Conservation Science
and Stewardship at
Audubon Canyon Ranch

THE ARDEID

2018

Disturbance ecology of herons and egrets Bird's eye view of habitat
A year following egrets Fire follower plants at Bouverie Preserve

Ardeid (Ar-DEE-id), N., refers to any member of the family Ardeidae, which includes herons, egrets, and bitterns.

THE ARDEID

In this issue

Cover: Redwood lily *(Lilium rubescens)* is one of the 'post-fire opportunist' wildflowers that bloomed this year at Bouverie Preserve. Photo by Tom Hilton/Creative Commons.
Ardeid masthead: Great Blue Heron ink wash painting by Claudia Chapline.

Above: A GPS tag used for egret telemetry studies. Measuring 6.5 cm or about 2.5 inches (plus the antennas), the solar-powered device weighs just 50 grams or about 1.75 ounces.

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Disturbance ecology of herons and egrets

Slow Local Recovery

by John P. Kelly

Figure 1. Great Egrets are among the Ardeidae whose conservation status ACR has evaluated. Pictured on the shore beyond this tidal flat is Cypress Grove Research Center.

Sometimes, a passing boat is noticed only after it is no longer in view. Tiny waves sweep the shoreline, rise to a brief crescendo, then give way to the persistent ambient conditions of the day. On most days, the wakes of passing boats, along with changes in wind and tidal currents, the daily routines of birds, the secret activities of myriad tiny creatures beneath the surface, and countless other phenomena are lost in the natural complexity that forms and reforms the more conspicuous, emergent displays of wetland life. More rarely, a sudden change in just one thing can destabilize an entire ecosystem.

The important ecological roles of herons and egrets (Ardeidae) as top predators in wetland landscapes may be highly sensitive to sudden changes that occur only rarely within any particular wetland system. Such sensitivity is seldom considered in evaluating species' conservation status, a process that typically targets entire species, subspecies, or genetically distinct populations as units of conservation. Based on such units, which generally extend across huge geographic scales, herons and egrets in North America are assumed to be of low conservation concern (IUCN, International Union for Conservation of Nature: http://www.iucnredlist.org; Reddish Egret *[Egretta rufescens]* is a noteworthy exception, considered vulnerable to extinction along the Gulf Coast of the United States and in Mexico, the Caribbean, and Central America). Even within regional landscapes such as the San Francisco Bay area, the ecological standing of herons and egrets is considered to be dynamic but stable over long periods of time (Kelly et al. 2006, 2007; Kelly and Nur 2015). However, major declines in nesting abundance within individual wetland systems can occur even when populations or regionwide abundances are stable. Therefore, the effective protection of these beautiful birds—and their important roles in sustaining the ecological health of individual wetlands—warrants a much closer look.

We know that herons and egrets establish nesting colonies not only to secure safe places to raise their young, but also to facilitate efficient access to foraging locations throughout the surrounding landscape (see page 3 box: Subregional Roles of Herons and Egrets). Conservation planning groups involving government agencies, nonprofit organizations, and local citizens tend to coalesce around concerns for the protection of particular watersheds or subregional wetland systems. For example, stakeholder groups have formed to address, specifically, the conservation of Tomales Bay, the Laguna de Santa Rosa, Suisun Marsh, and other wetland subsystems of San Francisco Bay area. At such scales, planning groups make management recommendations that directly affect the ecosystem needs of herons and egrets.

The conservation status of herons and egrets may be the most critical, ecologically, at scales corresponding to the individual wetland systems that provide the resources needed for both nesting and foraging. Within each system, the numbers of nesting birds fluctuate with a rhythm that differs dramatically from the regional or global dynamics of populations, which typi-

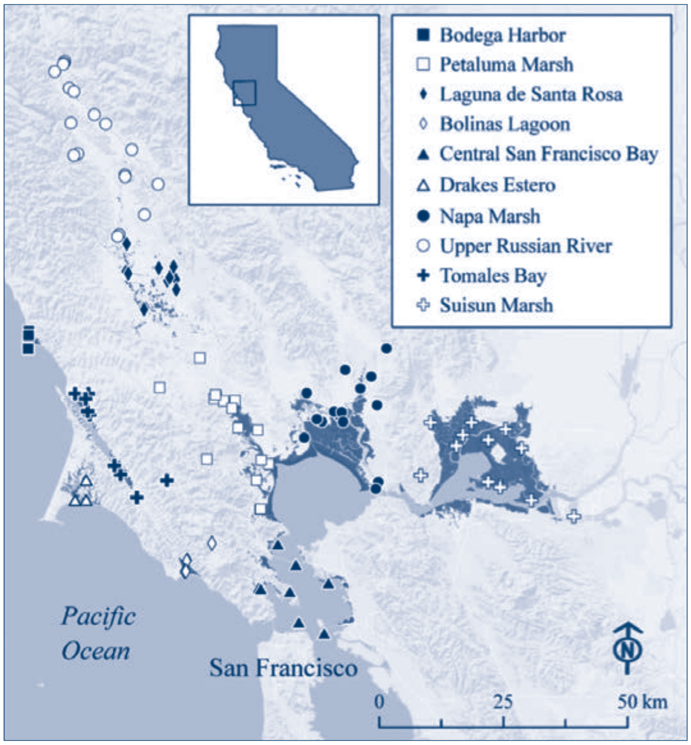

Figure 2. Colony sites used by nesting Great Blue Herons, Great Egrets, Snowy Egrets, and Black-crowned Night-Herons within 10 km of each subregional core wetland system in the northern San Francisco Bay area, California, USA.

Table 1. Wetland subregions in the northern San Francisco Bay area, California, the areal extent of the core wetland habitat considered suitable for foraging by ardeids in each subregion, and the areal extent of the associated landscape within 10 km of the core wetlands (Figure 2).

Wetland Subregion	Core Wetland Area (km^2)	Subregional Area (km^2)
Laguna de Santa Rosa	20.7	1,499
Petaluma Marsh	53.1	1,177
Napa Marsh	129.6	1,342
Suisun Marsh	249.2	1,947
Central San Francisco Bay	12.8	1,298
Tomales Bay	11.	1,222
Bolinas Lagoon	4.7	497
Bodega Harbor	2.4	481
Drakes Estero	10.9	699
Upper Russian River	2.2	1,426

Table 2. Mean nest abundances and standard errors (SE) of colonial ardeid species within subregional wetland systems of the northern San Francisco Bay area, California, 1991–2010 (n = 20).

	Great Blue Heron		Great Egret		Snowy Egret		Black-crowned Night-Heron	
Subregion	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Bodega Harbor	3.6	0.40	11.8	10.43	2.1	13.65	1.3	0.40
Bolinas Lagoon	13.0	0.96	77.2	2.20	4.1	0.76	0.0	–
Central San Francisco Bay	22.9	1.56	120.7	1.90	158.1	5.10	219.3	27.81
Drakes Estero	3.3	0.65	8.4	1.90	0.0	–	0.0	–
Laguna de Santa Rosa	41.4	1.86	55.4	5.26	34.9	16.87	85.1	11.09
Napa Marsh	121.1	10.14	24.2	5.59	106.8	1.71	122.1	9.86
Petaluma Marsh	20.4	1.81	22.1	0.48	10.4	0.92	39.2	4.25
Suisun Marsh	93.4	5.98	424.3	23.45	2.1	0.92	0.6	0.55
Tomales Bay	31.0	2.35	36.4	0.75	0.0	–	0.7	0.22
Upper Russian River	22.8	2.65	2.6	0.48	0.0	–	0.9	0.80
Entire region (all subregions)	372.9	12.72	783.1	27.03	318.5	22.41	469.2	31.83

cally drive priorities for conservation. Similarly, the subregional status of these birds cannot be discerned from changes observed at the colony-site scale, because the trends and fates of individual nesting colonies are averaged out as nesting birds relocate within and between individual wetland systems. Consequently, the rhythm of life most relevant to both the foraging and nesting needs of herons and egrets has remained mysterious—until now.

Conservation status within individual wetlands

I recently collaborated with Sarah Millus (former ACR Biologist) and Emiko Condeso (ACR Ecologist and GIS Specialist) to investigate the effects of sudden major declines in the abundances of four ardeid species within major subregional wetland systems of the San Francisco Bay area (Kelly et al. 2018). We examined the extent to which sudden major subregional declines in nesting abundance, below selected thresholds of annual change, affect the future numbers of Great Blue Herons *(Ardea herodias)*, Great Egrets *(A. alba)*, Snowy Egrets *(Egretta thula)*, and Black-crowned Night-Herons *(Nycticorax nycticorax)*. Specifically, we used time-series models within each of ten wetland systems of the northern San Francisco Bay area to estimate the number of years subregional numbers of herons and egrets need to recover from sudden major declines in subregional nest abundance.

We used the California Aquatic Resource Inventory (San Francisco Estuary Institute 2016) to approximate the boundary and areal extent of the central, "core wetland system" in each wetland subregion (Table 1). Nesting colonies within 10 km of each core wetland system were assumed to be within foraging range of the associated wetlands and grouped to facilitate the analysis of subregional nesting abundances (Table 1; Figure 2).

The locations of all known colony sites in each subregion were determined as part of ACR's ongoing, annual effort to monitor approximately 60 active colony sites each year in the northern San Francisco Bay area (Table 2; Figure 2). Most colony sites are visited at least four times each breeding season, primarily by 60 to 100 qualified field observers who generously volunteer their time to contribute to ACR heron and egret research.

To evaluate the effects of sudden major declines in nesting activity, we analyzed up to ten 20-year time series of annual nesting abundances for each species—one time series for each species in each wetland subregion (Figure 2). Our analytical approach controlled for all trends and other background dynamics in each wetland system, allowing us to estimate the isolated impacts of sudden major declines and associated rates of recovery. We defined thresholds of sudden major decline in a manner similar to defining a 100-year flood (a floodwater level with a 1% chance of annual occurrence): we defined 0.80, 0.90, and 0.95 impact thresholds as "major decline" in annual nest abundance that were more extreme than 80%, 90%, or 95% of the observed changes for each species within each subregion. Therefore, the absolute thresholds of sudden major decline were allowed to differ among species and subregions with different nesting dynamics or levels of tolerance to human activity, potential nest predators, or other sources of disturbance.

Our results further allowed for average interannual movements of nesting birds between subregions and for average rates of recruitment of first-time breeders from other areas. Therefore, we make no claims that subregional nesting dynamics operate independently as closed systems—they definitely do not! As expected, this new look into the dynamics of nesting herons and egrets at scales delineated simply by their access to individual wetland systems and the flow of water across the landscape raises many unanswered questions about mechanisms that might account for the observed impact and recovery rates (see box: "Subregional Roles of Herons and Egrets").

Seriously slow recovery

The predicted time required, on average, for subregional nest numbers to recover to less than 5% of the original impact was 18.8 years for Great Blue Heron, 13.0 years for Great Egret, 7.2 years for Snowy Egret, and 14.5 years for Black-crowned Night-Heron (Table 3; Figures 3 and 4 on page 4). The confidence intervals in our results further suggested the possibility of substantially shorter or longer periods of recovery (Figures 3 and 4). Estimated recovery rates appeared to be faster in subregions with more extensive core wetlands, although this

Table 3. The impacts of sudden major declines in subregional nest abundance on four heron and egret species at three impact thresholds. Years to 95% recovery, with 95% confidence intervals (CI), is the predicted time for the impact to drop below 5% of the initial decline in nest abundance. (Initial impacts are back-transformed from modelled $\log_e$ values; *P [modelled coefficient] < 0.001.)

