POTENTIAL PALUDICULTURE PLANTS OF THE HOLARCTIC

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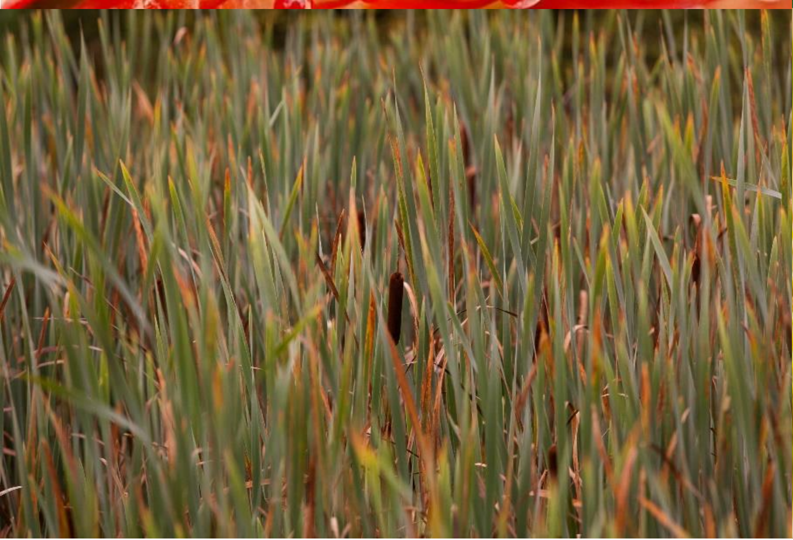
Proceedings of the Greifswald Mire Centre
04/2022






Impressum

Cover pictures: top left *Drosera uniflora* (Photo: Hans Joosten), top right *Iris pseudacorus*, bottom left *Typha* sp., bottom right *Sphagnum* sp. (Photos: Tobias Dahms)

Zitiervorschlag | suggestion for citation:
Abel, S. & Kallweit, T. (2022) Potential Paludiculture Plants of the Holarctic. Proceedings of the Greifswald Mire Centre 04/2022 (self-published, ISSN 2627-910X), 440 p.

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Impressum | Imprint

Herausgeber | publisher:
Greifswald Moor Centrum | Greifswald Mire Centre
c/o Michael Succow Stiftung
Ellernholzstraße 1/3
17489 Greifswald
Germany
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Das Greifswald Moor Centrum ist eine Kooperation von Universität Greifswald, Michael Succow Stiftung und DUENE e.V. | The Greifswald Mire Centre is a cooperation between University of Greifswald, Michael Succow Foundation and DUENE e.V.

UNIVERSITÄT GREIFSWALD
Wissen lockt. Seit 1456

Succow Stiftung

DUENE e.V.
at the Institute of Botany and Landscape Ecology

Acknowledgment

We would like to thank Prof. Hans Joosten for the idea for the DPPP as well as for inspiration and advice during the establishment phase of the DPPP and for this publication. John Couwenberg, Dierk Michaelis, Jürgen Müller and Christian Schröder gave advice on the structure of the publication and the evaluation of the plant's suitability for paludiculture. Thank you also for the continuous motivation to keep up the work.

A special thanks goes to all the reviewers from all over the world, who contributed with their knowledge about specific plants to the accuracy of the portraits: Anne Bogdanksi, Paul Brouwer, Rod Chimner, William Conner, Yvonne Fabian, Steffen Fehrenz, Bertalan Galambosi, John L. Gallagher, Greta Gaudig, Vittoria Giannini, Sabine Heinz, Lourdes Falen Horna, Laura Kenefic, Emilie Kirk, Mathias Krebs, Dierk Michaelis, Almut Mrotzek, Jürgen Müller, Nicoletta Nassi o Di Nasso, Claudia Oehmke, Uygar Özesmi, Juhani Päivänen, John Pastor, Teryl Roper, Achim Schäfer, Michael Straub, Renske Vroom, Sabine Wichmann, Wendelin Wichtmann and George Zimmermann.

The authors would like to thank Wendelin Wichtmann, Manuela Bog and Dierk Michaelis for reviewing the final manuscript.

We also thank Kora Uellendahl and Hannah Bergmann helping us format the portraits.

This work was carried out based on data of the Database of potential paludiculture plants (DPPP). The DPPP was established in the framework of the project 'VIP-Vorpommern Initiative für Paludikultur', funded by the German Ministry of Education and Research (BMBF) within the program 'Sustainable Land Management'.

Table of Content

1. Introduction

In the light of climate change and the necessity to reach the goals of the Paris Agreement of 2015, the sustainable use of peatlands and particularly their restoration has gathered momentum and urgency (Tanneberger et al. 2021). About fifteen years ago, the concept of paludiculture was contrived to provide an additional impetus for peatland restoration, since thus the areas restored can ideally be used without further peat degradation whilst a concurrent revenue can be earned (Wichtmann & Joosten 2007).

Paludiculture (lat. *palus* = swamp) is defined as the productive use of wet and rewetted peatlands under conditions in which the peat is preserved, subsidence is stopped and greenhouse gas emissions are minimized (Wichtmann et al. 2016).

In recent decades, various paludicultures have been tested in pilot projects on rewetted peatlands. The cultivation, harvest and use of cattail (*Typha* spp.), black alder (*Alnus glutinosa*) and peat moss (*Sphagnum* spp.) have been investigated with promising results. The use of the common reed (*Phragmites australis)* as a traditional wetland crop for thatching illustrates also the practical and economic feasibility of paludiculture today (Becker et al. 2020). Technical solutions for harvesting in wet peatlands are available or in development to fulfil the requirements of specific paludiculture crops (e.g., for peat mosses or cattails).

Paludiculture plants or paludi-crops are plants that thrive under wet conditions, produce utilizable biomass in sufficient quantity and quality and ideally contribute to peat formation or at least to peat conservation. Paludi-crops can either be cultivated on wet peatlands or harvested from spontaneous (successional) peatland vegetation. Examples of traditional paludicultures exist from all over the world, with reed cutting for thatch having a long tradition enduring until today (Haslam 2010). Similar applications can be found with different plant species around the world. For example, boats and building materials made from wetland plants were used and produced in a similar manner traditionally with totora (*Schoenoplectus californicus)* in Peru (La Barre 1946), with tule (*Schoenoplectus acutus*) on the west coast of North America (Turner & Bell 1971) or with berdi (*Typha domingensis*) by the marsh Arabs in southern Iran and Iraq (Thesiger 1964; Westphal-Hellbusch & Westphal 1962) (cf. Figure 1). Other examples of traditional use of wet peatlands include the pasture use or mowing of wet meadow peatlands for fodder or litter, gathering berries or the use of medicinal plants (cf. Wichtmann et al. 2016). Today, especially the new emerging bioeconomy shows multiple applications for biomass from paludiculture. Paludiculture is ideally suited to meet the guiding principle of reconciling the bioeconomy and sustainable production (climate protection, water protection, nature conservation etc.).

Figure 1: Boats and building materials were produced and used in a similar manner traditionally with wetland plants. Left: Papyrus boats from Lake Chad, on display at the Papyrus museum (Syracuse). Picture by Giovanni Dall'Orto (Wikimedia commons). Right: Totora boat at Lake Titicaca. Picture by Dennis Jarvis (Wikimedia commons).

This has fostered the search for more paludi-crops. The research results have been compiled in the 'Database of Potential Paludiculture Plants', the DPPP. This project was initiated already in 2013 with a worldwide scope (Abel et al. 2013; GMC 2021). The literature search for the DPPP (as well as here) included primary (journals, books, proceedings) and secondary (abstracts, internet sources, other bibliographic tools) sources, and amounts to a total of 1128 plant entries. For this compilation, 95 species or species groups were selected from the DPPP for the Holarctic, and one species exemplary for the tropics. **Not all species listed herein are inevitably suitable for paludiculture**. But many of them do show a promising potential, possibly revealed through further research. Others were included to discuss their potential and feasibility in a critical way and demonstrate the boundaries of paludiculture in terms of peat conservation (e.g., *Aronia melanocarpa, Arundo donax, Miscanthus x giganteus, Oryza sativa*). The overall aim of this compilation “Paludiculture plants of the Holarctic” is thus to assess the potential of almost 100 wetland plants of the Holarctic for paludiculture, characterize them in individual plant portraits and to collate the most important current literature for their utilisation and cultivation. Promising species for paludiculture in the temperate zone in Europe for different utilisation options are listed in Table 1.

The species portraits are categorized according to morphology, geographic distribution, natural habitat, site-specific properties, propagation and establishment, management, harvest, productivity, cultivation experience and the utilisation options (see detailed description of the plant portrait and definition of the categories in Chapter 2). The information given there can only be approximate, as they have been collated from a range of studies where different methods for measurement were used. Whenever possible, reviews from researchers currently working on particular species were solicited and their suggestions carefully considered. In total, 29 reviewers checked the portraits (cf. Acknowledgment). Finally, on account of the great many scattered references – especially concerning utilization – this compilation cannot possibly be deemed to contain each and every study that might be worth consulting. The following portraits should therefore be seen as providing up-to-date reviews with which the reader might be guided to the pertinent literature if further enquiry is desired. The work on the portraits has taken several years, with research and practice on paludiculture progressing in giant steps. The authors are aware that by the time of publication some portraits are already outdated, as new papers are constantly being published.

The editors hope that more research to paludiculture plants will hereby be stimulated, further enriching the range of potential paludiculture plants. A short outlook at the end of this document presents one species (*Mauritia flexuosa*) that we find promising for paludiculture outside the Holarctic. Especially in the tropics a wealth of potential paludiculture plants exists. For the editors it was not possible to include them in this publication owing to language barriers and missing literature. We hope that others will continue with PPP portraits for the rest of the world.

2. Limits of paludiculture

Peat conservation & peat accumulation in paludiculture

As the conservation of the peat soil is one of the primary concerns of paludiculture, it is important to understand how peat is accumulated in mires. Peat formation takes place when the cycling of matter is incomplete (Joosten & Clarke 2002), i.e., when the primary production of plants exceeds the decomposition of the formed organic material (Clymo 1983). The decomposition can be hampered by the absence of oxygen achieved by water saturation (Clymo 1983; Joosten & Clarke 2002). Other factors that limit decay are the chemical and structural composition of the organic material, determining the 'ability to decay'. This ability varies with species, plant parts and substances (Koppisch 2001). Hence, some plant species, organs and substances are more inclined to accumulate peat than others.

To maintain peat-preserving conditions, constant high water tables close to the surface are a precondition for paludiculture. The limit for peat conservation in temperate peatlands is the geometric mean of summer water levels of around 10 cm below surface, for moss dominated peatlands and alder carrs probably -20 cm[1]. **Water levels close to the surface or inundation will ensure peat conservation**. Slight water level fluctuations over the year can be tolerated.

The portrayed plant species are facultative or obligate wetland plants. They tolerate high water tables or inundation at least temporarily. For some species further research is necessary to assess their ability to grow in wet peatlands, i.e., under peat-conserving conditions. More details are given in the respective portraits. For some species, we recommend a cultivation in "moderately rewetted peatlands", which means peatlands, or parts of a peatland, where complete rewetting up to peat conserving water tables is not possible (e.g., because of modified hydrology in the catchment area or strong relief). In these areas plants could be cultivated that do not tolerate constant high water tables. Compared with deeply drained intensive agriculture on peatlands, subsidence and peat degradation can probably be reduced significantly. Be aware that this type of cultivation can no longer be called paludiculture.

Plant material: species and plant parts

A large number of potential paludicrops listed here can contribute to peat formation under certain conditions, e.g., *Phragmites australis*, *Sphagnum* spp., *Carex* spp., *Alnus glutinosa*. These are potentially peat forming plants, their plant remnants (e.g., roots, fibres, stalks, leaves) were documented in peat cores of natural peatlands. The ability of other species to form peat remains unknown. Even for very suitable paludiculture target species, such as cattails, the peat-forming potential is unclear (Succow & Joosten 2001).

The belowground biomass seems to be the main input for peat formation in peatlands that are dominated by vascular plants (e.g., Aerts et al. 1992; Barthelmes 2010; Bernard et al. 1988; Coleman

[1] Peat mineralization can be determined by CO_2-emissions, whereas water levels determine CO_2-emissions. The limits presented here are based on meta studies from Tiemeyer et al. (2020) and Couwenberg et al. (2011).

1976; Hartmann 1999; Hoyos-Santillan et al. 2015; Grosse-Brauckmann 1990; Michaelis et al. 2020; Prager et al. 2012). There, roots and rhizomes are growing into the already accumulated peat and form a so called 'displacement peat'. Mosses are growing upwards, while the basal parts are dying off within the anaerobic zone, being consequently partly conserved (Grosse-Brauckmann 1990).

Paludiculture should use that part of net primary production (NPP) that is not necessary for peat formation; this can amount to 80-90% of the NPP (cf. Bauer 2004; Hartmann 1999; Saarinen 1996; Sjörs 1991). Consequently, the harvest of the aboveground biomass of vascular plants is probably possible without disrupting the peat conserving process. But it also follows that the harvest of underground parts of vascular plants would probably inhibit new peat formation and should be avoided. It would disturb the soil and probably promote peat degradation. If the harvest of underground parts is wanted, caution and the least destructive method to do so should be employed. However, this utilisation cannot be called paludiculture anymore. In the case of mosses, only as much of the fresh biomass should be harvested that some part of the living moss remains and regeneration is ensured.

Peat preservation is less likely when **annual or short living plants** are cultivated. These plants usually need a regular mechanical preparation of the topsoil to prepare the seed bed or the planting site for the next crop rotation. In general, a high frequency of soil preparation makes peat preservation unlikely. An exception could be the planting or seeding of the desired crops within a closed plant layer. The promotion of annual or short living target species in an existing vegetation stand can especially be interesting for the production of high value products like pharmaceuticals. For example, sundew species (*Drosera* spp.) could be cultivated within an existing peatmoss lawn (cf. *Drosera* plant portrait).

The peat preservation potential is more likely with **perennial** plants that are cultivated in permanent cultures with rotational harvests or a final harvest after a long growing period (forestry). Due to the longer life span of the plants, the frequency of required soil cultivation measures to establish the crop is usually lower. Also, more belowground biomass can be produced that is necessary to achieve peat preservation or even peat accumulation.

The (re-)initiation of peat accumulation would be the favourable case under paludiculture. This is dependent on different parameters like the plant species, cultivation and harvest practice as well as the water and nutrient regime. Up to now, new peat accumulation has been proven in rewetted peatland sites for restoration (e.g., Graf et al. 2015; Günther et al. 2015; Hinzke et al. 2021; Mrotzek et al. 2020; Schwieger et al. 2021; Tuittila et al. 1999) but not for recently installed paludiculture demonstration sites. The reason for this is the lack of paludiculture trials with sufficient age. Long-term peat formation potential is therefore still largely unknown for paludiculture. An exception are the salt meadows on coastal flood peatlands that are used as pasture or hay-meadow. According to Jeschke (1987), trampling by cattle even favoured the formation of salt grassland peat, making it an anthropo-zoogenous peatland. Trampling compacts the soil and reduces aeration and thereby decomposition of organic material, allowing peat to accumulate. Harvest with light, tracked machinery can have a similar positive influence on peat accumulation, due to slight compaction of the upper soil that lead to lower decomposition rates (Kotowsky et al. 2013; Närmann 2018). However, there is hardly any literature about the harvest influence on peat formation in paludiculture (e.g., Kotowsky et al. 2013).

Further research is necessary to understand and adapt the management to conserve the peat in paludiculture as well as to assess the peat-accumulating potential and requirements for new paludicrops.

Paludiculture types

Paludiculture comprises various agricultural production systems that can be divided in two groups (after Tanneberger et al. 2020):

- Permanent grassland paludiculture = wet meadows, wet pastures
- Cropping paludiculture

Permanent grassland paludiculture can range from harvesting vegetation on semi-natural sites to the spontaneous establishment of ‘permanent grassland paludiculture’ after rewetting. The succession can lead to a gradual change in species composition following increased water tables and management. Such shift in species composition would comply with existing legal or planning requirements and can possibly even benefit nature protection objectives. The vegetation is adapted to the site conditions and developed from diaspores from the surrounding.

In ‘cropping paludiculture’, plants such as Alder, Common Reed, Cattail, Peat moss and Reed Canary Grass are cultivated as target crop and replace the existing vegetation. On areas where the vegetation is subject to protection, replacement by paludiculture crops may be limited. The regional nature conservation regulations need to be checked and respected. Here it is necessary to know the requirements of the plants and the culture and to choose a suitable peatland site, or vice versa. Also the invasive properties and their possible effects on natural habitats and native species should be considered before introducing exotic species as regionally new paludiculture crops.

Table 1: Promising species for paludiculture in the temperate zone in Europe with experiences in cultivation and potential market demand of the biomass.

Latin name	English name	Life form	Most promising uses	Used plant parts
Alnus glutinosa	Black alder	Tree	Timber for carpentry, interior fittings, furniture; veneer; combustion	Wood
Azolla filiculoides	Duckweed	Fern	Fodder; fertiliser (N-fixation); food	Whole plant
Carex spp.	Sedges	Graminoid	Packaging and disposable tableware; panels; fodder; bedding; combustion; biogas; paper	Aboveground biomass
Drosera rotundifolia	Sundew	Forb/herb	Medicinal use	Aboveground biomass
Glyceria maxima	Reed manna grass	Graminoid	Fodder; biogas	Aboveground biomass

Mentha aquatica	Water mint	Forb/herb	Flavour, tea	Leaves
Myrica gale	Bog myrtle	Shrub	Insect repellent; flavour (e.g., beer); medicinal uses; cosmetics	Leaves
Phragmites australis	Reed	Graminoid	Thatching material; insulation material; construction material; packaging and disposable tableware; fodder; combustion; biogas; paper	Aboveground biomass
Phalaris arundinacea	Reed canary grass	Graminoid	Packaging and disposable tableware; panels; fodder; bedding; combustion, biogas	Aboveground biomass
Salix spp.	Willow	Shrub/tree	Fuel; fodder; weaving material (e.g., baskets)	Aboveground biomass
Sphagnum spp.	Peat moss	Moss	Founder material for restoration and Sphagnum farming; orchid cultivation; horticultural growing media replacing peat; substrates for carnivorous plants, for vivaria with amphibians, reptiles and spiders; substrate for hanging baskets, wreathes and vegetation walls	Aboveground biomass
Typha spp.	Cattail	Graminoid	Insulation material; filling material (seed hairs); construction material; packaging and disposable tableware; horticultural growing media replacing peat; fodder; pollen for feeding predatory mites; biogas, combustion	Aboveground biomass
Vaccinium oxycoccus; Vaccinium macrocarpon	Cranberry	Shrub	Food (fresh berries, juice)	Berries

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3. Plant portrait: structure & description

Scientific name: Latin name and author

Vernacular name: most common English vernacular names (German name)

Family: plant family

Life form: Classified in graminoid, forb/herb, shrub, tree, moss, fern.

