Stenaria nigricans var. *nigricans*	diamondflowers	x	x	
Eupatorium capillifolium	dogfennel			x
Rhynchosia reniformis	dollarleaf	x	x	
Rhynchosia difformis	doubleform snoutbean	x	x	
Phlox pilosa	downy phlox	x	x	
Paspalum praecox	early paspaulm	x	x	
Tripsacum dactyloides	eastern gamagrass	x	x	
Toxicodendron radicans	eastern poison ivy			x
Agrostis elliottiana	Elliott's bentgrass	x	x	
Bidens leptocephala	fewflower beggarticks	x	x	
Desmodium pauciflorum	fewflower ticktrefoil	x	x	
Eragrostis elliottii	field lovegrass	x	x	
Ionactis linariifolius	flaxleaf whitetop aster	x	x	
Paspalum floridanum	Florida paspalum	x	x	
Euphorbia corollata	flowering spurge	x	x	

* Species not recognized by the USDA PLANTS database (http://plants.usda.gov/java/)

+ Non-native species known to be invasive

Scientific Name	Common Name	Watson	Harcombe & Marks	DESCO
Trichostema dichotomum	forked bluecurls	x	x	
Ruellia humilis	fringeleaf wild petunia	x	x	
Hypoxis sessilis	glossyseed yellow star-grass	x	x	
Coreopsis tinctoria	golden tickseed	x	x	
Apios americana	groundnut; potato bean	x	x	
Yucca louisianensis	Gulf Coast yucca	x	x	
Muhlenbergia capillaris	hairawn muhly	x	x	
Lespedeza hirta	hairy lespedeza	x	x	
Lechea mucronata	hairy pinweed	x	x	
Desmodium ciliare	hairy small-leaf ticktrefoil	x	x	
Tradescantia hirsutiflora	hairyflower spiderwort	x	x	
Paspalum pubiflorum	hairyseed paspalum	x	x	
Croton argyranthemus	healing croton	x	x	
Physalis pubescens	husk tomato	x	x	
Lygodium japonicum+	Japanese climbing fern			x
Eragrostis capillaris	lace grass	x	x	
Gaillardia aestivalis	lanceleaf blanketflower	x	x	
Plantago aristata	largebracted plantain	x	x	
Symphyotrichum patens var. *patens*	late purple aster	x	x	
Scleria oligantha	littlehead nutrush			x
Chasmanthium sessiliflorum	longleaf woodoats			x
Ipomoea pandurata	man-of-the-earth	x	x	
Croton michauxii var. *ellipticus*	Michaux's croton	x	x	
Asclepias sp.	milkweed			x
Tephrosia onobrychoides	multibloom hoarypea	x	x	
Sisyrinchium angustifolium	narrowleaf blue-eyed grass	x	x	
Pityopsis graminifolia var. *graminifolia*	narrowleaf silkgrass	x	x	
Dichanthelium aciculare	needleleaf rosette grass			x
Clematis reticulata	netleaf leather flower	x	x	
Scleria reticularis	netted nutrush			x
Tragia urticifolia	nettleleaf noseburn	x	x	x
Penstemon laxiflorus	nodding beardtongue	x	x	
Baptisia nuttalliana	Nuttal's wild indigo	x	x	

* Species not recognized by the USDA PLANTS database (http://plants.usda.gov/java/)

+ Non-native species known to be invasive

Scientific Name	Common Name	Watson	Harcombe & Marks	DESCO
Desmodium nuttallii	Nuttall's ticktrefoil	x	x	
Polygonella polygama	October flower			x
Hymenopappus artemisiifolius	oldplainsman	x	x	
Dichanthelium laxiflorum	openflower rosette grass			x
Amorpha paniculata	panicled false indigo	x	x	
Desmodium paniculatum	panicledleaf ticktrefoil	x	x	
Chamaecrista fasciculata var. *fasciculata*	partridge pea	x	x	
Sporobolus junceus	pineywoods dropseed	x	x	
Strophostyles umbellata	pink fuzzybean	x	x	
*Gaillardia rosea**	pink gaillardia	x	x	
Liatris elegans	pinkscale blazing star	x	x	
Diodia teres	poorjoe	x	x	
Mimosa hystricina	porcupine mimosa	x	x	
Sisyrinchium campestre	prairie blue-eyed grass	x	x	
Rhynchosia latifolia	prairie snoutbean	x	x	
Aristida oligantha	prairie threeawn	x	x	
Alophia drummondii	propeller flower	x	x	
Desmodium rotundifolium	prostrate ticktrefoil	x	x	
Carex corrugata	prune-fruit sedge			x
Agalinis purpurea	purple false foxglove	x	x	
Eragrostis spectabilis	purple lovegrass	x	x	
Stillingia sylvatica	queen's-delight	x	x	
Hieracium gronovii	queendevil	x	x	
Pseudognaphalium obtusifolium	rabbit-tobacco	x		
Polygala polygama	racemed milkwort	x	x	
Eragrostis secundiflora	red lovegrass	x	x	
Pleopeltis polypodioides	resurrection fern			x
Symphyotrichum dumosum var. *dumosum*	rice button aster	x		
Glandularia canadensis	rose mock vervain	x	x	
Sabatia angularis	rosepink	x	x	
Richardia scabra	rough Mexican clover	x	x	
Lespedeza capitata	roundhead lespedeza	x	x	
Packera obovata	roundleaf ragwort	x	x	

* Species not recognized by the USDA PLANTS database (http://plants.usda.gov/java/)

[+] Non-native species known to be invasive

Scientific Name	Common Name	Watson	Harcombe & Marks	DESCO
Eupatorium rotundifolium	round-leaf throughwort	x	x	
Desmodium lineatum	sand ticktrefoil	x	x	
Andropogon hallii	sand bluestem	x	x	
Echinacea sanguinea	sanguine purple coneflower	x	x	
Chamaecrista nictitans ssp. *nictitans*	sensitive partridge pea	x	x	
Lespedeza cuneata	sericea lespedeza	x	x	
Gratiola pilosa	shaggy hedge hyssop	x	x	
Oligoneuron nitidum	shiny goldenrod	x	x	
Silphium simpsonii	Simpson's rosinweed	x	x	
Acalypha gracilens	slender 3-seed mercury	x	x	
Silphium gracile	slender rosinweed	x	x	
Carex digitalis	slender woodland sedge			x
Chasmanthium laxum	slender woodoats			x
Oxalis dillenii	slender yellow woodsorrel			x
Aristida longespica	slimspike threeawn	x	x	
Tragia smallii	Small's noseburn	x	x	x
Asimina parviflora	smallflower pawpaw	x	x	x
Agrimonia microcarpa	smallfruit agrimony	x	x	
Bidens mitis	smallfruit beggarticks	x	x	
Boltonia diffusa	smallhead doll's daisy	x	x	x
Bidens laevis	smooth beggartick	x	x	
Desmodium marilandicum	smooth small-leaf ticktrefoil	x	x	
Desmodium laevigatum	smooth ticktrefoil	x	x	
Houstonia micrantha	southern bluet	x	x	
Eurybia hemispherica	southern prairie aster	x	x	
Bidens bipinnata	Spanish needles	x	x	
Centrosema virginianum	spurred butterfly pea	x	x	
Ruellia pedunculata var. *pinetorium*	stalked wild petunia	x	x	
Galium tinctorium	stiff marsh bedstraw			x
Hypoxis rigida	stiff star-grass	x	x	
Desmodium obtusum	stiff ticktrefoil	x	x	
Lupinus perennis	sundial lupine			x
Helianthus angustifolius	swamp sunflower	x	x	

* Species not recognized by the USDA PLANTS database (http://plants.usda.gov/java/)

[+] Non-native species known to be invasive

Scientific Name	Common Name	Watson	Harcombe & Marks	DESCO
Lespedeza steuevei	tall lespedeza	x	x	
Eragrostis hypnoides	teal lovegrass	x	x	
Cnidoscolus texanus	Texas bullnettle	x		x
Aristolochia reticulata	Texas dutchman's pipe	x	x	
Euthamia gymnospermoides	Texas goldentop	x	x	
Berlandiera betonicifolia	Texas greeneyes	x	x	
Vernonia texana	Texas ironweed	x	x	
Senecio ampullaceus	Texas ragwort	x	x	
Verbena halei	Texas vervain	x	x	
Paspalum setaceum	thin paspaulm	x	x	
Viola triloba	three-lobe violet	x	x	
Desmodium sp.	ticktrefoil			x
Lespedeza procumbens	trailing lespedeza	x	x	
Lysimachia radicans	trailing yellow loosestrife			x
Rhynchosia tomentosa	twining snoutbean	x	x	
Melica mutica	twoflower melicgrass	x		
Dichanthelium commutatum	variable panicgrass			x
Clematis viorna	vasevine	x	x	
Desmodium viridiflorum	velvetleaf ticktrefoil	x	x	
Croton glandulosus var. *septentrionalis*	vente conmigo; tropic croton	x	x	
Lespedeza violacea	violet lespedeza	x	x	
Aristolochia serpentaria	Virginia snakeroot			x
Tephrosia virginiana	Virginia tephrosia	x	x	
Tragia urens	wavyleaf noseburn	x	x	x
Pteridium aquilinum	western brackenfern	x	x	
Dichanthelium acuminatum var. *fasciculatum*	western panicgrass	x	x	x
Ambrosia psilostachya	western ragweed	x	x	
Scleria triglomerata	whip nutrush			x
Boltonia asteroides	white doll's daisy	x	x	
Ageratina altissima	white snakeroot	x	x	
Pycnanthemum albescens	whiteleaf mountainmint	x	x	
Monarda fistulosa	wild bergamot	x	x	
Dioscorea villosa	wild yam			x

* Species not recognized by the USDA PLANTS database (http://plants.usda.gov/java/)

+ Non-native species known to be invasive

Scientific Name	Common Name	Watson	Harcombe & Marks	DESCO
Agrostis hyemalis	winter bentgrass	x	x	
Callirhoe papaver	woodland poppymallow	x	x	
Aristolochia tomentosa	woolly dutchman's pipe			x
Solidago rugosa	wrinkleleaf goldenrod	x	x	
Passiflora lutea	yellow passionflower	x	x	

* Species not recognized by the USDA PLANTS database (http://plants.usda.gov/java/)

+ Non-native species known to be invasive

Appendix D. Non-native plant species on the BITH Certified Species List (NPS 2015).

Scientific name	Common Name	Scientific name	Common Name
Aira elegans	annual silver hairgrass	*Echinochloa crus-galli*	barnyardgrass
Albizia julibrissin	silktree, powderpuff tree	*Echinochloa walteri*	coast cockspur grass
Alternanthera philoxeroides	alligatorweed	*Eichhornia crassipes*	common water hyacinth
Anagallis arvensis	scarlet pimpernel	*Elaeagnus pungens*	thorny elaeagnus, thorny olive
Ardisia crenata	coral ardisia, hen's eyes	*Eleusine indica*	Indian goosegrass, goose grass
Artemisia ludoviciana	white sagebrush	*Eremochloa ophiuroides*	centipede grass
Bambusa multiplex	hedge bamboo	*Euphorbia dentata*	toothed euphorbia, toothed spurge
Bothriochloa ischaemum var. *songarica*	king ranch bluestem, yellow bluestem	*Evolvulus sericeus*	silky evolvulus, silver dwarf morning-glory
Briza minor	little quakinggrass	*Facelis retusa*	annual trampweed
Bromus arvensis	field brome	*Gamochaeta antillana*	everlasting spp
Bromus catharticus	rescue brome, rescuegrass	*Gardenia jasminoides*	Cape jasmine
Bulbostylis barbata	watergrass	*Gymnostyles anthemifolia*	button burrweed
Cardamine debilis	roadside bittercress	*Hedera helix*	English ivy
Cardamine hirsuta	hairy bittercress	*Heliotropium indicum*	Indian heliotrope
Centaurium pulchellum	branched centaury	*Hypochaeris microcephala* var. *albiflora*	smallhead cat's ear,
Cerastium fontanum	common chickweed, common mouse-ear chickweed	*Ipomoea coccinea*	redstar
Cerastium glomeratum	sticky chickweed	*Ipomoea hederacea*	entireleaf morningglory, ivyleaf morningglory,
Cinnamomum camphora	camphor laurel, camphortree	*Iris pseudacorus*	paleyellow iris, yellow flag
Clematis terniflora	leatherleaf clematis, sweet autumn virginsbower	*Juncus capitatus*	leafybract dwarf rush
Cleome hassleriana	pink queen, spider-flower	*Kummerowia striata*	Japanese clover
Conyza bonariensis	asthmaweed, flax-leaf fleabane	*Lagerstroemia indica*	crapemyrtle
Cuphea carthagenensis	Colombian waxweed	*Lantana camara*	lantana, largeleaf lantana

Scientific name	Common Name	Scientific name	Common Name
Cuphea glutinosa	sticky waxweed	*Lathyrus hirsutus*	Caley pea, Singletary pea
Cyclospermum leptophyllum	marsh parsley	*Lespedeza cuneata*	Chinese lespedeza, sericea lespedeza
Cynodon dactylon	Bermudagrass	*Ligustrum lucidum*	glossy privet, tree privet
Cyperus esculentus	chufa flatsedge, yellow nutsedge	*Ligustrum sinense*	Chinese privet
Cyperus iria	ricefield flatsedge	*Lilium formosanum*	Formosa lily
Cyperus rotundus	nutgrass	*Lolium perenne*	perennial rye grass
Digitaria ischaemum	small crabgrass, smooth crab grass	*Lolium perenne* ssp. *perenne*	perennial rye grass, perennial ryegrass
Digitaria violascens	violet crabgrass	*Lonicera japonica*	Chinese honeysuckle, Japanese honeysuckle
Duchesnea indica	Indian strawberry	*Ludwigia grandiflora*	large-flower primrose-willow
Dysphania ambrosiodes	Mexican tea	*Lygodium japonicum*	Japanese climbing fern
Echinochloa colona	jungle rice, jungle ricegrass	*Malvastrum coromandelianum*	threelobe false mallow
Manihot grahamii	Graham's manihot	*Sherardia arvensis*	blue field-madder, field madder
Mazus pumilus	Japanese mazus	*Sida rhombifolia*	arrowleaf sida, Cuban jute
Medicago polymorpha	burclover, bur medick,	*Soliva mutisii*	Mutis' burrweed
Melia azedarach	chinaberrytree	*Soliva sessilis*	field burrweed, field soliva
Melilotus indicus	annual yellow sweetclover	*Sonchus asper*	spiny sowthistle, prickly sow thistle,
Morus alba	white mulberry	*Sonchus oleraceus*	annual sowthistle, common sowthistle,
Myriophyllum aquaticum	parrot feather watermilfoil, Brazilian watermilfoil	*Sorghum halepense*	Johnsongrass
Narcissus papyraceus	paperwhite narcissus	*Spiraea cantoniensis*	Reeves' meadowsweet
Narcissus tazetta	cream narcissus	*Stellaria media ssp. media*	common chickweed
Ophiopogon jaburan	lilyturf	*Teucrium cubense*	small coastal germander
Oxalis debilis var. corymbosa	pink woodsorrel	*Torilis arvensis*	spreading hedgeparsley
Parapholis incurva	curved sicklegrass	*Triadica sebifera*	Chinese tallow
Paspalum dilatatum	dallas grass, dallisgrass,	*Trifolium campestre*	field clover,

Scientific name	Common Name	Scientific name	Common Name
Paspalum notatum	Bahia grass, bahiagrass	*Trifolium dubium*	suckling clover
Paspalum urvillei	vaseygrass, Vasey's grass	*Trifolium incarnatum*	crimson clover
Perilla frutescens	beefsteakplant, beefsteak mint	*Trifolium lappaceum*	burdock clover
Phyllanthus urinaria	chamber bitter	*Trifolium repens*	white clover
Phyllostachys aurea	golden bamboo	*Trifolium resupinatum*	Persian clover, reversed clover
Poa annua	annual bluegrass,	*Verbascum thapsus*	common mullein
Polypogon monspeliensis	annual rabbitsfoot grass	*Verbena brasiliensis*	Brazilian vervain
Poncirus trifoliata	hardy orange	*Verbena rigida*	tuberous vervain
Pueraria montana var. lobata	Japanese arrowroot, kudzu	*Vernicia fordii*	tungoil tree
Pyracantha koidzumii	Formosa firethorn	*Veronica arvensis*	corn speedwell,
Pyrus calleryana	Callery pear	*Veronica polita*	gray field speedwell
Ranunculus muricatus	spinyfruit buttercup	*Vicia hirsuta*	hairy vetch, tiny vetch
Ranunculus parviflorus	smallflower buttercup, sticktight buttercup	*Vicia sativa ssp. nigra*	common vetch, garden vetch
Ranunculus sardous	hairy buttercup	*Vicia tetrasperma*	lentil vetch, smooth vetch
Rosa bracteata	Macartney rose	*Vicia villosa ssp. varia*	vetch woollypod, winter vetch
Rumex crispus	curly dock	*Vitex agnus-castus*	chaste tree, lilac chastetree
Rumex pulcher	fiddle dock	*Vitex negundo var. intermedia*	Chinese chastetree, negundo chastetree
Sacciolepis indica	glenwoodgrass	*Wahlenbergia marginata*	southern rockbell
Schedonorus arundinaceus	tall fescue	*Youngia japonica*	oriental false hawksbeard
Senna occidentalis	coffee senna, septicweed	*Zephyranthes candida*	autumn zephyrlily