Species	Number of observed sudden major declines	Initial impact (average % decline)	Year-to-year persistence of the impact % +/- SE	Years to 95% recovery (95% CI)
0.80 impact threshold				
Great Blue Heron	28	-46*	85 ± 3.6*	18.8 (9.0 – 28.7)
Great Egret	8	-69*	79 ± 3.2*	13.0 (8.6 – 17.4)
Snowy Egret	6	-72*	66 ± 7.1*	7.2 (3.6 – 10.9)
Black-crowned Night-Heron	10	-68*	81 ± 5.4*	14.5 (5.3 – 23.7)
0.90 impact threshold				
Great Blue Heron	13	-49*	83 ± 3.9*	15.8 (8.1 – 23.4)
Great Egret	3	-86*	79 ± 3.3*	13.1 (8.4 – 17.8)
Snowy Egret	1	-73*	63 ± 7.7*	6.6 (3.2 – 10.1)
Black-crowned Night-Heron	6	-73*	76 ± 5.7*	11.0 (5.1 – 17.0)
0.95 impact threshold				
Great Blue Heron	9	-61*	78 ± 3.6*	12.1 (7.7 – 16.6)
Great Egret	1	-96*	79 ± 3.2*	13.0 (8.6 – 17.5)
Snowy Egret	1	-73*	64 ± 7.7*	6.6 (3.2 – 10.1)
Black-crowned Night-Heron	3	-81*	74 ± 6.3*	10.1 (4.4 – 15.7)

Subregional Roles of Herons and Egrets

San Francisco Bay and the adjacent Central Valley of California have been recognized as a region of hemispheric importance to ardeids in North America, with critical value to heron species conservation in the Pacific flyway. Because nesting ardeids generally forage within a few to several kilometers of their nest sites, individual wetland systems within a regional wetland complex provide potentially important units for conservation—ecologically reasonable units corresponding to both the scales of hydrologic connectivity that distinguish individual wetland systems and the foraging and nesting requirements of individual herons and egrets. Within particular wetland systems such as coastal estuaries and lagoons, inland lakes, large tidal marshes, riverine floodplains, coastal embayments, and shallow wetland basins, unexpected sudden major declines in heron or egret nesting abundance may have dramatic ecosystem impacts if their collective ecological role as top predators is diminished. Ecological theory suggests that such declines could lead to cascading, top-down effects on the structure of food webs and, ultimately, to the loss of biological diversity. If so, our recent research suggests that system-wide recovery could take a very long time (Kelly et al. 2018).

Nesting herons and egrets respond to environmental changes beyond the immediate vicinity of their colony sites. Patterns of colony-site selection and reproductive success reflect adaptive responses to surrounding landscape conditions within their foraging range (Ardeid 2008: "The Protection of Nesting Landscapes"), to disturbance by potential nest predators (Ardeid 2004: "Vague Consequences of Omnipresence"), to interference associated with nearby human activities (Ardeid 2002: "A Safe Place to Nest"), and to climate change, especially heavy rainfall (Ardeid 2010: "Herons in the Mist").

Herons or egrets may readily abandon their nest attempts in response to changes in habitat conditions at a colony site or across the surrounding wetland landscape (Ardeid 2014: "Where Have All the Egrets Gone?" and "Ripples in the Pool"). After nest failure, or between nesting years, they may establish new nest locations within the same wetland subregion, relocate to a different subregion within the larger regional landscape, or disperse to another region (Ardeid 2012: "Outcasts on the Wing").

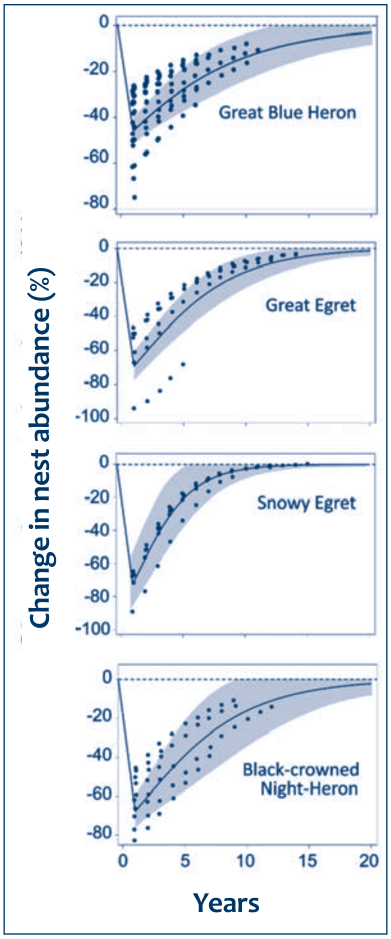

Figure 3. Predicted values (filled circles) of sudden major decline (below the lower 0.80 quantile of standard normal annual variation; Year 1) and subsequent recovery of heron and egret nest abundances over 20 years, within subregional wetland systems of the northern San Francisco Bay area, California. Values represent (back-transformed) percent annual change, relative to underlying background dynamics and trends, which were controlled for and reduced to zero (dashed line). Solid lines represent modeled impact and recovery patterns; shaded areas represent 95% confidence intervals.

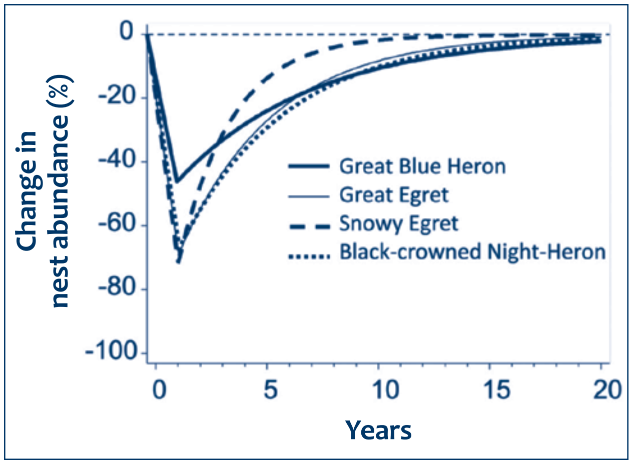

Figure 4. Comparison of recovery rates in subregional nest abundance among four ardeid species after sudden major declines (exceeding the lower 0.80 quantile of standard normal annual variation) within ten wetland subregions of the San Francisco Bay area, California (Table 3). The horizontal dashed line represents full recovery with a stable growth rate of zero, relative to other underlying trends.

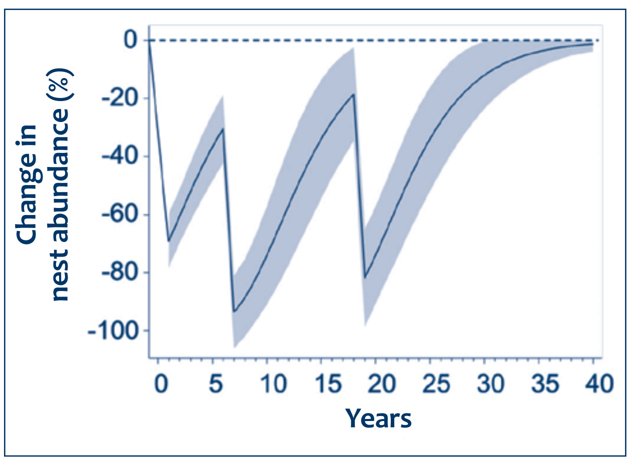

Figure 5. Predicted recovery of Great Egret nest abundance after repeated, major declines of –69%, –96%, and –86% in years 1, 7, and 19, respectively, with 79% annual persistence of the initial ($\log_e$) impact (Table 3), within ten subregions of the San Francisco Bay area, California. The horizontal dashed line represents full recovery with a stable growth rate of zero, relative to other underlying trends

effect was only marginally confirmed by our data and would benefit from additional study.

During our 20-year period of study, Great Blue Herons experienced a substantially higher frequency of sudden major declines than other species, but with significantly lower initial impacts (Table 3). Snowy Egrets exhibited the fastest annual recovery rates and Great Blue Herons exhibited the slowest annual recovery rates after a sudden major decline in nest abundance (34 ± 0.07% and 15 ± 0.04% [SE] per year, respectively). Great Egrets and Black-crowned Night-Herons exhibited intermediate rates of annual recovery (21 ± 0.03% and 19 ± 0.05% per year, respectively). Repeated sudden major declines in nest abundance at intervals shorter than the considerably long recovery times estimated by our results are likely to result in ongoing depression or decline of growth rates over very long periods of time (Figure 5).

We cannot conclusively explain why, based on our results, Snowy Egret nest abundances apparently recover more quickly than other species. However, their faster recovery rates may be associated with their lower sensitivity than other ardeids to boat disturbance and their tendency to select colony sites near developed areas of the northern San Francisco Bay area where they apparently tolerate higher levels of human activity. In addition, the relatively fast recovery rates exhibited by Snowy Egrets may be related to their consistent use of mixed colony sites where the presence of other species provides a continuing nesting stimulus.

Great Blue Herons were subject to more frequent major subregional declines in nest abundance than other species, but with relatively lower initial impact. This is likely the outcome of establishing smaller, more widely distributed nesting colonies than our other study species, possibly in response to higher rates of colony-site disturbance. The relatively slower subregional recovery rates we observed in Great Blue Herons are also consistent with potentially slower recruitment in less conspicuous, more isolated colony sites. If Great Blue Herons establish multiple, smaller colonies in a given subregion, major disturbance at any particular colony site will result in a smaller impact on subregional nest abundance. Among our study species, the relatively lower initial impacts of sudden major subregional declines on Great Blue Heron nest numbers are reflected in relatively stable subregional and regional abundances over more than 25 years (Kelly et al. 2007; Kelly and Nur 2015).

Great Egrets experienced more severe sudden declines in subregional nest abundance than other species. Great Egrets tend to nest in fewer, larger colonies than Great Blue Herons do. Thus, for Great Egrets and other species that typically nest in large colonies, major disturbance at the colony-site level is likely to have a greater impact on subregional nesting abundance.

Everything is connected

The long periods of recovery demonstrated by our study suggest that a sudden major decline in nest abundance in any particular wetland system may suppress the ecological roles of ardeids as top wetland predators for a long time. It is important to emphasize that the gradual recovery rates we observed may be enhanced or further reduced by other processes operating at subregional, regional, or larger spatial scales. For example, the number of nesting birds in a particular wetland subregion might increase if nesting dispersal stimulated by colony-site disturbance in a nearby subregion leads to an increase in local recruitment. Processes operating over larger spatial scales, including changes in population growth, nesting or natal dispersal, birth or death rates, or extrinsic processes such as weather or habitat change, might similarly reduce or enhance predicted subregional recovery rates after a sudden major decline in nest abundance. More obviously, predicted recovery from a sudden major decline in subregional abundance may be limited by concurrent degradation or loss of foraging habitat or by continuing nesting disturbance by humans or potential nest predators.