Main use category: Includes the economically important utilisation categories (cf. utilisation categories Table 1).

Parts mainly used: Includes which plant parts are used for the main utilisation categories.

Plant parts: aboveground biomass (everything except roots); flower; fruit; inner bark (the bark that is found just beneath the tough outer bark of trees and shrubs); leaves; manna (this is a sweet substance that is naturally exuded from certain plants, usually from the stems); nectar; plant (includes all plant parts); pollen; root; rhizomes; rubber; sap (usually of trees and usually, but not always, used as a drink); seed (includes nuts, cereals, peas and beans); seedpod (things such as Okra, French and Runner beans); stem (this often intergrades into leaves); wood

Morphology

Duration: perennial, annual, biennial; Height: from… to … in m; Leaf: arrangement (alternate, opposite, etc.), colour, retention (deciduous, evergreen), size, form; Breeding System: hermaphrodite (the flower has both male and female organs), monoecious (individual flowers are either male or female, but both sexes can be found on the same plant), dioecious (individual flowers are either male or female, but only one sex is to be found on any one plant, so that both male and female plants must be grown if seed is required); Inflorescence: size, colour, form; Fruit: size, colour, form, seed (size, colour, form); Root: description; Specifics: description.

Geographic distribution

Natural distribution of the plant: continents, selected country names for illustration.

Natural habitat: description

Site specific properties

Site specific parameters represent the ecological amplitude of the plant. The tolerances represent the deviation from a 'norm' site. The information was not available for all plants, nor can the available data be termed uniform or standardized. In some cases, the data had to be estimated or adjusted to the categories used here.

Water regime: Indicates the plant's tolerance to wetness conditions.

Moist soil: water table (median) between -70 cm below surface and 10 cm above surface ('Wasserstufe: 3+')

Wet: water table (median) between -15 cm below surface and 30 cm (or more) above surface ('Wasserstufen: 5+, 4+')

Flooded: inundated, water table mainly above surface ('Wasserstufe: 6+')

Trophic conditions: Indicates the plant's preference to the trophic conditions of the site.

Oligotrophic: very poor to poor soils or water (nutrient poor)

Mesotrophic: quite poor to intermediate soils or water (moderate nutrient poor)

Eutrophic: rich soils or water (nutrient rich)

pH: Indicates the maximum and minimum soil pH (top soil) within which the plant grows. For cultivars, the geographical range is defined as the area to which the cultivar is well adapted.

Acid: tolerant to a soil with a pH of the soil solution extract lower than 5.5

Subneutral: tolerant to a soil with a pH of the soil solution extract of 5.5 - 7.0

Alkaline: tolerant to a soil with a pH of the soil solution extract higher than 7.0

Light conditions: Indicates the relative tolerance to shade.

Shade intolerant; intermediate shade tolerant, shade tolerant

Salinity: Indicates the plant's tolerance to soil salinity. Tolerance to a soil salinity level is defined as only a slight reduction (not greater than 10 %) in plant growth.

> Low: tolerant to a soil with an electrical conductivity of the soil solution extract of 2.1 - 4.0 dS/m (=1300 - 2500 mg/l) = 1.3 - 2.5 ppb
>
> Medium: tolerant to a soil with an electrical conductivity of the soil solution extract of 4.1 - 8.0 dS/m (=2600 - 6400 mg/l)
>
> High: tolerant to a soil with an electrical conductivity of the soil solution extract of greater than 8.0 dS/m (>6400 mg/l)

Cultivation

Evaluation of the paludiculture potential and description of a potential cultivation in wet peatlands, ordered by the following themes:

Propagation and establishment: How can the plant be propagated and established for cultivation? Includes information about vegetative and/or generative propagation methods/techniques. Are special site requirements necessary?

Management: Is a certain management necessary (e.g., fertilisation, thinning, pest management)?

Harvest: When, how, how often?

Productivity: Depends on the available information: growth rate, yield, productivity.

Cultivation experiences: Enumerates implementation experiences of the respective paludiculture.

Utilisation

Information about the utilisation possibilities of the plant's biomass is provided. Utilisation options are structured into seven categories: human food; medicine and poison; animal fodder; ornament; agricultural conditioner and substrate; fuel; and raw material for industry (cf. Table 2).

Table 2: Utilisation categories used in the Database of potential paludiculture plants (DPPP).

Utilisation category	Species provide products that (directly & indirectly):
Human food	feed people (nourish and enjoy)
Medicine and poison	influence people's physical constitution (medicine, drugs, poisons)
Animal fodder	feed animals
Ornamental	influence people's mental constitution (flowers, odours, cosmetics)
Agricultural conditioner and substrate	support plant crops (for agri-, sylvi-, horticulture) and husbandry (growing media, fertilizers, herbi- & pesticides, enzymes)
Fuel	provides heat and/or energy (wood, cellulose, biomass)
Raw material	are useful non-food or non-energy materials (i.e., construction, chemical or insulation materials)

4. Potential paludiculture plants in the Holarctic

Displayed in alphabetical order

Picture: U.S. Fish and Wildlife Service

Abies balsamea (L.) Mill.

Balsam fir (Balsamtanne)

Family: Pinaceae
Life form: tree
Main use category: raw material
Used part: wood, resin

General information

Morphology: Height up to 23 m. Trunk diameter up to 0.6 m. Branches diverging at right angles, the lower ones often spreading and drooping. Leaves 1.2-2.5 cm x 1.5-2 mm, 1-ranked to spiraled, flexible; strong individual odor; adaxial surface dark green. Monoecious. Pollen cones at pollination red, purplish, bluish, greenish, or orange. Seed cones cylindric, 4-7 x 1.5-3 cm erect, (grow) upwards from the branch, gray-purple, turning brown before scale shed, sessile. Crown spirelike. Bark gray, thin, smooth, in age often becoming broken into irregular brownish scales [1].

Geographic distribution: North-eastern N. America - Newfoundland to Virginia, west to Alberta, Minnesota, and Ohio [2].

Natural habitat: Boreal forests, low swampy grounds where it is often the major component of the stand [3]. Also found on well-drained hillsides [3]. Balsam fir is more commonly found in mixed than in pure stands [4].

Site specific properties

Water regime: moist-wet
Trophic conditions: meso-eutrophic
pH: acid-subneutral
Light conditions: shade tolerant
Salinity: no tolerance

Cultivation

Balsam fir is a small to medium sized tree used primarily for pulp, lumber for light frame construction and as a Christmas tree [5]. It thrives on wet peatlands, although the growth is better on well-drained soil. It is probably peat forming [6], [7]. The ecological amplitude suggests that cultivation in moist-wet, rich peatlands could be possible. Long term flooding is detrimental, so Balsam fir is recommended for moderately rewetted peatland areas.

Propagation and establishment: Generative establishment from seeds is the dominant mode of reproduction of *A. balsamea* forests. Natural stands can show a wave of regeneration in windthrows, resulting from a reorganization of the spatial distribution of regeneration stages [8], [9]. Direct seeding or planting can be applied for propagation. The seed can be sown outdoors in March [10]. Germination is often poor ranging from about 20 to 50 %, usually taking about 6-8 weeks [10], [4]. Seeds remain viable for less than 1 year [5]. Seeds are dormant, so stored seeds should be moist stratified for 28 days at 1-5°C [2]. Seedling (or transplants) should be planted into their permanent positions in late spring or early summer, after the last expected frosts, when they are between 30 and 90 cm in height [11]. It is recommended to plant the trees on ridges to reduce the risk of detrimental flooding.

Management: Balsam fir can be managed under both even- and uneven-aged silvicultural systems [4]. In even-aged stands it is recommended to remove 20-25 % of the basal area every 10 years [12]. The idea behind continuous cover forestry is to retain an all-sized (uneven-aged) stand structure, where the only treatment is repeated single-tree harvesting. Currently there is a very heavy invasion of budworm moving in balsam fir stands from east coast towards west in Canada and US causing large-scale damage.

Harvest: The low load-bearing capacity of the wet peat soil makes the wood harvest difficult. Harvesting should be done in winter after the ground is frozen and snow-covered or via cable way technique [13] to minimize peat disturbance and its possible effect on water quality. Clear cutting should be avoided because it may create severe forest renewal problems, unacceptable (for tree growth) increases in the ground water levels, fast growing competition, frost, and wildlife damage [14]. Partial harvest or strip cutting to allow the regeneration of stands (provide seeds) is recommended. Be aware that the stand is subject to windthrow if more than 50 % of a stand is removed at one time [15].

Productivity: At maturity balsam fir is small- to medium-sized, depending on location and growing conditions. In general, heights range from 12 to 18 m with diameters ranging from 30 to 46 cm at breast height [5]. 9-10 years are required to produce a 2-meter Christmas tree. In a ranking with hard- and softwoods from around the world, balsam fir is highest with a total aboveground oven-dry biomass at age 50 of 184 t/ha. Annual increment or annual net primary production averages 10.3 t/ha [16]. In New Brunswick [17], dry-matter production of balsam fir in pure stands increased dramatically with increases in stand densities from 1,730 to 12,350 stems per ha. At an average age of 43 years, total above-ground biomass was 96 t/ha for the least dense stand and 143 t/ha for the densest stand. A comparison between a 60-year-old tree stand on a sample plot of a dense stand with 6,250 stems/ha and in the open part with 1,900 stems/ha showed merchantable volumes of 367 and 148 m^3/ha, respectively [12].

Growth is best on well-drained, sandy loam soils. Production on wet peatlands is much lower, the site index rarely exceeds 35, meaning that the tree grows approximately

10.7 m in 65 years [12]. Yield tables are available [12], [5].

Cultivation experiences: Widely cultivated in Canada and the U.S. [12]. Paludiculture is unknown.

Utilisation

Human food: The inner bark is edible when cooked. It is usually dried, ground into a powder and then used as a thickening in soups etc. or mixed with cereals when making bread [18], [19]. Fir bark is a delight to chew in winter or early spring, being slightly mucilaginous and sweetish, better raw than cooked [20]. Another report says that it is an emergency food and is only used when all else fails [21]. An aromatic resinous pitch is found in blisters in the bark [22]. When eaten raw it is delicious and chewy [23], [21]. Another report says that the balsam or pitch forms a highly concentrated, albeit unpleasant, food in extreme emergencies [20]. An oleoresin from the pitch is used as a flavouring in sweets, baked goods, ice cream, and drinks [21]. Tips of young shoots are used as a tea substitute [19], [21].

Medicine: The resin has been used throughout the world and is a very effective antiseptic and healing agent. It is used as a healing and analgesic protective covering for burns, bruises, wounds, and sores [24], [25], [26]. It is also used to treat sore nipples [24] and is said to be one of the best curatives for a sore throat [27]. The resin is also antiscorbutic, diaphoretic, diuretic, stimulant, and tonic [28], [29], [25]. It is used internally in propriety mixtures to treat coughs and diarrhoea, though taken in excess it is purgative [30]. A warm liquid of the gummy sap was drunk as a treatment for gonorrhoea [31]. A tea made from the leaves is antiscorbutic [28], [29]. It is used in the treatment of coughs, colds, and fevers [25]. The leaves and young shoots are best harvested in the spring and dried for later use [30]. This plant was widely used medicinally by various North American indigenous groups [32].

Ornament: It is one of the most popular Christmas trees [5]. Cultivated for Christmas trees also in Europe.

Fuel: Balsam fir wood is not prized for fuelwood, but industries that use balsam fir for pulp products are using increasingly larger quantities of wood waste to produce energy [5].

Raw material for industry: The wood is light, soft, coarse grained, but not strong and not very durable. It weighs 384 kg/m^3 [33]. Used mainly for pulp, and as lumber for the manufacture of crates and light frame construction etc. [34], [3], [26], [35]. Balsam fir is used in the U.S. for timber and plywood and is the mainstay of the pulp wood industry in the Northeastern states. The wood, which is rich in pitch, burns well and can be used as a kindling [32].

The balsamic resin 'Balm of Gilead' [36], [34] or 'Canada Balsam' [22], [26], [30] is obtained during July and August from blisters in the bark or by cutting pockets in the wood [25]. Another report says that it is a turpentine [29], usually collected during July and August by breaking the turpentine blisters into small metal cans with sharp-pointed lids. The term Canada Balsam is a misnomer because balsams are supposed to contain benzoic and cinnamic acids, both absent from the Canada oleoresin [20]. Turpentine is also a misnomer, implying that the oleoresin is entirely steam volatile. Actually, it contains 70–80 % resin, and only 16–20 % volatile oil [20]. Canada Balsam yields 15–25 % volatile oil, the resin being used for caulking and incense [20]. It is used in the manufacture of glues, candles and as a cement for microscopes and slides, since it has a high refractive index resembling that of glass [36], [34], [22], [3], [25], [26], [30]. The pitch has also been used as a waterproofing material for the seams of canoes [32]. The average yield is about 220-280 g per tree [29]. The resin is also a fixative in soaps and perfumery [29], [30]. Trees are then allowed to recuperate for 1-2 years before being harvested again [20]. The leaves and young branches are used as a stuffing material for pillows etc. - they impart a pleasant scent [34], [37], [32] and also repel moths [38]. The leaves contain an average of 0.65 % essential oil, though it can go up to 1.4 % or even higher [20]. One analysis of the essential oils reports 14.6 % bornyl acetate, 36.1 % b-pinene, 11.1 % 3-carene, 11.1 % limonene, 6.8 % camphene, and 8.4 % a-pinene [20]. To harvest the oil, it appears that the branches should be snipped from younger trees in early spring [20]. Fifteen-year-old trees yield 70 % more leaf oil than 110-year-old trees; oil yields are highest in January to March and September; they are lowest from April to August [20]. In addition, a thread can be made from the roots [32].

Co-benefits: Wildlife relies extensively on this tree for food and shelter.

Further reading: [5], [12]

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Pollinator

Acer rubrum L.

Red maple (Rot-Ahorn)

Family: Sapindaceae
Life form: tree
Main use category: raw material, energy
Used part: wood

General information

Morphology: Height up to 20 m. Leaves deciduous, opposite, long-petioled, blades 6-10 cm long and usually about as wide, dull green and smooth above, lighter green or silvery beneath. Polygamous, dioecious. Flowers pink to dark red, about 3 mm long, the staminate flowers fascicled and the pistillate flowers in drooping racemes. Fruits samaras in a pair, 2-2.5 cm long, clustered on long stalks, red to red-brown. Usually with a narrow compact crown, single-boled, or often in clumps of stems from one stump due to prolific sprouting; bark gray and thin [1].

Geographic distribution: Eastern N. America - Quebec to Florida, west to Texas, Minnesota, and Ontario [2].

Natural habitat: Usually found along the margins of lakes, in swamps, peat bogs and uplands. It also occasionally grows on dry rocky hillsides and sand dunes [3], [4]. The tree has a large ecological amplitude: red maple can probably thrive on a wider range of soil types, textures, moisture, pH, and elevation than any other forest species in North America [5].

Site specific properties

Water regime: moist-wet
Trophic conditions: meso-eutrophic
pH: acid-subneutral
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Natural stands of red maple are found throughout N. America. Many foresters consider the tree inferior and undesirable because it is often poorly formed and defective, especially on poor sites. On good sites, however, it may grow fast with good form and quality for saw logs. Red maple occurs naturally, amongst others, on peatlands. Cultivation experiences are available and probably transferable to wet peatlands. It is a facultative wetland plant, but the wide ecological amplitude suggests that a wet cultivation is possible. A plantation on a drained cutover peat bog in eastern Canada showed poor productivity but promising survival rates [6]. Unlike most species, red maple sometimes grows faster on poorly drained than on well-drained soils [7]. In Michigan, it was found that red maple of sprout origin grew almost twice as fast on wet organic soils as on mineral soils and drier organic soils (reviewed in [7]).

Propagation and establishment: Red maple is easily transplanted and one of the easiest trees to grow [1]. However, there are few germination requirements. Seed can be sown in the spring or early summer. It usually germinates immediately [2], also with very little light [7], given proper temperature and some moisture. Total germination is often 85-91 % [8]. Shading by a dense overstory canopy can depress first-year germination in red maple stands; thus, second-year germination is common [9]. Direct seeding or planting is possible. Sowed seeds and potted in a cold frame or in an outdoor nursery improve the competitiveness of the young plants in the field. The species is difficult to propagate vegetatively, except by means of stump sprouts [5]. Red maple stumps sprout vigorously, making it suitable for coppicing [5]. Small transplants do not tolerate standing water [10]. To reduce the risk from flooding, it is recommended to plant seedlings or young plants on ridges. Seedlings survive flooded conditions through several adaptations; however, their growth is slowed by continuous flooding [11]. On wet sites, red maple seedlings produce short taproots with long, well-developed laterals [7].

Management: Even-aged management is commonly recommended for red maple. Uneven-aged silvicultural systems, group selection and/or patch selection may be utilized for the management on moist and wet-moist sites with a potential for sawlog production. Pulpwood production is also recommended for wet sites.