Appendix E. Herbaceous species documented within BITH pine wetlands by MacRoberts and MacRoberts (1998), Watson (1982), Blanton and Associates, Inc. (2002), and DESCO (2007). LRU = Lance Rosier Unit, TCU = Turkey Creek Unit. o = orchid, * = insectivorous plant

		MacRoberts & MacRoberts (1998)		Watson (1982)	Blanton & Assoc. (2002)	DESCO (2007)
Scientific Name	**Common Name**	**LRU**	**TCU**		**LRU**	**TCU**
Buchnera americana	American bluehearts			x		
Rhynchospora caduca	anglestem beaksedge	x			x	
Chaetopappa asteroides	Arkansas leastdaisy			x		
Aristida purpurascens var. *virgata*	arrowfeather threeawn		x			x
Helianthus mollis	ashy sunflower			x		
Mecardonia acuminata	axilflower			x		
Mecardonia procumbens	baby jump-up			x		
Xyris baldwiniana	Baldwin's yelloweyed grass		x	x	x	
Agalinis fasciculata	beach false foxglove			x		
Bidens aristosa	bearded beggarticks			x		
Calopogon barbatus°	bearded grasspink			x		
Gaura sp.	beeblossom				x	
Bidens sp.	beggarticks				x	
Andropogon gerardii	big bluestem			x		
Axonopus furcatus	big carpetgrass				x	
Rudbeckia hirta	black-eyed susan			x		
Dichanthelium consanguineum	blood panicgrass	x				
Eryngium integrifolium	blueflower eryngo	x	x	x		x
Panicum tenerum	bluejoint panicgrass	x	x			x
Eleocharis obtusa	blunt spikerush			x		
Galium obtusum	bluntleaf bedstraw				x	
Viola lanceolata	bog white violet	x	x	x		
Xyris difformis var. *difformis*	bog yelloweyed grass	x				x
Oldenlandia boscii	Bosc's mille graines					x
Cyperus hystricinus	bristly flatsedge			x		
Andropogon virginicus	broomsedge bluestem			x	x	

° - orchid

* - insectivorous plant

Scientific Name	Common Name	MacRoberts & MacRoberts (1998) LRU	MacRoberts & MacRoberts (1998) TCU	Watson (1982)	Blanton & Assoc. (2002) LRU	DESCO (2007) TCU
Paspalum plicatulum	brownseed paspalum	x	x	x		
Rhynchospora cephalantha	bunched beaksedge			x		
Fuirena bushii	Bush's umbrella-sedge		x			
Andropogon glomeratus	bushy bluestem				x	x
Eryngium yuccifolium	button eryngo			x		
Symphyotrichum lateriflorum	calico aster				x	
Pluchea camphorata	camphor pluchea				x	
Pedicularis canadensis	Canadian lousewort			x		
Polygala nana	candyroot			x		
Bulbostylis ciliatifolia	capillary hairsedge					
Fimbristylis caroliniana	Carolina fimbry			x		
Ruellia caroliniensis	Carolina wild petunia				x	
Xyris caroliniana	Carolina yelloweyed grass	x	x	x		
Osmunda cinnamomea	cinnamon fern		x	x		
Gratiola neglecta	clammy hedgehyssop			x		
Hypericum gymnanthum	claspingleaf St. Johnswort			x		
Rhynchospora glomerata	clustered beaksedge	x		x		
Hyptis alata	clustered bushmint	x	x		x	
Oldenlandia uniflora	clustered mille graines			x		
Triantha racemosa	coastal false asphodel		x	x		x
Eragrostis refracta	coastal lovegrass	x	x		x	
Xyris ambigua	coastal plain yelloweyed grass	x	x	x		
Proserpinaca pectinata	combleaf mermaidweed	x			x	x
Hibiscus aculeatus	comfortroot			x		
Axonopus fissifolius	common carpetgrass	x	x			x
Hypoxis hirsuta	common goldstar	x	x	x		
Sporobolus compositus var. *compositus*	composite dropseed			x		
Eleocharis tuberculosa	cone-cup spikerush	x	x	x	x	x

° - orchid

* - insectivorous plant

Scientific Name	Common Name	MacRoberts & MacRoberts (1998) LRU	MacRoberts & MacRoberts (1998) TCU	Watson (1982)	Blanton & Assoc. (2002) LRU	DESCO (2007) TCU
Spartina sp.	cordgrass				x	
Eryngium prostratum	creeping eryngo			x		
Neeragrostis reptans	creeping lovegrass				x	
Hibiscus moscheutos	crimsoneyed rosemallow				x	
Hypoxis curtissii	Curtis' star-grass				x	
Dichanthelium dichotomum var. *dichotomum*	cypress panicgrass				x	
Carex joorii	cypress swamp sedge				x	
Bulbostylis capillaris	densetuft hairsedge			x		
Stenaria nigricans var. *nigricans*	diamondflowers			x		
Lobelia puberula var. *paciflora*	downy lobelia	x	x	x		
Sporobolus sp.	dropseed				x	
Polygala cruciata	drumheads		x	x		
Sisyrinchium minus	dwarf blue-eyed grass			x		
Eleocharis parvula	dwarf spikerush			x		
Hypericum mutilum	dwarf St. Johnswort				x	
*Drosera brevifolia**	dwarf sundew	x	x	x	x	
Paspalum praecox	early paspalum	x	x	x		x
Thelesperma flavodiscum	East Texas greenthread			x		
Symphyotrichum subulatum	eastern annual saltmarsh aster				x	
Sisyrinchium atlanticum	eastern blue-eyed grass	x	x			
Tripsacum dactyloides	eastern gamagrass				x	
Rhynchospora elliotti	Elliott's beaksedge	x	x			x
Andropogon gyrans var. *gyrans*	Elliott's bluestem			x		
Juncus elliottii	Elliott's rush			x		
Centella erecta	erect centella	x	x		x	x
Rhynchospora pusilla	fairy beaksedge	x				x
Manfreda virginica	false aloe			x		
Sida sp.	fanpetals				x	
Rhynchospora fascicularis	fascicled beaksedge			x		

° - orchid

* - insectivorous plant

Scientific Name	Common Name	MacRoberts & MacRoberts (1998) LRU	MacRoberts & MacRoberts (1998) TCU	Watson (1982)	Blanton & Assoc. (2002) LRU	DESCO (2007) TCU
Rhynchospora oligantha	featherbristle beaksedge		x	x	x	
Rhynchospora rariflora	fewflower beaksedge	x	x	x	x	x
Bidens leptocephala	fewflower beggarticks			x		
Asclepias lanceolata	fewflower milkweed			x		
Scleria pauciflora	fewflower nutrush			x	x	
Paspalum laeve	field paspalum	x			x	
Physostegia digitalis	finger false dragonhead			x		
Eriocaulon compressum	flattened pipewort			x		
Paspalum floridanum	Florida paspalum		x	x		x
Lobelia flaccidifolia	foldear lobelia	x		x		
Lycopodiella alopecuroides	foxtail clubmoss			x		
Rhexia petiolata	fringed meadowbeauty			x		
Scleria ciliata	fringed nutrush				x	
Helenium drummondii	fringed sneezeweed	x	x	x	x	
Ruellia humilis	fringeleaf wild petunia			x		x
Steinchisma hians	gaping grass				x	
Spiranthes longilabris°	giantspiral lady's tresses	x		x		
Rhynchospora globularis	globe beaksedge	x	x	x	x	x
Hypoxis sessilis	glossyseed yellow star-grass			x		
Aletris aurea	golden colicroot	x	x	x	x	
Coreopsis tinctoria	golden tickseed			x		
Marshallia graminifolia	grassleaf Barbara's buttons	x	x	x		
Juncus marginatus	grassleaf rush				x	
Rudbeckia maxima	great coneflower			x		
Agalinis viridis	green false foxglove					
Anthaenantia villosa	green silkyscale			x		
Spiranthes praecox°	greenvein lady's tresses	x			x	
Liatris tenuis	Gulf blazing star				x	
Eriocaulon koernickianum	gulf pipewort			x		

° - orchid

* - insectivorous plant

Scientific Name	Common Name	MacRoberts & MacRoberts (1998) LRU	MacRoberts & MacRoberts (1998) TCU	Watson (1982)	Blanton & Assoc. (2002) LRU	DESCO (2007) TCU
Muhlenbergia capillaris	hairawn muhly	x			x	
Fimbristylis puberula	hairy fimbry				x	x
Ludwigia pilosa	hairy primrose-willow	x	x			x
Scutellaria elliptica	hairy skullcap			x		x
Fuirena squarrosa	hairy umbrella-sedge			x	x	
Paspalum pubiflorum	hairyseed paspalum			x		
Rhexia virginica	handsome Harry			x		
Gentiana saponaria	harvestbells			x		
Gratiola sp.	hedgehyssop				x	
Dichanthelium oligosanthes var. *oligosanthes*	Heller's rosette grass				x	
Scutellaria integrifolia	helmet flower	x	x	x		
Ptilimnium capillaceum	herbwilliam	x	x	x		
Carex complanata	hirsute sedge				x	
Eupatorium hyssopifolium	hyssopleaf thoroughwort			x		
Xyris laxifolia var. *iridifolia*	irisleaf yelloweyed grass				x	
Eupatorium leucolepis	justiceweed	x	x	x		
Mimosa latidens	Kairn's sensitive-briar					x
Gaillardia aestivalis	lanceleaf blanketflower			x		
Coreopsis lanceolata	lanceleaf tickseed			x		
Eupatorium serotinum	lateflowering thoroughwort				x	
Juncus coriaceus	leathery rush			x		
Juncus repens	lesser creeping rush			x		
Ruellia strepens	limestone wild petunia			x		
Samolus ebracteatus	limewater brookweed			x		
Gaura lindheimeri	Lindheimer's beeblossom			x		
Schizachyrium scoparium	little bluestem	x	x		x	x
Spiranthes tuberosa°	little lady's tresses				x	
Lobelia sp.	lobelia				x	
Baptisia bracteata var. *leucophaea*	longbract wild indigo			x		

° - orchid

* - insectivorous plant

		MacRoberts & MacRoberts (1998)		Watson (1982)	Blanton & Assoc. (2002)	DESCO (2007)
Scientific Name	**Common Name**	**LRU**	**TCU**		**LRU**	**TCU**
Asclepias longifolia	longleaf milkweed	x	x	x	x	
Aristida palustris	longleaf threeawn	x	x			
Tridens strictus	longspike tridens	x		x	x	x
Xyris louisianica	Louisiana yelloweyed grass	x	x			
Polygala ramosa	low pinebarren milkwort	x	x	x		x
Hydrocotyle umbellata	manyflower marshpennywort			x		
Cyperus pseudovegetus	marsh flatsedge				x	
Rhexia mariana	Maryland meadowbeauty	x	x	x	x	x
Polygala mariana	Maryland milkwort	x	x	x	x	x
Mimosa sp.	mimosa; sensitive plant				x	
Rhynchospora mixta	mingled beaksedge			x	x	
Scleria muehlenbergii	Muehlenberg's nutrush			x		
Tephrosia onobrychoides	multibloom hoarypea	x		x	x	
Saccharum baldwinii	narrow plumegrass			x	x	
Iva angustifolia	narrowleaf marsh elder					x
Pycnanthemum tenuifolium	narrowleaf mountainmint			x		
Ludwigia linearis	narrowleaf primrose-willow	x		x		x
Pityopsis graminifolia	narrowleaf silkgrass		x		x	
Dichanthelium aciculare	needleleaf rosette grass					x
Juncus scirpoides	needlepod rush			x		
Woodwardia areolata	netted chainfern	x			x	
Scleria reticularis	netted nutrush	x	x			
Muhlenbergia schreberi	nimblewill				x	
Hypericum drummondii	nits and lice			x		
Rhynchospora inexpansa	nodding beaksedge	x		x	x	x
Spiranthes lacera var. *gracilis*°	northern slender lady's tresses			x		
Bigelowia nuttallii	Nuttall's rayless goldenrod					x

° - orchid

* - insectivorous plant

Scientific Name	Common Name	MacRoberts & MacRoberts (1998) LRU	MacRoberts & MacRoberts (1998) TCU	Watson (1982)	Blanton & Assoc. (2002) LRU	DESCO (2007) TCU
Physostegia virginiana ssp. *praemorsa*	obedient plant			x		
Rudbeckia fulgida	orange coneflower			x		x
Arnoglossum ovatum	ovateleaf cacalia	x	x	x	x	x
Lobelia appendiculata	pale lobelia			x		
Lobelia spicata	palespike lobelia			x		
Doellingeria umbellata	parasol whitetop			x		
Tridens ambiguus	pine barren fluffgrass	x	x		x	
Desmodium strictum	pine barren ticktrefoil			x		
Rhynchospora perplexa	pineland beaksedge					x
Asclepias obovata	pineland milkweed			x		
Bigelowia nudata ssp. *nudata*	pineland rayless goldenrod			x		
Sabatia gentianoides	pinewoods rose gentian	x	x	x		x
*Drosera capillaris**	pink sundew	x	x	x		x
Rhynchospora plumosa	plumed beaksedge	x	x	x	x	
Diodia teres	poorjoe				x	
Cyperus compressus	poorland flatsedge			x		
Mimosa hystricina	porcupine mimosa	x				
Liatris pycnostachya	prairie blazing star	x	x	x	x	x
Panicum brachyanthum	prairie panicgrass	x	x			
Ludwigia sp.	primrose-willow				x	
Polygala incarnata	procession flower			x	x	
Agalinis purpurea	purple false foxglove			x		
Anthaenantia rufa	purple silkyscale	x	x	x	x	
Helenium flexuosum	purplehead sneezeweed			x		
Tridens flavus	purpletop tridens			x		
Dichanthelium ravenelii	Ravenel's rosette grass					x
Eragrostis secundiflora	red lovegrass			x		
Juncus trigonocarpus	redpod rush					x
Panicum rigidulum var. *pubescens*	redtop panicgrass	x	x		x	

° - orchid

* - insectivorous plant

Scientific Name	Common Name	MacRoberts & MacRoberts (1998) LRU	MacRoberts & MacRoberts (1998) TCU	Watson (1982)	Blanton & Assoc. (2002) LRU	DESCO (2007) TCU
Ptilimnium costatum	ribbed mock bishopweed			x		
Symphyotrichum dumosum var. *dumosum*	rice button aster	x	x			
Xyris jupicai	Richard's yelloweyed grass			x		
Linum striatum	ridged yellow flax			x		
Agalinis oligophylla	ridgestem false foxglove			x		
Scleria hirtella	riverswamp nutrush			x		
Hibiscus lasiocarpos	rosemallow			x		
Silphium sp.	rosinweed				x	
Pluchea rosea	rosy camphorweed	x	x	x		
Gratiola virginiana	roundfruit hedgehyssop					x
*Drosera rotundifolia**	roundleaf sundew			x		
Eupatorium rotundifolium	roundleaf throughwort	x	x	x	x	
Osmunda regalis	royal fern		x	x	x	
Fuirena breviseta	saltmarsh umbrella-sedge	x		x		
Eleocharis montevidensis	sand spikerush			x		
Dichromena latifolia	sandswamp whitetop	x	x	x	x	
Rhynchospora debilis	savannah beaksedge	x				
Hibiscus coccineus	scarlet rosemallow			x		
Eriocaulon aquaticum	sevenangle pipewort			x		
Liatris acidota	sharp blazing star	x	x	x	x	x
Rudbeckia nitida	shiny coneflower			x		
Schizachyrium littorale	shore little bluestem			x		
Rhynchospora corniculata	shortbristle horned beaksedge				x	
Saccharum alopecuroides	silver plumegrass			x		
Silphium simpsonii	Simpson's rosinweed			x		
Orbexilum simplex	singlestem leather-root			x		
Rhynchospora gracilenta	slender beaksedge	x	x	x		