The similarity of recovery rates across levels of initial impact suggests that the observed rates may reflect species' inherent patterns of behavior or reproduction. For example, limited recovery rates may be "hard-wired" by characteristically low levels of colony-site fidelity, spatial limits of dispersal and intraregional movement, productivity rates and recruitment of new breeders, and the need to limit foraging movements to within a few-to-several kilometers of nests. If so, average recovery rates at subregional scales might be similar among regions or vary over much larger geographic scales. A particularly striking insight from this investigation is that most of the major subregional declines in nest abundance were associated with observed or inferred disturbance at a single colony site (Great Blue Heron: 68 ± 9% of sudden major declines, n = 28; Great Egret: 88 ± 13%, n = 8; Snowy Egret: 67 ± 21%, n = 6; Black-crowned Night-Heron: 100%, n = 10). Disturbances include interference by various nest predators, nearby human activity, and direct impacts to nesting substrates.

Sudden major declines in heron and egret nest abundances are generally noticed only after many birds have departed and are out of view. Our results reveal the persistent long-term effects of major nesting disturbance on individual wetland systems. Given such risks, this work provides a strong rationale for protecting the nesting herons and egrets that enrich individual wetland systems.

John P. Kelly, PhD, served as ACR's Director of Conservation Science until his retirement in 2018.

References cited

Kelly, J. P., K. Etienne, C. Strong, M. McCaustland, and M. L. Parkes. 2006. Annotated atlas and implications for conservation of heron and egret nesting colonies in the San Francisco Bay area. ACR Tech. Rpt. 90-3-17, Audubon Canyon Ranch, P.O. Box 808, Marshall, CA 94940. 236 pp.

Kelly, J. P., K. Etienne, C. Strong, M. McCaustland and M. L. Parkes. 2007. Status, trends, and implications for the conservation of heron and egret nesting colonies in the San Francisco Bay area. Waterbirds 30: 455–478.

Kelly, J. P., S. A. Millus, and T. E. Condeso. 2018. Nesting dynamics of four ardeid species at subregional scales: Recovery rates after sudden major declines in nest abundance. Waterbirds 41:223–339.

Kelly, J. P. and N. Nur. 2015. Wildlife–heron and egret nest density and nest survival indicators. Technical summary in State of the San Francisco Estuary 2015: Status and Trends Update on 33 Indicators of Ecosystem Health. San Francisco Estuary Partnership, San Francisco, California. http://www.sfestuary.org/about-the-estuary/soter.

San Francisco Estuary Institute (SFEI). 2016. California Aquatic Resource Inventory (CARI), version 0.2 GIS Data. http://www.sfei.org/cari.

ACR's "Pirate's Code"

In 1989, we published ACR's first issue of The Ardeid. Since then, this annual account of conservation science and stewardship at ACR has become a valuable bridge linking our technical contributions to the practical interests of citizen conservationists, decision makers, and dedicated observers of nature. Sometimes, direct action by ACR fills a similar gap to help protect the natural areas we love or to make sure our scientific contributions are clearly understood, here and in other parts of the planet. This is exactly what I love about ACR: full-spectrum conservation science, from original research to public policy and hands-on stewardship, and from nature education and public outreach to citizen action. Now, with my departure from ACR, my heart is exploding with gratitude and appreciation for everyone involved with ACR. Your amazing hearts and minds have enriched and inspired my life beyond measure. Thank you so much—what a team!

As I reflect on my time at ACR, I immediately think of ACR founder Marty Griffin's many inspiring insights into conservation action, which form a sort of "pirate's code." A key tenet of Marty's "code" that has guided my life at ACR is this: successful conservation is never complete and requires persistent action—as a way of life—fueled by deep personal connections to nature. And what a life! Although I'm sad about moving on, I'm also super excited to see so many new things happing at ACR!

I am especially thrilled to welcome Dr. Nils Warnock to ACR! I cannot think of anyone with a more perfect set of skills or more suitable personal style to lead ACR's "full-spectrum" work in conservation science. Nils arrives as a renowned avian ecologist and conservation scientist with extensive publications based on decades of scientific work, especially on shorebirds and waterbirds. He comes to ACR after eight years of leading Audubon Alaska and its numerous conservation campaigns involving the Arctic National Wildlife Refuge, Tongass National Forest, off-shore drilling, climate change, and several bird conservation initiatives. Nils also brings a ton of ecological knowledge about our region, with a long history of living and working in West Marin, previously serving as co-director of the Wetlands Division at PRBO (Point Blue Conservation Science). Nils and his wife Sarah—who is also a scientist and educator—have moved into ACR's Cypress Grove Research Center and are a fantastic addition to ACR!

Warmest wishes to all! — JK

Toward highly detailed predictive maps of bird-habitat relationships

Habitat From a Bird's Eye View

by Scott Jennings

A drive up Pine Flat Road to the crest of the Mayacamas Mountains in northeastern Sonoma County can be viewed as an ecological transect through many of the plant communities found in inland central California and the rich array of bird species that reside in these habitats. You begin in riparian lowland where Tree Swallows dart around willows and cottonwoods, and you try to decide if the uniform trill you hear is a Chipping Sparrow or Dark-eyed Junco. Traveling up in elevation, oak woodlands give way to oak savanna, with clown-faced Acorn Woodpeckers and the wheezy calls of Oak Titmouses. A break into open grasslands brings Rufous-crowned and Grasshopper Sparrows singing their open-county-adapted songs. Higher up, the road passes through the eponymous copse of tall ponderosa pine set in a flat between two hills, where the sharp call of Northern Flickers echoes through the trees and acrobatic Purple Martins dodge in and out of cavities. Finally, to the highest reach of the road where the musical song of the California Thrasher bids you to venture out into the characteristic hard chaparral for a glimpse of this secretive bird.

Not only is Pine Flat Road an excellent place to spend a morning birding, but the varied habitats it passes through also make it a useful laboratory for studying how birds use different habitats across the landscape. ACR's avian surveys along Pine Flat Road and in the Modini–Mayacamas Preserve, coupled with recent remote-sensed vegetation measurements, provide an opportunity for a highly detailed, broad-scale evaluation of the habitat relationships of birds living in this area, yielding information critical for meaningful conservation action.

A cornerstone of the field of ecology is the study of how organisms interact with their habitats. In the early 20th century, legendary California zoologist Joseph Grinnell and other researchers conducted foundational research on associations between bird and plant species. By the middle of the century, Macarthur and Macarthur (1961) were among the first to show that, in deciduous forests, it is really the physical structure or "architecture" of the habitat, rather than tree species per se, that is the dominant feature determining which species of bird will use that habitat. Specifically, they found that habitats with more vegetation layers (i.e. a greater diversity in vertical structure) provided

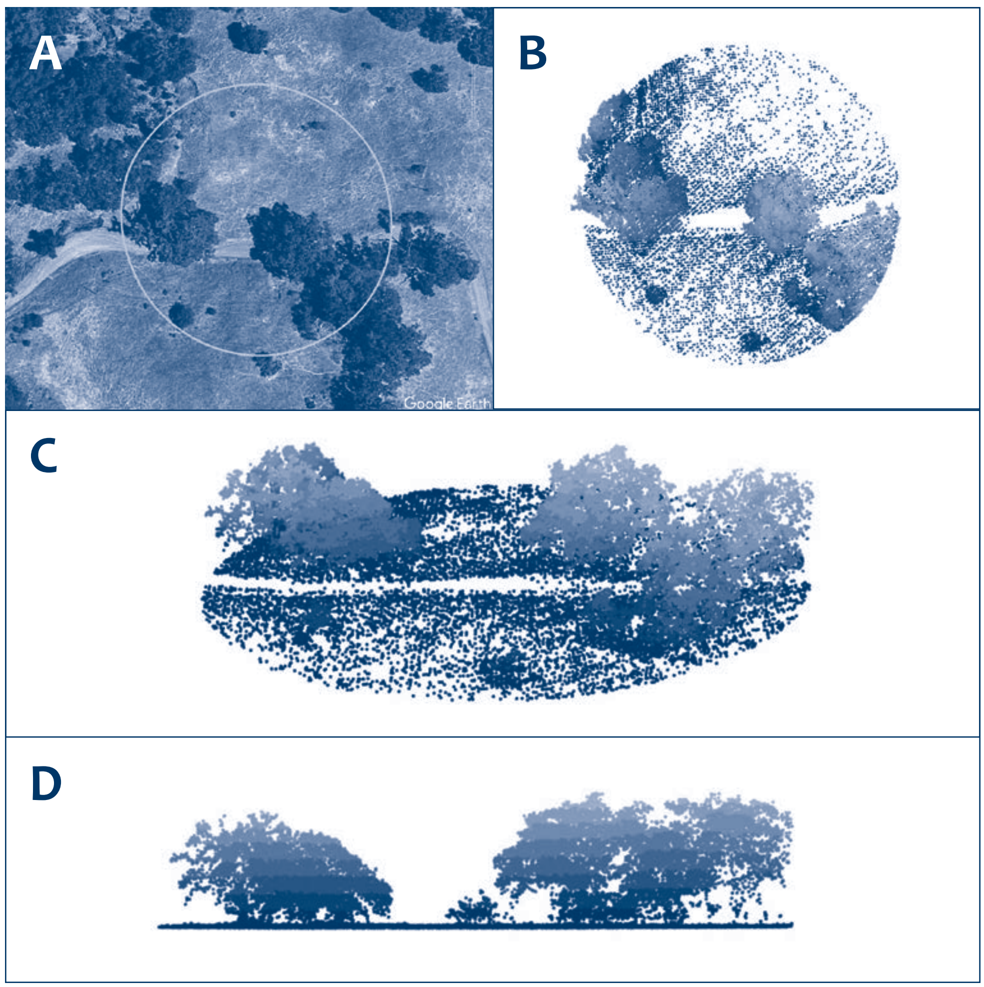

Figure 1. Demonstration of how LiDAR data represent vegetation structure. (A) Aerial image along Pine Flat Road, with the gray circle indicating a 50m radius around a bird count point. (B) Overhead, (C) oblique, and (D) side-on views of plotted LiDAR data for the same 50m radius circle, with the shapes of individual trees identifiable.