Red maple responds well to thinning. When or whether to thin a stand depends on site capability, management objectives, stand conditions, and operability. Intermediate thinning should be implemented at least 20 years prior to rotation. In upper Michigan, thinning was more effective for stimulating red maple growth than fertilization [12]. In the Canadian Maritimes, a 35-year-old coppice red maple stand was thinned by reducing each sprout clump to one of the better stems. The number of red maple stems was reduced from 2,610 to 560 per ha. Ten years later, these residual trees had more than doubled their volume to 63.8 m^3/ha [5].

Harvest: The low load-bearing capacity of the wet peat soil makes wood harvest difficult. Harvesting should be done in winter after the ground is frozen (if possible) with adapted machinery, cable way technique or helicopters to minimize peat disturbance and its possible harmful effect on water quality.

Pulpwood can be harvested after 20-30 years; saw logs for lumber and veneer after 40-60 years.

Productivity: Red maple is a fast-growing tree for the first 20-30 years of its life, but it may live for 75-100(-150) years [13], [5]. It reaches maturity in 70 to 80 years [5]. In general, it has a medium to fast growth rate with 5-8 m in 10 years [10]. An average diameter growth of 7.5-9 cm in 10 years is possible [7]. Average mature trees are 18-27 m in height and 46-76 cm in diameter [7]. Since red maple is usually found in mixed stands, little information is available about its potential yields.

Cultivation experiences: Planted widely as an ornamental tree in N. America.

Utilisation

Human food: The sap contains sugar and can be used as a drink or be concentrated into a syrup by boiling off the water [14], [15], [16], [17]. The syrup is used as a sweetener on many foods. This species only yields about half the quantity obtained from sugar maple [2].

Medicine: The bark has astringent properties and has been used as an application for sore eyes [18]. An infusion of the bark has been used to treat cramps and dysentery [19].

Ornament: Red maple is widely used as a landscape tree. The brilliant fall colouring is one of the outstanding features of red maple [5]. Several cultivars are available.

Fuel: Red maple is an excellent wood for fuel [1].

Raw material for industry: Wood - not strong, close grained, hard, very heavy [20], [4], [21]. It weighs 38 lb per cubic foot [21]. The grain of some old specimens is undulated, which gives beautiful effects of light and shade on polished surfaces [18]. The wood is commonly used for making furniture, turnery, pulp, etc. [20], [4], [21]. It is also used to make basket splints [19]. The leaves are packed around apples, rootcrops, etc. to help preserve them [22], [23]. The boiled inner bark yields a purple colour [18], [24], [4], and when it is mixed with lead sulphate it produces a black dye that can also be used as an ink [18]. The dye is dark blue according to another report [25].

Co-benefits: This species can successfully establish itself in recently cleared areas and partially open woodlands [13]. It can therefore be used as a pioneer species to speed the regeneration of woodland [2].

Further reading: [7]

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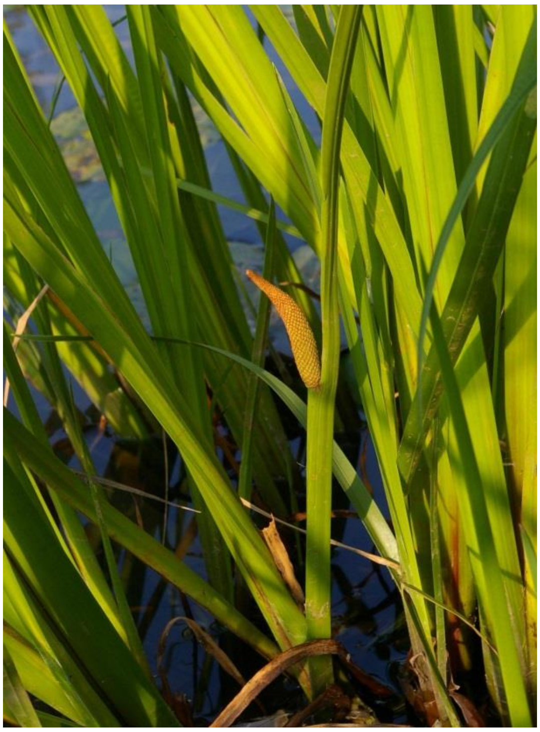
GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic



Acorus calamus L.

Sweet flag, calamus, flagroot
(Kalmus)

Family: Acoraceae
Life form: forb/herb
Main use category: medicine, food
Used part: rhizome, leaves

Picture: Christian Fischer

General information

Morphology: Perennial. Height 70-100 cm. Stock a stout rhizome: fleshy, creeping. Roots at lower side of rhizome. Leaves several, mid-green, often reddish at base, erect 70-100 × 1-2 cm, usually finely waved along the edge. Hermaphrodite. Spadix erect, 4.5-6.5 × 0.6-1.2 cm, densely flowered. Flowers yellowish green; leaf-like spathe mid-green, 30-50 cm, on peduncle. Flowering April to September. Infructescence 1.5-2 cm in diameter, straw-brown at maturity, berries densely arranged. Berry oblong-obovoid, 1 to few seeded [1], [2].

Geographic distribution: Europe, Asia to Indonesia and N. America. Probably indigenous to India [3]. There are three established caryotypes with different distributions (cf. Additional information).

Natural habitat: Found in moist soils and shallow water in ditches, marshes, swamps, river edges and ponds [4], [5], [6], [7].

Site specific properties

Water regime: moist-wet-flooded
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

Sweet flag is a valuable species with lots of benefits and an already existing market. It is traded in the international drug market and the raw material originates mainly from natural populations [8]. Due to its heavy collection and habitat loss, it is among the endangered medicinal plants [9]. Cultivation is known from wetlands in India and from cultivation trials of *Acorus* in normal field conditions (in Slovenia: [10]; in Finland: [8]) and also in a peatland in Finland [11]. The decrease of sweet flag populations calls for an immediate conservation of the natural stands and for starting targeted sweet flag field cultivation so that the demand for raw material can be satisfied.

A cultivation in wet peatlands and a large-scale harvest of the valuable roots will probably harm the peat soil and lead to degradation of the peat. Nevertheless, the high productivity and the existing knowledge about its cultivation make a paludiculture with sweet flag promising. A sustainable paludiculture with sweet flag will include the use of the aboveground biomass, but then the sufficiency of the market value is uncertain. The less degrading harvest of the roots is probably only feasible by hand harvesting.

Additional information:

The species is polymorphic and taxonomically complicated. Three caryotypes of *A. calamus* exist. Röst [12] seperated a diploid var. *americanus* (Raf.) Wulff (growing in N. America, temperate Asia), a tetraploid var. *angustata* Engl. (temperate E. Asia, tropical SE. Asia), and a sterile, triploid var. *calamus* (Himalayan area, possibly also E. Asia). Only the triploid strain reached Europe (via Constantinople) in the Middle Ages and later eastern N. America [13]. The essential oil composition can play a significant role in their discrimination. β-asarone is the most discussed compound of the essential oil, due to its toxic and carcinogenic effect. The diploid caryotype contains only traces of β-asarone in the essential oil of its rhizome. The triploid caryotype contains 9-13 % of β-asarone, and the tetraploid one contains 70-96 % [12].

Propagation and establishment: *Acorus calamus* can be propagated vegetatively by plant or rhizome division, and generatively via seeds. Seeds are collected when the spadix will turn brown in late summer or early fall. They can be sown immediately or stored in low humidity refrigeration. Ripe seeds should be sown in the fall or winter in a greenhouse (in a cold frame) and not buried deeper than 0.3 cm. The soil must be kept moist to saturated. The seeds will germinate in less than 2 weeks. When plants reach 7-10 cm, they are pricked out into individual pots. Conditions should continue to be kept very moist to saturated. In the spring, the seedlings are transplanted outdoors at 30 cm intervals. If moisture is adequate (probably saturated but not flooded), seed can also be sown outdoors from spring to early summer, given a weed-free environment [14], [3].

Vegetative propagation is best done in the fall or spring with firm rhizomes cut into 5-10 cm long sections. These are then transplanted 10-15 cm deep and 30 cm apart in nutrient-rich soil to their final location. An alternative to using rhizomes is to cut individual sprigs from clumped plants. These should also be planted 30 cm apart [14].

Soil preparation is necessary before planting or seeding to reduce weeds.

Management: *Acorus calamus* grows well under seasonal, shallow inundation. However, flooding of newly established plants or seeded areas should be avoided. Starter fertilizers may be used indoors to improve early growth but are unnecessary once transplanted outdoors into a rich soil [14].

In conventional utilisation the land is ploughed twice or thrice prior to the onset of rain. The field is prepared like paddy fields and the use of fertilizers is common [15]. In general, fertilization of wet or flooded soil is critical due to potential leakage of nutrients in surface water or groundwater.

Harvest: The aboveground biomass could be harvested with adapted machinery (light-weighed tracked vehicles with low soil pressure) in late summer. Information about stand stability and regrowth is not available.
Rhizomes for medicinal use should be harvested in early spring before the new growth, or late autumn. Rhizomes should be harvested when large and firm, generally after 2-3 years of growth (in temperate and boreal climates), before becoming hollow [16], [14]. Under subtropical conditions, e.g., in India, it can be harvested already after 6-8 months after rhizome transplantation [15].
Under paludiculture the roots could be harvested by hand to minimize the soil disturbance. The younger rhizome parts have to be left in the original peat for the regeneration of the population.
The root loses 70 % of its weight by drying but has an improved smell and taste. However, it deteriorates if stored for too long [7].
Within wet peat soil conditions, the mechanical harvest of the rhizomes is quite difficult. According to the Finnish experiences [11], the harvest could be carried out only by using an excavator. The harvested root mass consisted of leaves, rhizomes with roots and peat soil. This mass was cleaned by a strong "water-gun" (strong pipeline). After washing, it is possible to separate the rhizomes for commercial utilisation, but it is very labour consuming. A better utilization of the fresh plant mass could be the distillation for essential oil. The quality of this essential oil has to be studied, since the plant mass consists of root, rhizome, and leaves as well.

Productivity: The aboveground biomass can range between 14 and 20 t DM/ha [17]. 3 years after the transplantation of *Acorus* seedlings, the fresh and dry root yield was 62 and 17 t/ha, respectively, in a cultivation experiment in a peatland in Finland [11]. In India, the dry rhizomes' biomass was expected to be 4.2 t DM/ha and the fresh rhizome of around 10 t/ha [15]. In a cultivation trial in India the following rhizome yields have been achieved: 13.15 t/ha (seeded in autumn) and 6.6 t/ha (seeded in the rainy season). The harvesting during autumn after 12 months of growth after seeding gave maximum rhizome yields of 16.5 t/ha and 9.4 t/ha when harvested during the rainy seasons ([18] – no information if it is dry or fresh weight).
Populations tend to have greater shoot density and rhizome biomass in open wetlands that have waterlogged soils with high nitrogen content [19].

Cultivation experiences: Sweet flag has a long history of use as a medicinal and culinary plant. It has been cultivated for this purpose but was more commonly allowed to naturalize and was then harvested from the wild. Sporadically cultivated in S. and E. Asia, Indonesia, in most of Europe, occasionally in North America, and rarely in South America for the fragrant rhizomes [13]. Widely cultivated in India [20].

Utilisation

Human food: *Acorus calamus* has been widely used for various purposes among indigenous people [21], [22]. The rhizome is candied and made into a sweetmeat [23], [16], [24], [25], [26], [27], [28]. It can be peeled and washed to remove the bitterness and then eaten raw like a fruit [29], [30]. It makes a palatable vegetable when roasted [31] and can also be used as a flavour.

An essential oil obtained from the leaves is used for making aromatic vinegars [32]. In Germany, the rhizome is used to flavour liquors (Erzgebirge).

Medicine: Sweet flag is widely employed in modern herbal medicine as an aromatic stimulant and mild tonic [16]. In Ayurveda it is highly valued as a rejuvenator for the brain and nervous system and as a remedy for digestive disorders [33]. The root is anodyne, aphrodisiac, aromatic, carminative, diaphoretic, emmenagogue, expectorant, febrifuge, hallucinogenic, hypotensive, sedative, stimulant, stomachic, mildly tonic and vermifuge [16], [22], [34], [35], [36], [37], [38], [39], [40], [41]. It is used internally in the treatment of digestive complaints, bronchitis, sinusitis [42], and anorexia nervosa [7]. However, if the dose is too large, it will cause nausea and vomiting [3]. Sweet flag is also used externally to treat skin eruptions, rheumatic pains, and neuralgia [42]. It is a folk remedy for arthritis, cancer, convulsions, diarrhoea, dyspepsia, epilepsy etc. Caution is advised on the use of the root, especially in the form of the distilled essential oil, since large doses can cause mild hallucinations [31], [32]. A homeopathic remedy is made from the roots [36]. It is used in the treatment of flatulence, dyspepsia, anorexia, and disorders of the gall bladder [36].

β-asarone has toxic, carcinogenic, and sterilizing effects [44], [43]. In several European countries the use is strongly regulated. Only roots free from, or with a low content of, β-asarone should be used in human herb therapy (e.g., originated from the diploid caryotype).

Raw material for industry: The leaves are used in basket making or woven into mats [45]. Used for roof thatching [16].

The essential oil from the leaves and the roots is an insect repellent and insecticide [44], [46]. It is effective against houseflies [41]. When added to rice being stored in granaries it has significantly reduced loss caused by insect damage because the oil in the root has sterilized the male rice weevils [7]. An essential oil obtained from the leaves is used in perfumery [33].

Co-benefits: *Acorus calamus* is used for wetland restoration [47], [19].

Further reading: [17], [19], [48], [15]

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Kristian Peters

Agrostis canina L.

velvet bentgrass (Hunds- oder Sumpf-Straußgras)

Family: Poaceae
Life form: graminoid
Main use category: fodder
Used part: aboveground biomass

General information

Morphology: Perennial. Height: 10-60 cm. Culms erect or geniculate at base, often stoloniferous. Leaves from the bottom with rolled, thin linear blade, surface with veins, pale green to greyish-green, 3-20 cm × 1-3 mm, apex obtuse or acute. Hermaphrodite. Inflorescence a lax panicle, lanceolate to ovate in outline, 5-12(-20) cm, spreading at anthesis. Specifics: loosely tufted, stoloniferous, turf-forming [1], [2], [3], [4].

Geographic distribution: Native to Europe and temperate Asia, introduced to northeastern N. America [2], [5].

Natural habitat: On damp and wet places, in low-lying meadows, ditches, hollows, pond margins, swamps, and marshy ground, often growing with rushes, short sedge fens [6], [7]. Optimum on wet and very wet soils. Limited to nutrient poor soils, often on peat. Adapted to very acid soils [8].

Site specific properties

Water regime: wet
Trophic conditions: oligo-mesotrophic
pH: acid-subneutral
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

Paludiculture with *Agrostis canina* is unknown. The cultivation is recommended for poor and acid peat soils. It has a reasonable quality compared with other species that are found in the same natural communities (Molinion caeruleae, Juncion acutiflori and Caricion fuscae), but is low in productivity [8].

Propagation and establishment: Via seeds: sowing rates: 10-20 kg/ha for a pure stand, 5 kg in complex mixtures (8-10 species) [8]. Vegetative propagation is possible via division, but expensive and laborious. The grass has a rapid vegetative spread rate [9].

Management: The communities in which *A. canina* grows are generally not fertilized. With fertilization *A. canina* would probably be outcompeted by other species, because of its small size and slow growth [8]. In general, fertilization of wet or flooded soil is critical due to potential leakage of nutrients in surface water or groundwater.

Harvest: Clear preference for cutting (hay) meadows. Mowing is possible with adapted machinery. The grass has a moderate harvest regrowth rate [9].

Productivity: Very low production where it thrives spontaneously [8]. The aboveground biomass in a mixed stand with *Molinia caerulea* (dominant species) in a fen located at the Fichtelgebirge, Germany was 3.1 t DM/ha and with *Nardus stricta* 5.6 t DM/ha [10].

Cultivation experiences: Only known from turf cultivation.

Utilisation

Ornament: The ornamental variety 'Silver needles' is sometimes used in gardens and parks [8]. In general, it is planted on golf courses. Because of its short, soft green growth, *A. canina* has been used as a lawn grass [7].

Animal fodder: *Agrostis canina* is used as a forage grass [6]. The hay is well accepted by animals [8]. An analysis of forage of a wet shore meadow with *A. canina* in Sweden showed high organic matter and moderate crude protein contents (947 and 118 g/kg DM, respectively) with a metabolizable energy content of 8.1 MJ/kg DM [11].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Agrostis gigantea Roth

Redtop (Riesen-Straußgras)

Family: Poaceae
Life form: graminoid
Main use category: fodder
Used part: aboveground biomass

Pictures: Kristian Peters

General information

Morphology: Perennial. Height up to 150 cm. Culm erect, decumbent or semi-prostrate. Leaf blades flat 5-20 cm long; 2-8 mm wide, with a prominent ligule. Hermaphrodite. Inflorescence an open panicle with ascending branches, reddish colouring, 8-25 cm long; 3-15 cm wide. The roots can reach a depth of 120 cm under favourable conditions. Sod-forming grass [1], [2], [3].

Geographic distribution: Native to Europe, Asia, and N. Africa. It was introduced to N. America in the 18th century as a lawn, meadow, and pasture grass. It has since become naturalized and widely distributed throughout the U.S. and Canada [1].

Natural habitat: *Agrostis gigantea* occurs in areas with shallow water, wet meadows, and stream banks from sea level to 2,500 m. It can be found growing in pure stands or with other wetland/wet meadow species such as sedges, rushes, and other grasses. It is also common in riparian areas growing in association with cottonwood, alder, and willow species [1].

Site specific properties

Water regime: moist-wet
Trophic conditions: meso-eutrophic
pH: acid-alkaline
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Agrostis gigantea is recommended for a wet meadow paludiculture mixed with other species for fodder production.