° - orchid

* - insectivorous plant

		MacRoberts & MacRoberts (1998)		Watson (1982)	Blanton & Assoc. (2002)	DESCO (2007)
Scientific Name	**Common Name**	**LRU**	**TCU**		**LRU**	**TCU**
Lycopodiella caroliniana	slender clubmoss		x	x		
Physostegia intermedia	slender false dragonhead			x		
Fimbristylis autumnalis	slender fimbry			x		
Schizachyrium tenerum	slender little bluestem			x		x
Sabatia campanulata	slender rose gentian			x		
Silphium gracile	slender rosinweed			x		
Chasmanthium laxum	slender woodoats				x	
Xyris torta	slender yelloweyed grass	x		x		
Scleria georgiana	slenderfruit nutrush	x	x			
Aristida longespica	slimspike threeawn			x		
*Pinguicula pumila**	small butterwort	x	x	x	x	
Bidens mitis	smallfruit beggarticks			x		
Eleocharis microcarpa	smallfruit spikerush	x	x	x	x	
Boltonia diffusa	smallhead doll's daisy	x	x	x	x	x
Bidens laevis	smooth beggarticks			x		
Pogonia ophioglossoides°	snakemouth orchid			x		
Platanthera nivea°	snowy orchid			x		
Saccharum brevibarbe var. *contortum*	sortbeard plumegrass			x		
Rhynchospora microcarpa	southern beaksedge			x		
Burmannia capitata	southern bluethread	x	x			
Lycopodiella appressa	southern bog clubmoss	x	x	x	x	x
Eurybia hemispherica	southern prairie aster			x		
Carex glaucescens	southern waxy sedge	x			x	
Sisyrinchium sagittiferum	spearbract blue-eyed grass			x		
Sphagnum sp.	sphagnum moss	x	x		x	x
Ludwigia hirtella	spindleroot	x		x		
Andropogon ternarius	splitbeard bluestem			x	x	x
*Drosera intermedia**	spoonleaf sundew				x	
Rhynchospora divergens	spreading beaksedge					

° - orchid

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Scientific Name	Common Name	MacRoberts & MacRoberts (1998) LRU	MacRoberts & MacRoberts (1998) TCU	Watson (1982)	Blanton & Assoc. (2002) LRU	DESCO (2007) TCU
Spiranthes vernalis°	spring lady's tresses	x		x		
Rhynchospora colorata	starrush whitetop			x	x	
Gratiola brevifolia	sticky hedgehyssop	x	x	x		
Oxypolis rigidior	stiff cowbane		x			
Galium tinctorium	stiff marsh bedstraw			x		
Hypoxis rigida	stiff star-grass			x		
Linum medium	stiff yellow flax	x	x	x	x	
Pluchea foetida	stinking camphorweed			x	x	x
Saccharum giganteum	sugarcane plumegrass	x			x	
Mitreola sessilifolia	swamp hornpod	x	x	x		
Helianthus angustifolius	swamp sunflower	x		x	x	x
Panicum virgatum	switchgrass	x				
Dichanthelium acuminatum var. *acuminatum*	tapered rosette grass				x	x
Eragrostis hypnoides	teal lovegrass			x		
Eriocaulon decangulare	tenangle pipewort	x	x	x	x	x
Eriocaulon texense	Texas pipewort			x		
Sabatia campestris	Texas star			x		
Coreopsis linifolia	Texas tickseed	x	x	x		x
Rhynchospora filifolia	threadleaf beaksedge	x		x		x
Aristida sp.	threeawn				x	
Calopogon tuberosus°	tuberous grasspink	x	x	x	x	
Fimbristylis vahlii	Vahl's fimbry			x		
Dichanthelium scoparium	velvet panicum				x	
Diodia virginiana	Virginia buttonweed	x	x		x	
Woodwardia virginica	Virginia chainfern	x	x	x		x
Panicum verrucosum	warty panicgrass	x	x			
Oxypolis filiformis	water cowbane	x	x			
Callitriche sp.	water-starwort				x	
Eupatorium glaucescens	waxy thoroughwort			x		
Juncus debilis	weak rush			x		

° - orchid

* - insectivorous plant

		MacRoberts & MacRoberts (1998)		Watson (1982)	Blanton & Assoc. (2002)	DESCO (2007)
Scientific Name	**Common Name**	**LRU**	**TCU**		**LRU**	**TCU**
Scleria triglomerata	whip nutrush				x	
Sisyrinchium albidum	white blue-eyed grass			x		
Boltonia asteroides	white doll's daisy			x		
Bartonia verna	white screwstem		x			
Ageratina altissima	white snakeroot			x	x	
Eupatorium album	white throughwort			x		
Lachnocaulon anceps	whitehead bogbutton		x		x	
Hydrocotyle verticillata	whorled marshpennywort			x		
Asclepias verticillata	whorled milkweed			x		
Lythrum alatum var. *lanceolatum*	winged lythrum			x		
Chaptalia tomentosa	woolly sunbonnets	x	x	x		
Dichanthelium scabriusculum	wooly rosette grass	x	x			
Solidago caesia	wreath goldenrod			x		
Dichanthelium wrightianum	Wright's rosette grass	x	x			
Coelorachis rugosa	wrinkled jointtail grass	x		x		
Solidago rugosa	wrinkleleaf goldenrod			x		
Platanthera ciliaris°	yellow fringed orchid			x		
Rhexia lutea	yellow meadowbeauty	x	x	x	x	x
Schoenolirion croceum	yellow sunnybell	x	x	x	x	
*Sarracenia alata**	yellow trumpets		x	x	x	x
*Utricularia subulata**	zigzag bladderwort	x	x		x	x
Viola x *primulifolia*			x	x		
Total		**100**	**88**	**205**	**107**	**57**

° - orchid

* - insectivorous plant

Appendix F. Avian species identified in BITH. Species in bold indicate Neotropical migrant species from TPWD (2015) present in the preserve. P = Probable, U = Unconfirmed, N = Not in Park, X = Confirmed, 1 = Beaumont Unit only, 2 = Loblolly Unit only, 3 = Turkey Creek Unit only.

Species	NPS (2015b)	Fisher (1974)	Bryan et al. (1976)	Biercevicz (1977)	Deuel and Fisher (1977)	Ramsey (1980)[1]	McGuffin (1984)[2]	BBS (All Routes)	CBC (Both)	Granger (2015)
Acadian Flycatcher	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Black-necked Stilt	**P**	**X**		**P**						
American Avocet	P	X								
American Bittern	P	X		P						
American Black Duck	U	P								
American Coot	P	X		P					X	
American Crow	X	X	X	X	X	X	X	X	X	X
American Golden Plover	**P**	**X**								
American Goldfinch	P	X	X		X	X			X	
American Kestrel	X	X		X				X	X	
American pipit									X	
American Redstart	**X**	**X**	**X**		**X**			**X**		
American Robin	P	X		P	X	X	X	X	X	
American Swallow-tailed Kite	P									
American Tree Sparrow		X								
American White Pelican	P	X		P					X	
American Wigeon	P	X		P					X	
American Woodcock	P	X					X		X	
Anhinga	**X**	**X**	**X**	**X**				**X**	**X**	
Bachman's Sparrow	P	X	X					X	X	
Bachman's Warbler	P			P						

Species	NPS (2015b)	Fisher (1974)	Bryan et al. (1976)	Biercevicz (1977)	Deuel and Fisher (1977)	Ramsey (1980)[1]	McGuffin (1984)[2]	BBS (All Routes)	CBC (Both)	Granger (2015)
Baird's Sandpiper	**P**	**X**								
Bald Eagle	P	X							X	
Baltimore Oriole, Northern Oriole	**X**	**X**	**X**	**X**	**X**					
Bank Swallow	**X**	**X**		**X**						
Barn Owl	P	X		P						
Barn Swallow	**P**	**X**	**X**	**P**	**X**			**X**		
Barred Owl	X	X	X	X	X		X	X	X	
Bay-breasted Warbler	**P**	**P**			**X**	**X**				
Bell's Vireo	**P**	**X**								
Belted Kingfisher	P	X	X	X	X	X			X	
Bewick's Wren	P	X							X	
Black Skimmer	**P**			**P**						
Black Tern	**P**	**X**		**P**						
Black Vulture	X	X	X	X			X	X	X	
black-and-white vireo		X								
Black-and-white Warbler	**X**		**X**	**X**	**X**	**X**	**X**	**X**	**X**	
Black-bellied Plover	**P**	**X**		**P**						
Black-bellied Whistling-duck	P								X	
Black-billed Cuckoo	**P**	**X**								
Blackburnian Warbler	**P**	**X**								
Black-crowned Night Heron	**P**	**X**		**P**				**X**	**X**	
Black-headed Grosbeak	**P**	**X**								
black-legged kittiwake		X								
Black-necked Grebe, Eared Grebe	P	X								
Blackpoll Warbler	**P**	**X**								

Species	NPS (2015b)	Fisher (1974)	Bryan et al. (1976)	Biercevicz (1977)	Deuel and Fisher (1977)	Ramsey (1980)[1]	McGuffin (1984)[2]	BBS (All Routes)	CBC (Both)	Granger (2015)
Black-shouldered Kite, Black-winged Kite	P (?)									
Black-throated Blue Warbler	**P**	**P**								
Black-throated Green Warbler	**P**	**X**					**X**			
Blue Grosbeak	**X**	**X**	**X**	**X**				**X**		
Blue Jay	X	X	X	X	X	X	X	X	X	X
Blue-gray Gnatcatcher	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Blue-headed vireo									**X**	
Blue-winged Teal	P	X		P	X				X	
Blue-winged Warbler	**P**	**X**					**X**			
Boat-tailed Grackle	P	X		P					X	
Bobolink	**P**	**P**								
Bonaparte's Gull	P	X							X	
Brewer's Blackbird	P	X							X	
Broad-winged Hawk	**X**	**X**	**X**	**P**	**X**		**X**	**X**	**X**	
Brown Creeper	P	X			X	X	X		X	
Brown Thrasher	X	X		X	X	X	X	X	X	
Brown-headed Cowbird	X	X	X	P	X	X	X	X	X	X
Brown-headed Nuthatch	X	X	X	X	X			X	X	
Buff-breasted Sandpiper	**P**	**X**								
Bufflehead	P	P							X	
Canada Goose	P	X						X	X	
Canada Warbler	**P**	**X**				**X**				
Canvasback	P	X							X	
Cape May Warbler	**P**	**P**								
Carolina Chickadee	X	X	X	X	X	X	X	X	X	X

Species	NPS (2015b)	Fisher (1974)	Bryan et al. (1976)	Biercevicz (1977)	Deuel and Fisher (1977)	Ramsey (1980)[1]	McGuffin (1984)[2]	BBS (All Routes)	CBC (Both)	Granger (2015)
Carolina Wren	X	X	X	X	X	X	X	X	X	X
Caspian Tern	**P**	**X**		**P**					**X**	
Cattle Egret	**X**	**X**	**X**	**X**	**X**		**X**	**X**	**X**	
Cave swallow								**X**		
Cedar Waxwing	P	X						X	X	
Cerulean Warbler	**P**	**X**								
Chestnut-sided Warbler	**P**		**X**		**X**	**X**				
Chimney Swift	**X**	**X**	**X**	**X**	**X**			**X**		**X**
Chipping Sparrow	**X**	**X**	**X**	**X**				**X**	**X**	
Chuck-will's-widow	**X**	**X**	**X**	**X**		**X**		**X**		
Cinnamon Teal	**P**	**P**								
Clapper Rail	P			P						
Clark's Nutcracker	U	X								
Clay-colored Sparrow	P	P								
Cliff Swallow	**P**	**X**						**X**	**X**	
Common gallinule		X		P				X	X	
Common Goldeneye	P	X								
Common Grackle	X	X	X	X	X			X	X	
Common Ground Dove	P	X							X	
Common Loon	P	X							X	
Common Moorhen	**P**									
Common Nighthawk	**X**	**X**	**X**	**X**			**X**	**X**		
Common Pigeon (Rock Dove/Pigeon)	P			P				X	X	
Common Snipe	X	X		P					X	
Common Tern	**P**	**X**							**X**	

Species	NPS (2015b)	Fisher (1974)	Bryan et al. (1976)	Biercevicz (1977)	Deuel and Fisher (1977)	Ramsey (1980)[1]	McGuffin (1984)[2]	BBS (All Routes)	CBC (Both)	Granger (2015)
Common Yellowthroat	**X**	**X**	**X**	**X**				**X**	**X**	
Connecticut warbler		P								
Cooper's Hawk	X	X	X	X					X	
Couch's kingbird									X	
Crested Caracara	P	X								
Dark-eyed Junco	P	X							X	
Dickcissel	**P**	**X**								
Double-crested Cormorant	X	X		X					X	
Downy Woodpecker	X	X	X	X	X		X	X	X	X
Dunlin	P	X								
Eared grebe									X	
Eastern Bluebird	P	X	X					X	X	
Eastern Kingbird	**P**	**X**	**X**	**X**				**X**	**X**	
Eastern Meadowlark	P	X		P				X	X	
Eastern Phoebe	X	X		X	X	X	X	X	X	
Eastern Screech-owl	X	X	X						X	
Eastern towhee	P	X			X		X	X	X	
Eastern Wood-pewee	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	
Eskimo Curlew	**P**									
Eurasian collared-dove								X	X	
Eurasian Teal (Green-winged Teal)	P									
European Herring Gull (Herring Gull)	P	X							X	
European Starling	P	X		P		X		X	X	
Evening Grosbeak	P	X							X	
Field Sparrow	P	X							X	

Species	NPS (2015b)	Fisher (1974)	Bryan et al. (1976)	Biercevicz (1977)	Deuel and Fisher (1977)	Ramsey (1980)[1]	McGuffin (1984)[2]	BBS (All Routes)	CBC (Both)	Granger (2015)
Fish Crow	P	X	X	P	X	X		X	X	
Forster's Tern	**P**	**X**		**P**					**X**	
Fox Sparrow	P	X				X			X	
Franklin's Gull	**P**									
Fulvous Whistling Duck	P			P						
Gadwall	P	X							X	
Golden Eagle	U	X								
Golden-crowned Kinglet	P	X					X		X	
Golden-winged Warbler	**P**	**X**								
Grasshopper Sparrow	**P**	**X**							**X**	
Gray Catbird	**X**	**X**	**X**	**X**	**X**	**X**		**X**	**X**	**X**
Gray-cheeked Thrush	**P**	**P**								
Great Blue Heron	X	X	X	X	X	X	X	X	X	
Great Crested Flycatcher	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		
Great Egret	**X**	**X**	**X**	**P**				**X**	**X**	
Great Horned Owl	X	X	X	X			X		X	
Greater Prairie Chicken	N	P								
Greater Roadrunner	X	X	X	X				X	X	
Greater Scaup	P	X								
Greater White-fronted Goose	P	X		P					X	
Greater Yellowlegs	**P**	**X**		**P**					**X**	
Great-tailed Grackle	P	X		P					X	
Green Heron	**X**	**X**	**X**	**X**	**X**	**X**		**X**	**X**	
green-winged teal		X							X	
Groove-billed Ani	**P**	**X**		**P**						

Species	NPS (2015b)	Fisher (1974)	Bryan et al. (1976)	Biercevicz (1977)	Deuel and Fisher (1977)	Ramsey (1980)[1]	McGuffin (1984)[2]	BBS (All Routes)	CBC (Both)	Granger (2015)
Gull-billed Tern	**P**			**P**						
Hairy Woodpecker	X	X	X	X	X			X	X	
Harris' Sparrow	P	X							X	
Henslow's Sparrow	P	X							X	
Hermit Thrush	P	X			X	X	X		X	
Hooded Merganser	P	X							X	
Hooded Warbler	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		**X**
Horned Grebe	P	X								
Horned Lark	P	X		P						
House Finch	X									
House Sparrow	X	X	X	P				X	X	
House Wren	**P**	**X**							**X**	
Hudsonian Godwit	**P**	**P**								
Inca Dove	P	X						X	X	
Indigo Bunting	**X**	**X**	**X**	**X**	**X**		**X**	**X**		**X**
Ivory-billed Woodpecker	N	P								
Kentucky Warbler	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		
Killdeer	P	X	X	P				X	X	
King Rail	P	X		P						
Lapland Longspur	P	P							X	
Lark Sparrow	P	X	X						X	
Laughing Gull	**P**			**P**					**X**	
Le Conte's Sparrow	P	X							X	
Least Bittern	**P**	**X**		**P**						
Least Flycatcher	**P**	**P**							**X**	

Species	NPS (2015b)	Fisher (1974)	Bryan et al. (1976)	Biercevicz (1977)	Deuel and Fisher (1977)	Ramsey (1980)[1]	McGuffin (1984)[2]	BBS (All Routes)	CBC (Both)	Granger (2015)
Least Sandpiper	**P**	**X**								
Least Tern	P									
Lesser Scaup	P	X		P					X	
Lesser Yellowlegs	**P**	**X**							**X**	
Lincoln's Sparrow	**P**	**X**							**X**	
Little Blue Heron	**X**	**X**	**X**	**X**	**X**	**X**		**X**	**X**	
Loggerhead Shrike	X	X		X				X	X	
Long-billed Curlew	P	X		P						
Long-billed Dowitcher	P	P								
Long-eared Owl	P									
Louisiana Waterthrush	**X**	**X**	**X**		**X**			**X**		
Magnificent Frigatebird	P			P						
Magnolia Warbler	**P**	**X**				**X**			**X**	
Mallard	P	X		P					X	
Marbled Godwit	P	X								
Marsh Wren	P	X							X	
Merlin	**P**	**X**							**X**	
Mississippi Kite	**P**	**X**		**X**	**X**			**X**		
Mottled Duck	X	X		X						
Mourning Dove	X	X	X	X	X	X		X	X	X
Mourning Warbler	**P**	**X**								
Nashville Warbler	**P**	**P**								
Neotropic cormorant	P			P					X	
Northern Bobwhite	X	X	X	X	X			X	X	
Northern Cardinal	X	X	X	X	X	X	X	X	X	X