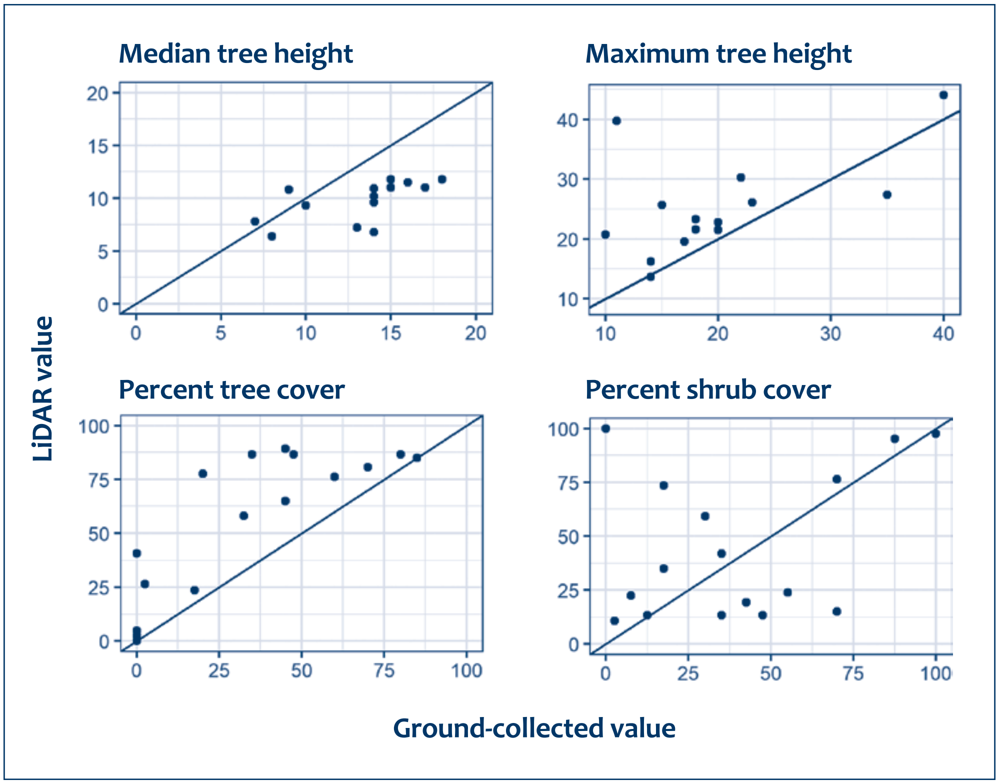

Figure 2. Relationships between ground-collected and LiDAR-derived measures of habitat structure. The diagonal 1:1 line is where we would expect the points to fall if LiDAR and field-based measurements yielded the same values.

more ecological niches, including nesting sites and more insects, and supported more bird species than habitats with simpler vertical structure. Twenty years later, Rotenberry and Wiens (1980) built upon previous work to show that both horizontal and vertical diversity in habitat structure were important in predicting abundances of individual bird species in the arid shrub-steppe habitat of the Great Basin. An important addition of this work was that not only does the overall bird community respond to habitat structure, but also the abundance of individual species could be predicted.

Guiding conservation action

The foundational work of Grinnell, Macarthur, Wiens, Rotenberry and others has been instrumental not only to ecological theory but also to applied conservation and management. The principles, equations and ideas introduced by these early researchers allowed a more rigorous understanding of bird–habitat relationships, which in turn enabled conservation planners and land managers to conserve and manage habitats to maximize bird populations. For example, bird species distribution modeling has informed conservation reserve planning around the world, and fire-risk modeling and post-fire management for bird populations have been improved by studies of bird–habitat associations.

Our current knowledge of bird–habitat relationships has gone far in guiding wiser use and protection of lands that sustain biodiversity. However, new threats to biodiversity are operating over larger areas and longer time spans than before. Managing for these threats requires an understanding of organism–habitat relationships that is both more detailed and covers a wider area than traditional field-based habitat measurements have provided.

Until recently, habitat structure has been difficult to measure at a fine enough resolution to determine how individual birds select or associate with different habitat features, and at the same time over large enough areas to be relevant to the processes shaping entire bird populations. In recent decades, however, remote sensing (measuring physical attributes of Earth from aircraft or satellites) has dramatically improved the measurement of habitat characteristics over large areas. Applications of remote sensing for ecological studies began with measures of two-dimensional habitat characteristics. For example, satellite-based optical sensors can measure how the "greenness" of the landscape or seascape changes over time, and ecologists use this information to show how the spatial arrangement of primary productivity (photosynthesizing organisms) influences the distribution and movements of other organisms over large areas. For example, large herbivorous mammals follow a "green wave" of spring growth as they migrate across the intermountain west of the U.S. and, similarly, seabirds and marine mammals concentrate their foraging in areas of the ocean where primary productivity is greatest. Aerial imagery has also allowed scientists to better understand how the arrangement of different patches of habitat shape where animals live and how they move across the landscape.

However, the two-dimensional measures described above do not provide any information about vertical habitat structure, which is so important to birds occupying a three-dimensional habitat. In the last 15 to 20 years, a new method of measuring habitat structure has begun to be used in ecological studies: Light Detection and Ranging (LiDAR). In LiDAR, a ground-based or aircraft-mounted device emits laser beams and records the exact, three-dimensional (latitude, longitude, elevation) location of any surface that reflects the laser back to the sensor. When mounted on the underside of an airplane, these devices can collect extremely detailed data on elevation and habitat features across vast areas. Because LiDAR can register several reflections per square meter, the resulting "point cloud" of data contains enough detail to identify individual trees and shrubs and to estimate their approximate shape (height, width) and the density of their foliage (Figure 1). In the early 2010's, LiDAR data were collected across all of Sonoma County as part of Sonoma Veg Map, a project to map the topographical and vegetative characteristics of the county (http://sonomavegmap.org/). These highly detailed data are an amazing resource that has been made available for public use—including for the study of bird–habitat relationships.

ACR biologists and a select crew of dedicated volunteer expert birders have monitored landbird populations in the central Mayacamas Mountains for several years: on the Modini Ingals Ecological Preserve since 2011 (Kelly 2011), and along the entire length of Pine Flat Road since 2013 (Condeso 2014). Surveys are based on repeated visits to a series of fixed points where an observer stands for five minutes and records all the birds they see or hear within certain distances. The standardized monitoring methods allow data collected by different observers during different years to all be compared. An objective of these studies is to compare bird abundance data to the highly detailed habitat data made available by the Sonoma Veg Map project. To help achieve this goal, field-based vegetation data were collected at each bird count point along Pine Flat Road (Vose 2015), to allow verification of the relationships between bird abundances and LiDAR-derived habitat measures and to better understand what the LiDAR data are really telling us about vegetation structure.

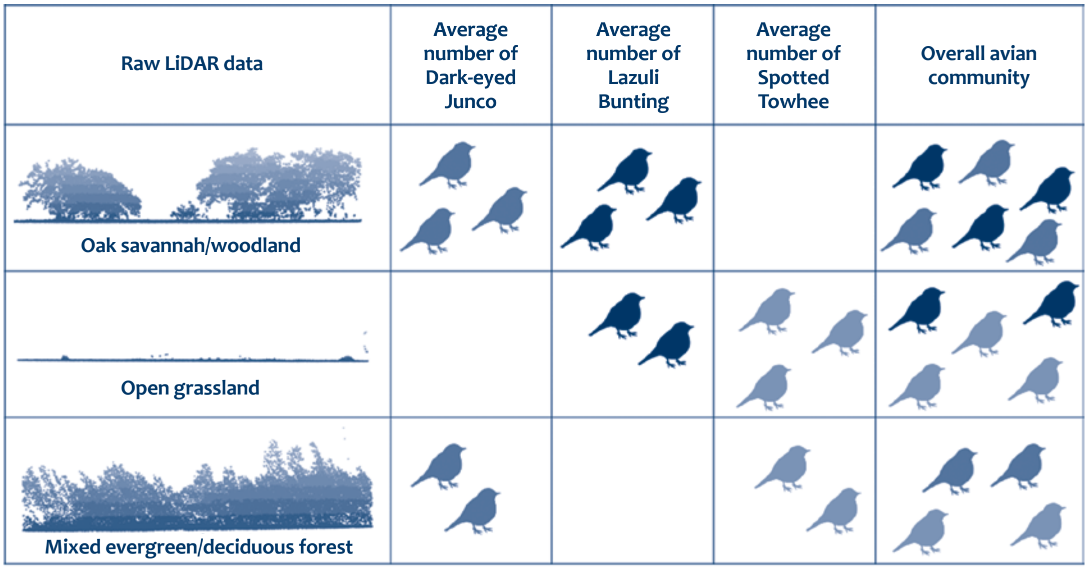

Figure 3. Habitats with different structures support different numbers of various bird species. These differences in avian communities are determined by the specific habitat requirements of individual species. Bird survey data can be combined with highly detailed LiDAR data on habitat structure to model, predict and map these bird species-specific habitat requirements over large areas, and ultimately to generate better predictions of the overall avian community in particular habitats.

Maximizing LiDAR utility

The goal of using LiDAR is the same as when using field-based habitat data: to develop metrics of vegetation structure that can accurately predict bird abundance. LiDAR presents us with a tremendous amount of information about habitat structure. Even over the relatively small areas where we can reasonably count birds from a given point on the ground (~400m radius circle), there can be over 1,000,000 LiDAR data points! This information is needed to understand and predict how different bird species are distributed across the landscape, but it remains a challenge to summarize the data so that it can be mathematically compared to bird abundance data.

Ecologists initially used LiDAR to replicate habitat measurements that were already being collected by field-based methods. For example, LiDAR-generated measures of canopy height, cover, and complexity have been shown to be good indices of forest characteristics such as total plant biomass and tree trunk diameter, and have been particularly useful in aiding forest management practices. In bird–habitat analyses, LiDAR-derived variables equivalent to those derived from field habitat measurements have been useful for predicting how many different bird species may co-exist in an area. However, effective conservation may require a more nuanced understanding of exactly which bird species exist in which area and, hopefully, why—information that simpler models of habitat structural diversity and bird community diversity may not provide.

Contemporary research is increasingly taking advantage of the rich information in LiDAR point clouds to derive new variables that are not possible with field-collected data. Beyond simple indices of whether a habitat has diverse structure, these new variables provide ways to measure precisely how the vegetation is distributed vertically and horizontally. These variables show great promise to dramatically increase our ability to predict how birds are distributed across the landscape. Researchers have only begun to scratch the surface of what is possible using LiDAR data to predict abundances of bird species with specialized habitat requirements.

LiDAR meets bird data

With the LiDAR data provided by the Sonoma Veg Map project and ACR's bird and vegetation data from the central Mayacamas Mountains, we are well poised to take a role in developing and testing new LiDAR-derived variables for their ability to predict bird abundances. The first step in this process has been to compare LiDAR and field-collected measures of vegetation height and cover, to provide a benchmark for how we interpret the LiDAR data and to provide greater context when we compare bird and LiDAR data. In making these comparisons, we found generally close agreement between field-based and LiDAR-generated measures of percent cover and median height of the tree layer (Figure 2, page 7). However, there was less agreement between field and LiDAR measures of maximum tree height and of the "shrub" layer. These disagreements reveal some important limitations of the LiDAR data: they do not provide enough detail to identify plant species or differentiate short trees from tall shrubs based on structure. Instead, if habitat structure metrics are desired for the different vegetation layers, a single height boundary must be decided upon, below which everything

Conservation Keys

- Understanding how habitat structure influences bird species abundance is critical for effective and efficient conservation of entire avian communities.
- New threats to biodiversity require measuring and predicting bird–habitat relationships over larger areas than has previously been possible with on-the-ground measures of habitat structure.
- Fine-scale, remote-sensed measures of habitat structure across all of Sonoma County now allow predictions of bird abundance across a wide swath of the county.

is defined as “shrub” (perhaps misclassifying some low trees) and above which everything is defined a “tree” (misclassifying tall shrubs).

Following our initial data exploration, we are now investigating the value of additional variables derived from the LiDAR data to represent vegetation structure. Variables that do not rely on somewhat arbitrary height definitions may prove particularly useful. For example, we are developing and testing variables that can differentiate between shrub- and canopy-dominated habitats based on the height of the densest part of the LiDAR point cloud.