Propagation and establishment: *Agrostis gigantea* can be established by seed, sprigs, or sods. For seeding, it should be planted at a depth of 0-6 mm into a smooth, firm, moist, weed-free seed bed. Flooded conditions in the establishment phase should be avoided. For pasture and range plantings, a seeding rate of 0.6 kg/ha (= 68 g/1000 m^2) is recommended [1], with a maximum of 2 kg/ha. Another report recommends a very high sowing rate of 10-20 kg/ha for pure stands and 5 kg/ha for complex mixtures with 8-10 species [4], which is with a TGW (thousand grain weight) of 0.05-0.08 g highly questionable. Seedlings display low vigour and seeding often results in poor stands; however, once established, stands of redtop will readily spread and persist for many years. Thus, excessive seeding rates are not recommended, particularly in mixtures. *Agrostis gigantea* is seldom seeded alone. Better forage and high-quality hay are produced if it is mixed with species such as *Alopecurus geniculatus*, *Lotus* spp. and/or *Trifolium* spp. *Agrostis gigantea* is also a good companion grass in mixtures dominated by *Phalaris arundinacea*.
Seeding in early fall or early spring is recommended [1].

Management: The soil surface should be kept moist-wet during establishment. Stands respond well to applications of fertilizer and lime. Nitrogen should not be applied until the second growing season [1]. In general, fertilization of wet or flooded soil is critical due to potential leakage of nutrients in surface water or groundwater.
Stands of *A. gigantea* should not be grazed until the plants are at least 20 cm tall. It does not tolerate intensive grazing [4]. Pasture mixes will need to be grazed closely in a rotation to keep plants producing palatable regrowth on wet sites. *Agrostis gigantea* should not be grazed closer than 8 cm [1].

Harvest: Hay is cutted in early flowering stage for best quality. Forage contains 8-9 % protein when cut at full bloom and 12-14 % when cut before bloom [1].

Productivity: Annual yields range from 8 to 12 t DM/h [5]. Standing aboveground biomass in a *Carex appendiculata*, *Glyceria maxima*, *Poa sphondylodes* and *Agrostis gigantea* dominated ungrazed swamp meadow at Xilin River Basin, Inner Mongolia, China reportedly provides 5.7 t DM/ha [6].

Cultivation experiences: It is cultivated as a forage species and for erosion control or restoration in N. America [1] and for energy purposes in the Czech Republic [5].

Utilisation

Animal fodder: One of the primary uses of *A. gigantea* is for grass hay [1], [7]. The forage in moist and wet meadows generally remains green and palatable throughout the growing season. It has fairly good palatability to livestock in spring and early summer, but palatability decreases after seeds are mature and is poor in the winter [1], [8].

Fuel: The biogas production from a mixture with *A. gigantea* biomass is fully comparable with the biogas produced from slurry alone. Average yields of 265 m^3/t organic dry matter are normally achieved, while maximum yields with 378 m^3/t organic dry matter are also possible [5].

Co-benefits: *Agrostis gigantea* is commonly used for erosion control in plantings along riparian zones and wetlands. Its root system is well suited for holding soils on wetlands, waterways, ditchbanks and burned or cutover-timberland. It has been used to recapture sites which are very acid, or land affected with heavy metals and poor soil quality such as mine spoils. [1].

Further reading: [4]

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Pictures: Kristian Peters

Agrostis stolonifera L.

creeping bentgrass (Weißes Straußgras)

Family: Poaceae
Life form: graminoid
Main use category: fodder
Used part: aboveground biomass

General information

Morphology: Perennial. Height: 30-50(-100) cm. Culms erect or geniculate, 2-5 noded. Leaf sheaths smooth; blades linear, flat, or rolled inwards, 4-10 cm × 2-10 mm, apex acute to acuminate. Hermaphrodite. Panicle narrow, linear to lanceolate in outline, 5-20 cm, open only at anthesis. Flowering in August. Specifics: tufted, stoloniferous; stolons slender, leafy, widely spreading, developing after anthesis [1], [2].

Geographic distribution: Native to Eurasia and N. Africa. Introduced to N. America prior to 1750, now naturalized throughout southern Canada and most of the U.S. [2].

Natural habitat: Creeping bentgrass occurs in a wide variety of habitats including forest openings, grasslands, shrublands, prairies, sandhills, meadows, marshes, bogs, vernal pools, and stream and lake margins [2]. It grows in all types of salt grassland and reedbeds. It is the main component of the wet types of salt grassland [3].

Site specific properties

Water regime: moist-wet
Trophic conditions: eutrophic
pH: acid-alkaline
Light conditions: shade intolerant
Salinity: high tolerance

Cultivation

Agrostis stolonifera is a facultative wetland plant and has a clear preference for cool to wet sites. It is a component of the wet fen meadows. The subspecies *A. stolonifera* subsp. *maritima* grows in salt grasslands on coastal flood peatlands that are used as pasture or hay-meadow in a traditional way of paludiculture [4].

Propagation and establishment: *Agrostis stolonifera* reproduces by seed and by stolons. It can set seed in one growing season, thus sometimes functioning as an annual. In southern Ontario, Canada, seeds have a 52 % germination rate after 30 days under approximately optimal germination conditions; seeds were cold stratified for 9 months prior to planting. Grasses in the genus *Agrostis* are seed-banking species. In pastures and meadows of Europe, creeping bentgrass seeds can survive in the soil for at least 1 year. In a northern subarctic community in Manitoba, Canada, creeping bentgrass is a persistent perennial that spreads vegetatively to form clumps or large patches but sometimes fails to reproduce by seed, although flowering is observed [2]. It is rarely sown in practice. Pure sowing rates with 10-20 kg/ha or mixed with other species (*Lolium perenne*) are recommended [5]. Pure seeding hardly succeeds under natural field conditions, because of slow establishment. Mixtures with nursery species are therefore recommended to improve the establishment and save seeds and money.

Management: Depends on concrete site conditions and on the kind of utilization (pasture or mowing). In the conventional practice, a moderate fertilization is recommended in pure stands and in mixtures; N fertilization of exclusively mown stands can be increased to 300 kg/ha in permanent grasslands [5]. In a rich soil it is probably less or negligible, as well as on sites that are frequently flooded. Lower salt marshes with a higher frequency of flooding are more suitable for *A. stolonifera*, because of lower salinity [6]. In general, fertilization of wet or flooded soil is critical due to potential leakage of nutrients in surface water or groundwater.

Harvest: Tolerance of cutting and grazing is quite indifferent. It depends on site conditions and hence on productivity and the adapted management. In the conventional practice a mixed (cutting-grazing) regime or a silage cutting regime (3 cuts per year) is particularly suitable. While close grazing keeps it under control, it is favoured by long periods and a high cutting height [5]. *Agrostis stolonifera* is favoured by cattle grazing in salt marshes at the expense of taller reed plants [6].

Productivity: *Agrostis stolonifera* shows a moderate productivity. Soil moisture and nutrient availability greatly influence its productivity. On wet soils the yield is higher than on well drained ones [5]. Fertilization (N rate 100 kg/ha) can increase annual yields from 1-2 to 7-8 t DM/ha with 2 cuts per year [5].

Cultivation experiences: Cultivated in N. America and Europe.

Utilisation

Ornament: *Agrostis stolonifera* is widely used in turf culture, especially for golf courses [2].

Animal fodder: It can be used as a pasture grass. The energy content of *Agrostis stolonifera* on wet fen meadows in NE Germany is strongly dependent on the harvest time. The metabolizable energy ranges from 7.5 MJ/kg dry matter in May to 5.0 MJ NEL/kg dry matter in July [7]. It has a German forage value (Futterwertzahl) of 7 [3]. The protein content is poor [2].

Creeping bentgrass provides important forage for livestock because it stays green and palatable throughout the summer [2]. On moist sites, creeping bentgrass produces good forage throughout the growing season, but is less productive and less palatable than many introduced perennial grasses [2].

Co-benefits: It can be used for stabilizing wet soils, for establishing field margins along river sides and for restoration in wet habitats [5].

Further reading: [7], [5], [6]

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Picture: Kristian Peters

Alnus glutinosa (L.) Gaertn.

black alder (Schwarz-Erle)

Family: Betulaceae
Life form: tree
Main use category: raw material
Used part: wood

General information

Morphology: Perennial. Height 20-30(-37) m. Bark dark brown, fissured. Leaves 6-12 cm long, short-stalked obovate-elliptical to suborbicular. Young leaves somewhat glutinous, later a glossy dark green. Monoecious. Male catkins slender cylindrical, pendulous, reddish, 5-10 cm long; female catkins 1-3 cm long, ovoid, pedunculate, dark brown to black, hard, superficially similar to some conifer cones. Fruit a narrowly winged nutlet. Symbiotic relationship with the nitrogen-fixing bacterium *Frankia alni*. Adventitious roots with lenticels [1], [2], [3], [4].

Geographic distribution: Most of temperate Europe to Siberia, W. Asia and N. Africa [2]. At least in Finland going up to latitudes 64°-65° N [5].

Natural habitat: Wet fertile mineral soils on lakesides and along streams, often forming pure stands (carrs) in succession to marsh or fen [6]. Also, on meso-eutrophic mires, even on thick peat layers.

Site specific properties

Water regime: moist-wet-flooded
Trophic conditions: meso-eutrophic
pH: subneutral
Light conditions: intermediate shade tolerant
Salinity: low tolerance

Cultivation

Black alder grows naturally on wet, nutrient rich sites and is potentially peat forming. In black alder stands on mires the highest peat accumulation rates can be found in wet alder carrs with mean annual water tables of 0-20 cm below the surface where in absence of long-term flooding the production of highly decomposition resistant wood roots (lignin) is high [7]. These natural conditions reflect that black alder could be considered for a wet cultivation and should be imitated in paludiculture to favour peat accumulation. Most suitable are peatlands with a wetness of moist/wet: "Wasserstufe" 4+ [8] since persistent inundation is detrimental for the growth of the species. Black alder is probably one of the best species with which to establish forest cover quickly on certain types of cutaway peatlands. It has soil-improving qualities due to its vigorous fibrous root system and its capacity to fix atmospheric nitrogen [9].

Propagation and establishment: Black alder is a pioneer species. The generative establishment from seeds is the dominant mode of reproduction of natural regenerated stands. Germination rates are highly variable, ranging from 10-90 % depending on the crop year and the stand conditions. Since it is intermediate shade-tolerant, natural regeneration of black alder is not possible under the canopy of a mature stand. In natural conditions, alder regeneration is dependent on soil disturbance or changes in the forest cover caused by diseases or clear-felling [3]. Black alder can be propagated generatively from seeds in nurseries. The seeds can be sown in autumn or spring. When plants are large enough (120 cm, ~2 yrs.), they can be planted outside in autumn [8]. In most cases, bare rooted plants are used [3]. They should be planted on ridges to avoid detrimental permanent flooding. Vegetative propagation via cuttings is also possible. The genetic origin of black alder must be considered because both form and growth rate vary across Europe [10].

For timber production 3,000-3,500 plants per ha should be planted, with a row spacing of 2.4-2.8 m and a distance between plants of 1.2 m [8]. Others propose planting densities varying from 800 to 1,600 stems/ha [3].

Black alder can sprout from dormant basal buds. Around 500 vital sticks per ha are needed to establish a stand [12]. After 3 to 4 coppices, the capability of sprouting is reduced, and plants need to be substituted.

Management: Alder does not suffer from exposure [9]. However, it is susceptible to spring frost damage in its northern range when planted on open ground. Rewetted fens with degraded consolidated peat on top are suitable for cultivating black alder [8]. The production of timber on humid or wet sites is possible with sufficient groundwater movement. Long-term flooding of standing water is detrimental and high saline conditions lead to diminished total height, diameter at breast height and growth rate [11]. The most valuable return through growing black alder is to grow high-quality timber of 50-60 cm diameter at breast height (d.b.h.) and a bole length of around 6 m. The rotation required to produce such trees will be between 50 and 70 years [3]. With longer rotations the risk of heart rot is increasing.

Heavy and frequent thinning is recommended in young stands beginning at age 10-15, as its shade tolerance is rather low, and the increment will strongly diminish under high competition by neighbouring trees. Recent prescriptions suggest that the stem numbers should be reduced to 200-300/ha by age 20-30 (see [3] for thinning prescriptions). A rotational cultivation is possible because the stems sprout after cutting. Alder coppice is suited to biomass production.

Harvest: The low load-bearing capacity of wet peat soil makes the wood harvest difficult. Harvesting should be done in winter after the ground is frozen and snow-covered, with tracked machinery or via cable way technique [12], [13] to minimize peat disturbance and its possible negative effects on water quality. The coppice forest should be harvested with adapted machinery (e.g., with tracks).

Productivity: Black alder is a relatively short-lived (max. 100-160 years) pioneer species with a growth pattern characterized by very high growth rates when young, but with an early decrease [3]. For instance, a 20-year-old stand reaches 50 % and a 40-year-old stand already 80 % of the total height of an 80-year-old stand [12]. Within the first 20 years maximum mean annual increments of 1.1 cm/yr can be reached. Increment tables are available [14] (summary in [3]). The productivity in a 20-40 year rotation is at least 10 m^3/ha*yr (approx. 5.5 t dm/ha*yr) [12]. To produce high-quality timber, the solid volume of a 60-year-old alder forest may be as high as 424 m^3/ha [14]. The total biomass increment of a 30-year-old coppice forest is around 400 m^3/ha.

Cultivation experiences: On cutaway peatlands in Ireland [9]. In NE Germany on rewetted fen peatlands [8], [12], [13].

Utilisation

Medicine: The bark is astringent, cathartic, febrifuge, and tonic [14], [15], [16], [17], [18]. The fresh bark can cause vomiting, hence dried bark is used for all but emetic purposes [19]. A decoction of the dried bark is used to bathe swellings and inflammations, especially of the mouth and throat [14], [4], [19], [20]. The powdered bark and the leaves have been used as an internal astringent and tonic, whilst the bark has also been used as an internal and external haemostatic against haemorrhage [19], [21]. The dried bark of young twigs or the inner bark of branches (2-3 years old) are used for this purpose [4]. Harvesting is done in the spring and the raw material is dried for later use [4]. Boiling the inner bark in vinegar produces moreover a useful wash to treat lice and a range of skin problems such as scabies and scabs [19]. The liquid can also be used as a toothwash [18]. The leaves are astringent and used as galactogogue and vermifuge [15]. They are also used to help reduce breast engorgement in nursing mothers [20]. In addition, a decoction of the leaves is used in folk remedies for treating cancer of the breast, duodenum, oesophagus, face, pylorus, pancreas, rectum, throat, tongue, and uterus [18].

Fuel: Because of its coppicing ability, alder could play a role in biomass production for fuel [9]. The wood also makes a good charcoal [14], [22].

Raw material for industry: The wood is very durable in water, elastic, soft, fairly light, easily worked and easily split. It is often used for situations where it has to remain underwater and it is used for furniture, veneer, pencils, bowls, woodcuts, clogs etc. It is a popular saw timber and is accordingly much valued by cabinet makers [14], [15], [23], [24], [25], [17], [26], [27], [22].

Alder bark has been used variously in skin colouring [28]. A cinnamon dye is obtained from the shoots if they are harvested in March [14]. If they are dried and powdered, the colour will be a tawny shade [14]. The bark and the fruits contain up to 20 % tannin [17], [29], [30], [31], but they also contain so much dyestuff (imparting a dark red shade) that its utility is limited [14], [15]. The leaves are also a good source of tannin [14]. Real culinarians use black alder chips for smoking fish. In glass-making, the liquid glass-mass is blowed into wooden forms (or shapes); one of the best materials being black alder wood.

Co-benefits: Black alder contributes particularly to riverine ecosystems and to the services they provide. It contributes to biodiversity by providing habitats for a specific flora and fauna both on the tree itself and in the flooded root system. Also, it assists with water filtration and purification in waterlogged soils, and the root system helps to control floods and stabilize riverbanks (for a review see [3]).

Further reading: [8], [12], [13], [3], [5]

Similar species:
Alnus glutinosa subsp. *barbata* (C.A.Mey.) Yalt. Native to Europe, Asia, NE. Turkey to N. Iran. The tree grows in peatlands and is potentially peat forming [32]. It grows fast and is economically valuable [33].

Alnus incana subsp. *rugosa* (Du Roi) R.T.Clausen

Speckled alder is native to Central N. America: northeastern USA and southeastern Canada. It grows shrub-like, up to 10 m. Speckled alder colonizes stream banks, lake shores, and damp meadows and also occurs in fens, bogs, and nutrient-rich swamp communities. It grows on moist or wet soils and is adapted to flooding periods [34]. The wood can be used as fuel.

Alnus japonica (Thunb.) Steud.
Japanese alder is native to wet lowlands, swamp areas along rivers and lakes in the cool temperate zone of Japan [35], [36]. It is distributed in E. Asia - Korea, Japan, Russia, Taiwan (far east), Northern E. China [37], [38] and exotic in SE Asia [38]. The tree reaches growth heights of 20 m and produces valuable wood.

Alnus maritima (Marshall) Muhl. ex Nutt.
Seaside alder is a rare species, native to Eastern and Central N. America - Delaware, Maryland, and Oklahoma (endemic). It grows along edges of ponds and small streams, often in standing water. Its growth is generally restricted to damp or wet soils in sunny areas. It reaches heights up to 10 m. The wood is light, soft, close-grained. Light brown in colour with thick, hardly distinguishable heartwood [39].

Alnus serrulata (Aiton) Willd.
Common smooth alder is native to Eastern N. America. It grows in fresh tidal marshes, nontidal marshes, shrub swamps and forested wetlands [40]. The wood is soft and brittle [41]. It is of little commercial value [42]. The shrub shows fast growth rates of 60 cm per year [40], but apparently without coppice potential [34].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Pictures: Matt Lavin

Alopecurus arundinaceus Poir.

creeping meadow foxtail
(Rohr-Fuchsschwanz)

Family: Poaceae
Life form: graminoid
Main use category: fodder
Used part: aboveground biomass

General information

Morphology: Long-lived perennial. Height up to 1 m. Culms sometimes solitary, erect. Leaf sheaths loose, smooth; leaf blades dark gray-green, 5-20 cm long, 3-8 mm wide. Panicle broadly cylindrical, 4-8 cm long, gray-green, blackish at maturity. Loosely tufted, with long, slender rhizomes [1].

Geographic distribution: Native to Eurasia: from the Arctic to Italy, Turkey, Iran, Afghanistan, and most frequently in the steppe zones. The eastern limit is in Siberia, and the western limit is in the British Isles [2].
Introduced to N. America.