Species	NPS (2015b)	Fisher (1974)	Bryan et al. (1976)	Biercevicz (1977)	Deuel and Fisher (1977)	Ramsey (1980)[1]	McGuffin (1984)[2]	BBS (All Routes)	CBC (Both)	Granger (2015)
Northern Flicker	P	X	X	X	X	X	X	X	X	
Northern Harrier	P	X		P					X	
Northern Mockingbird	X	X		X	X			X	X	
Northern Parula	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		**X**
Northern Pintail	P	X		P					X	
Northern Rough-winged Swallow	**P**	**X**	**X**	**P**	**X**			**X**		
Northern Saw-whet Owl	U	X								
Northern Shoveler	P	X							X	
Northern Waterthrush	**P**	**X**								
Olive-sided Flycatcher	**P**	**X**							**X**	
Orange-crowned Warbler	**P**	**X**			**X**				**X**	
Orchard Oriole	**X**	**X**	**X**	**X**				**X**		
Osprey, Western Osprey	**P**	**X**		**P**					**X**	
Ovenbird	**X**	**X**	**X**							
Painted Bunting	**X**	**X**	**X**	**X**				**X**		
Palm Warbler	**P**	**X**							**X**	
Pectoral Sandpiper	**P**	**X**								
Peregrine Falcon	**P**	**X**		**P**						
Philadelphia Vireo	**P**	**X**								
Pied-billed Grebe	P	X		P					X	
Pileated Woodpecker	X	X	X	X	X	X	X	X	X	X
Pine Siskin	P	X							X	
Pine Warbler	X	X	X	X	X			X	X	X
Piping Plover	U	P								
Prairie falcon		X								

Species	NPS (2015b)	Fisher (1974)	Bryan et al. (1976)	Biercevicz (1977)	Deuel and Fisher (1977)	Ramsey (1980)[1]	McGuffin (1984)[2]	BBS (All Routes)	CBC (Both)	Granger (2015)
Prairie Warbler	**X**	**X**	**X**	**X**				**X**	**X**	
Prothonotary Warbler	**X**	**X**	**X**	**X**	**X**	**X**		**X**		**X**
Purple Finch	P	X	X		X				X	
Purple Gallinule	**P**	**X**		**P**						
Purple Martin	**X**	**X**		**X**	**X**			**X**		
Red Crossbill	U	X								
Red-bellied Woodpecker	P	X	X	X	X	X	x	X	X	X
Red-breasted Merganser	P	X								
Red-breasted Nuthatch	P	X					X		X	
Red-cockaded Woodpecker	X	X	X	X					X	
Reddish Egret	**P**			**P**						
Red-eyed Vireo	**X**	**X**	**X**	**X**	**X**		**X**	**X**		**X**
Redhead	P	X							X	
Red-headed Woodpecker	X	X	X	X	X		X	X	X	
Red-shouldered Hawk	X	X	X	X	X	X	X	X	X	X
Red-tailed Hawk	X	X		X				X	X	
Red-winged Blackbird	X	X	X	P		X	X		X	
Ring-billed Gull	P	X		P					X	
Ring-necked Duck	P	X							X	
Ring-necked pheasant				P						
Roseate Spoonbill	**P**	**X**		**P**						
Rose-breasted Grosbeak	**P**	**X**			**X**	**X**				
Ross's goose									X	
Rough-legged hawk		P								
Royal tern				**P**						

Species	NPS (2015b)	Fisher (1974)	Bryan et al. (1976)	Biercevicz (1977)	Deuel and Fisher (1977)	Ramsey (1980)[1]	McGuffin (1984)[2]	BBS (All Routes)	CBC (Both)	Granger (2015)
Ruby-crowned Kinglet	X	X		X	X	X	X		X	
Ruby-throated Hummingbird	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		**X**
Ruddy Duck	P	X							X	
Ruddy Turnstone	**P**	**P**		**P**		**X**				
Rufous Hummingbird	P								X	
Rusty Blackbird	P	X							X	
Sanderling	**P**	**X**		**P**						
Sandhill Crane	P	X								
Sandwich tern				**P**						
Savannah Sparrow	P	X							X	
Scarlet Tanager	**P**	**X**					**X**			
Scissor-tailed Flycatcher	**P**	**X**		**P**				**X**		
Seaside sparrow				P						
Sedge Wren	P	X							X	
Semipalmated Plover	**P**	**X**		**P**						
Semipalmated Sandpiper	**P**	**X**		**P**						
Sharp-shinned Hawk	X	X		X			X	X	X	
Sharp-tailed sparrow (Nelson's)		X								
Short-billed Dowitcher	**P**	**X**								
Short-eared Owl	P	P								
Snow Goose	P	X		P					X	
Snowy Egret	**X**	**X**	**X**	**X**		**X**		**X**	**X**	
Solitary Sandpiper	**P**	**X**								
Solitary Vireo	P	X			X				X	
Song Sparrow	X	X		X					X	

Species	NPS (2015b)	Fisher (1974)	Bryan et al. (1976)	Biercevicz (1977)	Deuel and Fisher (1977)	Ramsey (1980)[1]	McGuffin (1984)[2]	BBS (All Routes)	CBC (Both)	Granger (2015)
Sora	P	X								
Spotted Sandpiper	**X**	**X**	**X**		**X**				**X**	
Spotted towhee									X	
Sprague's Pipit	P	X								
Stilt sandpiper	**P**	**P**								
Summer Tanager	**P**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		
Surf scoter		X								
Swainson's Hawk	**P**	**X**							**X**	
Swainson's Thrush	**P**	**X**								
Swainson's Warbler	**P**	**X**	**X**	**X**	**X**		**X**	**X**		
swallow-tailed kite		**X**								
Swamp Sparrow	P	X							X	
Tennessee Warbler	**P**	**X**								
Tree Swallow	P	X		P	X		X		X	
Tricolored Heron	**X**	**X**	**X**	**X**					**X**	
Tufted Titmouse	X	X	X	X	X	X	X	X	X	X
Turkey Vulture	X	X	X	X	X	X	X	X	X	X
Upland Sandpiper	**P**	**X**								
Veery	**P**	**P**			**X**				**X**	
Vermilion Flycatcher	P	X							X	
Vesper Sparrow	P	X							X	
Virginia Rail	P	X								
Warbling Vireo	**P**	**X**					**X**			
Water Pipit	P	X								
Western Grebe	U									

Species	NPS (2015b)	Fisher (1974)	Bryan et al. (1976)	Biercevicz (1977)	Deuel and Fisher (1977)	Ramsey (1980)[1]	McGuffin (1984)[2]	BBS (All Routes)	CBC (Both)	Granger (2015)
Western Kingbird	**P**	**X**								
Western Meadowlark	P	P								
Western Sandpiper	**P**	**X**		**P**						
Western Tanager	**P**	**X**								
whimbrel		**P**								
Whip-poor-will	**P**	**X**								
White Ibis	**X**	**X**	**X**	**P**					**X**	
White-breasted Nuthatch	X	X	X	X			X	X	X	
White-crowned Sparrow	P	X							X	
White-eyed Vireo	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
White-faced Ibis	**P**	**X**		**X**						
White-rumped Sandpiper	**P**	**P**								
White-tailed kite								X	X	
White-throated Sparrow	P	X			X	X	X		X	
White-winged dove								**X**		
Whooping Crane	U	X								
Wild Turkey	P	X								
Willet	P	P		X						
Willow flycatcher		**X**								
Wilson's phalarope	**P**	**X**								
Wilson's snipe									X	
Wilson's warbler	**P**	**X**							**X**	
Winter wren	P	X			X	X	X		X	
Wood duck	X	X	X	X	X	X	X	X	X	
Wood stork	**X**	**X**	**X**	**X**						

Species	NPS (2015b)	Fisher (1974)	Bryan et al. (1976)	Biercevicz (1977)	Deuel and Fisher (1977)	Ramsey (1980)[1]	McGuffin (1984)[2]	BBS (All Routes)	CBC (Both)	Granger (2015)
Wood thrush	**X**	**X**	**X**	**X**	**X**		**X**	**X**	**X**	
Worm-eating Warbler	**X**	**X**	**X**	**X**	**X**		**X**	**X**		
Yellow Warbler	**P**	**X**				**X**			**X**	
Yellow-bellied Flycatcher	**X**	**X**	**X**							
Yellow-bellied Sapsucker	P	X			X	X	X		X	
Yellow-billed Cuckoo	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		**X**
Yellow-breasted Chat	**X**	**X**	**X**	**X**	**X**			**X**		**X**
Yellow-crowned Night-Heron	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	
Yellow-headed Blackbird	P	X								
Yellow-rumped Warbler	P				X	X	**X**		X	
Yellow-throated Vireo	**X**	**X**	**X**	**X**	**X**	**X**		**X**	**X**	**X**
Yellow-throated Warbler	**X**	**X**	**X**	**X**	**X**			**X**	**X**	
Confirmed Species	91	266	92	86	83	58	62	100	176	28
Probable Species	203	27	0	68	0	0		0	0	0
Total Species Richness	***294***	***293***	***92***	***154***	***83***	***58***	***62***	***100***	***176***	***28***

Appendix G. Relative abundance of all species observed during McGuffin (1984)'s census of the LU of BITH. Relative abundance was not calculated for six observed species, as these species were deemed to be transient and not likely to be frequently observed in the preserve.

Species	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Acadian Flycatcher				0.47	4.13	5.71	7.29	7.77	6.81			
American Crow	1.73	2.06	1.86	1.39	2.04	2.85	4.25	1.1	1.91	6.7	2.34	2.46
American Robin	2.33										28.04	0.4
American Woodcock											0.34	
Barred Owl	0.58		0.95	0.47	1.24	1.43	0.61	1.12	0.49		0.34	0.82
Black Vulture				1.89								
Black-throated Green Warbler					0.82							
Blue Jay	2.9	1.03	4.18	4.25	1.65	2.85	0.3	3.35	2.43	2.64	2.03	2.46
Blue-gray Gnatcatcher					1.65							
Blue-winged Warbler						1.43						
Broad-winged Hawk				1.41								
Brown Creeper	1.16											
Brown Thrasher	8.04	6.25	5.21							18.2	3.31	4.1
Brown-headed Cowbird					0.82							
Carolina Chickadee	10.27	7.24	5.68	8.49	1.65	4.28	6.68	4.47	3.85	8.04	8.67	8.99
Carolina Wren	1.15	3.13	1.87	2.83	5.78	5.71	9.72	5.63	10.75	5.03	4.65	4.92
Downy Woodpecker		3.13	1.89	0.47	2.06	2.85	1.21		0.49	1.34	1.02	4.05
Eastern Phoebe			1.89						0.49	0.33	2.62	0.82
Eastern Towhee	0.58											
Eastern Wood-Pewee		1.04		1.89	2.48	2.85	1.2	2.2	0.97			

Species	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Golden-crowned Kinglet	1.16											
Great Crested Flycatcher					0.82	2.85		0.56	0.49			
Great Horned Owl				0.24		0.71			0.24	0.33		
Hermit Thrush	3.49	3.13	1.42								0.34	3.28
Hooded Warbler				2.26			6.59	3.35	4.38	0.33		
Indigo Bunting				0.47								
Kentucky Warbler				0.47	2.89							
Northern Cardinal	2.84	4.17	18.86	15.7	8.87	9.86	10.09	14.7	9.49	8.88	3.35	3.28
Northern Flicker	3.7	2.08	1.89							4.02	6.21	4.92
Northern Parula				2.83	3.3	4.28	1.21		0.97			
Pileated Woodpecker	2.33	2.08	2.84	0.93	1.65	4.28	3.64	3.35	3.36	2.34	1.71	0.82
Red-bellied Woodpecker	6.25	7.22	6.97	1.89	3.3	2.85	5.47	3.35	5.19	4.66	3.66	8.44
Red-breasted Nuthatch		1.04										
Red-eyed Vireo				2.83	1.98	4.28	1.21	1.12	1.46			
Red-headed Woodpecker	6.98	7.3	10.99	11.33	6.69	7.25	9.84	12.01	12.98	11.1	5.43	10.83
Red-shouldered Hawk			0.95	1.41	0.82	1.43			0.24	1.69	1.02	0.82
Ruby-crowned Kinglet	4.07	2.08	1.89								1.36	2.46
Ruby-throated Hummingbird				1.41	0.82		2.43	1.12				
Scarlet Tanager					0.82							
Sharp-shinned Hawk				0.47							0.34	
Summer Tanager				0.47	0.82							
Swainson's Warbler				1.41	1.24	1.43						
Tufted Titmouse	9.31	9.38	6	7.93	23.17	9.91	10.27	11.02	8.53	14.74	3.05	6.56

Species	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Turkey Vulture	4.62	0.52	0.47	0.94	0.82		0.61			0.33	0.68	0.82
Warbling Vireo							0.61	1.12				
White-breasted Nuthatch							0.61					
White-eyed Vireo	3.49	9.56	8.69	13.66	16.03	18.03	13.72	22.65	23.97	6.62	1.36	1.64
White-throated Sparrow	17.19	23.35	8.05	8.37							15.42	24.62
Winter Wren										0.33	0.68	
Wood Duck	2.3	2.07	1.87	0.94								
Wood Thrush					0.41	2.85	1.21		0.49			
Worm-eating Warbler				0.47								
Yellow-bellied Sapsucker	3.49	1.04	1.42							2.01	2.03	2.46
Yellow-billed Cuckoo							1.21					
Yellow-crowned Night Heron					0.41							
Yellow-rumped Warbler			4.13									

Appendix H. Species observed, abundance, and the total number of points they were observed at during GULN monitoring of the TCU in 2014 (Granger 2015).

Species	Total Individuals	Distinct Points	Total Flyovers
Acadian Flycatcher	8	7	0
American Crow	19	14	0
Blue Jay	11	9	0
Blue-gray Gnatcatcher	10	7	0
Brown-headed Cowbird	5	5	0
Carolina Chickadee	14	10	0
Carolina Wren	20	14	0
Chimney Swift	3	2	3
Downy Woodpecker	6	6	0
Gray Catbird	1	1	0
Hooded Warbler	16	10	0
Indigo Bunting	3	3	0
Mourning Dove	14	10	1
Northern Cardinal	61	20	0
Northern Parula	8	4	0
Pileated Woodpecker	3	3	0
Pine Warbler	5	4	0
Prothonotary Warbler	1	1	0
Red-bellied Woodpecker	18	12	0
Red-eyed Vireo	11	10	0
Red-shouldered Hawk	3	3	0
Ruby-throated Hummingbird	2	2	0
Tufted Titmouse	29	17	0
Turkey Vulture	1	1	1
White-eyed Vireo	40	20	0
Yellow-billed Cuckoo	9	8	0
Yellow-breasted Chat	2	2	0
Yellow-throated Vireo	5	5	0

Appendix I. List of species that have been documented within or very near preserve units (Fisher and Rainwater 1978, Lewis et al. 2000, DFWHS 2010, NPS 2015). Latin names represent the current Latin name on NPSpecies (NPS 2015); if a species was not identified on NPSpecies, then the most recent www.itis.gov Latin name was used.