Ultimately, it is unlikely that any single variable will describe habitat structure adequately to predict abundance of individual bird species. Therefore, once we have established habitat variables that we think will reasonably represent habitat structure for each species, we will then combine those variables into a small set of bird species-specific hypotheses about the relationships between habitat structure and bird abundance. Finally, we will use statistical models to test which hypothesis best explains the patterns of bird abundance that we’ve observed. The top models will be used to generate predictive maps of the abundance of individual bird species over larger areas of the Central Mayacamas Mountains. This will allow us to better understand the habitat-based factors that contribute to the patterns of individual bird species abundance, which will in turn allow us to better predict the overall avian community of the area (Figure 3).

The final products of our work will provide an important new tool for conservation planning and ecosystem management in this corner of Sonoma County. They will also set the stage for the next phases of ACR’s landbird research program: evaluating the relationships between bird abundances, habitat characteristics, and wildfire management practices such as prescribed burns and vegetation clearing.

Scott Jennings is an Avian Ecologist at ACR’s Cypress Grove Research Center.

References cited

Condeso, E. 2014. Branching out: ACR launches a new long-term monitoring survey on Pine Flat Road. The Ardeid 2014:10–12.

Kelly, J. P. 2011. First surveys: Documenting the avian richness of the Modini Ingalls Ecological Preserve. The Ardeid 2011:6–9.

Macarthur, R. H., and J. W. Macarthur. 1961. On bird species diversity. Ecology 42:594–598.

Rotenberry, J. T., and J. Wiens. 1980. Habitat structure, patchiness, and avian communities in North American steppe vegetation: A multivariate analysis. Ecology 61:1228–1250.

Vose, G. 2015. Data report: Vegetation survey at avian point count stations along Pine Flat Road, in northern Sonoma County, California. ACR Tech. Rpt. 2013-3-1

Welcoming Nils Warnock, PhD, as ACR’s new Director of Conservation Science

In August 2018, Dr. Nils Warnock joined ACR as the new Director of Conservation Science. With a passion for birds that began in childhood, Nils has studied and worked professionally to address the conservation issues that birds face in our rapidly changing world. For the last eight years he served as the executive director of Audubon Alaska and vice president of the National Audubon Society. Nils started his career in West Marin, at Point Blue Conservation Science, where he was the co-director of the Wetlands Division from 2000 to 2008. He earned a PhD in Ecology from the University of California at Davis and San Diego State University.

Nils is a Fellow of the American Ornithological Society and has over 30 years of experience in the ecology and conservation of Pacific Flyway birds, especially shorebirds. He has done extensive research in California, especially Marin County and San Francisco Bay, as well as throughout the Pacific and East Asian–Australasian flyways.

At ACR, Dr. Warnock will lead and implement ACR’s core science agenda, which addresses real problems in Bay Area landscapes, including challenges to dwindling biodiversity and habitat loss, threats to wetlands, effects of climate change, and the protection of the natural systems that surround North Bay communities.

Nils and his wife Sarah have taken up residence at Cypress Grove Research Center, as their son Noah and daughter Anna have recently fledged. We welcome Nils Warnock to ACR!

Insights from birds with GPS tags

A Year Following Egrets

by David Lumpkin

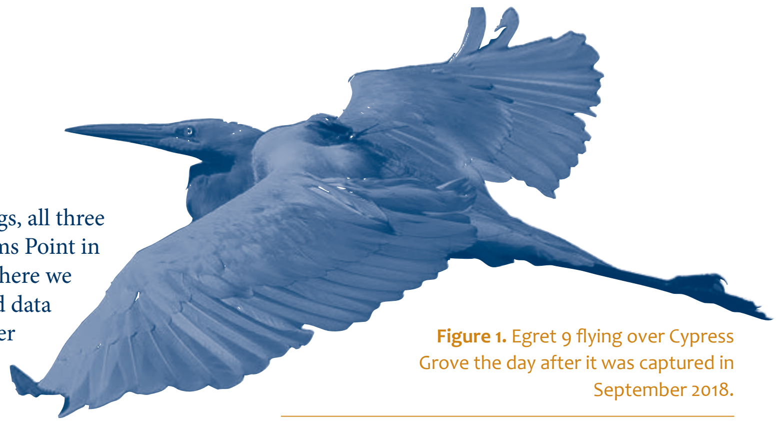

Figure 1. Egret 9 flying over Cypress Grove the day after it was captured in September 2018.

To a Great Egret *(Ardea alba)*, Tomales Bay is full of food, but that food is not always available. Every two weeks, around the full and new moons, the lowest tides and greatest foraging opportunity coincide with the early morning, making breakfast on the bay an easy affair. During low tides, hundreds of acres of intertidal eelgrass are exposed, allowing egrets to stab at herring during spawning events or to hunt pipefish, which try to wrap themselves around the egret's bill to avoid being swallowed. As the tide cycle shifts and morning tides become higher, the eelgrass is exposed for fewer hours per day, reducing foraging opportunities on the bay. During these times, egrets switch to inland ponds and creeks to hunt small fish or walk the surrounding pastures in groups to capture rodents.

In June 2017, ACR's team at the Cypress Grove Research Center put Global Positioning System (GPS) satellite tags on three Great Egrets (described in The Ardeid 2017). While we already knew that Great Egrets on Tomales Bay alter their behavior with the tides, we didn't realize how in-tune with tidal cycles they are until we began using GPS tags to study the movements of individual birds. In the last year, ACR's Heron and Egret Telemetry Project has provided us with incredible insight into the habits of local Great Egrets, confirming some of our suspicions but also shattering many of our expectations. We haven't yet collected enough data for formal analyses, but the information these tags are providing is already teaching us a tremendous amount about how these birds move across the landscape, and about the interconnections of conservation efforts near and far.

Missing in action

As it turns out, cell reception is limited on Tomales Bay, hindering our tags' automatic data uploads. But fortunately we can also locally download data from the tags using a handheld receiver. In the first few weeks following the deployment of our tags, all three egrets remained near Toms Point in northern Tomales Bay, where we could regularly download data with the handheld receiver then eagerly rush back to the office to upload the data to a computer and see what the birds had been doing. About a month after tagging, suddenly two of the three egrets could no longer be found on Tomales Bay. Worried something might have happened to them, and perplexed that they might leave an area where they likely had active nests, I drove parts of Marin and Sonoma counties with poor cell reception with a roof-mounted antenna connected to the handheld receiver, hoping to stumble across a signal.

Eventually, along Chileno Valley Road, Egret 3 (we named each egret sequentially in capture order) flew out of a ditch just long enough for a brief look at the bird and a chance to download a few GPS points from the tag. We learned that she (sex is determined genetically from a drop of blood collected during tagging) had been sleeping each night in a patch of trees on a remote Chileno Valley ranch and foraging along nearby creeks and farm ponds each day. Over the next few months, both Egret 2 and Egret 3 exhibited similar patterns: they would spend roughly a week on Tomales Bay, then fly inland for about the same length of time. When on the bay, they spent the mornings chasing prey along the shallow mudflats, following the tide in and out to match their preferred water depth of about 20–30 cm (Figure 2). When inland, both birds sought creeks and farm ponds, periodically roosting in tall patches of trees. When the tides transitioned to a more extreme part of the cycle, with eelgrass beds exposed earlier in the morning, they returned to Tomales Bay.

In contrast, Egret 1 never traveled far from Toms Point. He displayed a different approach to dealing with higher tides, often focusing on a freshwater pond at Toms Point. I watched him forage there several times. Though this pond was well covered by aquatic plants, he was consistently able to find small fish, picking them out from tiny gaps in foliage.

New discoveries in fall and winter

Great Egrets tagged by researchers in the eastern United States migrate large distances to avoid harsh winters: egrets tagged in Kansas spend winter in southern Mexico; birds breeding in New York winter in the Carolinas. One individual tagged on the Outer Banks of North Carolina even traveled all the way to Columbia, by way of Cuba. In contrast, Great Egrets are present year-round in the San Francisco Bay area. To our knowledge, it had not yet been determined if the individual birds that nest in the Bay area remain all winter, or if the local breeders leave the region and are replaced, perhaps by birds from farther north.

On the night of July 5th 2017, Egret 3 gave us a bit of data to puzzle over by flying towards Petaluma after sunset, spending the night in Helen Putnam Regional Park, then returning to her normal stomping grounds near the coast. Egrets 2 and 3 had often moves between inland and coastal areas in the morning or evening, though seldom after dark. In contrast, at the end of this flight to Petaluma, Egret 3 didn't seem to spend any time foraging, and she had passed plenty of regular roost sites that were much nearer to her usual foraging areas, so the flight showed no obvious purpose. On 14 August, Egret 3 flew to Petaluma in the evening. She

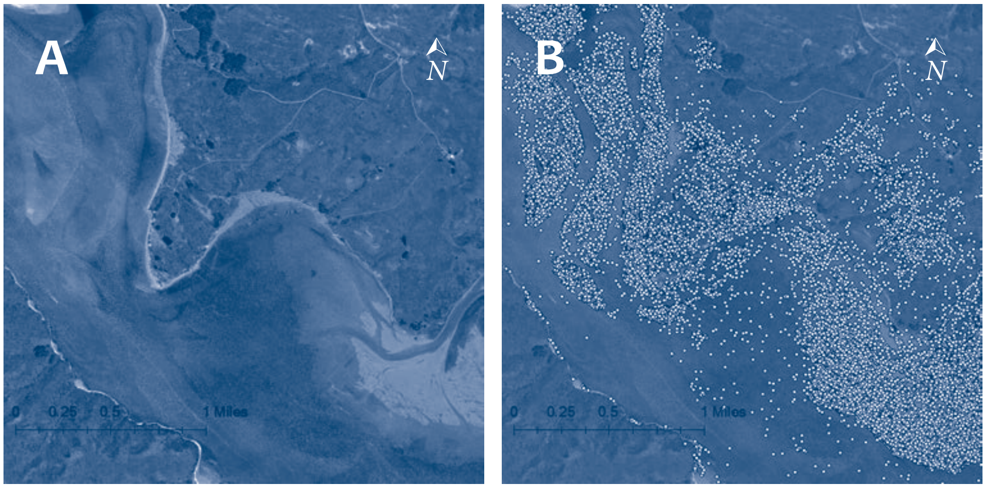

Figure 2. (A) The waters around Toms Point in northern Tomales Bay, with deep channels winding between shallow eelgrass beds (dark areas) and unvegetated mud flats. **(B)** The same area with points from GPS-tagged Great Egrets, showing the birds' use of eelgrass beds and other shallow areas.

roosted there for a few hours, then as darkness fell she flew east over the Napa Marsh, across the Sacramento River delta, and all the way to the east side of the Central Valley in the foothills of the Sierras (Figure 3C). The 98-mile flight took 3.5 hours.

Egret 3's timing seemed plausible for fall migration, but we were surprised that she would travel here during the area's driest time of year, when we assume food resources for a wetland predator would be at their annual minimum. Tagging studies in eastern North America revealed that many Great Egrets breeding there migrate hundreds of miles south in staged trips lasting multiple days. We awaited each data download in anticipation about whether this was simply the first stage of a longer journey or the Sierra foothills would be Egret 3's final destination. In November she spent a few weeks hunting in fields on the outskirts of Sacramento, just a stone's throw from I-80. But she soon returned to the same foothill location—near a creek where she spent the remainder of the winter, on a stretch just a couple of miles long.