Natural habitat: It grows native on wet, salty soils, on flood plains, along rivers and streams, and in bogs [2].

Site specific properties

Water regime: moist-wet
Trophic conditions: meso-eutrophic
pH: acid-subneutral-alkaline
Light conditions: shade intolerant
Salinity: medium tolerance

Cultivation

Creeping foxtail is well suited for pasture or haymaking [3]. It can be interseeded in natural wet meadows to enhance productivity for forage production [4], [5]. Whether or not it can be used in paludiculture is, however, not known to the authors.

Propagation and establishment: Generative via seeds [2]. They are light and hairy, difficult to harvest as well as to plant. It is recommended to mix the seeds with a carrier (cracked corn or rice hulls). Seedlings are small and weak after emergence, and growth is slow during the first two months. Once the rhizomes begin to form, growth improves. Seeding is possible from spring to late summer, avoiding the hot mid-summer period. The seedbed should be weed-free and moist [3]. Several cultivars are available, e.g., 'Garrison'.

Management: It withstands flooding of 60-90 cm for 30 days without injury and performs

well on wet and flooded permafrost soils in Alaska to mountain meadows in New Mexico [2]. Nitrogen fertilization is required to maintain high forage production and is essential in seed production fields [2], [4].
It is well-suited for pastures because of its early growth and rapid recovery after grazing [2]. The dense sod can withstand trampling, and will recover from heavy, dense grazing. Mixed stands with *Astragalus cicer* make excellent pasture on wet meadows [2]. When seeding with a legume, it is recommended to plant in alternate rows.

Harvest: Grazing is possible during the whole season. It produces high yields of palatable forage throughout the season. Plants break winter dormancy early in spring, and leaves remain green and palatable even during the hottest months [3]. Hay harvest is best before flowering (June to mid-July [4]) with adapted machinery that can operate in wet-boggy conditions without harming the soil.

Productivity: Mean unfertilized, first-cutting yield range from 3.8 t DM/ha on 15th of June to 6.1 t DM/ha on 15th of August in a wet meadow where 'Garrison' creeping foxtail was interseeded 4 years prior to the experiment in Nebraska; the fertilization of 135 kg N/ha in spring increased the yield from 5 to 8.5 t DM/ha for the different harvest dates [4].

Cultivation experiences: Known from N. America [4], [5].

Utilisation

Ornament: It is decorative, used for establishing small recreation areas [6].

Animal fodder: It provides a good forage grass, used primarily for pasture and haying. Its palatability is excellent, and it is used readily by all kinds of livestock [2]. The crude protein content of the biomass from a saline soil in Canada was 11% [7].

Comment: The closest competitor to creeping foxtail on wet sites is reed canarygrass. Reed canarygrass produces more dry matter than creeping foxtail, but when digestibility of dry matter and percentage of protein are considered, yields are comparable [2].

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Picture: Kristian Peters

Alopecurus geniculatus L.

floating-, marsh- or water foxtail (Knick-Fuchsschwanz)

Family: Poaceae
Life form: graminoid
Main use category: fodder
Used part: aboveground biomass

General information

Morphology: Perennial. Height 10-60 cm. Culms erect or decumbent, rooting at the nodes. Ligules 2-5 mm, obtuse; leaf blades 2-12 cm x 1-4(-7) mm, rolled when young; with clear veins, green to greyish green; upper sheaths somewhat inflated. Hermaphrodite. Panicles 1.5-7 cm x 4-8 mm. Habit caespitose [1], [2].

Geographic distribution: Native to Europe and W. Asia with a large distribution in temperate climates. Invasive species in the Far East and N. America [3], [4].

Natural habitat: On wet to very wet soils often in small dips or in hollows of micro-reliefs. Usually on clay or peat soils that are rich in nutrients [5]. Riverbanks and watersides, roadsides and ditch edges, damp meadows [3].

Site specific properties

Water regime: wet
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: shade intolerant
Salinity: medium tolerance

Cultivation

Alopecurus geniculatus can be a good component on nutrient rich wet pastures due to its high tolerance of trampling. In general, it shows low yields and a limited quality for fodder use [6]. But since high water tables are tolerated, paludiculture with *A. geniculatus* might be possible. The economic feasibility, however, remains questionable. The interaction between mowing, productivity and peat accumulation is not known to the authors.

Propagation and establishment: Water foxtail reproduces sexually by seeds and vegetatively by rooting at stem nodes. The number of seeds produced per plant has not been quantified. Seeds remain viable in the soil for at least three years, but the maximum period of seed viability is unknown [4]. Cold stratification is not required for germination [7]. Planting season is spring and fall. 1,230 seeds per kg can be obtained [8]

Management: It is incompatible with other forage species because of its low competitiveness [6]. Fertilizers can probably increase yield, but the risk of competition with high productive forage species would thus be increased. Temporary flooding is tolerated, while transplantation to drier water regimes is detrimental [9].

Harvest: The species is tolerant of cutting, grazing, and trampling. Grazed grasslands or mixed (cutting-grazing) management are clearly preferred [2]. Frequent cutting and mowing can reduce plant yield and prevent seeding of *A. geniculatus* [4].

Productivity: Low productivity [2].

Cultivation experiences: Water foxtail is grown as a forage grass in Russia [3].

Utilisation

Animal fodder: Used as a pasture and forage grass [3]. It represents quite a good forage grass on wet meadows. The energy content is strongly dependent on the harvest time, and ranges from 7.1 MJ/kg dry matter in May to 5.8 MJ/kg in July [10]. It has a German forage value (Futterwertzahl) of 4 [11].
It is however characterized as a fodder species with a rather slow decrease in digestibility [10].

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Picture: Kristian Peters

Althaea officinalis L.

marshmallow (Echter Eibisch, Sumpf-Eibisch)

Family: Malvaceae
Life form: forb/herb
Main use category: medicine
Used part: root, leaf

General information

Morphology: Perennial. Height: 1(-2) m. Stem erect, densely stellate hirsute. Roots with a thick and short rhizome. Leaf blade ovate-orbicular or cordate, 3-lobed, or not lobed, 3-8 × 1.5-6 cm, papery, surfaces tomentose, margin bluntly dentate. Hermaphrodite. Flower calyx cup-shaped, persistent, 5-parted. Corolla pink, ca. 2.5 cm in diameter; petals ca. 1.5 cm. Flowering in July. Fruit disk-shaped schizocarp, ca. 8 mm in diameter, enclosed by calyx. Seeds reniform [1].

Geographic distribution: C. Europe and S. Europe, to N. Africa and W. Asia [2].

Natural habitat: The upper margins of salt and brackish marshes, sides of ditches and grassy banks near the sea [3], [4].

Site specific properties

Water regime: moist-wet soil
Trophic conditions: meso-eutrophic
pH: subneutral-alkaline
Light conditions: intermediate shade tolerant
Salinity: medium tolerance

Cultivation

Paludiculture with *Althaea officinalis* is unknown. Cultivation instructions are only available from conventional cultivation on mineral soil. Information on propagation and establishment are probably transferable to paludiculture because the ecological amplitude of the plant suggests that cultivation in wet peatlands might be possible. However, it is not known whether a peat conserving cultivation with high water tables is feasible. The medicinal used plant parts of *A. officinalis* are predominantly the roots, but the leaves also contain smaller amounts of the valuable mucilage [5], [6]. A perennial culture of *A. officinalis* with annual rotational harvests of the leafy aboveground material will probably conserve the peat soil, but since it does not tolerate long term monoculture [5], [7] this seems to be no option. The harvest of the valuable roots could harm the peat soil and probably lead to further degradation, like the necessity of a new installation of the field after the root has been harvested.

Propagation and establishment: *Althaea officinalis* can be propagated vegetatively by plant or rhizome division, and generatively via seeds. Seeds can be sown directly in the field in spring (April to May) or in autumn (only in regions with mild winters) with 3-6 kg seeds/ha or 20-30 plants per m² [5]. The germination is often erratic [8], but stratification can improve germination rates. Seeding in an outdoor seedbed or in a cold frame is also possible with 20 kg seeds/ha. The seedlings are separated and transplanted into the permanent position at the end of September or April with a density of 8-10 plants/m² [9], [5]. Seeds are usually quite expensive.

Vegetative propagation: divisions of roots can be taken in spring or autumn, e.g., during the harvesting process of the rhizome as a co-benefit. The yield of plants grown from root divisions are 20-40 % higher than from plants propagated generatively [5]. Root divisions should have at least one or two buds and a length of 3 cm and are planted 5-10 cm deep [5].

Seedlings or cuttings are planted with 40 x 30 cm spacings [9]. Weeding is necessary before and after planting. Planting on ridges could be a method to reduce the risk of flooding. *Althaea officinalis* is sometimes planted in mixed cultures with vegetables or other medicinal herbs, but predominately it is planted in annual monocultures [9].

Management: *Althaea officinalis* can survive under water without any damages for 10-15 days [7]. Long term flooded conditions are most likely not tolerated.

With shortages of nitrogen, only thin and woody rhizomes are developed. Fertilization is therefore common in the conventional practice. If it is planted to produce the leavy aboveground biomass in quantity, the plant has an even higher demand for nitrogen [9]. In such cases, the crop is fertilized with nitrogen after every harvest.

Plantations of marshmallow in Serbia were exposed to attacks of several phytopathogenic fungi in different stages of plant development during the vegetation period. Numerous fungal diseases can decrease the yield and quality of herbal raw material every year [10].

Cultivation should be circulated at the latest after 2 years. The plant does not tolerate monoculture and should therefore be cultivated by switching with other cultures. The changing of cultures should be done so that 3-4 years pass until white marshmallow is cultivated again on the same place [7].

Harvest: The leaves are harvested in July when the plant is just coming into flower and can be dried for later use. Harvesting all leaves from 40 cm to the top is to be prevented, since root development will be disturbed. The root is best harvested in autumn (end of October, beginning of November), preferably from 2-year-old plants [8], [6]. The roots must be washed, cut in pieces of 4-10 cm, and dried for later use. Normally they have been peeled, but since this is a very laborious and costly work, they are only washed in special washing machines [5]. During the harvest of the roots, the root sprouts can be taken for the next year’s planting.

Productivity: The root harvest of annual cultures ranges from 1 to 2 t DM/ha [9]. Older cultures have higher yields but lower quality. The fresh root yield of generatively established plants is approx. 15 t, and considerably higher when established with root divisions (review in [5]). The aboveground biomass ranges between 1.2 and 1.5 t/ha (no information if dried or fresh) [9]. One ha can yield 1.2-2 t of dry roots, 500-600 kg of dry leaves, and nearly 150 kg of dry flowers [7, data from Kosovo].

In a hydroponic system, root yields range from 13 to 60 g DM/m² [11], depending on nutrient concentration, flow regime, and electrical conductivity.

Cultivation experiences: Formerly cultivated in France, N Italy, S and Middle Germany, Balkan, Hungary, and the southern parts of the former USSR. In the last years the cultivation decreased [12].

Utilisation

Human food: The leaves can be eaten raw or cooked [13], [14], [15]. They are used as a potherb to thicken soups [16], [17] or as a green vegetable [12]. Raw leaves have a mild and pleasant taste but are rather fibrous and somewhat hairy [2].
The root is edible raw or cooked [18], usually used as a vegetable [14], [16], [19], [17], but also dried, ground into a powder, made into a paste and roasted to make the sweet 'marshmallow' [14], [20], [3], [4], [18]. The root contains about 37 % starch, 11 % mucilage, 11 % pectin [21]. The water left over from cooking any part of the plant (especially the root [17]) can be used as a substitute for egg-white in making meringues etc. [16]. A tea is made from the flowers [17] and also from the root [17].

Medicine: Marshmallow is a very useful household medicinal herb. Its soothing demulcent properties make it very effective in treating inflammations and irritations of the mucous membranes such as the alimentary canal, the urinary and the respiratory organs [6], [14], [21], [22]. The root counters excess stomach acid, peptic ulceration, and gastritis [21]. It is also applied externally to bruises, sprains, aching muscles, insect bites, skin inflammations, splinters etc. [14], [8]. The whole plant, but especially the root, is antitussive, demulcent, diuretic, highly emollient, slightly laxative and odontalgic [14], [4], [23], [24], [25], [6]. An infusion of the leaves is used to treat cystitis and frequent urination [21]. The root can be used in an ointment for treating boils and abscesses [21]. For a review see [26].

Ornament: It is sometimes used as an ornamental plant. However, more common for that purpose is *A. rosea*.

Raw material for industry: A fibre from the stem and roots is used in paper-making [23], [18], [27], [28]. The dried and powdered root has been used to bind the active ingredients when making pills for medicinal use [29]. A glue can be made from the root [27]. An oil from the seed is used in making paints and varnishes [27].

Further reading: [5 (in German)]

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GREIFSWALD MIRE CENTRE **Potential plants for paludiculture in the Holarctic**

Picture: Rasbak

Amelanchier canadensis (L.) Medik.

Canadian serviceberry
(Kanadische Felsenbirne)

Family: Rosaceae
Life form: tree or shrub
Main use category: food, ornamental
Used part: fruit

General information

Morphology: Perennial. Height up to 6 m. Leaves deciduous, elliptic, about 5 cm long; white fuzzy when young, becoming shiny green when maturing; in autumn brilliant yellow, red, or orange. Hermaphrodite. Petals 5, white, in erect clusters up to 5 cm long. Fruits 1.25 cm long, bluish black, edible pomes. Multi-stemmed shrub with a dense, bushy spread up to 3 m across. Tends to build thickets by forming numerous suckers [1].

Geographic distribution: Eastern N. America - Nova Scotia to Ontario, south to Florida [2].

Natural habitat: Swamps, bogs, low ground, woods, and thickets [3]. Tolerates infrequent flooding by water containing some salt [4].

Site specific properties

Water regime: moist-wet
Trophic conditions: eutrophic
pH: acid-subneutral
Light conditions: intermediate shade tolerant
Salinity: medium tolerance

Cultivation

The Canadian serviceberry is cultivated in North America, Japan, Korea, Russia, Middle Asia, and Russian Far East [5]. The sweet fruits are eaten fresh and used for preparing wine. Cultivation instructions are available from cultivation on mineral soil, but paludiculture is unknown to the authors. Information on propagation and establishment are probably transferable to paludiculture because the ecological amplitude of the plant suggests that cultivation in wet peatlands might be possible. However, it is not known whether a peat conserving cultivation with high water tables is feasible.

There is at least one named variety of this species with superior fruits. 'Prince William' is a large multi-stemmed shrub to 3 metres tall and 2 metres across [6], [7]. It crops heavily and its good quality fruit is about 12 mm in diameter [6].

Propagation and establishment: Generative and vegetative propagation is possible. The untreated seeds can be sown in fall or cold-stratified in spring. A cold-moist stratification for 90-120 days improves germination [8], [9]. The fruits should be collected as soon as they ripen and cleaned immediately to prevent fermentation. Fertile seeds are dark brown with a leathery seed coat. Seed extraction is usually done by macerating the fruit and washing them over screens. Dry and cold storage for up to five years is possible [8]. *Amelanchier canadensis* can be rooted from late winter/early spring hardwood cuttings or softwood cuttings that should be taken in the summer [8]. The suckers need to have been growing for 2 years before being dug up, otherwise they will not have formed roots [2]. They can be planted out straight into their permanent position [2]. It is recommended to plant the young trees on ridges, to avoid flooding. Plants will begin to produce fruit 2 to 3 years after planting.

Harvest: Fruits should be picked as soon as they are ripe (blue-black), because they are readily eaten by birds.

Productivity: The tree shows a medium growth rate: approx. 75 cm/yr [4]. The plant can produce 7-15 t/ha of fruit [10].

Cultivation experiences: Only known from mineral soil for ornamental use.

Utilisation

Human food: The fruits are edible raw or cooked [11], [12], [13], [14]. It contains a few small seeds at the centre and has a sweet flavour with a hint of apple [15], [16]. It can be eaten out of hand, used in pies, preserves etc. or dried and used like raisins [6]. When the fruit is thoroughly cooked in puddings or pies the seed imparts an almond flavour to the food [6]. The fruit is rich in iron and copper [17]. In addition, fruits are used to prepare wine [5]. Native Americans and European settlers also used the dried fruits to flavour pemmican, a type of hard, dried meat and suet that was preserved without salt [1].

Medicine: A tea made from the root bark (mixed with other unspecified herbs) was used as a tonic in the treatment of excessive menstrual bleeding and also to treat diarrhoea [18], [19]. A bath of the bark tea was used on children with worms [18], [19]. An infusion of the root was used to prevent miscarriage after an injury [19], and a compound concoction of the inner bark provides a disinfectant wash [19].

Ornament: It is used as an ornamental tree, due to its nice blossoms. It is sometimes made into a bonsai.

Raw material for industry: The wood is hard, strong, and close-grained. It is used for tool handles and small implements [20], [21].

Co-benefits: This species can be used as a dwarfing rootstock for *Malus* spp. (apples) and *Pyrus* spp. (pears) [10]. Plants can be grown as an informal hedge [7], but any trimming is best done after flowering [7]. Being a fairly wind-tolerant species, it can be used to give protection from the wind as part of a mixed shelterbelt [7].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Angelica archangelica L.

Angelica (Engelwurz)

Family: Apiaceae
Life form: forb
Main use category: medicine, food
Used part: root, seeds

Picture: Kristian Peters

General information

Morphology: Biennial to perennial (monocarpic, cultivated form biennial, wild form quadrennial). Height: 2(-3) m. Stem erect, up to arm-thick. Leaves 2- to 3-pinnate, up to 60 cm, lobes oblong-ovate, acutely serrate. Deciduous. Hermaphrodite. Inflorescence of large, globular umbels. Flowering in July in the second year; post-flowering die-off. Flowers are small and numerous, petals yellowish or greenish white to cream. Fruit is pale yellow, oblong, with rather thick, corky wings [1], [2].

Geographic distribution: Meridional, temperate, boreal, and arctic regions of Europe, Asia, and N. America [3].