Scientific Name	Common names	Fisher and Rainwater (1978)	Lewis et al. (2000)	Crump (2008-2010)	Herpetological Society/USGS (2010+)	NPS (2015)
Macrochelys temminckii	alligator snapping turtle	x		x		Present
Alligator mississipiensis	American alligator				x	Present
Lithobates catesbeianus	American bullfrog	x	x		x	Present
Acris blanchardi	Blanchard's cricket frog				x	Present
Nerodia fasciata confluens	broadbanded water snake				x	Not listed
Eumeces laticeps	broad-headed skink	x	x	x	x	Present
Lithobates clamitans clamitans	bronze frog	x				Not listed
Storeria dekayi	brown snake	x	x	x	x	Present
Pseudacris fouquettei	Cajun chorus frog				x	Present
Deirochelys reticularia	chicken turtle	pp				Present
Masticophis flagellum	coachwhip	x	x	x	x	Present
Incilius nebulifer	coastal plain toad	x	x		x	Present
Terrapene carolina	common box turtle	x	x	x		Present
Thamnophis sirtalis	common garter snake	x				Present
Sternotherus odoratus	common musk turtle			x		Unconfirmed
Chelydra serpentina	common snapping turtle	x		x	x	Present
Hyla chrysoscelis	Cope's gray treefrog	x*				Present

*the two frog species were recorded as the same during Fisher and Rainwater (1978) field studies.

pp=probably present as described by Fisher and Rainwater (1978)

Scientific Name	Common names	Fisher and Rainwater (1978)	Lewis et al. (2000)	Crump (2008-2010)	Herpetological Society/USGS (2010+)	NPS (2015)
Elaphe guttata	cornsnake	x		x		Present
Agkistrodon piscivorus	cottonmouth	x	x	x	x	Present
Lithobates areolatus	crawfish frog	x				Present
Nerodia rhombifer	diamondback water snake	x			x	Present
Eurycea quadridigitata	dwarf salamander	x	x	x		Present
Sceloporus undulatus	eastern fence lizard	x	x	x	x	Present
Heterodon platyrhinos	eastern hognose snake	pp	x		x	Probably Present
Kinosternon subrubrum	eastern mud turtle	x			x	Present
Gastrophryne carolinensis	eastern narrow-mouthed toad	x	x	x	x	Present
Notophthalmus viridescens	eastern newt	x				Present
Scaphiopus holbrookii	eastern spadefoot		x			Unconfirmed
Ambystoma tigrinum	eastern tiger salamander					Present
Graptemys pseudogeographica	false map turtle	x		x		Not listed
Eumeces fasciatus	five-lined skink	x	x	x	x	Present
Tantilla gracilis	flat-headed snake					Unconfirmed
Anaxyrus fowleri	fowler's toad				x	Present
Ophisaurus spp.	glass lizards					n/a
Regina rigida	glossy crayfish snake	x			x	Present
Regina grahamii	Graham's crayfish snake					Unconfirmed
Hyla versicolor	gray treefrog	x*	x	x	x	Present

*the two frog species were recorded as the same during Fisher and Rainwater (1978) field studies.

pp=probably present as described by Fisher and Rainwater (1978)

Scientific Name	Common names	Fisher and Rainwater (1978)	Lewis et al. (2000)	Crump (2008-2010)	Herpetological Society/USGS (2010+)	NPS (2015)
Elaphe guttata emoryi	great plains ratsnake	x				Not listed
Anolis carolinensis	green anole	x	x	x	x	Present
Lithobates clamitans	green frog		x	x	x	Present
Hyla cinerea	green treefrog	x	x		x	Present
Scincella lateralis	ground skink	x	x	x	x	Present
Necturus beyeri	Gulf Coast waterdog		x	x		Unconfirmed
Regina rigida sinicola	Gulf crayfish snake				x	Not listed
Nerodia clarkii clarkii	gulf salt marsh snake					Unconfirmed
Micrurus fulvius	harlequin coralsnake	x	x	x		Present
Siren intermedia	lesser siren		x	x		Unconfirmed
Pituophis ruthveni	Louisiana pine snake					Unconfirmed
Ambystoma opacum	marbled salamander	x	x	x		Present
Hemidactylus turcicus	Mediterranean house gecko					Unconfirmed
Apalone mutica mutica	midland smooth softshell turtle	x		x		Present
Lampropeltis triangulum	milk snake, milksnake		x		x	Unconfirmed
Nerodia cyclopion	Mississippi green water snake					Present
Graptemys kohnii	Mississippi map turtle	x				Present
Diadophis punctatus stictogenys	Mississippi ringneck snake					Unconfirmed
Ambystoma talpoideum	mole salamander					Unconfirmed

*the two frog species were recorded as the same during Fisher and Rainwater (1978) field studies.

pp=probably present as described by Fisher and Rainwater (1978)

Scientific Name	Common names	Fisher and Rainwater (1978)	Lewis et al. (2000)	Crump (2008-2010)	Herpetological Society/USGS (2010+)	NPS (2015)
Farancia abacura	mud snake, mudsnake	x			x	Present
Agkistrodon contortrix	northern copperhead	x	x	x	x	Present
Acris crepitans	northern cricket frog	x	x	x		Not listed
Lithobates pipiens	northern leopard frog	x				Not listed
Terrapene ornata	ornate box turtle	x				Present
Graptemys ouachitensis	Ouachita map turtle			x		Present
Apalone spinifera pallida	pallid spiny softshell turtle	x				Unconfirmed
Lithobates palustris	pickerel frog					Unconfirmed
Lithobates grylio	pig frog				x	Present
Nerodia erythrogaster	plain-bellied water snake		x	x	x	Present
Trachemys scripta	pond slider	x			x	Not listed
Lampropeltis calligaster	prairie kingsnake				x	Unconfirmed
Sistrurus miliarius	pygmy rattlesnake					Unconfirmed
Coluber constrictor	racer	x	x	x	x	Present
Sternotherus carinatus	razor-backed musk turtle	x		x	x	Present
Storeria occipitomaculata	red-bellied snake	x	x			Present
Eleutherodactylus cystignathoides	Rio Grande chirping frog				x	Present
Pseudemys concinna	river cooter	pp		x	x	Present
Virginia striatula	rough earthsnake				x	Unconfirmed

*the two frog species were recorded as the same during Fisher and Rainwater (1978) field studies.

pp=probably present as described by Fisher and Rainwater (1978)

Scientific Name	Common names	Fisher and Rainwater (1978)	Lewis et al. (2000)	Crump (2008-2010)	Herpetological Society/USGS (2010+)	NPS (2015)
Opheodrys aestivus	rough green snake	x	x		x	Present
Graptemys sabinensis	Sabine map turtle				x	Not listed
Cemophora coccinea	scarlet snake					Unconfirmed
Cnemidophorus sexlineatus	six-lined racerunner	x	x	x	x	Present
Ophisaurus attenuatus	slender glass lizard			x	x	Unconfirmed
Ambystoma texanum	small-mouth salamander					Present
Eumeces anthracinus pluvialis	southern coal skink					Unconfirmed
Desmognathus auriculatus	southern dusky salamander			x		Unconfirmed
Lithobates sphenocephalus	southern leopard frog		x	x	x	Present
Nerodia fasciata	southern water snake	x	x	x	x	Present
Lampropeltis getula holbrooki	speckled kingsnake	x			x	Present
Apalone spinifera	spiny softshell turtle			x	x	Present
Ambystoma maculatum	spotted salamander					Unconfirmed
Pseudacris crucifer	spring peeper	x	x	x	x	Present
Hyla squirella	squirrel treefrog	x	x	x	x	Present
Pseudacris streckeri	Strecker's chorus frog					Unconfirmed
Pseudacris triseriata	striped chorus frog	x	x	x		Not listed
Micrurus tener tener	Texas coral snake				x	Not listed
Malaclemys terrapin littoralis	Texas diamondback terrapin					Not In Park

*the two frog species were recorded as the same during Fisher and Rainwater (1978) field studies.

pp=probably present as described by Fisher and Rainwater (1978)

Scientific Name	Common names	Fisher and Rainwater (1978)	Lewis et al. (2000)	Crump (2008-2010)	Herpetological Society/USGS (2010+)	NPS (2015)
Phrynosoma cornutum	Texas horned lizard					Unconfirmed
Elaphe obsoleta	Texas ratsnake	x	x	x	x	Present
Amphiuma tridactylum	three-toed amphiuma		x	x		Present
Crotalus horridus	timber rattlesnake		x		x	Unconfirmed
Bufo spp.	toad species			x		Not listed
Pseudacris feriarum	upland chorus frog	pp				Not listed
Lampropeltis gentilis	western milksnake				x	Not listed
Gastrophryne olivacea	western narrow-mouthed toad					Unconfirmed
Thamnophis proximus	western ribbon snake	x	x	x	x	Present
Opheodrys vernalis blanchardi	western smooth green snake					Unconfirmed
Anaxyrus woodhousii	Woodhouse's toad	x	x			Unconfirmed
Nerodia erythrogaster flavigastor	yellow-bellied water snake	x			x	Not listed
Total Number of Amphibian Species	**38**	**16**	**18**	**15**	**14**	
Total Number of Reptile Species	**69**	**36**	**22**	**29**	**40**	
Total	**107**	**52**	**40**	**44**	**54**	

*the two frog species were recorded as the same during Fisher and Rainwater (1978) field studies.

pp=probably present as described by Fisher and Rainwater (1978)

Appendix J. The number of individuals counted in BITH from all available sources.

Scientific Name	Common Names	Fisher and Rainwater (1978)	Lewis et al. (2000)	Crump (2008-2010)	Herpetological Society/USGS (2010+)	NPS (2015)
Macrochelys temminckii	alligator snapping turtle	1**		2		Present
Lithobates catesbeianus	American bullfrog	26	8		2	Present
Nerodia fasciata confluens	broadbanded water snake			2	2	Not listed
Eumeces laticeps	broad-headed skink	3	27	1		Present
Lithobates clamitans clamitans	bronze frog	186		2		Not listed
Storeria dekayi	brown snake	4	24	1	4	Present
Masticophis flagellum	coachwhip	3	25	1		Present
Incilius nebulifer	Coastal plain toad	21	115		2	Present
Terrapene carolina	common box turtle	3	4	1		Present
Thamnophis sirtalis	common garter snake	2				Present
Sternotherus odoratus	common musk turtle			1		Unconfirmed
Chelydra serpentina	common snapping turtle	1		1	2	Present
Elaphe guttata	corn snake, cornsnake	2		1		Present
Agkistrodon piscivorus	cottonmouth	17	2	5	8	Present
Lithobates areolatus	crawfish frog	3				Present
Nerodia rhombifer	diamondback water snake	2			1	Present
Eurycea quadridigitata	dwarf salamander	43	3	23		Present
Sceloporus undulatus	eastern fence lizard	9	4	10	1	Present
Heterodon platyrhinos	eastern hognose snake		22		3	Probably Present

*this value was including both the gray tree frog (*Hyla versicolor*) and the Cope's gray tree frog (*H. chrysoscelis*).

**this was found as one dead carapace of an alligator snapping turtle, not a living turtle

Scientific Name	Common Names	Fisher and Rainwater (1978)	Lewis et al. (2000)	Crump (2008-2010)	Herpetological Society/USGS (2010+)	NPS (2015)
Kinosternon subrubrum	eastern mud turtle	1				Present
Gastrophryne carolinensis	eastern narrow-mouthed toad	36	7	4		Present
Notophthalmus viridescens	Eastern newt	1				Present
Scaphiopus holbrookii	Eastern spadefoot		97			Unconfirmed
Graptemys pseudogeographica	false map turtle	33		4		Not listed
Eumeces fasciatus	five-lined skink	29	83	7	3	Present
Regina rigida	glossy crayfish snake	2				Present
Hyla versicolor	gray treefrog	205*	66	8	3	Present
Elaphe guttata emoryi	Great Plains ratsnake	2				Not listed
Anolis carolinensis	green anole	126	93	1	1	Present
Lithobates clamitans	green frog		33		1	Present
Hyla cinerea	green treefrog	75	5		1	Present
Scincella lateralis	ground skink	159	262	9	1	Present
Necturus beyeri	gulf coast waterdog		1	7		Unconfirmed
Regina rigida sinicola	Gulf crayfish snake				1	Not listed
Micrurus fulvius	harlequin coralsnake	1	19	3		Present
Siren intermedia	lesser siren		3	9		Unconfirmed
Ambystoma opacum	marbled salamander	4	47	10		Present
Apalone mutica mutica	midland smooth softshell turtle			1		Present

*this value was including both the gray tree frog (*Hyla versicolor*) and the Cope's gray tree frog (*H. chrysoscelis*).

**this was found as one dead carapace of an alligator snapping turtle, not a living turtle

Scientific Name	Common Names	Fisher and Rainwater (1978)	Lewis et al. (2000)	Crump (2008-2010)	Herpetological Society/USGS (2010+)	NPS (2015)
Lampropeltis triangulum	milk snake, milksnake		6		1	Unconfirmed
Graptemys kohnii	Mississippi map turtle	16				Present
Farancia abacura	mud snake, mudsnake	2			2	Present
Agkistrodon contortrix	northern copperhead	13	62	2	12	Present
Acris crepitans	northern cricket frog	22	2	3		Not listed
Lithobates pipiens	northern leopard frog	216				Not listed
Terrapene ornata	ornate box turtle	3				Present
Graptemys ouachitensis	Ouachita map turtle			2		Present
Nerodia erythrogaster	plain-bellied water snake		6			Present
Trachemys scripta	pond slider	19				Not listed
Lampropeltis calligaster	prairie kingsnake				2	Unconfirmed
Coluber constrictor	racer	4	29	2	3	Present
Elaphe obsoleta	rat snake, Texas ratsnake	9	20	1	4	Present
Sternotherus carinatus	razor-backed musk turtle	2		2		Present
Storeria occipitomaculata	red-bellied snake	1	7			Present
Trachemys scripta elegans	red-eared slider			27	1	Present
Pseudemys concinna	river cooter			1		Present
Opheodrys aestivus	rough green snake	2	3		1	Present
Cnemidophorus sexlineatus	six-lined racerunner	1		5		Present

*this value was including both the gray tree frog (*Hyla versicolor*) and the Cope's gray tree frog (*H. chrysoscelis*).

**this was found as one dead carapace of an alligator snapping turtle, not a living turtle

Scientific Name	Common Names	Fisher and Rainwater (1978)	Lewis et al. (2000)	Crump (2008-2010)	Herpetological Society/USGS (2010+)	NPS (2015)
Ophisaurus attenuatus	slender glass lizard			1	1	Unconfirmed
Desmognathus auriculatus	southern dusky salamander			2		Unconfirmed
Lithobates sphenocephalus	southern leopard frog		260	3		Present
Nerodia fasciata	southern water snake	24	6			Present
Lampropeltis getula holbrooki	speckled kingsnake	1			1	Present
Apalone spinifera	spiny softshell turtle			1		Present
Pseudacris crucifer	spring peeper	3	9	7		Present
Hyla squirella	squirrel treefrog	34	7	1		Present
Pseudacris triseriata	striped chorus frog	10	4	3		Not listed
Micrurus tener tener	Texas coral snake				1	Not listed
Amphiuma tridactylum	three-toed amphiuma		1	3		Present
Crotalus horridus	timber rattlesnake		7		1	Unconfirmed
Bufo spp.	toad species			16		Not listed
Pseudacris feriarum	upland chorus frog	pp				Not listed
Thamnophis proximus	western ribbon snake	9	19	3	3	Present
Anaxyrus woodhousii	Woodhouse's toad	326	462			Unconfirmed
Nerodia erythrogaster flavigastor	yellow-bellied water snake	12		4	7	Not listed

*this value was including both the gray tree frog (*Hyla versicolor*) and the Cope's gray tree frog (*H. chrysoscelis*).

**this was found as one dead carapace of an alligator snapping turtle, not a living turtle

Appendix K. Trapping data for the Beaumont Unit in BITH between 1985 and 2012 (NPS 2012c).

Year	Number of Nights Trapped	Average Number of Traps Per Night	Raccoon	Opossum	Gray Fox	Red Fox	Nutria	Stripped Skunk	Mink	Muskrat	Ring-tailed Cat	Beaver	Otter	Total Game Count
1985	42	27	27	21	0	0	0	0	5	0	0	0	2	82
1986	37	36	36	23	2	0	15	0	5	1	0	0	2	120
1987	20	39	27	25	0	0	1	0	5	0	0	0	0	97
1988	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	55	30	12	15	0	0	22	1	2	0	0	0	0	82
1990	39	32	20	31	5	0	5	0	4	0	0	0	0	97
1991	47	32	29	25	0	0	5	0	6	0	0	0	0	97
1992	15	12	7	5	0	0	3	0	1	0	0	1	0	29
1993	30	30	19	14	0	0	4	0	4	0	0	2	0	73
1994	10	4	0	0	0	0	0	0	0	0	6	0	0	10
1995	9	28	12	5	0	0	1	0	1	0	0	0	0	47
1996	5	12	8	6	0	1	0	0	0	0	0	0	0	27
1997	7	7	8	2	0	0	0	0	0	0	0	0	0	17
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Year	Number of Nights Trapped	Average Number of Traps Per Night	Raccoon	Opossum	Gray Fox	Red Fox	Nutria	Stripped Skunk	Mink	Muskrat	Ring-tailed Cat	Beaver	Otter	Total Game Count
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	8	15	8	2	0	0	0	0	1	0	0	13	4	43
2007	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	17	12	5	14	0	0	0	0	0	0	0	0	1	32
2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**341**	**316**	**218**	**188**	**7**	**1**	**56**	**1**	**34**	**1**	**6**	**16**	**9**	**537**

Appendix L. Trapping data from the Jack Gore Baygall Unit in BITH between 1983 and 2012 (NPS 2012c).