Eventually Egret 1 left Marin County as well. He traveled south along Tomales Bay, crossed San Francisco Bay near the Richmond Bridge, and followed the San Joaquin River all the way down to the Tulare Basin, in the southern San Joaquin Valley. In contrast to Egret 3, he took several days to make the trip, foraging in wetland wildlife refuges along the way. His movements paint a fascinating picture of the landscape. The outline of the historic, vast and seasonal Tulare Lake is still visible in satellite imagery of the southern end of the San Joaquin Valley. But now the region has been converted to one of the most productive agricultural areas of the world, gridded by a network of irrigation canals and roads. Egret 1 spent the winter in the ditches and canals of this industrialized landscape, traveling in straight lines and 90-degree angles. Like Egret 3, Egret 1 made a brief trip away from his primary wintering area in November. On the 24th and 25th, he made an approximately 60-mile loop, following the California Aqueduct northward, then turned around following the San Joaquin River back southward, ending up where his flight started (Figure 3A).

We didn't receive any data from Egret 2's tag between November and early April, and following the other two egrets' departures from Tomales Bay, we wondered where Egret 2 had gone for winter. However, it turned out she stayed relatively local for the winter, spending the entire time in the Two Rock Valley between Tomales Bay and Petaluma. Although she foraged almost exclusively at a pond just 300 meters from my commute, her whereabouts had remained a mystery because cell reception in that area is poor and her favorite pond was sheltered by topography, such that her tag's signal couldn't reach the road (Figure 3B).

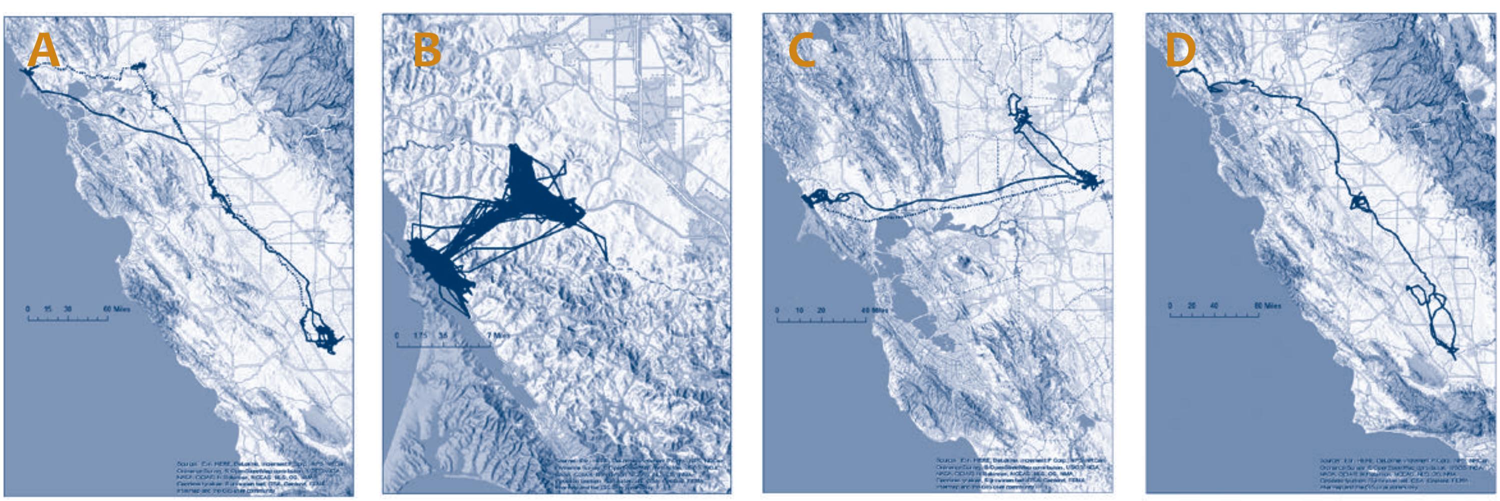

Figure 3. Movement paths of GPS-tagged Great Egrets. (A) Path travelled by Egret 1 to the southern San Joaquin Valley then back to Tomales Bay. (B) Local movements near Tomales Bay by non-migrating Egret 2. (C) Migration by Egret 3 to the Sacramento Valley then back to Tomales Bay. (D) Summer movement to the San Joaquin Valley by Egret 4. Solid lines for Egrets 1 and 3 represent late summer movements and fall migration; dotted lines represent spring return migration and summer movements.

Fire season

I lost count of how many times I've been asked what our birds did when the October 2017 fires in Sonoma County were blazing. Our other tagged egrets had left the region by then, but Egret 2 was still spending most of her time some 12 km (8 miles) inland from Tomales Bay. During the first week after the fires started, Egret 2 mostly stayed put on lower Walker Creek. The tidal cycle was such that this was a period of low eelgrass availability on Tomales Bay; for most previous periods with similar tides she had flown inland. In fact, several times between the 8th and 14th of October, when the fires and smoke were most intense, she did fly towards the inland location, but she returned to the coast within three hours each time, rather than spending several consecutive nights inland as she normally had. Of course, I can't speak for the bird's motivations, but during the fires, I was certainly happy to have the excuse to work at Cypress Grove, just south of Walker Creek, where the air quality was much better than it was farther inland.

The breeding season

In mid-April, Egret 2 returned to Tomales Bay. She began making frequent short trips to the colony at Blakes Landing on the east shore of Tomales Bay between Walker Creek and ACR's Cypress Grove Research Center, suggesting she might be building a nest. After several days of combing carefully through the colony with my telescope I eventually found the tag's small antenna poking out through her plumage. By early July, both chicks in her nest had successfully fledged.

Conservation Keys

- Great Egret foraging behavior appears to be determined by daily and weekly tidal patterns. Tagged egrets exploit intertidal eelgrass on Tomales Bay during favorable low tides, and forage in upland habitats or inland streams and ponds on days with limited low tides.
- California's Central Valley provides important winter foraging habitat for a portion of the population of Great Egrets breeding on Tomales Bay.
- By combining GPS tracking data with observations of birds at colonies, we can correlate use of space with reproductive success to inform conservation policies and land management.

Egret 3 returned to Tomales Bay in mid-April, retracing her fall path to the Central Valley. She spent the spring and summer foraging along Walker Creek and in Tomales Bay's eelgrass beds and roosting in a grove of trees on the bay's east shore. This grove was once an egret colony but now is a regular nighttime roost with no evidence of Egret 3 or any other egret attempting to nest there.

Egret 1 departed the Tulare Basin in late March, around when we would expect a migrating egret to return to its breeding ground to begin nesting. However, he took nearly the entire spring to travel north along the San Joaquin River, spending up to a few weeks in each of several locations along the way. He spent a month in the lower Sacramento River beginning in mid-May, then took a slow trip through Suisun Marsh to finally reach Tomales Bay in mid-June, near the end of the breeding season. Over the course of the spring, he visited several known Great Egret nesting colonies, but he didn't make repeated visits to any of those sites and appears not to have attempted nesting.

New egrets join the flock

We captured seven more egrets during the spring, summer, and early fall of 2018. Our first captures of 2018 were in the late spring, and the first few months of these birds' movements have already taught us new things about our local area and provided new information on how the landscape influences productivity.

Egret 4 led us to an unknown colony, located between Tomales and Petaluma, with several nesting pairs of Great Egrets and Great Blue Herons. For two weeks, Egret 4 had a consistent routine, spending each night in the colony and foraging nearby, leading us to think she might be nesting there. On 3 June, however, right in the middle of the breeding season, she ceased visiting the colony and instead began a slow, 20-mile-per-day trip east to Stockton then south through the Central Valley, stopping and foraging in wetlands (Figure 3D).

We tagged Egret 5 on 8 June and soon learned he had an active nest at the Blakes Landing colony. Locating this nest in the colony turned out to be much easier than Egret 2's. Serendipitously, I arrived at the colony one day just in time to watch Egret 5 fly to his nest, feed the three large chicks, and depart, all within the span of four minutes. It appears these three chicks fledged successfully as well. Determining the fate of all nesting attempts by tagged egrets will allow us to link movement and habitat use behaviors to reproductive success.

Looking forward

In just our first year tracking Great Egrets, we have already learned a tremendous amount. With ten egrets now tagged and transmitting data back to us, we are poised to begin learning even more about how the Bay Area breeding population interacts with and influences the landscape around us.

Our tagged birds have demonstrated an ecological link between Tomales Bay and other habitats in California. Drought conditions, other climate change effects, and land use and conservation decisions in the Central Valley may have repercussions for egrets breeding on Tomales Bay. Within the northern Bay area we have discovered the importance of neighboring upland habitat—largely privately owned rangeland—to egrets nesting on Tomales Bay. This highlights important opportunities for conservation partnerships between ACR and local land management agencies and private landowners.

The GPS-tagged egrets have raised many interesting questions. Why do some Tomales Bay egrets migrate to the Central Valley while others spend the winter locally? What is the relationship between migration and the likelihood of attempting to breed or the number of chicks produced? Selective benefits of migration are well established, but the two migrating egrets in our study did not pass along any genetic material in 2018. The causes of their movement and lack of breeding remain mysteries to us. As we tag more birds, and collect additional years of data, we will learn how their behaviors influence breeding success, and how habitat quality and availability directly affect egret populations.

Our tags provide us with novel individual-level information that can help us interpret the trends we observe in monitoring egret and heron colonies in the northern Bay area. Identifying the links between foraging habitat and breeding success will allow us to inform conservation decisions to benefit egrets and herons and the habitats they rely on. Ultimately, this new research will dramatically enhance our understanding of ardeid behavior and the conditions these birds need to thrive in a changing world.

David Lumpkin is an Avian Ecologist at ACR's Cypress Grove Research Center.

Following the "fire followers" at Bouverie Preserve

Chaparral Rediscovered

by Jennifer Potts and Jeanne Wirka

Figure 1. Wildfire-burned ridge at Bouverie Preserve, with chaparral shrubs already resprouting between charred knobcone pine trunks.

On October 8, 2017, the Nuns Fire erupted in Sonoma Valley and burned the vast majority of Bouverie Preserve's 535 acres, destroying all but two of its buildings. Within a week's time, the Nuns fire moved through Sonoma and Napa counties, consuming 56,556 acres. It was just one of several major fires that made up the historic North Bay fires of 2017.

For many people, the fires were considered devastating and destructive. From an ecologist's perspective however, the fires were in many ways healing and rejuvenating. Fire can be nature's way of cleansing itself: a means to clear out dead and overly dense vegetation, recycle nutrients, and eliminate pathogens. Fire also has a remarkable way of stimulating a rare flora that appears for just few short years and then disappears. It can be hard to reconcile the human and natural perspectives about fire, but we know that fire will move through our landscape again and we have an opportunity to learn from it.

Bouverie's post-fire treasure chest: chaparral

The Bouverie Preserve is blanketed by chamise-dominated chaparral on the hot, rocky southwest slopes of the Mayacamas Mountain range. At first introduction, chaparral is an impenetrable shrubby tangle that resists exploration by even the most intrepid field biologists. But looked at closely, chaparral hosts an extensive suite of plants and animals found in no other habitat of California. Of the 4,846 native vascular plant species found in the state, 24% occur in chaparral and 44% of these are considered rare or endangered (Keeley 2005).