Natural habitat: Moist shady or damp places [1], [4], [5], [6], [7]. Moist-wet forb meadows, along streams [8].

Site specific properties

Water regime: moist-wet
Trophic conditions: eutrophic
pH: acid-subneutral
Light conditions: intermediate shade tolerant
Salinity: low tolerance

Cultivation

Paludiculture is unknown from this species. Cultivation instructions are available from conventional cultivation on mineral soil. Information on propagation and establishment are probably transferable to paludiculture because the ecological amplitude of the plant suggests that a cultivation in wet peatlands could be possible. The harvest of the valuable roots could harm the peat soil and probably lead to further degradation, just like the necessity of the new installation of the field after root harvest. A peat conserving paludiculture with Angelica would exclude the harvest of below-ground biomass. The cultivation is recommended in eu- or polytrophic rewetted fen peatlands.

Propagation and establishment: *Angelica archangelica* is propagated generatively via seeds. The seed can be sown in a cold frame as soon as it is ripe (July/August) since the seeds show a strong dormancy that is hard to break [2]. It requires light for germination [9]. Plants should be planted in their permanent positions in spring with spacings of 50-75 cm x 25-30 cm [2]. The seed can also be sown in an outdoor nursery field as soon as it is ripe. They should be sown into the field in spring of the next year, with a spacing of 60 x 35-50 cm on ridges [10]. For seed production a spacing of 100 x 60 cm is best. Weeding is always necessary before and after planting. Direct seeding is possible with fresh seeds collected in July/August with a sowing amount of 4 kg seeds/ha [2]. There are several cultivars with high oil yields available [2].

Management: A frost-hardy plant. The growing plant is almost untroubled by pests and diseases [4]. When well-sited, the plant will often self-sow, sometimes to the point of nuisance [11]. It requires a very fertile soil [9], thus N-P-K fertilization is common. If the field is prepared for the root harvest, all flowering stalks have to be removed to increase the root growth [10]. In the first growing year a thick beet-like root establishes itself, in the second year the plant flowers.

Harvest: Leaves and stalks are harvested during the plant's second year [2]. The stems are best harvested in spring and the leaves (thereafter dried) in late spring before the plant begins to flower [12]. The roots should be harvested in the second or the third year after seeding to gain higher yields [10], at the end of September until mid-October in a dry season. The roots can be sold fresh or dried for later use or sale.

Productivity: Yield in organic soils is usually higher than in mineral soils. Average yield of fresh roots is 7-10 t/ha, providing 1.7-2.5 t/ha of dry root drug and 6-10 kg/ha of essential oil [13], [10]. Another reference gives values of 12-22 t/ha of fresh root mass and 3-6 t/ha dry roots [2]. The fresh rootstock of one plant can weigh 150-250 g [2]. The dried root contains 0.35 % essential oil, the seed about 1.3 % [14] Another report gives values of 0.6-1.2 % for roots [2]. Yields of the essential oil vary according to variety and location; plants growing at higher altitudes have higher yields with a better aroma [14]. The fruit yield ranges from 0.8 to 1.5 t/ha [10], up to 2.5 t/ha [2].

Cultivation experiences: Cultivated in Europe: e.g., in France (especially in Marais Poitevin), Poland, Netherlands and Germany. In Germany it was, amongst other sites, cultivated in moist-wet organic soils (German: Anmoor) [15].

Utilisation

Human food: The leaves are edible raw or cooked [4], [5], [6], [7], [16], [17]. Being a liquorice-like flavour [18], they can be used as a flavouring in mixed salads [19]. They are also used to sweeten tart fruits [19]. Angelica is still eaten as a vegetable in Greenland and the Faeroe Islands and has generally a long history of use in Nordic countries [20]. Stalks and young shoots can be eaten cooked or raw [7], [16]. The stalks should be peeled [21], then they can be used like celery [18], or to sweeten tart fruits [17] and to make jam [12]. They are often crystallised in sugar and used as sweets and cake decorations [12]. An essential oil is obtained from the root and seeds, which is used as a food flavouring [18], [22], [23], [24]. However, the mere seeds are also used as a flavouring [12]. The root is edible when cooked [16]. A tea can be made from the leaves, seeds, or roots [18]. The roots and seeds of Angelica are used to flavour liqueurs such as Bénédictine and Chartreuse [11].

Medicine: Angelica has a long folk-history of use as a medicinal herb [20], in particular for the treatment of digestive disorders and problems with blood circulation [4], [25]. The root is most active medicinally. It should be harvested in the autumn of its first year of growth, sliced longitudinally if necessary and dried quickly [4]. If well stored, the root retains its medicinal virtues for many years [4]. The leaves and seeds can also be used [4]. The plant is antispasmodic, carminative, diaphoretic, diuretic, expectorant, stimulant, stomachic, tonic [4], [5], [22], [26], [27], [28]. An infusion is used to ease flatulence, indigestion, chronic bronchitis, and typhus [12]. It stimulates blood flow to the peripheral parts of the body, making it valuable in the treatment of poor circulation. It is therefore considered a specific treatment for Buerger's disease, a condition that narrows the arteries of the hands and feet [25]. An essential oil from the seeds is sometimes used externally to relieve rheumatic conditions [12]. For a review of essential oils see [29].

Ornament: An essential oil from the root and seeds is used in perfumery [4], [22], [23], [24].

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Picture: H. Zell

Apium graveolens L.

wild celery
(Echter Sellerie, Sumpfsellerie)

Family: Apiaceae
Life form: forb/herb
Main use category: medicine, food
Used part: leaves, stem, seeds

General information

Morphology: Biennial. Height 15-150 cm. Stem sulcate, solid. Leaf 1- to 2-pinnate; segments 5-50 mm, deltate, rhombic or lanceolate, lobed and serrate or almost crenate. Hermaphrodite. Flower umbels 1.5 to 4 cm across, leaves usually opposite; peduncles short; rays 3-8(-16), 0.5-2.5 cm, slender; umbellules 7- to 25-flowered, 6-9 mm across. Petals whitish. Flowering and fruiting from April-July. Fruit 1.3-1.5 × 1-2 mm, broadly ovoid. Plant strongly fragrant [1], [2].

Geographic distribution: C. Europe and S. Europe, to temperate areas of Africa and Asia [3].

Cultivated: Cosmopolitan species, widely cultivated.

Natural habitat: Ditches, close to rivers and other damp locations, especially near the sea in salt marshes [4], [5], [6].

Site specific properties

Water regime: moist-wet
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: shade intolerant
Salinity: high tolerance

Cultivation

Apium graveolens is the wild relative of the commonly used celery (*Apium graveolens* var. *dulce*). Paludiculture is unknown from this species. The ecological amplitude of the plant suggests that a cultivation in wet peatlands could be possible. However, it is not known whether a peat conserving cultivation with high water tables is feasible. A peat conserving paludiculture with *A. graveolens* would exclude the harvest of below-ground biomass. The harvest of the valuable roots will probably harm the peat soil and lead to further degradation.

Propagation and establishment: *Apium graveolens* can be propagated generatively via seeds. They can be sown in spring or autumn in situ. If seeds are short in supply, they can be sown in a cold frame in spring and transplanted later in the field.

Management: It can be cultivated using saline water up to ECiw 8 dS/m [7]. Since cultivation of this species is unknown, there are no information on management available.

Harvest: The root is harvested in the autumn and can be used fresh or dried [8]. The whole plant is harvested when it is fruiting and is usually liquidized to extract the juice [8]. The seeds are harvested as they ripen and dried for later use [8].

Productivity: Yield of seeds (cremocarps) amounts to 1.0-1.5 t/ha [7].

Cultivation experiences: No information found.

Utilisation

Human food: The leaves are edible raw or cooked [9], [10]. Mainly used as a flavouring in soups and other dishes [11], [12], [4], [13]. Leaves can also be eaten raw but have a very strong flavour [9]. They are even toxic if consumed in large amounts [8]. The seed can be used as a flavouring too, added in small quantities to soups and stews [8]. An essential oil from the seed is also used as a flavouring [13], [10]. The root is edible when cooked [14].

Medicine: Wild celery has a long history of medicinal and food use [15]. It is an aromatic bitter tonic herb that reduces blood pressure, relieves indigestion, stimulates the uterus and is anti-inflammatory [8]. The ripe seeds, herb and roots are aperient, carminative, diuretic, emmenagogue, galactogogue, nervine, stimulative, and tonic [16], [12], [17], [18]. Wild celery is said to be useful in cases of hysteria, promoting restfulness and sleep, diffusing through the system a mild sustaining influence [16]. The herb should not be prescribed for pregnant women [8]. Seeds purchased for cultivation purposes are often dressed in a fungicide, and should therefore not be used for medicinal purposes [8]. An essential oil obtained from the plant has a calming effect on the central nervous system. Some of its constituents display antispasmodic, sedative, and anticonvulsant actions. It has furthermore been shown to be of value in treating high blood pressure [18]. A homeopathic remedy is made from the herb [4] which is used to treat rheumatism and kidney complaints [4].

Agricultural conditioner and substrate: The growing plant is an insect repellent. It repels the cabbage white butterfly, making it a good companion for brassicas [19].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Kristian Peters

Aronia melanocarpa (Michx.) Elliott

black chokeberry (Aronia, schwarze Apfelbeere)

Family: Rosaceae
Life form: shrub
Main use category: food, medicine, raw material
Used part: fruit

General information

Morphology: Perennial. Height 1-3.5 m. Leaves deciduous, alternate, simple, petiolate, serrate; quite glabrous. Hermaphrodite. Multitude of small white flowers (1.5 cm in diameter) in corymbs (flowering in May); hypanthium urn-shaped with 5 sepals persistent on top of the fruit (inferior ovary). Fruit a berry-like pome, up to 1 cm in diameter, dark purple to black when ripe in August and September [1], [2].

Geographic distribution: Native to eastern N. America - Nova Scotia to Ontario, south to Virginia and North Carolina [1]. Due to extensive planting widespread in Europe and Asia [3].

Natural habitat: Grows in wetlands (bogs, swamps, savannahs, lowland woods, the edges of water bodies), but also occurs in drier thickets or clearings on bluffs or cliffs [1].

Site specific properties

Water regime: moist-wet
Trophic conditions: mesotrophic
pH: acid-subneutral
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Aronia melanocarpa is currently rapidly gaining momentum as a small new fruit crop [3], [4]. Paludiculture with *A. melanocarpa* is unknown. Cultivation instructions are available from conventional cultivation on mineral soil or from drained peat soils. Information on propagation and establishment may be transferable to paludiculture because the ecological amplitude of the plant suggests that a cultivation in moist to wet peatlands could be possible. Wet cultivation has to be tested, especially how berry yields can be sustained. The productivity on wet peatlands is probably less than on drier sites. Until now, it is not known whether a peat conserving cultivation with high water tables is feasible.

Propagation and establishment: *Aronia melanocarpa* can be propagated generatively via seeds and vegetatively with division or in-vitro established material [3]. The ripe seeds can be sown in an outdoor seedbed in autumn or in a cold frame. Pre-soaking of stored seeds overnight and cold stratification of such seeds for 3 months at 2°C improve germination rates [5]. The seed germinates in 1-3 months at 15°C [6]. Seeds should be extracted promptly after fruit collection [7]. Poor germination results from seeds that have not been separated from the fruit pulp [1]. Vegetative propagation can be done via cuttings of half-ripe wood [5] or division of suckers in the dormant season [8]. The latter option is promising since the material can be planted straight out into its permanent position [9]. The seedlings or divisions can be planted out in autumn or spring. The customary cultivation is hedge planting with spacings of 0.7-1.5 m between plants and 2-4 m between rows [3]. Planting on ridges reduces the risk of flooding. The cultivars 'Viking' and 'Nero' are the primary cultivars available for fruit production in the United States [10]. Both are tetraploid forms with large, relatively sweet berries and represent the highest yielding cultivars currently available [11].

Management: *Aronia melanocarpa* shows a high tolerance to frost, to different types of soil and to moisture regimes, low susceptibility to diseases and pests. It is resistant to temporary floods, but permanent flooding conditions are not tolerated. Experiments in drained cutover peatlands have shown that adding fertilizer is necessary for the establishment of black chokeberry plantations and to obtain good yields [12]. Control of invading weeds and grasses is important. Thinning of older stems is recommended every few years after the 4th-6th growing year [1]. In the conventional practice the use of fertilizer is common (organic and low N-P-K additions) [3].

Harvest: The fruits can be harvested manually or mechanically using a special harvester as for black currant, blueberry or aronia [3], [13]. After the mechanical harvest, hand picking is recommended [3]. Harvest time is from August to September, after 80-90 days of fruit ripening [3]. All fruits are ripe simultaneously and can be harvested in one harvest cycle [3]. Fruits are storable for a couple of weeks when low temperatures are maintained.

Productivity: Black chokeberry is extensively grown in Europe on mineral soils, where yields of up to 17 kg fruits/plant*yr have been reported [1]. Similarly, 13 to 24 kg/plant were obtained for 5-year-old plantings of various selected cultivars of black chokeberry grown in Oregon, USA [11]. The plants can be harvested after the 2nd growing year. When grown in hedges, 10-14 t/ha (fresh fruit mass) can be achieved, and in good years even 20 t/ha [3]. In Quebec, Canada, its cultivation on drained cutover peatlands yields 1.9 kg fruits/plant*yr and on mineral soil 2.4 kg/plant*yr [13]. The productivity on wet peatlands is unknown to the authors but is probably less.

Cultivation experiences: On drained cutover peatlands in Canada [12], [13]. In Europe, *A. melanocarpa* has been grown on mineral soil since the 1980s: primarily in Poland, Czech Republic, Bulgaria, Slovenia, Denmark, and Finland [3].

Utilisation

Human food: The fruit is edible when cooked. While consumption of raw fruits in small amounts is harmless, big amounts are not advisable because of the poisonous Amygdalin in the seeds, releasing hydrocyanic acid. Generally, the fruit has a good flavour but is very astringent and sour-tasting [14]. The fruit should be fully ripe before being eaten and tastes best after a frost or two [9]. It makes a good juice and jelly when sugar is added and is also dried and used for making pemmican (dried meat) [14]. It is moreover often used as an additive in juices, frozen fruit mixtures, in yoghurts, liquors, ice cream or pralines [3].

Medicine: An infusion of the berries has been used in the treatment of colds [15]. Because of their high anthocyanin content, black chokeberry fruits are among those foods with the highest antioxidant level and possess recognized antimutagenic properties [16].

Raw material for industry: The fruit is a source of pectin [14], a substance that is used to thicken jams etc. and as a culture medium in laboratories. The strong, stable natural colour is used in the food industry [1], [3].

Further reading: [3] (in German), [12], [13]

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Picture: Peter Forster

Arundo donax L.

giant cane, arundo (Pfahlrohr)

Family: Poaceae
Life form: graminoid
Main use category: energy, raw material
Used part: aboveground biomass

General information

Morphology: Perennial. Height 2-8 m. Erect culm, 1-4 cm in diameter, branching; rarely flowering in 2nd year. Leaf up to 60 x 6 cm, flat, glaucous, scabrid at margin. Hermaphrodite. Inflorescence a dense terminal, lax panicle (30-60 cm long). Root fibrous, arising from long, woody, creeping rhizomes. Growth often in large clumps [1], [2]. C3 photosynthesis.

Geographic distribution: S. Europe - native to the Mediterranean and S. Asia, India, and Sri Lanka; introduced to subtropical and warm/temperate regions worldwide [3].

Natural habitat: Along irrigation ditches, on sand bars and levees, riversides, occasionally in marshes [2], [4]. Highly invasive, e.g., 'unwanted organism' in New Zealand.

Site specific properties

Water regime: moist-wet
Trophic conditions: (oligo) meso-eutrophic
pH: subneutral-alkaline
Light conditions: shade intolerant
Salinity: low tolerance

Cultivation

Paludiculture with *A. donax* is unknown. A successful cultivation on peat in a pilot study in Tuscany (Italy), aiming for peatland restoration, nutrient uptake, and biomass production, showed promising results [5]. Whether a peat conserving cultivation with constant high water tables is feasible remains unknown. Cultivation instructions are available from conventional cultivation on mineral soil. Information on propagation and establishment are probably transferable to paludiculture because the ecological amplitude of the plant suggests that a cultivation in wet peatlands could be possible. It is widely used in constructed wetlands. Because of its capacity to grow vigorously in marginal land, it is considered as a dangerous weed plant [7]. However, the lack of sexual reproduction leads to no dispersion of seeds from cultivated fields.

Propagation and establishment: *Arundo donax* is an almost sterile plant. The inflorescence does not or very rarely produce viable seeds. Generative propagation is not feasible for large cultivation.
Vegetative propagation can be done via stem or rhizome cuttings. In general, the use of rhizomes achieves better survival rates [8]. Large rhizome divisions can be planted out directly into their permanent positions. This could be done with an adapted potato planter, whereby 1-1.5 plants per m^2 are sufficient. Best planting depth is 10-20 cm. The establishment of the crop on a large scale is very expensive, however. Planting shoot cuttings directly in the field [9] is another practical option for paludiculture sites because abundant water is favourable for the survival rate. The conventional vegetative propagation method (via stem or rhizomes) may limit large-scale cultivation since it is time-consuming and involves considerable cost and effort. In vitro tissue culture as an alternative to conventional methods of vegetative propagation may therefore represent a useful tool for large-scale propagation [10]. This micropropagated plantlets apparently guarantee higher survival rates, more secondary stems and above-ground biomass as compared to the ones from rhizome [11].

Management: The length of cropping life lasts about 12-15 years [7]. In general, weeding treatments seem to be not necessary after establishment [7], since the stand was not affected by weed competition in the second year in central Italy [8]. A field experiment in central Italy also showed that fertilisation can enhance crop biomass yield (dry) from 23 to 27 t/ha. This 15 % increase was possible with an energy consumption of 70 % of the overall energy cost [12], making the extra fertilizer quite unprofitable.