Year	Number of Nights Trapped	Average Number of Traps Per Night	Raccoon	Opossum	Gray Fox	Nutria	Coyote	Stripped Skunk	Spotted Skunk	Mink	Muskrat	Beaver	Bobcat	Otter	Total Game Count
1983	136	97	75	29	2	3	2	2	2	7	6	0	1	0	129
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	32	12	12	5	0	2	0	0	0	0	0	0	0	0	19
1986	136	87	57	55	0	1	0	0	0	1	0	0	0	0	114
1987	46	38	15	16	0	2	0	0	0	0	0	0	0	0	33
1988	52	32	29	20	0	2	0	0	0	0	0	1	0	0	52
1989	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1990	10	12	3	7	0	0	0	0	0	0	0	0	0	0	10
1991	10	12	0	7	0	0	0	0	0	0	0	0	1	0	8
1992	20	10	10	0	0	0	0	0	0	2	0	0	0	0	12
1993	10	21	41	0	0	0	0	0	0	1	0	1	0	0	43
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	29	32	81	10	3	2	0	0	0	5	0	0	0	2	103
1997	97	16	297	9	0	2	0	0	0	3	0	0	0	2	313
1998	42	39	55	0	0	0	0	0	0	0	0	0	0	0	55
1999	50	20	121	7	0	0	0	0	0	6	0	4	0	2	140
2000	42	18	48	7	1	0	0	0	0	0	0	0	2	2	60
2001	73	19	173	23	0	0	0	0	0	5	0	0	4	4	209
2002	44	20	236	19	0	0	0	0	0	14	0	0	0	4	273
2003	64	20	176	14	0	2	0	0	0	10	0	0	1	5	208
2004	54	19	126	9	0	0	0	0	0	3	0	0	0	0	138

Year	Number of Nights Trapped	Average Number of Traps Per Night	Raccoon	Opossum	Gray Fox	Nutria	Coyote	Stripped Skunk	Spotted Skunk	Mink	Muskrat	Beaver	Bobcat	Otter	Total Game Count
2005	14	10	41	32	0	0	0	0	0	2	0	0	2	0	77
2006	19	18	75	13	0	2	0	0	0	2	0	9	5	0	106
2007	50	17	88	10	0	0	0	0	0	0	0	0	1	0	99
2008	10	20	52	4	0	0	0	0	0	0	0	0	4	0	60
2009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	16	30	35	8	0	0	0	0	0	2	0	3	0	0	48
2012	11	2	1	0	0	0	0	0	0	0	0	0	0	0	1
Total	**1,067**	**621**	**1,847**	**304**	**6**	**18**	**2**	**2**	**2**	**63**	**6**	**18**	**21**	**21**	**2,310**

Appendix M. Trapping data for the Lance Rosier Unit between 1985 and 2012 (NPS 2012c).

Year	Number of Nights Trapped	Average Number of Traps Per Night	Raccoon	Opossum	Gray Fox	Red Fox	Nutria	Mink	Badger	Beaver	Bobcat	Otter	Total Game Count
1985	67	69	45	9	0	0	2	0	0	0	1	0	57
1986	43	43	32	4	0	0	0	0	0	0	0	0	36
1987	30	46	45	1	0	0	0	0	0	0		0	46
1988	24	19	16	5	0	0	0	0	2	0	0	0	23
1989	0	0	0	0	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	4	12	6	0	0	0	0	0	0	0	0	0	6
1992	37	41	63	1	3	2	0	3	0	1	0	1	74
1993	10	21	41	0	0	0	0	1	0	1	0	0	43
1994	23	59	36	1	2	0	0	2	0	0	0	0	41
1995	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	8	19	18	8	0	1	0	2	0	0	0	0	29
1997	22	18	47	7	0	0	0	2	0	0	1	0	57
1998	12	6	15	0	0	0	0	2	0	0	0	0	17
1999	28	17	31	0	7	1	0	0	0	0	0	0	39
2000	9	7	8	0	0	0	0	0	0	0	0	0	8
2001	10	9	3	5	0	0	0	0	0	0	0	0	8
2002	9	6	4	1	0	0	0	0	0	0	0	0	5
2003	3	12	5	0	0	0	0	0	0	0	0	0	5
2004	0	0	0	0	0	0	0	0	0	0	0	0	0

Year	Number of Nights Trapped	Average Number of Traps Per Night	Raccoon	Opossum	Gray Fox	Red Fox	Nutria	Mink	Badger	Beaver	Bobcat	Otter	Total Game Count
2005	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	8	7	16	10	0	0	0	0	0	0	0	0	26
2007	20	12	11	14	4	0	0	0	0	0	0	0	29
2008	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	23	6	4	3	1	0	0	0	0	0	0	0	8
2011	18	9	6	8	3	0	0	0	0	0	0	0	17
2012	20	8	3	6	2	1	0	0	0	0	0	0	12
Total	**428**	**446**	**455**	**83**	**22**	**5**	**2**	**12**	**2**	**2**	**2**	**1**	**586**

Appendix N. Trapping data for the Neches Bottom Unit in BITH between 1983 and 2012 (NPS 2012c).

Year	Number of Nights Trapped	Average Number of Traps Per Night	Raccoon	Opossum	Gray Fox	Nutria	Coyote	Spotted Skunk	Mink	Beaver	Bobcat	Otter	Total Game Count
1983	30	48	65	3	0	0	0	0	4	0	0	0	72
1984	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	21	20	18	16	0	0	0	0	1	0	0	0	35
1986	32	55	30	13	0	2	0	0	4	0	0	0	49
1987	50	22	67	12	0	0	0	0	4	3	0	0	19
1988	15	22	7	5	0	1	0	0	0	0	0	0	13
1989	34	33	52	13	0	1	0	0	6	5	0	1	78
1990	24	24	11	3	0	0	0	0	3	0	0	0	17
1991	34	36	7	23	0	0	0	0	7	0	3	1	41
1992	28	24	16	6	0	0	0	0	2	3	0	0	27
1993	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	12	12	8	2	0	0	0	2	2	3	0	0	17
1996	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	10	10	10	0	0	0	1	0	0	0	0	0	11
2002	6	25	10	3	0	0	0	0	0	0	0	0	13
2003	0	0	0	0	0	0	0	0	0	0	0	0	0

Year	Number of Nights Trapped	Average Number of Traps Per Night	Raccoon	Opossum	Gray Fox	Nutria	Coyote	Spotted Skunk	Mink	Beaver	Bobcat	Otter	Total Game Count
2004	12	24	67	7	0	0	0	0	0	0	0	0	74
2005	10	12	32	8	0	2	0	0	3	0	0	0	45
2006	16	17	59	9	0	4	0	0	1	7	0	2	82
2007	10	24	42	59	9	0	0	0	0	0	0	0	110
2008	7	20	26	2	0	0	0	0	3	0	0	0	31
2009	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**351**	**428**	**527**	**184**	**9**	**8**	**1**	**2**	**27**	**21**	**3**	**4**	**734**

Appendix O. Mussel species that are listed in Howells (1997) table of species with an additional column listing the NPS species (recreated from Howells 1997, Ford 2013 and 2014; NPS 2014).

Scientific Name	Common Name	NPS (2014)	Ford (2013/14)	Howells (1997)	TX Status
Amblema plicata	threeridge (includes ssp. *costata*)	X	X	X	
Anodonta suborbiculata	flat floater			X	
Arcidens confragosus	rock pocketbook	X	X	X	
Cyrtonaias tampicoensis	Tampico pearly mussel			X	
Fusconaia askewi	Texas pigtoe		X	X	threatened
Fusconaia flava	Wabash pigtoe	X		X	
Fusconaia lananensis	triangle pigtoe	X	x	X	threatened
Glebula rotundata	round pearlshell	X	X	X	
Lampsilis cardium	plain pocketbook			X	
*Lampsilis fragilis**		X			
Lampsilis hydiana	Louisiana fatmucket	X	X	X	
Lampsilis satura	sandbank pocketbook	X	X	X	threatened
Lampsilis teres	yellow sandshell	X	X	X	
Lasmigona complanata	white heelsplitter			X	
Leptodea fragilis	fragile papershell		X	X	
Ligumia subrostrata	pondmussel	X	X	X	
Megalonaias nervosa	washboard	X	X	X	
Obliquaria reflexa	threehorn wartyback	X	X	X	
Obovaria jacksoniana	southern hickorynut	X	X	X	threatened
Plectomerus dombeyanus	bankclimber	X	X	X	
Pleurobema riddelli	Louisiana pigtoe	X	X	X	threatened

* Latin name for species does not correspond to a common name

Scientific Name	Common Name	NPS (2014)	Ford (2013/14)	Howells (1997)	TX Status
Potamilus amphichaenus	Texas heelsplitter	X	X	X	threatened
Potamilus ohiensis	pink papershell	X		X	
Potamilus purpuratus	bleufer	X	X	X	
Pyganodon grandis	giant floater	X	X	X	
Quadrula apiculata	southern mapleleaf	X	X	X	
*Quadrula askew**		X			
Quadrula asperata	Alabama orb	X			
Quadrula houstonensis	smooth pimpleback			X	
Quadrula nobilis	Gulf mapleleaf		X	X	
Quadrula nodulata	wartyback	X	X	X	
Quadrula pustulosa	pimpleback			X	
Quadrula pustulosa mortoni	western pimpleback	X	X	X	
Quadrula quadrula	mapleleaf			X	
Strophitus subvexus	southern creekmussel	X			
Strophitus undulatus	creeper, squawfoot	X	X	X	
Toxolasma cylindrellus	pale lilliput pearly mussel	X			
Toxolasma parvum	lilliput		X	X	
Toxolasma texasiense	Texas lilliput			X	
Tritogonia verrucosa	pistolgrip	X	X	X	
Truncilla donaciformis	fawnsfoot	X	X	X	
Truncilla macrodon	Texas fawnsfoot			X	threatened
Truncilla truncata	deertoe	X	X	X	
Uniomerus declivis	tapered pondhorn		X	X	
Uniomerus tetralasmus	pondhorn	X	X	X	

* Latin name for species does not correspond to a common name

Scientific Name	Common Name	NPS (2014)	Ford (2013/14)	Howells (1997)	TX Status
Uniomerus tetralasmus manubius	pondhorn (includes ssp. *manubius*)	X			
Utterbackia imbecillis	paper pondshell		X	X	
Villosa lienosa	little spectacle case	X	X	X	
Total # of Species		**33**	**32**	**42**	**7**

* Latin name for species does not correspond to a common name

Appendix P. Distribution of the observed species in Howells (1997) freshwater mussel survey.

Scientific Name	Common Name	Neches	Trinity
Amblema plicata	threeridge	x	x
Anodonta suborbiculata	flat floater	i	i
Arcidens confragosus	rock pocketbook	x	x
Cyrtonaias tampicoensis	Tampico pearly mussel		i
Fusconaia askewi	Texas pigtoe	x	x
Fusconaia flava	Wabash pigtoe	x	?
Fusconaia lananensis	triangle pigtoe	x	
Glebula rotundata	round pearlshell	x	x
Lampsilis cardium	plain pocketbook		
Lampsilis satura	sandbank pocketbook	x	?
Lampsilis hydiana	Louisiana fatmucket	x	x
Lampsilis teres	yellow sandshell	x	x
Lasmigona complanata	white heelsplitter	i	i
Leptodea fragilis	fragile papershell	x	x
Ligumia subrostrata	pond mussel	x	x
Megalonaias nervosa	washboard	x	x
Obliquaria reflexa	three-horn wartyback	x	x
Obovaria jacksoniana	southern hickorynut	x	x
Plectomerus dombeyanus	bankclimber	x	x
Pleurobema riddellii	Louisiana pigtoe	x	x
Potamilus amphichaenus	Texas heelsplitter	x	x
Potamilus ohiensis	pink papershell		
Potamilus purpuratus	bleufer	x	x
Pyganodon grandis	giant floater	x	x
Quadrula apiculata	southern mapleleaf	x	x
Quadrula houstonensis	smooth pimpleback		x
Quadrula nobilis	Gulf mapleleaf	x	x
Quadrula nodulata	wartyback	x	

i = probably introduced to the area

? = Species distribution is unknown

Scientific Name	Common Name	Neches	Trinity
Quadrula pustulosa	pimpleback		
Quadrula pustulosa mortoni	western pimpleback	x	x
Quadrula quadrula	mapleleaf		
Strophitus undulatus	squawfoot	x	x
Toxolasma parvum	lilliput	x	x
Toxolasma texasiense	Texas lilliput	x	x
Tritogonia verrucosa	pistolgrip	x	x
Truncilla donaciformis	fawnsfoot	x	x
Truncilla macrodon	Texas fawnsfoot		?
Truncilla truncata	deertoe	x	x
Uniomerus declivis	tapered pondhorn	x	x
Uniomerus tetralasmus	pondhorn	x	x
Utterbackia imbecillis	paper pondshell	x	x
Villosa lienosa	little spectaclecase	x	?

i = probably introduced to the area

? = Species distribution is unknown

Appendix Q. The number of fish observed in each survey; reader should note that Moriarty and Winemiller (1997) only sampled in Village Creek.

Scientific Name	Common Name	Suttkus and Clemmer (1979)	Moriarty and Winemiller (1997)	Moring (2003)
Anguilla rostrata	American eel	67	0	0
Strongylura marina	Atlantic needlefish, silver gar	0	0	1
Elassoma zonatum	banded pygmy sunfish	226	22	8
Lepomis symmetricus	bantam sunfish	59	0	5
Ictiobus cyprinellus	bigmouth buffalo	1	0	0
Ictiobus niger	black buffalo	1	0	0
Pomoxis nigromaculatus	black crappie	91	0	14
Notropis atrocaudalis	blackspot shiner	198	11	9
Fundulus olivaceus	blackspotted topminnow	1,739	137	32
Fundulus notatus	blackstripe topminnow	843	0	148
Moxostoma poecilurum	blacktail redhorse	14	15	62
Cyprinella venusta	blacktail shiner	27,100	1,148	644
Cycleptus elongatus	blue sucker	1	0	4
Lepomis macrochirus	bluegill	2,200	61	404
Etheostoma chlorosomum	bluntnose darter	782	14	3
Amia calva	bowfin	3	0	0
Labidesthes sicculus	brook silverside	1,218	98	11
Pimephales vigilax	bullhead minnow	31,671	583	462
Cyprinus carpio	common carp	1	0	1
Semotilus atromaculatus	creek chub	52	0	0
Erimyzon oblongus	creek chubsucker	23	0	0
Lepomis marginatus	dollar sunfish	221	0	15
Notropis atherinoides	emerald shiner	847	0	12
Centrarchus macropterus	flier	63	64	0
Notropis buchanani	ghost shiner	1,553	0	0
Dorosoma cepedianum	gizzard shad	186	0	297
Notemigonus crysoleucas	golden shiner	507	8	1
Fundulus chrysotus	golden topminnow	9	0	5
Etheostoma parvipinne	goldstripe darter	2	0	0
Ctenopharyngodon idella	grass carp, silver orfe	0	0	1
Esox americanus	grass pickerel	91	7	10

Scientific Name	Common Name	Suttkus and Clemmer (1979)	Moriarty and Winemiller (1997)	Moring (2003)
Lepomis cyanellus	green sunfish	59	0	6
Etheostoma histrio	harlequin darter	69	1	0
Menidia beryllina	inland silverside	10	0	25
Notropis chalybaeus	ironcolor shiner	20	0	0
Erimyzon sucetta	lake chubsucker	29	0	0
Micropterus salmoides	largemouth bass	88	0	150
Lepomis megalotis	longear sunfish	1,998	45	761
Notropis volucellus	mimic shiner	4,073	45	86
Hybognathus nuchalis	Mississippi silvery minnow	953	18	8
Etheostoma asprigene	mud darter	82	0	0
Hybopsis amnis	pallid shiner	1,171	30	15
Opsopoeodus emiliae	pugnose minnow	763	16	7
C. lutrensis X *C. venusta*	red and blacktail shiner hybrid	24	0	0
Cyprinella lutrensis	red shiner	37,075	0	156
Lepomis auritus	redbreast sunfish	3	0	15
Lepomis microlophus	redear sunfish	145	2	24
Micropterus coosae	redeye bass	0	0	12
Lythrurus umbratilis	redfin shiner	1,261	0	0
Lythrurus fumeus	ribbon shiner	2,860	327	0
Carpiodes carpio	river carpsucker	58	0	14
Morone saxatilis	rockfish, striped bass	0	0	5
Notropis sabinae	sabine shiner	12,237	194	0
Ammocrypta vivax	scaly sand darter	2,465	118	18
Notropis shumardi	silverband shiner	1	0	0
Etheostoma gracile	slough darter	89	6	1
Ictiobus bubalus	smallmouth buffalo	13	0	78
Macrhybopsis aestivalis	speckled chub	1,293	0	0
Micropterus punctulatus	spotted bass	632	31	179
Minytrema melanops	spotted sucker	107	10	15
Lepomis punctatus	spotted sunfish	114	9	38
Fundulus blairae	starhead topminnow	165	8	0
Mugil cephalus	striped mullet	11	9	51
Phenacobius mirabilis	suckermouth minnow	59	3	0

Scientific Name	Common Name	Suttkus and Clemmer (1979)	Moriarty and Winemiller (1997)	Moring (2003)
Etheostoma fusiforme	swamp darter	2	8	0
Notropis amabilis	Texas shiner	0	0	2
Dorosoma petenense	threadfin shad	1,471	1	284
Chaenobryttus gulosus	warmouth	291	3	51
Notropis texanus	weed shiner	2,039	153	29
Gambusia affinis	western mosquitofish	6,348	263	14
Ammocrypta clara	western sand darter	97	0	0
Etheostoma clarum	western sand darter	0	7	4
Morone chrysops	white bass	110	0	4
Pomoxis annularis	white crappie	991	21	83

Appendix R. List of species and NPS (2015) occurrence status with record of documentations within BITH.