What are the secrets behind this diversity? Periodic fire and specialized plant adaptations are two keys to the botanical treasure chest. Over thousands of years, chaparral has been shaped by a natural fire regime of large, high-intensity fires. In recent recorded history, we know that fire has been returning every 30–90 years to Northern California chaparral (Safford et al. 2011). Under this fire regime, the resident plant species have adapted strategies for rapid regeneration.

For the dominant chaparral shrub species—for example, chamise *(Adenostoma fasciculatum),* manzanita *(Arctostaphylos),* and ceanothus species)—post-fire recovery begins as soon as the flames pass. For some species, the regeneration strategy of choice is sprouting new photosynthetic material. These 'obligate sprouter' species—such as Pacific madrone *(Arbutus menziesii)* and toyon *(Heteromeles arbutifolia)*—produce very few seedlings but vigorously resprout from specialized underground woody tissue known as lignotubers. At the opposite end of the reproductive spectrum, 'obligate seeders' produce copious seedlings but are incapable of resprouting (e.g. ceanothus, manzanita species). Seeds from these species can lie dormant in the soil for hundreds of years until exposure to heat and chemicals from smoke or ash open the hard seed coat and allow germination to begin. Somewhere in the middle of this spectrum of recovery strategies, 'facultative seeders'—for example, chamise, scrub oak *(Quercus berberidifolia),* and some manzanita species—can both establish large numbers of seedlings and resprout after fire. These species are well equipped to handle a range of fire regimes, given their dual reproductive capability.

One example of an obligate seeder is the rare Sonoma ceanothus *(Ceanothus sonomensis),* perhaps the most treasured shrub recovery documented at Bouverie. Bouverie is home to one of only 30 known occurrences of this species. Sonoma ceanothus is endemic to Northern California, with the existing populations along the Hood Mountain range above Sonoma Valley. With such a limited range, Sonoma ceanothus has been given a California Native Plant Society 1B.2 ranking (Box 1). Prior

Figure 2. Left to right: Brewer's redmaid *(Calandrinia breweri)*, a post-fire endemic; narrow-anthered California brodiaia *(Brodiaia leptandra)*, a post-fire specialist; redwood lily *(Lilium rubescens)*, a post-fire opportunist.

to the fire, we knew of only one individual and it was difficult to locate due to outcompeting species that overtopped it. Since the fire, the Resource Ecology team found a sprinkling of new seedlings in an isolated pocket of the preserve. These new individuals will be recorded in the California Natural Diversity Database and monitored continuously to track their survival.

Towering above the rare Sonoma ceanothus, the tall scraggly knobcone pine *(Pinus attenuata)* marks the edges of chaparral with its messy architecture. Unlike its shrub associates below, knobcone pine has its own unique regeneration strategy. Knobcone seeds are stored high in the tree canopy, safe from hungry seed predators, and tightly sealed in twisted cones. Knobcone pine cones are considered 'serotinous', a term that describes the resinous seal that 'glues' the cones shut until a high-intensity fire melts the resin. Almost instantly after exposure to intense heat, the cone scales peel back and release the hidden seeds inside, showering the still-smoking forest floor with new recruits.

While post-fire shrub and tree recovery explain many of the secrets behind chaparral diversity, the true treasure trove in this ecosystem is found within the 'fire followers'—a showy flush of herbaceous species that burst from the ashes and last for only a few years. Similarly stimulated by fire cues like the obligate seeding shrubs, this specialized suite of plants irrupts from a rich underground seed bank to begin a fast and furious life cycle. Within just a few short years after fire, the fire followers will germinate, reach maturity, and deposit millions of tiny seeds that will persist in the soil until the next fire. Fire followers can be grouped into three categories based on the timing of their emergence and persistence after a fire.

Box 1. CNPS-listed rare and endangered plant species at Bouverie that benefit from fire.

Common name	Scientific name	Habitat	CNPS classification
Napa false Indigo	*Amorpha californica* var. *napensis*	pygmy redwood forest	1B.2
Sonoma sunshine	*Blennosperma bakeri*	vernal pools	1B.1
narrow-anthered California brodiaea	*Brodiaea leptandra*	chaparral	1B.2
Sonoma ceanothus	*Ceanothus sonomensis*	chaparral	1B.2
Brewer's redmaids	*Calandrinia breweri*	chaparral	4.2
bristly leptosiphon	*Leptosiphon acicularis*	oak woodland	4.2
redwood lily	*Lilium rubescens*	pygmy redwood forest	4.2

The California Native Plant Society's Rare Plant Ranking system allows communication of a species' distribution within and without the state, and the degree of threat the species faces. It is comprised by 1 or 2 characters, then a decimal point, followed by a number. The characters ahead of the decimal point describe the range of the species, while the number after the decimal classify the level of threat.

Plant range:

- **1A.** Plants presumed extirpated in California and either rare or extinct elsewhere
- **1B.** Plants rare, threatened, or endangered in California and elsewhere
- **2A.** Plants presumed extirpated in California but common elsewhere
- **2B.** Plants rare, threatened, or endangered in California but more common elsewhere
- **3.** Review List: Plants about which more information is needed
- **4.** Watch List: Plants of limited distribution

Level of threat:

- **0.1** Seriously threatened in California (over 80% of occurrences threatened / high degree and immediacy of threat)
- **0.2** Moderately threatened in California (20-80% occurrences threatened / moderate degree and immediacy of threat)
- **0.3** Not very threatened in California (less than 20% of occurrences threatened / low degree and immediacy of threat or no current threats known)

Post-fire endemics: Species that only occur one to two years after fire. Responsible for the showy flush of post-fire color in chaparral, these species are mostly obligate seeders that have been stored in the seed bank for decades or even hundreds of years. Among Bouverie's post-fire endemics, Brewer's redmaids *(Calandrinia breweri)* is most notable, with a CNPS 4.2 rare plant classification for its limited distribution throughout the state.

Post-fire specialists: Species that are most abundant in the first two years following fire but are expected to persist during early successional transitions. These species are significant contributors to the botanical spike in post-fire diversity, adding tens to hundreds of species to a given site. Among the post-fire specialists documented at Bouverie this spring were hundreds of narrow-anthered California brodiaea (*Brodiaea leptandra;* CNPS rating 1B.2). This species is only found in the Northern and Central Coast ranges of California and is considered endangered in its range.

Post-fire opportunists: Species that are present prior to the fire but take advantage of reduced competition to germinate in large numbers. Uncovered after years of dormancy, the uncommon redwood lily (*Lilium rubescens;* CNPS rating 4.2) emerged like a bouquet from the ashes in Bouverie's pygmy redwood forest. Fragrant trumpet-shaped blossoms attracted pollinators including bees and swallowtail butterflies early in the summer of 2018.

Documenting fire followers

The jaw-dropping flush of fire followers seen at Bouverie in the first post-fire spring was a rare event. With each passing year, the shrub canopy will close and the understory annuals will seemingly blink out—until the next fire. These fire-following ephemeral species provide a rare opportunity for biologists to capture the hidden diversity in chaparral.

The Bouverie Resource Ecologists and ACR's Fire Forward (formerly the Fire Ecology Program; Berleman 2017) teams have been tracking post-fire plant response to ensure that integrity of our chaparral ecosystem is intact. From our observations, ecological diversity is appropriately rich, and recovery is proceeding according to the natural processes to which the ecosystem is adapted. Additional botanical surveys in spring 2019 will help build a data baseline which we can reference after the next wildfire. Species declines after future fires may indicate that the fire regime is out of balance, either with too many or too few fires, or even fires occurring at different times of year than they historically did. ACR's Fire Forward program will be watching indicator species such as knobcone pine and Sonoma ceanothus to determine if vegetation management practices like prescribed fire or shaded fuel breaks may be necessary to maintain the natural disturbance regimes.

In addition to on-the-ground monitoring, the stewardship team placed several time-lapse cameras in early November 2017. Each camera is set to take one photo at the same time each day to document recovery rates across the different habitat types. Many of the photos show enough detail to track response of individual trees, shrubs and herbaceous plants. We are now linking the single photos into a time-series video to show post-fire recovery for ACR's science and education programs.

Collaboration with university researchers is also shedding light on complex ecological processes affected by fire. Dr. Gretchen LeBuhn and Molly Hayes at San Francisco State have chosen Bouverie as a living laboratory to understand pollinator network recovery in oak woodlands after fire. Dr. Ross Meentemeyer and his associates at Sonoma State are preparing to remeasure long-term Sudden Oak Death plots to map disease distribution before and after the fire.

As scientists, we are excited to be part of this rare time in history when we can capture a strong pulse on the landscape. Fire and disturbance are nature's tools for maintaining equilibrium and resiliency, and we have special opportunity to watch the recovery process unfold. ACR will continue to share new findings with our supporters as we delve deeper into the ecological wonders of fire.

Jennifer Potts is the Resource Ecologist at ACR's Bouverie Preserve.

Jeanne Wirka served as ACR's Director of Stewardship until 2018.

References cited

Berleman, S. 2017. The foundation: California fire ecology. The Ardeid 2017: 4–6.

Keeley, J. E. 2005. Fire as a threat to biodiversity in fire-type shrublands. In: Proceedings of the conference, planning for biodiversity: Bringing research and management together. USDA Forest Service, Pacific Southwest Research Station. General Technical Report PSW-GTR-195.

Safford, H.D., K. van de Water, and D. Schmidt. 2011. California Fire Return Interval Departure (FRID) map, 2010 version. USDA Forest Service, Pacific Southwest Region and The Nature Conservancy-California. URL: http://www.fs.fed.us/r5/rsl/clearinghouse/r5gis/frid/

Visiting investigators Audubon Canyon Ranch hosts graduate students and visiting scientists who rely on the undisturbed, natural conditions of our preserves to conduct investigations in conservation science.

Dispersal vectors and risk assessment of noxious weed spread: Medusahead invasion in California rangelands. Emily Farrer, University of California, Berkeley.

Context and scale of seagrass effects on estuarine acidification. Tessa Hill, Bodega Marine Lab, University of California, Davis.

The role of microbiota in mediating local adaptation and plant influence on ecosystem function in a marine foundation species. Melissa Kardish, University of California, Davis.

Interactions between marsh plants along a longitudinal gradient: The effect of environmental conditions and local adaptation. Akana Noto, University of California, San Diego.

Long-term monitoring of the Giacomini wetland. Lorraine Parsons, Point Reyes National Seashore.

Analysis of sedimentation in natural and restored marshes. Lorraine Parsons, Point Reyes National Seashore

Effects of non-motorized recreation on medium- and large-sized mammals in the San Francisco Bay Ecoregion. Michelle Reilly, Northern Arizona University.

Spatial and temporal variability in eelgrass genetic structure. Laura K. Reynolds, University of California, Davis.

The wildlife photo index: Monitoring connectivity and ecosystem health. Susan E. Townsend, Wildlife Ecology and Consulting/Pepperwood Preserve.

Sonoma County Vegetation & Habitat Mapping Program. Mark Tukman, Tukman Geospatial and Sonoma County Agricultural Preservation and Open Space District.

Paternity comparison of seeds sired by a variety of pollinators to Clarkia concinna. Kathleen Kay, University of California, Santa Cruz.

Understanding the effects of habitat modifiers on community structure in California salt marshes. Janet Walker, Bodega Marine Lab, University of California, Davis.

Monitoring Avian Productivity and Survival (MAPS) banding station at Livermore Marsh. Steve Albert, The Institute for Bird Populations, Point Reyes Station.