Harvest: *Arundo donax* is a perennial plant that can be harvested in the second year after establishment. The growth of the below-ground plant organs is impaired by two harvests in the same year, and thus annual harvesting is recommended [13]. The purpose of use determines the harvest time, however (cf. Chapter Grasses). For example, delaying the harvest from autumn to winter does not affect the productivity of the crop but increases the dry matter content of the biomass [12].

Productivity: *Arundo donax* shows very high growth rates: it can grow more than 5 cm per day under optimal conditions [14]. The mature crop can reach an above-ground dry yield of about 30 t/ha or more in Southern Europe [15], [16]. Preliminary results of a pilot study in a rewetted peatland in Tuscany (Italy) showed high yields of 38.4 t DM/ha for *A. donax* [5]. In Northern America, dry biomass yields varied from 22 to 65 t/ha*y for the third growing season [17].

Cultivation experiences: *Arundo donax* is cultivated as a bioenergy and fibre crop on mineral soil, mainly related to experimental activities. It has been successfully cultivated in a rewetted peatland in Tuscany (Italy) [5].

Utilisation

Human food: The rhizome can be eaten raw or cooked [18], or dried and ground into a powder to make bread, usually in conjunction with cereal flours [19], [20]. It can also be roasted or boiled [18]. The leaves are edible when cooked as a potherb [18]. They are very bitter [21]. The young shoots are also used [21].

Medicine: The root is diaphoretic, diuretic, emollient and galactofuge [19]. An infusion is said to stimulate menstrual discharge and diminish milk flow [22], [23]. A paste of the root is applied to the forehead to treat headaches [23]. Isolated alkaloids have been experimentally shown to raise the blood pressure and contract the intestine and uterus [22]. Boiled in wine with honey, the root or rhizome has been used for treating cancer [24].

Ornament: Used as an ornamental plant [14].

Fuel: *Arundo donax* is mainly used as an energy crop with a calorific mean value of dried giant reed biomass around 17 MJ/kg [12]. It can be used for direct combustion or biogas production for energy and heat production, or to produce biofuels, such as bioethanol [7].

Raw material for industry: Brooms are made from the terminal panicles [19]. The leaves can be woven into mats and similar products, whilst the split and flattened stems are used to make screens, walls of houses etc. [25], [1], [26], [18]. A yellow dye is obtained from the pollen [27]. In addition, it has been used as a source of cellulose for rayon and it is considered as a source of paper pulp [14], [28].

Co-benefits: It is used in constructed wetlands for wastewater treatment [29], for soil stabilization and restoration of ecosystems, e.g., contaminated soils that lost their microbial community [30].

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Picture: Derek Ramsey

Asclepias incarnata L.

swamp milkweed
(Sumpf-Seidenpflanze)

Family: Apocynaceae
Life form: forb/herb
Main use category: food, medicine, ornamental, raw material
Used part: bark, flowers, roots, shoots, seeds

General information

Morphology: Perennial. Height 30-90 cm. Leaves long, narrow, lance-shaped, opposite. Hermaphrodite. Flowers in bright pink, white and purple terminal clusters. Follicles distinctly tear-shaped (c. 12 cm), green when unripe, hardening to brown. Seeds attached to fluffy hairs (comas) that allow drifting via the wind. Contains white sap (less than many of its relatives). Rhizomatous [1].

Geographic distribution: N. America - Quebec to Manitoba and Wyoming, south to Texas and New Mexico [2].

Natural habitat: It grows in wet meadows, floodplains, riverbanks, pond shores, stream banks, wet woods, sphagnum bogs, swamps, and marshes, but also occurs in drier areas such as prairies, fields, and roadsides [1].

Site specific properties

Water regime: moist-wet
Trophic conditions: no information found
pH: acid-alkaline
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

Paludiculture with *A. incarnata* is unknown. The ecological amplitude of swamp milkweed suggests that a cultivation in wet peatlands could be possible. Cultivation is only known from gardening, e.g., to attract butterflies. Information on propagation and establishment are probably transferable to paludiculture. A peat conserving paludiculture with *A. incarnata* would exclude the harvest of below-ground biomass. The harvest of the roots will probably harm the peat soil and lead to further degradation.

Propagation and establishment: Swamp milkweed can be propagated via division or seeding. The seed can be sown in a greenhouse as soon as it is ripe in the autumn or in late winter [3], [4]. Stored seeds need 4-12 weeks cold stratification [1]. They should be planted outside when they are in active growth in late spring or early summer.
Vegetative propagation is possible via division in spring or basal cuttings in late spring [2]. Swamp milkweed spreads through rhizomes,

standard planting densities are not available. Individual plants do not propagate vegetatively. Aboveground growth dies back each autumn, and new stems (often more than one) are produced each spring from the root stock [5].

Management: Swamp milkweed is a relatively long-lived (and slow-growing) herbaceous perennial [1], so once established, parts of the aboveground biomass (e.g., the seedpods, flowers) can be used for several years.
Constant water saturated soil and periods of standing water can be tolerated. It occurs naturally in a range of wet conditions [1].

Harvest: The follicles should be harvested shortly before opening (early fall). Fruits mature from August through October and the follicles split open on one side to release seeds during October and November [1]. The unopened flowers can be harvested from June to August. Flowers begin to open during the last week of June or the first week in July and continue until August or September [1].

Productivity: No information found.

Cultivation experiences: Only known from gardening.

Utilisation

Human food: The unopened flower buds are edible when cooked [6], [7], [8]. Its taste being somewhat reminiscent of peas [9]. They can also be dried and stored for later use [10]. The young shoots are edible when cooked as an asparagus substitute [9], [11]. Tips of older shoots are cooked like spinach [9]. Young follicles, when cooked, have a pea-like flavour, they are very appetizing, and usually harvested when 3-4 cm long [9]. Flower clusters can be boiled down to make a sugary syrup [9]. Young shoots, inflorescences, and leaves should be cooked with several changes of water, otherwise it may be toxic. This plant causes dermatitis and should therefore be handled with caution [12].

Medicine: A tea made from the roots is anthelmintic, carminative, diuretic, emetic, strongly laxative and stomachic [7], [13], [14], [15]. The tea is said to remove tapeworms from the body in one hour [15]. It has also been used in the treatment of asthma, rheumatism, syphilis, worms and as a heart tonic [13], [14], [16]. An infusion of the roots is used as a strengthening bath for children and adults [15].

Ornament: Several cultivars are available. They are used especially in gardens designed to attract butterflies (monarch butterfly). The nectar of the plant attracts many other species of butterflies and insects as well. The plants are also sold as freshly cut flowers, mostly for their long-lasting display of the flowers, but sometimes for the distinctive fruits.

Raw material for industry: The seed floss is used to stuff pillows etc. or is mixed with other fibres to make cloth [17], [18]. It is a Kapok substitute and used in lifejackets or as a stuffing material [4], [18]. The downy parachutes (comas) attached to each seed are six times more buoyant than cork and five times warmer than wool. Large quantities of milkweed were grown for use as stuffing in pillows and lifejackets during World War II [1]. It is very water repellent. The floss has also been used to mop up oil spills at sea. Rubber can be made from latex contained in the leaves and stems [17]. A good quality fibre is obtained from the bark [4], [6], [7], [17], [19], [20]. It is also used in twine and cloth [20]. Follicles contain oil and wax which are of potential importance [18].
Co-benefits: Swamp milkweed is used for wetland restoration.

Further reading: [21]

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Picture: Kurt Stüber

Azolla filiculoides Lam.

Azolla, Pacific mosquitofern, red water fern (Großer Algenfarn)

Family: Salviniaceae
Life form: fern
Main use category: agricultural conditioner, food, energy, raw material
Used part: whole plant

General information

Morphology: Perennial. Size: 1-4 cm. Free floating. The main stem grows at the surface of the water with alternate fronds (leaves) and adventitious roots at regular intervals. Secondary stems develop at the axils of certain leaves. Stems prostrate when immature, 1-3 cm, internodes elongate to 5 mm, becoming nearly erect to 4 cm when mature and densely clustered. Hairs on upper leaf, lobes strictly unicellular. Heterosporous. Megasporocarp warty with raised angular bumps, each with a tangle of filaments, and one megaspore within. Microsporocarps are around 2 mm in diameter and contain 32-64 microsporangia, containing 4-5 massulae which harness 5-8 microspore cells. Plants can change colour from green to red/purple as a result of changes in sunlight intensity (and shade), as well as ambient temperature. Symbiotic relationship with nitrogen-fixing cyanobacterium *Nostoc azollae* that lives in the dorsal lobe cavity of its leaf and is able of vertical transfer via the megasporocarp [1], [2], [3], [4].

Geographic distribution: *Azolla filiculoides* was originally distributed from Alaska to the southernmost part of South America. Nowadays it is widespread in Eurasia, Africa, and Australia.

Natural habitat: Azolla occurs in quiet freshwater shallow lakes, ponds, ditches, and canals, and has been introduced in rice paddies.

Site specific properties

Water regime: flooded
Trophic conditions: oligo-mesotrophic-eutrophic
pH: acid-subneutral
Light conditions: intermediate shade tolerant
Salinity: low tolerance

Cultivation

Azolla is a water fern and among the fast-growing marine macrophytes in the world [22]. It is fixing both CO_2 and N_2 and can grow at high rates. Azolla is a candidate crop for the new bio-based economy that can help to solve the earth's resource shortage problems and is therefore already called the tiny super plant [5]. Its use as a bio-fertilizer to provide a natural source of the crucial nutrient nitrogen is ancient. It was, however, never domesticated, possibly because it is not a seed plant. It seems promising that Azolla could be used as bioengineer or a wet crop on peatland sites that are inundated after rewetting. As a biofertilizer it could also be used with other paludiculture crops that are nutrient limited and constantly flooded. Azolla is already suggested as biofertilizer for acid peatland water in Indonesia [6]. The cultivation has to be treated with care because Azolla is considered as a weed. Whether a peat conserving paludiculture with Azolla is feasible needs still to be demonstrated and research is necessary on GHG emissions. Frequent harvest of Azolla will probably prevent the build-up of organic material, and consequently anoxia and GHG emissions.

Propagation and establishment: Azolla exhibits both sexual (involving a complex cycle) and asexual or vegetative reproduction [1]. It can be propagated generatively via spores or vegetatively via in vitro subcultures. Since the latter is laborious and expensive, the former appears more promising. *Azolla filiculoides* spores can be collected year-round from dense sporulating populations that can be maintained in rainwater at temperatures varying from 5 to 15°C with 14 hours of light [7]. The vegetative propagation consists of multiplication by simple fragmentation of the fronds. Nursery ponds are generally used to ensure the supply.

Management: Azolla is a floating macrophyte and not dependent on soil or water depths. It can grow in muddy soil but drying out is detrimental. Wind damage is less with low water tables when the plant has some contact with the soil. Azolla needs all the macro- and micro-nutrients for its normal growth and vegetative multiplication, but phosphorus is often the most limiting element for its growth. For normal growth, 0.06 mg/l/day is required [8]; 20 mg/l is the optimum concentration [12], [21]. Azolla needs sufficient Fe as well [30]. The challenge of cultivating Azolla on peatlands will be linked to this: High Fe concentrations often result in the binding and low availaility of P; stressing the role of nutrient stoichiometry [30]. The optimum temperature of *Azolla filiculoides* ranges between 20 and 25°C, whereby the min. and max. temperatures are 0 and 42°C, respectively [8], [9]. It is cold tolerant, surviving even in fragmented parts under thin ice [3].

Harvest: Currently there is no established harvesting technique for Azolla biomass. Azolla populations can have a high leaf area index without negative effect on growth. Harvesting a part of the population on a frequent basis provides a basis for further production. According to one report, Azolla can be harvested every week from an artificial system [10].

Productivity: Azolla shows very high growth rates, doubling biomass in 2 days under favourable conditions [1]. The maximum standing crop range from 1.7 to 5.2 t/ha. With a cyclic harvesting strategy large yields per year can be attained with reported dry matter productions of 39 t/ha*yr and 9 t protein/ha*yr [11]. If no nitrogen is supplied, Azolla can fix all the nitrogen required, with a small penalty on growth and nitrogen content [12], [13]. In the presence of 40 mg/l ammonia *A. filiculoides* still fixes 50-78 % of the total incorporated nitrogen [14], depending on the strain. Generally, the crude protein content is about 19-30 % of the dry mass during the optimum conditions for growth; under natural conditions, values near

20-22 % are frequent. Azolla plants have high ash contents, varying between 14 and 20 % [8]. Under good conditions the plants can overgrow each other in layers and develop mats up to 5 cm thick [5].

Cultivation experiences: Known from mineral soil or from artificial ponds. In Korea Azolla is cultivated for fodder, in China for fodder and green manure [15]. There are several pilot studies that cultivated Azolla [7], [16], also one on peatlands in the Netherlands [29].

Utilisation

Human food: Azolla is thought to be suitable for human consumption, although only experimental preparation of food products has hitherto been attempted. This is now changing and some of the impetus has come from studies into diets that could be used for space stations and space travel. Azolla's nutritional value is similar to that of Alfalfa sprouts and Spirulina [17]. It is a rich source of proteins, minerals, amino acids, vitamins and carotenoids. The quality of the protein in Azolla is good, although there are some deficiencies of the amino acids methionine, histidine and lysine. It is possible to cook tasty food using Azolla as the main cooking ingredient [17].

Animal fodder: It is a high-protein (ranging from 19 to 30 %) animal feed, but with a limited digestibility. It is frequently used as a feed supplement for aquatic and terrestrial animals [18], [19], [8].

Fuel: The crude lipid fraction makes up 6.6-14 % of Azolla dry weight. Azolla lipids can be converted into biodiesel [20], [23]. An analysis of pyrolysis products showed that Azolla produce a large spectrum of bio-oils. This large spectrum of petrochemicals and straight-chain C 10 - C 21 alkanes can be directly used as diesel fuel supplement, or as a glycerine-free component of biodiesel [16]. See [21], [22], [23].

Agricultural conditioner and substrate: Azolla is an exceedingly good source of nitrogen-rich biomass that can be used as a fertilizer or can be added to the compost heap [18]. It can be grown as a green manure crop in rice fields, taro or water chestnut (*Trapa*) plantations [23], [24]. Mixtures of different paludicrops (e.g., *Sphagnum*, *Typha*) are currently being tested as nutrient-rich substrates [R. Vroom, pers. comm.]. As Azolla grows, it forms a floating, light-proof mat of living plants that suppresses weed growth, significantly reducing labor costs [24].

Raw material for industry: Azolla biomass contains several Azolla specific (ω20) compounds [23]. Specific long chain lipids include long-chain waxes, which can be used for a variety of industrial applications, such as cosmetics, candles, coatings, printing inks, plasticizers, lubricants, and pharmaceuticals. Long-chain ω20 alcohols, wax esters and n-hydroxy fatty acids have potential to produce high-value specialty chemicals [20]. Their unique composition, however, complicates the determination of their market potential.

Co-benefits: Azolla is used for phytoremediation as it can accumulate nutrients (i.e., phosphorus) and heavy metals [26], [27], [13]. As floating mats of Azolla efficiently block oxygen diffusion into the water layer, the anaerobic mobilisation of P from nutrient-rich soils, linked to microbial iron reduction, is strongly enhanced [29]; researchers assume that this only happens when a lot of organic material is present in the water [R. Vroom, pers. comm.], so further research is necessary. The dual application of *A. filiculoides* and *Landoltia punctata*, that efficiently absorbs N and P components of wastewater, can advantageously complement each other if sequentially used for efficient recovery of N and P nutrients from swine wastewater [16]. Another advantage of the application of Azolla for bioremediation is related to its ability to efficiently inhibit the growth of microalgal and cyanobacterial populations by producing a thick mat on the surface of the water, which prevents penetration of oxygen and light [16]. The presence of microalgal populations in final water-effluents is highly undesirable and, in many cases, requires additional purification stages.

Further reading: [22], [28], [31]

Similar species: There are several other aquatic macrophytes that have some potential to be used in similar innovative ways as Azolla. Examples are: *Salvinia* spp., *Lemna* spp.

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Picture: Sheri Hagwood

Beckmannia syzigachne (Steud.) Fernald.

American sloughgrass
(Gewöhnliches Doppelährengras)

Family: Poaceae
Life form: graminoid
Main use category: fodder
Used part: aboveground biomass

General information

Morphology: Annual or short-lived perennial. Height up to 1 m. Stem leafy. Leaves flat, 3-10 mm wide, linear, scabrid; sheaths overlapping. Hermaphrodite. Branched inflorescence a closed panicle. Flowering June to September. Shallow root system. Grows solitary or in small clumps [1], [2], [3].

Geographic distribution: The species is native to N. America (US: throughout the northwest and north central states, occurs occasionally in the northeast) [1]. E. Europe to Central Asia [4].

Natural habitat: Wet meadows, swamps, marshes, and shallow water [5].

Site specific properties

Water regime: moist-wet-flooded
Trophic conditions: meso-eutrophic
pH: subneutral-alkaline
Light conditions: intermediate shade tolerant
Salinity: medium tolerance

Cultivation

Beckmannia syzigachne is an obligate wetland plant [1]. The high palatability makes it a good candidate for paludiculture to produce forage, but its cultivation in wet peatlands is unknown. Being a short-lived perennial, there is some effort necessary to ensure the regeneration of the stand. *Beckmannia syzigachne's* potential for utilization as a pasture or hay crop does not appear to be limited by complex germination requirements, low forage yield potential or poor seed production. More extensive ecotype collection and evaluation for forage yield and quality and adaptability to short-term forage production in peatlands seems warranted [6].

Propagation and establishment: Direct seeding is the preferred method since there are no dormancy restrictions that would inhibit rapid and uniform germination. Reports of the rate of seed germination vary, but it may be improved by rubbing or dehulling the seed (and possibly light abrasion of the seed coat), and by providing alternating temperature regimes [1], [6]. It rapidly colonizes mudflats or disturbed ground and produces abundant seed crops. By tilling the planting site, weeds can be discouraged during the establishment period. Seed sown on the surface floats readily and migrates with flowing water, so an adequate but shallow soil or mulch coverage must be insured. The best planting times are late fall to allow fall establishment or a dormant seeding, which would promote early spring establishment. The free flowing spikelets present no difficulty for conventional planting equipment. Spikelets should be planted at a depth of 7-15 mm deep in the soil [1]. There are 110,000 seeds per kg (± 20 %) with hulls intact. Recommended single species seeding rates can vary widely, depending on the site and purpose of the planting, ranging from 5 to 20 kg/ha. [1]. Processing the seed once harvested can be challenging, because the *Beckmannia* seed is very small and special precautions are needed to ensure that small weed seeds are not included in the final product [1].