Scientific Name	Common Name	NPS (2015)	Moriarty and Winemiller (1997)*	Suttkus (1979)	Moring (2003)	Winemiller et al. (2014)	Occurrence
Lepisosteus spatula	alligator gar	x		x	x	x	Present
Anguilla rostrata	American eel	x		x			Present
Strongylura marina	Atlantic needlefish	x			x	x	Present
Elassoma zonatum	banded pygmy sunfish	x	x	x	x		Present
Enneacanthus obesus	banded sunfish	x					Unconfirmed
Lepomis symmetricus	bantam sunfish	x		x	x		Present
Anchoa mitchilli	bay anchovy	x				x	Present
Fundulus nottii	bayou topminnow	x					Present
Ictiobus cyprinellus	bigmouth buffalo	x					Present
Percina macrolepida	bigscale logperch	x		x	x		Present
Ictiobus niger	black buffalo	x					Present
Ameiurus melas	black bullhead	x		x			Present
Pomoxis nigromaculatus	black crappie	x		x	x		Present
Notropis atrocaudalis	blackspot shiner	x	x	x	x		Present
Fundulus olivaceus	blackspotted topminnow	x	x	x	x		Present
Fundulus notatus	blackstripe topminnow	x		x	x	x	Present
Moxostoma poecilurum	blacktail redhorse	x	x	x	x		Present
Cyprinella venusta	blacktail shiner	x	x	x	x	x	Present
Ictalurus furcatus	blue catfish	x		x	x	x	Present
Cycleptus elongatus	blue sucker	x		x	x		Present
Lepomis macrochirus	bluegill	x	x	x	x	x	Present

*fish survey was in Village Creek only.

Scientific Name	Common Name	NPS (2015)	Moriarty and Winemiller (1997)*	Suttkus (1979)	Moring (2003)	Winemiller et al. (2014)	Occurrence
Enneacanthus gloriosus	bluespotted sunfish	x					Unconfirmed
Etheostoma chlorosomum	bluntnose darter	x	x	x	x	x	Present
Amia calva	bowfin	x		x			Present
Labidesthes sicculus	brook silverside	x	x	x	x	x	Present
Ictalurus nebulosus	brown bullhead	x					Probably Present
Pimephales vigilax	bullhead minnow	x	x	x	x	x	Present
Ictalurus punctatus	channel catfish	x	x	x	x	x	Present
Ichthyomyzon castaneus	chestnut lamprey	x		x	x		Present
Notropis potteri	chub shiner	x					Unconfirmed
Cyprinus carpio	common carp	x			x		Present
Semotilus atromaculatus	creek chub	x					Present
Erimyzon oblongus	creek chubsucker	x					Present
Etheostoma proeliare	cypress darter	x	x	x	x		Present
Ctenogobius boleosoma	darter goby					x	
Lepomis marginatus	dollar sunfish	x		x	x		Present
Percina sciera	dusky darter	x	x	x	x	x	Present
Notropis atherinoides	emerald shiner	x		x	x		Present
Dormitator maculatus	fat sleeper					x	
Pylodictis olivaris	flathead catfish	x	x		x		Present
Centrarchus macropterus	flier	x	x	x		x	Present
Noturus nocturnus	freckled madtom	x	x	x	x		Present
Aplodinotus grunniens	freshwater drum	x	x	x	x	x	Present

*fish survey was in Village Creek only.

Scientific Name	Common Name	NPS (2015)	Moriarty and Winemiller (1997)*	Suttkus (1979)	Moring (2003)	Winemiller et al. (2014)	Occurrence
Ctenogobius shufeldti	freshwater goby					x	
Notropis buchanani	ghost shiner	x		x			Present
Dorosoma cepedianum	gizzard shad	x		x	x	x	Present
Notemigonus crysoleucas	golden shiner	x	x	x	x	x	Present
Fundulus chrysotus	golden topminnow	x		x	x		Present
Etheostoma parvipinne	goldstripe darter	x					Present
Ctenopharyngodon idella	grass carp, silver orfe	x			x		Present
Lepomis cyanellus	green sunfish	x		x	x	x	Present
Fundulus grandis	Gulf killifish					x	
Etheostoma histrio	harlequin darter	x	x	x			Present
Trinectes maculatus	hogchoker	x		x		x	Present
Menidia beryllina	inland silverside	x			x	x	Present
Notropis chalybaeus	ironcolor shiner	x					Present
Erimyzon sucetta	lake chubsucker	x					Present
Micropterus salmoides	largemouth bass	x		x	x	x	Present
Heterandria formosa	least killifish					x	
Lepomis megalotis	longear sunfish	x	x	x	x	x	Present
Percina macrocephala	longhead darter						
Lepisosteus osseus	longnose gar	x		x	x	x	Present
Notropis volucellus	mimic shiner	x	x	x	x	x	Present
Hybognathus nuchalis	Mississippi silvery minnow	x	x	x	x		Present
Agonostomus monticola	mountain mullet	x					Unconfirmed

*fish survey was in Village Creek only.

Scientific Name	Common Name	NPS (2015)	Moriarty and Winemiller (1997)*	Suttkus (1979)	Moring (2003)	Winemiller et al. (2014)	Occurrence
Etheostoma asprigene	mud darter	x		x			Present
Microphis brachyurus	opossum pipefish					x	
Lepomis humilis	orangespotted sunfish	x					Unconfirmed
Polyodon spathula	paddlefish	x					Present
Hybopsis amnis	pallid chub, pallid shiner	x	x	x	x		Present
Aphredoderus sayanus	pirate perch	x	x	x			Present
Opsopoeodus emiliae	pugnose minnow	x	x	x	x	x	Present
Lepomis gibbosus	pumpkinseed	x					Probably Present
Lucania parva	rainwater killifish	x				x	Present
Cyprinella lutrensis	red shiner	x			x	x	Present
Lepomis auritus	redbreast sunfish	x			x		Present
Lepomis microlophus	redear sunfish	x	x	x	x	x	Present
Micropterus coosae	redeye bass	x			x		Present
Etheostoma whipplei	redfin darter	x		x			Present
Esox americanus	redfin or grass pickerel	x	x	x	x		Present
Lythrurus umbratilis	redfin shiner	x					Present
Lepomis miniatus	redspotted sunfish					x	
Lythrurus fumeus	ribbon shiner	x	x	x		x	Present
Carpiodes carpio	river carpsucker	x		x	x		Present
Percina shumardi	river darter	x		x			Present
Morone saxatilis	rockfish, striped bass	x			x		Present
Membras martinica	rough silverside	x					Unconfirmed

*fish survey was in Village Creek only.

Scientific Name	Common Name	NPS (2015)	Moriarty and Winemiller (1997)*	Suttkus (1979)	Moring (2003)	Winemiller et al. (2014)	Occurrence
Notropis sabinae	sabine shiner	x	x	x		x	Present
Poecilia latipinna	sailfin molly					x	
Ammocrypta vivax	scaly sand darter	x	x	x	x		Present
Cyprinodon variegatus	sheepshead minnow					x	
Macrhybopsis hyostoma	shoal chub					x	
Notropis shumardi	silverband shiner	x		x			Present
Alosa chrysochloris	skipjack shad					x	
Etheostoma gracile	slough darter	x	x	x	x		Present
Ictiobus bubalus	smallmouth buffalo	x			x	x	Present
Ichthyomyzon gagei	southern brook lamprey	x			x		Present
Fundulus blairae	southern/western starhead topminnow	x	x	x			Present
Macrhybopsis aestivalis	speckled chub	x		x			Present
Micropterus punctulatus	spotted bass	x	x	x	x	x	Present
Lepisosteus oculatus	spotted gar	x	x	x	x	x	Present
Minytrema melanops	spotted sucker	x	x	x	x		Present
Lepomis punctatus	spotted sunfish	x	x	x	x		Present
Mugil cephalus	striped mullet	x	x	x	x	x	Present
Phenacobius mirabilis	suckermouth minnow	x	x	x			Present
Etheostoma fusiforme	swamp darter	x	x				Present
Noturus gyrinus	tadpole madtom	x		x	x		Present
Notropis amabilis	Texas shiner	x			x		Present
Dorosoma petenense	threadfin shad	x	x	x	x	x	Present

*fish survey was in Village Creek only.

Scientific Name	Common Name	NPS (2015)	Moriarty and Winemiller (1997)*	Suttkus (1979)	Moring (2003)	Winemiller et al. (2014)	Occurrence
Chaenobryttus gulosus	warmouth	x	x	x	x	x	Present
Notropis texanus	weed shiner	x	x	x	x	x	Present
Gambusia affinis	western mosquitofish	x	x	x	x	x	Present
Ammocrypta clara	western sand darter	x		x			Present
Etheostoma clarum	western sand darter	x	x		x		Present
Morone chrysops	white bass	x		x	x	x	Present
Pomoxis annularis	white crappie	x	x	x	x	x	Present
Morone mississippiensis	yellow bass	x				x	Present
Ameiurus natalis	yellow bullhead	x			x		Present

*fish survey was in Village Creek only.

Appendix S. The complete list of species and the distributions by creek/river as found by either Suttkus and Clemmer (1979), Moriarty and Winemiller (1997), Moring (2003), and/or Winemiller et al. (2014).

		Neches River			Beech Creek	Turkey Creek		Hickory Creek	Big Sandy Creek		Menard Creek		Village Creek			Little Pine Island Bayou	
Scientific Name	**Common Name**	**1979**	**2003**	**2014**	**1979**	**1979**	**2003**	**1979**	**1979**	**2003**	**1979**	**2003**	**1979**	**1997**	**2003**	**1979**	**2003**
Lepisosteus spatula	alligator gar	x	x	x											x		
Anguilla rostrata	American eel	x															
Strongylura marina	Atlantic needlefish		x	x													
Elassoma zonatum	banded pygmy sunfish	x			x	x		x	x				x	x		x	x
Enneacanthus obesus	banded sunfish																
Lepomis symmetricus	bantam sunfish	x											x		x	x	
Anchoa mitchilli	bay anchovy			x													
Fundulus nottii	bayou topminnow																
Ictiobus cyprinellus	bigmouth buffalo																
Percina macrolepida	bigscale logperch	x					x										
Ictiobus niger	black buffalo															x	
Ameiurus melas	black bullhead	x			x			x					x			x	
Pomoxis nigromaculatus	black crappie	x	x			x							x			x	x
Notropis atrocaudalis	blackspot shiner	x	x		x		x	x	x					x			
Fundulus olivaceus	blackspotted topminnow	x			x	x	x	x	x	x	x	x	x	x	x	x	
Fundulus notatus	blackstripe topminnow	x	x	x			x			x		x			x	x	x
Moxostoma poecilurum	blacktail redhorse	x	x				x		x	x	x	x	x	x	x		x
Cyprinella venusta	blacktail shiner	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Ictalurus furcatus	blue catfish	x	x	x													x

Scientific Name	Common Name	Neches River 1979	Neches River 2003	Neches River 2014	Beech Creek 1979	Turkey Creek 1979	Turkey Creek 2003	Hickory Creek 1979	Big Sandy Creek 1979	Big Sandy Creek 2003	Menard Creek 1979	Menard Creek 2003	Village Creek 1979	Village Creek 1997	Village Creek 2003	Little Pine Island Bayou 1979	Little Pine Island Bayou 2003
Cycleptus elongatus	blue sucker		x														
Lepomis macrochirus	bluegill	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Enneacanthus gloriosus	bluespotted sunfish																
Etheostoma chlorosomum	bluntnose darter	x		x	x	x		x	x		x		x	x		x	x
Amia calva	bowfin	x											x				
Labidesthes sicculus	brook silverside	x		x	x	x		x	x				x	x	x	x	x
Ictalurus nebulosus	brown bullhead																
Pimephales vigilax	bullhead minnow	x	x	x	x		x	x	x	x	x		x	x	x	x	x
Ictalurus punctatus	channel catfish	x	x	x					x	x		x	x	x	x	x	x
Ichthyomyzon castaneus	chestnut lamprey	x	x													x	
Notropis potteri	chub shiner																
Cyprinus carpio	common carp											x				x	
Semotilus atromaculatus	creek chub				x				x								
Erimyzon oblongus	creek chubsucker				x				x								
Etheostoma proeliare	cypress darter	x			x	x		x	x				x	x		x	x
Ctenogobius boleosoma	darter goby			x													
Lepomis marginatus	dollar sunfish	x			x	x			x	x			x		x	x	x
Percina sciera	dusky darter	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Notropis atherinoides	emerald shiner	x	x												x	x	
Dormitator maculatus	fat sleeper			x													
Pylodictis olivaris	flathead catfish		x				x							x	x	x	x
Centrarchus macropterus	flier	x		x	x			x	x				x	x		x	

Scientific Name	Common Name	Neches River			Beech Creek	Turkey Creek		Hickory Creek	Big Sandy Creek		Menard Creek		Village Creek			Little Pine Island Bayou	
		1979	2003	2014	1979	1979	2003	1979	1979	2003	1979	2003	1979	1997	2003	1979	2003
Noturus nocturnus	freckled madtom	x			x	x	x	x	x	x	x		x	x		x	x
Aplodinotus grunniens	freshwater drum	x	x	x										x	x	x	x
Ctenogobius shufeldti	freshwater goby			x													
Notropis buchanani	ghost shiner	x														x	
Dorosoma cepedianum	gizzard shad	x	x	x											x	x	x
Notemigonus crysoleucas	golden shiner	x		x	x	x		x			x		x	x		x	x
Fundulus chrysotus	golden topminnow	x								x	x				x		
Etheostoma parvipinne	goldstripe darter				x				x								
Ctenopharyngodon idella	grass carp														x		
Lepomis cyanellus	green sunfish	x	x	x	x			x	x				x		x	x	x
Fundulus grandis	Gulf killifish			x													
Etheostoma histrio	harlequin darter	x				x								x		x	
Trinectes maculatus	hogchoker	x		x													
Menidia beryllina	inland silverside		x	x						x					x	x	x
Notropis chalybaeus	ironcolor shiner				x												
Lepomis gibbosus	kiver, pumpkinseed																
Erimyzon sucetta	lake chubsucker				x			x					x			x	
Micropterus salmoides	largemouth bass	x	x	x	x	x	x		x	x	x		x		x	x	x
Heterandria formosa	least killifish			x													
Lepomis megalotis	longear sunfish	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Percina macrocephala	longhead darter																
Lepisosteus osseus	longnose gar	x	x	x													x

Scientific Name	Common Name	Neches River 1979	Neches River 2003	Neches River 2014	Beech Creek 1979	Turkey Creek 1979	Turkey Creek 2003	Hickory Creek 1979	Big Sandy Creek 1979	Big Sandy Creek 2003	Menard Creek 1979	Menard Creek 2003	Village Creek 1979	Village Creek 1997	Village Creek 2003	Little Pine Island Bayou 1979	Little Pine Island Bayou 2003
Notropis volucellus	mimic shiner	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x
Hybognathus nuchalis	Mississippi silvery minnow	x	x											x	x		
Agonostomus monticola	mountain mullet																
Etheostoma asprigene	mud darter	x															
Microphis brachyurus	opossom pipefish			x													
Lepomis humilis	orangespotted sunfish																
Polyodon spathula	paddlefish																
Hybopsis amnis	pallid shiner	x	x			x		x	x	x			x	x		x	x
Aphredoderus sayanus	pirate perch	x	x		x	x	x	x	x	x		x	x	x	x	x	x
Opsopoeodus emiliae	pugnose minnow	x	x	x	x	x		x	x		x		x	x	x	x	x
Lucania parva	rainwater killifish			x													
Cyprinella lutrensis	red shiner	x	x	x						x	x				x	x	
Lepomis auritus	redbreast sunfish										x	x			x		x
Lepomis microlophus	redear sunfish	x	x	x		x	x						x	x	x	x	x
Micropterus coosae	redeye bass		x												x		
Etheostoma whipplei	redfin darter	x															
Esox americanus	redfin pickerel	x			x	x	x	x	x			x	x	x	x	x	x
Lythrurus umbratilis	redfin shiner				x	x		x	x		x						
Lepomis miniatus	redspotted sunfish			x													
Lythrurus fumeus	ribbon shiner	x		x	x	x		x	x		x		x	x		x	
Carpiodes carpio	river carpsucker	x	x												x		
Percina shumardi	river darter	x															