In Progress

Current projects by Audubon Canyon Ranch focus on the stewardship of preserves, ecological restoration, and issues in conservation science.

Bolinas Lagoon Heron and Egret Project. All heron and egret nesting attempts in Bolinas Lagoon have been monitored annually since 1967. The heronry at the Martin Griffin Preserve was abandoned in 2014, but we are continuing to track nest abundances and reproductive performance in the lagoon, including the active heronry near Bolinas.

Tomales Bay Shorebird Census. Since 1989, qualified birders have helped ACR monitor shorebird use in Tomales Bay. The data are used to investigate winter population dynamics, habitat values, and other topics. A paper by John Kelly and Emiko Condeso, on the benefits to shorebirds of the Giacomini Wetland tidal marsh restoration, was the featured article in the July 2017 issue of *Restoration Ecology*.

Tomales Bay Waterbird Survey. Since the winter of 1989–90, teams of qualified observers have conducted winter waterbird censuses from survey boats on Tomales Bay. The results provide information on the habitat values and conservation needs of more than 50 species.

Northern San Francisco Bay Area Heron and Egret Project. Annual monitoring of all known heron and egret nesting colonies in five northern Bay Area counties began in 1990. Results are used to measure the effects of climate change, impacts human disturbance, and the status of herons and egrets in the San Francisco Bay area (www.egret.org/atlas).

Heron and Egret Telemetry Project. Using GPS satellite telemetry to track the movements, regional landscape use, and foraging behaviors of Great Egrets throughout the Bay Area and beyond, we are investigating how individual movement and habitat use influence population changes.

Biological Species Inventory. Resident biologists maintain ongoing inventories of native plant, animal, and fungal species known to occur on ACR lands.

Hydrogeomorphological Assessment of Martin Griffin Preserve Canyons. Gwen Heistand is working with Lauren Collins (Watershed Sciences, Seattle, WA) and Jason Pearson (Lotic Environmental Services, Novato, CA) to characterize watershed conditions in MGP's four canyons, incorporating climate change and linkages with the Bolinas Lagoon ecosystem.

Cape Ivy Control. ACR stewardship staff have been implementing a phased approach to the control of non-native, invasive cape ivy *(Delairea odorata)* in the riparian corridor of Volunteer Canyon.

Golden Gate Biosphere Reserve. ACR's Martin Griffin Preserve, a member of the United Nations Golden Gate Biosphere Preserve since the 1990s, will now become part of the "core area" of this regional partnership.

Monitoring and Control of Non-Native Crayfish. Bouverie Preserve staff and volunteers are continuing to control invasive signal crayfish *(Pacifastucus lenisculus)* in Stuart Creek to reduce the impacts on native amphibians, steelhead, and other species.

Non-Native *Spartina* and Hybrids. ACR is continuing to collaborate with the San Francisco Estuary Invasive Spartina Project to coordinate and conduct field surveys and removal of invasive, non-native *Spartina* in Tomales Bay.

Perennial Pepperweed in Tomales Bay. We are conducting baywide surveys of shoreline marshes and removing isolated infestations of invasive, non-native pepperweed *(Lepidium latifolium)*, known to quickly cover estuarine wetlands, compete with native species, and alter habitat values.

Saltmarsh Ice Plant Removal. After eradicating non-native ice plant from ACR's Toms Point on Tomales Bay, we are continuing to remove resprouts, along with occasional new patches introduced from other areas by high tides and currents.

Vernal Pool Restoration. We are monitoring native plants in Bouverie Preserve's vernal pools, including a patch of the federally endangered plant Sonoma sunshine *(Blennosperma bakeri)* that ACR restored in 2009, and controlling invasive plants using manual removal and prescribed cattle grazing.

Yellow Starthistle at Modini Mayacamas Preserves. Sherry Adams investigated the responses of native and non-native grassland plants to the removal of non-native yellow starthistle *(Centaurea solstitialis)* and developed guidelines to reduce the spread of this invasive pest plant.

Invasive Species Management at Modini Mayacamas Preserves. We collaborate with volunteers on early detection, monitoring, and elimination of wildland weeds such as distaff thistle *(Carthamus lanatus)* and barbed goatgrass *(Aegilops triuncialis)*. For widespread species, such as milkthistle *(Silybum marianum)* and yellow starthistle *(Centaurea solstitialis)*, we use containment to limit their spread into new areas.

Songbirds of the Central Mayacamas Mountains. We measure breeding bird–habitat relationships using point counts along Pine Flat Road, near Healdsburg, and in ACR's Modini Mayacamas Preserve. Interested birders who can identify birds by ear and would like to volunteer to conduct counts are encouraged to contact ACR's Cypress Grove Research Center (cgrc@egret.org).

Fire Forward Initiative. ACR staff are engaging the public and media in fire ecology and fire preparedness education and outreach; coordinating with diverse regional agencies and land managers to design and implement fuels treatments, including prescribed burning, mechanical thinning, grazing, and browsing; and establishing and conducting scientific monitoring of fire and fuels treatments effects. Through science-based approaches to land management, including prescribed fire and other fuels treatments, we can learn to live with fire rather than suffer catastrophic losses.

Living with Lions. A collaborative project involves tracking the movements of mountain lions fitted with GPS satellite collars, to study wildlife corridors, regional abundance, and the conservation needs of mountain lions in areas east of Highway 101 in Sonoma County. ACR is working together with with Sonoma Land Trust, Sonoma County Regional Parks, California State Parks, and other members of the Wildlife Observers' Network Bay Area (WONBA) convened by Pepperwood Preserve.

Ecological Restoration of the Inverness Shoreline. After removing non-native vegetation and all buildings on property donated by Helen McLaren, ACR is restoring two acres of habitat with a natural gradient of riparian and tidal wetlands.

Wet Meadow Restoration at Ferguson Spring, Modini Mayacamas Preserves. We are removing invasive vegetation and planting native species along an intermittent waterway that has become incised due to the placement of an historic road that is no longer in use.

McDonnell Creek Restoration, Modini Mayacamas Preserves. ACR is removing an unused road-crossing over a creek and restoring the channel to protect downstream creek habitat and stabilize the site with local native plants.

Double-crested Cormorant Population Dynamics in the San Francisco Estuary. We are contributing to work by a team of Bay Area scientists to assess the regional population growth of Double-crested Cormorants in the context of long-term impacts of habitat change, bridge construction, and other human activities in the San Francisco Estuary.

THE ARDEID

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MGP – Martin Griffin Preserve
BP – Bouverie Preserve
CGRC – Cypress Grove Research Center
MMP – Modini Mayacamas Preserves

The Watch

Volunteers for ACR research or habitat restoration projects since *The Ardeid* 2017. Please contact ACR's Cypress Grove Research Center (cgrc@egret.org) if you are interested in volunteering for projects C, H, HT, S, or W (see below), or if your name should have been included in the 2018 list.

Project Classifications: B—Bouverie Stewards ▮ **C**—Songbirds of the Central Mayacamas ▮ **F**—Fire Forward ▮ **H**—Heron and Egret Project ▮ **HT**—Heron and Egret Telemetry Project ▮ **L**—Living with Lions ▮ **MG**—Martin Griffin Preserve Stewards ▮ **MP**—Modini Mayacamas Preserves Stewards ▮ **R**—Other ACR Research and Stewardship ▮ **S**—Tomales Bay Shorebird Census ▮ **W**—Tomales Bay Waterbird Census

Nancy Abreu (H), Bob Ahders (B, MP), Steve Albert (S), Sarah Allen (S, W), Bob Battagin (H, S), Tom Baty (H, W), Gordon Beebe (S), Gordon Bennett (W), Gail Berger (W), Patti Blumin (H), Janet Bodle (H, S), Janet Bosshard (H), Carol Boykin (H), Bill Bridges (H), Denice Britton (H), Ron Brown (H), Pam Browning (H), Brianne Brussee (H), Laura Bryan (L), Phil Burton (H), Denise Cadman (H), Kim Caffrey (H), Misty Cain (H), Ann Cassidy (H), Joanna Castaneda (H), Joanne Castro (H), Richard Cimino (S), Judith Corning (S, W), Bob Cox (B), Jeff Demarest (MP), Kim Detiveaux (B), Laura Detiveaux (B), Mark Dettling (W), Marisa D'Souza (H), Daniel Edelstein (H), Robert Eggert (H), Jules Evens (S), Eric Fessenden (B, MP), Ginny Fifield (L, HT), Binny Fischer (H, W), Mary Anne Flett (S), Jobina Forder (B), Ruth Friedman (H), Dennis Fujita (B, MP), Tom Gaman (S), Juan Garcia (C, R, S, W), Anthony Gilbert (S), Carolyn Greene (S), Steve Hadland (H), Kathy Hageman (H), Bob Hahn (B, MP), Madelon Halpern (H), Lauren Hammack (H), Roger Harshaw (W), Luanna Helfman (C, H S, W), Hugh Helm (B), Earl Herr (B), Howard Higley (W), Lisa Hug (S), Richard James (HT, R), Lorraine Johnson (MG), Tom Joynt (B), Gail Kabat (W), Richard Kavinoky (F), Guy Kay (H), Kate Keiser (H), Beverly Kerbow (MP), Joan Lamphier (H, S, W), Brett Lane (H), Judy Laursen (B), Robin Leong (H), Ann Linder (H), Iris Lombard (S), Stephen Long (C), Carolyn Longstreth (S, W), John Longstreth (S, W), Nina Madrid (H), Ron Mallory (H, W), Meg Marriott (H), Mark McCaustland (W), Dominik Mosur (S), Gerald Mugele (B, H), Kathleen Mugele (H, S), Dan Murphy (S), Sheryl Nadeau (H), Len Nelson (H), Don Neubacher (S, W), Wally Neville (H), David Noyes (B), Ed Nute (S), Amy Oglin (H), Rebecca Olsen (W), Tony Paz (MG), Margaret Petrie (H), Todd Plummer (S, W), Libby Porzig (HT), Penny Proteau (H), Louis Ptak (W), Peter Pyle (S), Greg Raynor (H), David Reichel (H), Cheryl Reynolds (H), Louise Riedel (B), Julie Roemer (H), Mary Rooney (S), Glenda Ross (B), Ellen Sabine (H), Don Schmidt (MP), Ken Schneider (S), John Schwonke (B), Noellene Schwonke (B), Victoria Seher (H), Deb Sheppard (H), Nima Sherpa (MP), Sylvie Silverstein (H), Paul Skaj (W), Tom Slyker (H), Joe Smith (W), Jackie Sones (W), Jude Stalker (W), Lang Stevenson (S), Kandice Strako (W), Kate Symonds (H), Phoebe Tanner (H), Francis Toldi (W), David Traver (B), Tessa Wardle (S), Dorothy Weicker (B), Anna Weinstein (W), Tom White (S), Alan Wight (C), Ken Wilson (W), David Wimpfheimer (S, W), Patty Wimpfheimer (W), Judy Withee (B), Don Wong (H), Patrick Woodworth (C, H, S, W)

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THE ARDEID

Conservation Science and Stewardship at Audubon Canyon Ranch

Breakfast on the Bay Great Egrets forage in intertidal eelgrass on Tomales Bay. New GPS-telemetry data collected by ACR are showing the importance of this dynamic habitat to local egrets (see page 10).