Scientific Name	Common Name	Neches River			Beech Creek	Turkey Creek		Hickory Creek	Big Sandy Creek		Menard Creek		Village Creek			Little Pine Island Bayou	
		1979	2003	2014	1979	1979	2003	1979	1979	2003	1979	2003	1979	1997	2003	1979	2003
Membras martinica	rough silverside																
Notropis sabinae	sabine shiner	x		x									x	x			
Poecilia latipinna	sailfin molly			x													
Ammocrypta vivax	scaly sand darter	x	x		x	x	x	x	x	x	x		x	x	x	x	
Cyprinodon variegatus	sheepshead minnow			x													
Macrhybopsis hyostoma	shoal chub			x													
Notropis shumardi	silverband shiner	x															
Alosa chrysochloris	skipjack shad			x													
Etheostoma gracile	slough darter	x						x	x		x		x	x	x		
Ictiobus bubalus	smallmouth buffalo		x	x											x	x	x
Ichthyomyzon gagei	southern brook lamprey		x		x	x	x	x	x	x			x		x		
Macrhybopsis aestivalis	speckled chub	x											x			x	
Micropterus punctulatus	spotted bass	x	x	x			x	x	x	x	x	x	x	x	x	x	x
Lepisosteus oculatus	spotted gar	x	x	x										x	x	x	x
Minytrema melanops	spotted sucker	x			x	x	x	x	x		x		x	x	x	x	
Lepomis punctatus	spotted sunfish	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
Fundulus blairae	starhead topminnow	x											x	x		x	
Morone saxatilis	striped bass		x												x		
Mugil cephalus	striped mullet	x	x	x			x						x	x	x		x
Phenacobius mirabilis	suckermouth minnow	x				x					x		x	x			
Etheostoma fusiforme	swamp darter												x	x			
Noturus gyrinus	tadpole madtom	x			x	x	x	x	x		x	x			x	x	

Scientific Name	Common Name		Neches River 1979	Neches River 2003	Neches River 2014	Beech Creek 1979	Turkey Creek 1979	Turkey Creek 2003	Hickory Creek 1979	Big Sandy Creek 1979	Big Sandy Creek 2003	Menard Creek 1979	Menard Creek 2003	Village Creek 1979	Village Creek 1997	Village Creek 2003	Little Pine Island Bayou 1979	Little Pine Island Bayou 2003
Notropis amabilis	Texas shiner															x		
Dorosoma petenense	threadfin shad		x	x	x										x		x	x
Chaenobryttus gulosus	warmouth		x	x	x	x	x	x	x	x	x	x		x	x	x	x	x
Notropis texanus	weed shiner		x	x	x		x		x	x				x	x	x	x	x
Gambusia affinis	western mosquitofish		x	x	x	x	x	x	x	x	x	x	x	x	x		x	x
Ammocrypta clara	western sand darter		x											x				x
Etheostoma clarum	western sand darter										x				x	x		
Morone chrysops	white bass		x	x	x												x	
Pomoxis annularis	white crappie		x	x	x		x					x			x	x	x	x
Morone mississippiensis	yellow bass				x													
Ameiurus natalis	yellow bullhead					x				x	x			x			x	x
Total Number of Species		*118*	*70*	*46*	*51*	*37*	*33*	*26*	*34*	*39*	*26*	*28*	*16*	*47*	*44*	*48*	*56*	*43*

Appendix T. TCEQ environmental flow standards adopted for five gages in the Neches River Basin. The Sabine River near Evadale and Village Creek near Kountze appear in the two far-right columns (reproduced from Winemiller et al. 2014).

Season	Flow status	Neches River near Neches, Texas (NENE)	Neches River near Rockland, Texas (NERO)	Angelina River near Alto, Texas (ANAL)	Neches River near Evadale, Texas (NEEV)	Village Creek near Kountze, Texas (VIKO)
Winter (Jan-Mar)	Subsistence	1.4 cms (51 cfs)	1.9 cms (67 cfs)	1.6 cms (55 cfs)	6.5 cms (228 cfs)	2.4 cms (83 cfs)
	Base	5.6 cms (196 cfs)	8.7 cms (306 cfs)	7.8 cms (277 cfs)	54.5 cms (1,925 cfs)	7.5 cms (264 cfs)
	Pulse	1 per season Trigger: 23.6 cms Duration: 10 days Volume:154,878.6 ha-m	1 per season Trigger: 87.2 cms Duration: 14 days Volume:666,366 ha-m	1 per season Trigger: 45.9 cms Duration: 13 days Volume: 300,888.1 ha-m	1 per season Trigger: 57.2 cms Duration: 6 days Volume:169,601.2 ha-m	1 per season Trigger: 56.9 cms Duration: 13 days Volume:299,372.1 ha-m
Spring (Apr-Jun)	Subsistence	0.6 cms (21 cfs)	0.8 cms (29 cfs)	0.5 cms (18 cfs)	7.5 cms (266 cfs)	1.4 cms (49 cfs)
	Base	2.7 cms (96 cfs)	11.9 cms (420 cfs)	2.5 cms (90 cfs)	51.1 cms (1,804 cfs)	3.3 cms (117 cfs)
	Pulse	2 per season Trigger: 23.2 cms Duration: 12 days Volume:165,426 ha-m	2 per season Trigger: 48.7 cms Duration: 12 days Volume:313,758.3 ha-m	2 per season Trigger: 31.1 cms Duration: 14 days Volume:195,519.7 ha-m	2 per season Trigger: 108.5 cms Duration: 12 days Volume:557,641 ha-m	2 per season Trigger: 39.1 cms Duration: 13 days Volume:187,218 ha-m
Summer (Jul-Sep)	Subsistence	0.3 cms (12 cfs)	0.6 cms (21 cfs)	0.3 cms (11 cfs)	8.2 cms (288 cfs)	1.2 cms (41 cfs)
	Base	1.3 cms (46 cfs)	1.9 cms (67 cfs)	1.1 cms (40 cfs)	16.4 cms (580 cfs)	2.2 cms (77 cfs)
	Pulse	1 per season Trigger: 3.2 cms Duration: 4 days Volume:10,855.5 ha-m	1 per season Trigger: 5.5 cms Duration: 5 days Volume:12,549.8 ha-m	1 per season Trigger: 4.1 cms Duration: 8 days Volume:21,338 ha-m	1 per season Trigger: 43.6 cms Duration: 9 days Volume:175,154.6 ha-m	1 per season Trigger: 9.7 cms Duration: 8 days Volume:49,931.8 ha-m
Fall (Oct-Dec)	Subsistence	0.4 cms (13 cfs)	0.6 cms (21 cfs)	0.5 cms (16 cfs)	6.5 cms (228 cfs)	1.2 cms (41 cfs)
	Base	2.3 cms (80 cfs)	2.5 cms (90 cfs)	1.5 cms (52 cfs)	14.5 cms (512 cfs)	2.8 cms (98 cfs)
	Pulse	2 per season Trigger: 9.8 cms Duration: 8 days Volume:43,705.6 ha-m	2 per season Trigger: 14.6 cms Duration: 8 days Volume:66,251.5* ha-m	2 per season Trigger: 16.6 cms Duration: 12 days Volume:97,593.7 ha-m	2 per season Trigger: 44.5 cms Duration: 7 days Volume:14,428.6 ha-m	2 per season Trigger: 20.2 cms Duration: 9 days Volume:92,632.1 ha-m

* The volume of 66,251.5 ha-m is a calculation based on trigger flow rate and duration. The value published by TCEQ of 5,261.5 ha-m (649 ac-ft) is an obvious error (Winemiller et al. 2014).

Appendix U. Environmental flow regimes recommended for maintenance of native biota and ecological processes for the Neches River at Evadale and Village Creek near Kountze. Derived from the Sabine/Neches BBEST biological overlay, MBFIT hydrologic separation method, and HEFR summarization (reproduced from Winemiller et al. 2014).

Season	Flow status	Neches River near Evadale, Texas (NEEV)	Village Creek near Kountze, Texas (VIKO)
Winter (Jan-Mar)	Dry year	49.8 cms (1,760 cfs)	6.8 cms (240 cfs)
	Average year	73.3 cms (2,590 cfs)	12.0 cms (424 cfs)
	Wet year	141.0 cms (4,980 cfs)	19.0 cms (672 cfs)
	Pulse	2 per season Trigger: 56.6 cms Duration: 6 days Volume:175,941 ha-m	2 per season Trigger: 56.9 cms Duration: 13 days Volume:299,372.1 ha-m
		1 per season Trigger: 246.4 cms Duration: 22 days Volume:2,068,437 ha-m	1 per season Trigger: 58.6 cms Duration: 13 days Volume:309,157.4ha-m
Spring (Apr-Jun)	Dry year	44.0 cms (1,553 cfs)	3.0 cms (106 cfs)
	Average year	58.6 cms (2,070 cfs)	5.4 cms (189 cfs)
	Wet year	109.5 cms (3,868 cfs)	9.5 cms (335 cfs)
	Pulse	2 per season Trigger: 97.4 cms Duration: 12 days Volume:521,945.3 ha-m	2 per season Trigger: 39.1 cms Duration: 13 days Volume:187,218 ha-m
		1 per season Trigger: 246.4 cms Duration: 23 days Volume:2,029,458 ha-m	1 per season Trigger: 58.6 cms Duration: 15 days Volume:256,590.7 ha-m
Summer (Jul-Sep)	Dry year	13.3 cms (471 cfs)	2.0 cms (70 cfs)
	Average year	60.6 cms (2,140 cfs)	2.6 cms (91 cfs)
	Wet year	90.9 cms (3,210 cfs)	3.8 cms (135 cfs)
	Pulse	2 per season Trigger: 33.7 cms Duration: 7 days Volume:126,714.5 ha-m	2 per season Trigger: 9.7 cms Duration: 8 days Volume:49,931.8 ha-m
		1 per season Trigger: 96.0 cms Duration: 13 days Volume:520,453.5 ha-m	1 per season Trigger: 23.0 cms Duration: 13 days Volume:92,567.2 ha-m
Fall (Oct-Dec)	Dry year	12.4 cms (438 cfs)	2.5 cms (89 cfs)
	Average year	36.2 cms (1,280 cfs)	3.9 cms (138 cfs)
	Wet year	74.5 cms (2,630 cfs)	6.7 cms (236 cfs)

Season	Flow status	Neches River near Evadale, Texas (NEEV)	Village Creek near Kountze, Texas (VIKO)
	Pulse	2 per season Trigger: 32.6 cms Duration: 6 days Volume:98,582.7 ha-m	2 per season Trigger: 20.2 cms Duration: 9 days Volume:92,632.1 ha-m
		1 per season Trigger: 108.2 cms Duration: 13 days Volume:553,295.5 ha-m	1 per season Trigger: 58.6 cms Duration: 13 days Volume:252,480.4 ha-m

Appendix V. Current oil and gas pipelines that cross BITH. Reproduced from Sobczak et al. (2010). Pipelines are organized by management unit.

No.	Operator	Product	Preserve Identifier	Size of Pipeline	Construction Date
Beaumont					
1.	Centana Intrastate Pipeline LLC	Natural gas	B-2	1-6”	1959
2	Houston Pipe Line Company	Not in service	B-3	1-6”	1961
Big Sandy Creek					
3.	Tennessee Gas Pipeline Company	Natural gas	BS-1	1-24”	1944
4.				1-31”	1949
5.				1-30”	1952
6.	El Paso Field Service LP	Natural gas	BS-2	1-4”	1983-1984
7.				1-3’	1996
Hickory Creek Savannah					
8.	El Paso Field Services	Natural gas	HC-1	1-8’	1949
9.	Houston Pipe Line Company	Not in service	HC-4	1-6”	1949
10.	Energy Transfer Company	Natural gas	HC-5	1-10”	1929-1930
11.	Tennessee Gas Pipeline Company	Not in service	HC-6	N/A	
Jack Gore Baygall/Neches Bottom					
12.	El Paso Field Services	Natural gas	JG-1	1-4”	1945
13.	El Paso Field Services	Natural gas	JG-2	1-4”	1949
14.	Lion Oil Company	Crude oil	JG-3	1+-10”	1932
15.	El Paso Field Services	Natural gas	JG-4	1-8”	1961
16.	Oxy Petroleum Company	Not in service	JG-5	1-2.5”	1954
17.	Black Lake Pipeline	NGL	JG-6	1-8”	1967
18.	El Paso Field Services	Natural gas	JG-7	1-6”	Unknown
19.	El Paso Field Services	Natural gas	JG-8	1-8”	Unknown
Lance Rosier					
20.	Black Lake Pipeline	NGL	LR-1	1-8”	1967
21.	Sunoco Pipeline LP	Crude oil	LR-2	1-6”	1950
22.	Black Hills Operating Co., LLC	Crude oil	LR-3	1-12”	1930s

LPG - liquid petroleum gas

NGL - natural gas liquids

No.	Operator	Product	Preserve Identifier	Size of Pipeline	Construction Date
23.	Chevron Pipe Line Company	Empty	LR-4	1-12”	1931
24.	Sunoco Pipeline LP	Crude oil	LR-5	1-10”	1931
25.	Mobile Pipe Line Company	Crude oil	LR-6	1-20”	1954
26.	Kinder Morgan Texas Pipeline, LP	Natural gas	LR-7	1-18”	1954
27.				1-20”	
28.	Sunoco Pipeline LP	Crude oil	LR-8	1-6”	1950
29.	Chevron Pipe Line Company	Not in service	LR-9	1-12”	Late 1920s
30.	Sunoco Pipeline LP	Crude oil	LR-10	1-26”	1953
31.	Sunoco Pipeline LP	Not in service	LR-11	1-6”	1952
32.	SETEX Oil and Gas Company	Not in service	LR-12	1-4”	1952
33.	Big Thicket Pipe Line LLC	Natural gas	LR-13	1-6”	2000
Lower Neches River Corridor					
34.	Trunkline Gas Company	Natural gas	LN-1	2-24”	1950
35.					1966
36.	Gulf State Pipe Line Co., Inc.	Naptha	LN-2	1-8”	1974
37.	Transcontinental Gas Pipe Line Corp.	Natural gas	LN-3	1-30”	1949
38.	Houston Pipe Line Company	Natural gas	LN-4	1-8”	1961
.39.	Lion Oil Company	Crude oil	LN-5	1-10”	1932
40.	Houston Pipe Line Company	Natural gas	LN-6	1-30”	1974
Menard Creek Corridor					
41.	Mobile Pipe Line Company	Crude oil	MC-1	1-20”	1954
42.	Kinder Morgan Texas Pipeline, LP	Natural gas	MC-2	1-18”	1954
43.				1-20”	
44.	Sunoco Pipeline LP	Crude oil	MC-3	1-26”	1953
45.	Chevron Pipeline Company	Not in service	MC-4	2-24”	1957
46.		LPG			1970
47.				2-10”	
48.					
49.	Louis Dreyfus Pipeline LP	NGL	MC-5	1-12”	1971

LPG - liquid petroleum gas
NGL - natural gas liquids

No.	Operator	Product	Preserve Identifier	Size of Pipeline	Construction Date
50.	TE Products Pipeline Co LP	NGL	MC-6	1-10”	1993
51.	Mustang Pipeline Company	HVL	MC-7	1-10”	1995
Pine Island Bayou-Little Pine Island Bayou Corridor					
52.	Unocal Corporation	Crude oil	PI-1	1-10”	1929-1930
53.	Kinder Morgan Texas Pipeline, LP	Natural gas	PI-2	1-18”	1954
54.				1-20”	
55.	Mobile Pipe Line Company	Crude oil	PI-3	1-20”	1954
56.	Link Energy Texas LLC	Crude oil	PI-4	1-8”	1930s
57.	Transcontinental Gas Pipe Line Corp	Natural gas	PI-5	1-30”	1949
58.	Houston Pipe Line Company	Natural gas	PI-6	1-12:	1959
59.	Transcontinental Gas Pipe Line Corp	Natural gas	PI-7	1-10”	1949-1950
60.	Houston Pipe Line Company	Natural gas	PI-8	1-4”	1981
61.	El Paso Field Services	Natural gas	PI-9	1-8”	Unknown
62.	Kinder Morgan Texas Pipeline, LP	Natural gas	PI-10	1-4”	1929
Turkey Creek					
63.	Houston Pipe Line Company	Natural gas	TC-1	1-4”	1968
64.	Houston Pipe Line Company	Natural gas	TC-2	1-10”	1952
65.	Enterprise Products Operating LP	Natural gas	TC-3	1-6”	1956
66.		Not in service		1-6”	
67.	El Paso Field Services	Not in service	TC-4	2-4”	1956
68.					
69.	Driscoll	Natural gas	TC-5	1-2”	1977
70.	El Paso Field Services	Natural gas	TC-6	1-8”	1976
Upper Neches River Corridor					
71.	Black Lake Pipeline	NGL	JC-6	1-8”	1967

LPG - liquid petroleum gas
NGL - natural gas liquids

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Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

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