Management: As a short-lived species, a pattern of deferred, rotational grazing may be needed every two or three years to allow for seed production and natural regeneration of the stand. The plant requires a high water table (not specified) [1].

Harvest: Best cutting time is when heads emerge and before flowering to yield the highest forage quality and quantity [7]. It regrows slowly after cutting and should be used only once a year [7]. Harvest should be conducted with adapted machinery with low ground pressure, e.g., tracked vehicles (caterpillars) with harvesting equipment.

Productivity: In the Northern Plains, forage production is considered as moderate to high [1].
In a wetland in Oregon (USA) the following amounts of biomass were found depending on added nutrient supply [8]:

- 5.7 t DM/ha (soil with 0.56 µg/g dry soil Ammonium, 0.01 Nitrate, 9.49 Phosphate)
- 9.5 t DM/ha (soil with 1.38 µg/g dry soil Ammonium, 0.51 Nitrate, 9.38 Phosphate).

Cultivation experiences: Known from North America [1], but unknown whether it has been grown in wet peatlands.

Utilisation

Human food: Seed is edible when cooked [9], [10], [11], [12], [13], and has a mild flavour. It can be ground into a flour and used as a cereal. The seed is very small but is easily harvested. It has then to be separated from its husk, which is a very fiddly operation [4].

Animal fodder: *Beckmannia syzigachne* provides palatable forage for livestock and is frequently hayed or grazed [1]. Palatability is rated high for all classes of livestock [1]. It is high in protein and nonstructural carbohydrates [1], has an average total digestible nutrient (TDN) level of 55 % and a crude protein content of 9 % at heading. As it matures, forage palatability and quality decrease rapidly [7].

Raw material for industry: The plant is used for making bedding and pillows [14].

Co-benefits: It is used for wetland restoration as well as erosion control along ditches, streams, waterways, and the shorelines of lakes or ponds.
Further reading: [1], [6]

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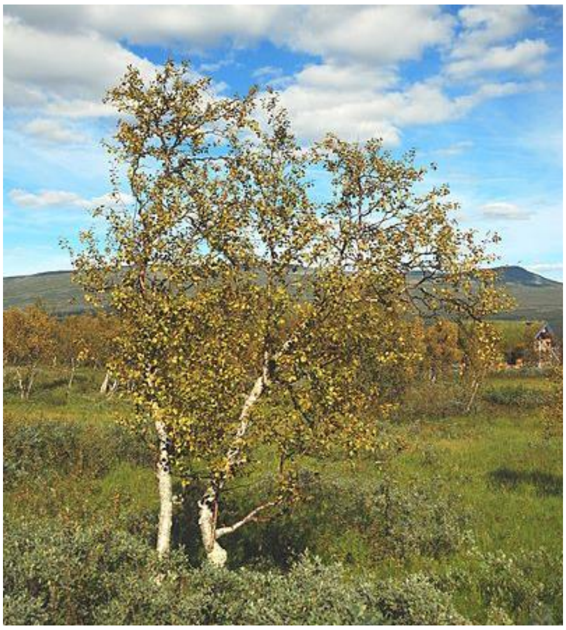

Picture: Ankara

Betula pubescens Ehrh.

downy birch (Moorbirke)

Family: Betulaceae
Life form: tree or shrub
Main use category: raw material, fuel, food, medicine
Used part: wood, sap, bark, leaves

General information

Morphology: Perennial. Height 1-20 m. Leaf blade ovate or rhombic-ovate, margins serrate, apex acute. Monoecious. Fruiting catkins pendulous or subpendulous, cylindric, shattering with fruits in late fall. Samaras with wings equal to, or somewhat broader than, the body. The bark is brownish white or white-grayish, smooth, rather close, or readily exfoliating in paper-thin sheets [1], [2].

Geographic distribution: Most of Europe, east to W. Siberia and C. Asia [3].

Natural habitat: *Betula pubescens* grows on a wide range of soils but prefers more acidic, wetter, peatier soils than *B. pendula*, especially in the uplands. It is a generally short-lived tree of wet woodland usually with alder, other birches, and willows as the predominant tree species. It can rapidly colonise open, unshaded ground, particularly burned areas, open heathland, and cut-out peat bogs [4]. Minerotrophic mires.

Site specific properties

Water regime: moist-wet
Trophic conditions: oligo-meso-eutrophic
pH: acid-subneutral
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

Betula pubescens grows naturally on wet peatlands and is successfully tested for cultivation on drained cutover bogs in Finland and Ireland. Since the tree can grow on wet sites, paludiculture seems promising. In some cases, cutaway peatlands are naturally colonised by *B. pubescens* forming thickets. Heavy young stand treatment (= thinning) has to be done to form a more valuable stand. When growing on wet peatlands the size and quality is often too poor for veneer and saw logs [5]. Only on fertile peatland sites is it possible to grow veneer or saw logs [6]. In general, however, *B. pubescens* exhibit a poor form and can lose its apical dominance as it grows taller [7]. So, the main aim should be to produce pulp wood or fuel wood. A birch stand offers several ecological benefits (cf. [8] p. 161). It is also a potentially peat-forming species [9], [10]. In connection with peatland restoration projects, *B. pubescens* has shown to be problematic: on a restored site it may dominate and overgrow other tree species like Scots pine and Norway spruce which may have been the dominating tree species on the former pristine mire site [11].

Propagation and establishment: *Betula pubescens* is a pioneer species. The generative establishment from seeds is the dominant mode of reproduction. Germination rate is high and regulated by light and temperature change. Planting can be done with bare-root or containerised stocks, the latter being preferred because it is the safer and more resistant method, especially on deeper peat soils [7]. Tall (60-90 cm) birch seedlings have been traditionally used in Finland, but it is also possible to plant shorter containerised seedlings (20-25 cm) without serious negative effects on performance in later years [7]. Vegetative propagation: in general, birches can sprout from dormant basal buds. Vigorous coppicing is a typical feature of downy birch. The growth of the coppice shoots is much faster than that of planted seedlings at an early stage, but they are reached and overgrown by the planted seedlings after 4-5 years [6].

If high water tables are present, it is recommended to plant the young seedlings on ridges to prevent flooding.

After a review of Päivänen & Hånell [8] it seems that for industrial raw wood, young stand treatment in pure stands should aim for a density of 2,000-2,500 young trees/ha. Only one commercial thinning is recommended at the dominant height of 14 m, which yields a harvest of about 30 m³/ha and leaves 900-1,000 trees/ha for further development. At the age of approximately 50 years most of the trees can be harvested for pulp or energy wood.

Management: An experiment in the Czech Republic reported better growth on wet than on dry sites on a cutover peatland [12]. However, long-term flooding cannot be tolerated by *B. pubescens*. Fertilisation experiments on drained peatlands have shown only a small increase in biomass production with NPK [13]. Heavy weed growth, especially *Juncus effusus*, can be a severe problem following fertilisation [14]. Mowing and weed-wiping are two recommended methods for weed control [15]. It is probably unprofitable to use commercial fertilizers when establishing *B. pubescens* stands.

Naturally developed *B. pubescens* stands on peatlands can be managed for different targets. When managed for pulp wood production, young downy birch stands can be thinned at 4-6 m height to a density of 2,000-2,500 stems/ha. The initial thinning shows a low response [16]. With a height of 13-14 m one commercial thinning can be carried out to a density of 1,000 stems/ha. In this management regime, final cutting takes place at the age of 50-60 years [6], [17]. If the goal is the production of fuel wood, then the first thinning can be delayed up to a stand dominant height of 10-11 m [6]. A thinning in downy birch stands may increase slightly the size of stems to be removed in future cuttings, but with exception for very light thinning it may decrease the production of biomass and merchantable wood [16]. The only financial benefits of tending or thinning of downy birch stands seem to be earlier incomes and lower harvesting costs, resulting from the larger stems removed in thinning and final cutting. There is not a higher increment or greater value of wood produced [16]. However, the alternative to grow two-storied spruce-birch mixed stands should be considered, when Norway spruce has regenerated naturally in a pulpwood sized downy birch stand ([8], p. 163). Downy birch forms a nurse crop and provides shelter to spruce seedlings. The best birch stems may grow up to veneer size.

On the most productive peatland sites, *B. pubescens* can be grown up to the dimensions of veneer logs [18]. These trees should have been originated from seeds. The stand can be thinned (2nd thinning) and the best quality stems left to reach timber size. The final cut would be at a stand age of 60-70 years [Finnish reference in 8].

A rotational cultivation is possible because the stems sprout after cutting. A very short rotation of 1 or 2 years is not recommended. A rotation cycle of 4 years may not decrease the yield, but the mean annual increment (MAI) increases with rotation length. Optimum rotation length for biomass production should be 16 years or longer to achieve high MAI [20], [21]. Some authors, however, consider short rotation of *B. pubescens* economically unprofitable [6], [20].

Harvest: The low load-bearing capacity of the wet peat soil makes the wood harvest difficult. Harvesting should be done in winter after the ground is frozen and snow-covered to minimize peat soil disturbance and its possible harmful effects on water quality.

The sap can be harvested in early spring, before the leaves unfurl, by tapping the trunk. The flow is best on sunny days following a heavy frost. The sap is often concentrated into a sugar. Between 4 and 7 litres can be drawn off a mature tree in a day and this will not kill the tree so long as the tap hole is filled up afterwards [22]. However, prolonged or heavy tapping will damage or even kill the tree.

Productivity: *Betula pubescens* is short-lived, and at an early stage a fast-growing tree species. The naturally seeded birch stands measured in a cutaway peatland in Ireland had an estimated biomass production of 3.1-5.8 t DM/ha*yr [23]. Studies on cutaway peatlands in Finland showed the following results for a 6-, 11- and 19-year-old birch plantation: 4.1, 6.5 and 5.9 t/ha*yr, respectively (with an initial planting density of 20,000 plants/ha) [13]. The yield of stem volume including the bark (MAI) was 4 m^3/ha*yr in dense birch stands on peatlands with a mean annual aboveground biomass increment of 2.5 t/ha*yr in unthinned and very lightly thinned birch thickets [16].

An equation to estimate the aboveground biomass from the diameter at breast height is available for downy birch [24]. A tentative estimation of the Yield Class is YC 8-10 [7], [25]. In Ireland, an unthinned stand of downy birch at the age of 42 years showed a standing volume of 203 m^3/ha [25].

Cultivation experiences: Known from northern Europe [6], e.g., Ireland [23] and Finland [20].

Utilisation

Human food: The sap can be used fresh or cooked. It has a sweet flavour [26], [27], [28]. Wine and beer can be fermented from the sap [29]. It can also be processed into a syrup by reverse osmosis and evaporation under reduced pressure [30]. Furthermore, it is often concentrated into a sugar by boiling off the water completely. The inner bark can be used cooked or dried, ground into a powder and then used with cereals for making bread etc. [26], [27], [31]. This is, however, more considered a famine food [3], [28]. Young leaves can be eaten raw or cooked [27], [28]. A tea is made from the leaves [27] and another tea is made from the essential oil in the inner bark [32].

Medicine: Anti-inflammatory, cholagogue, diaphoretic [32], [33], [34]. The bark is diuretic and laxative [35]. The inner bark is bitter and astringent, and used in treating intermittent fevers [36]. An oil obtained from the inner bark is also astringent and used in the treatment of various skin afflictions, especially eczema and psoriasis [36], [37]. The bark is usually obtained from trees that have been felled for timber and can be distilled at any time of the year [37]. The buds are balsamic [35]. The young shoots and leaves secrete a resinous substance which has acid properties; when combined with alkalis, it is a tonic laxative [36]. The leaves are anti-cholesterolemic and diuretic [35]. They also contain phytosides, which are effective germicides [35]. An infusion of the leaves is used in the treatment of gout, dropsy, and rheumatism, and is recommended as a reliable solvent of kidney stones [36]. The young leaves and leaf buds are harvested in the spring and dried for later use [37]. A decoction of the leaves and bark is used for bathing skin eruptions [36], and the boiled and powdered wood has been applied to chafed skin [38]. The vernal sap is diuretic [36]. Moxa is made from the yellow fungous excrescences of the wood, which sometimes swell out of the fissures [36].

Fuel: The wood is locally used as firewood. The bark is a very good tinder.

Agricultural conditioner and substrate: The leaves are a good addition to the compost heap, improving fermentation [39].

Raw material for industry: The wood is soft, light and durable. It is used for a wide range of purposes including furniture, tool handles, carving, toys etc. [40], [37]. It is a source of charcoal that is used by artists and is also pulped and used for making paper [37].
The bark is used to make drinking vessels, canoe skins, roofing material and even shoes, and backsacks during the old times. It is waterproof, durable, tough, and resinous [41], [42]. Only the outer bark is removed, whereby the tree is not killed. It is most easily removed in late spring to early summer. The bark is pressed flat and stored until the following spring [38].
A black paint is obtained from the soot of the plant [42]. Glue can be made from the sap and cordage from the fibres of the inner bark. This inner bark can also be separated into thin layers and used as a substitute for oiled paper [36]. A decoction of the inner bark is used to preserve cordage, it is rich in tannin. The bark contains up to 16% tannin [43]. A brown dye is obtained from the inner bark. An oil similar to Wintergreen oil (obtained from *Gaultheria procumbens*) is obtained from the inner bark [32], [42].
The young branches (especially stump shoots) are very flexible and are used to make whisks, besoms etc. [44]. They are also used in thatching and to make wattles [36].
A high-quality charcoal is obtained from the bark. It is used by artists, painters etc. [3].
A tar-oil is obtained from the white bark in spring. It has fungicidal properties and is also used as an insect repellent [34], [36], [42], [45]. It makes a good shoe polish [42]. Another report says that an essential oil is obtained from the bark and this so-called 'Russian Leather' has been used as a perfume [46].
In Finland a bundle of birch twigs with fresh leaves is used to gently slap the skin and create further stimulation of the pores and cells during a sauna session. However, *B. pendula* is more durable for this purpose. The bundles of twigs can also be dried and used during the dormant period after refreshing in hot water. Various medicinal and non-medicinal uses of *Betula* spp. are provided in [47].

Co-benefits: As a pioneer species, it readily invades old fields, cutover peatlands, cleared or burnt-over land and creates conditions suitable for other forest trees to become established [8]. Since it is relatively short-lived and intolerant of shade, it is eventually out-competed by shade-tolerant trees like Norway spruce [41], [48]. On the other hand, if Scots pine (also intolerant of shade) is the target tree species, *B. pubescens* thicket has to be thinned or cleaned off early enough. It is used as a nurse crop for Norway spruce (against spring frost).

Further reading: [6], [7]

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Picture: Dacrycarpus

Brasenia schreberi J.F.Gmel.

water shield (Haarnixenkraut)

Family: Cabombaceae
Life form: forb/herb
Main use category: food, medicine
Used part: leaves

General information

Morphology: Perennial. Height up to 10 cm above water table. Stems 1-2 m, glabrous, base rhizomatous. Leaf blade 3.5-13.5 × 2-8 cm, glabrous; petiole 25-40 cm. Hermaphrodite. Flowers ca. 2 cm diameter, peduncle 6-10 cm; perianth parts dull purple, 10-20 × 2-7 mm; petals slightly longer and narrower than sepals. Stamens 1/2 as long as petals; anthers linear, ca. 4 mm. Flowering June. Fruits 6-10 mm. Seeds 1-2, 2.5-4 × 2-3 mm, fruiting in October [1], [2], [3].

Geographic distribution: N. America: Nova Scotia to Manitoba and Nebraska, south to Florida, Texas and Mexico. Central America (Guatemala and Belize); South America (southeast Venezuela); E Asia; Africa, and E Australia [2].

Natural habitat: Oligotrophic or mesotrophic ponds, lakes, and sluggish streams from sea level to 2,000 metres [2].

Site specific properties

Water regime: flooded
Trophic conditions: oligo-mesotrophic
pH: acid-subneutral
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

Paludiculture is unknown from this species. It is cultivated in shallow ponds in China and Japan. The ecological amplitude of the plant suggests that a cultivation in rewetted peatlands with permanent flooded areas could be possible. A responsible peat-conserving paludiculture would exclude the harvest of the roots. The harvest of the underground organs would most likely disturb the peat soil and lead to further degradation.

Propagation and establishment: *Brasenia schreberi* can be propagated generatively via seeds or vegetatively via division.

Management: *Brasenia schreberi* is a floating plant and should be grown in still lime-free water up to 1.8 m deep [4]. It prefers a rich soil [4]. The aquatic and edaphic requirements should be considered, as the production of its valuable mucilage depends on it [5].

Harvest: The harvest is done manually.
Productivity: A Japanese study conducted in an irrigation pond in Matsue, Shimane Prefecture, found an annual net production, which is expressed by the cumulative potential dry weight of new borne leaves, ranging from 1.5 to 2.4 t DM/ha*yr within 3 years [6].
Seasonal maximum leaf mass for an irrigation pond in Matsue, Shimane Prefecture, Japan, is reported as 0.5-0.8 t DM/ha [6].

Cultivation experiences: Japan [7], China [8].

Utilisation

Human food: The young, curled leaf tips, which are coated with a thick transparent mucilage, are eaten as a salad with vinegar, sake, and soy sauce, or added to soups as a thickener [9], [10], [11]. It is considered a great delicacy in Japan where they are often bottled and sold in local markets [11]. They are mainly used in the spring [12]. A nutritional analysis is available [13]. The root is edible when cooked [14], [9], [15]. Peeled, boiled, and eaten, they can also be dried and stored for later use or ground into a powder [11].

Medicine: The leaves are astringent [16]. They are crushed and applied to abscesses and boils [13], and are also used in the treatment of phthisis and dysentery [16]. A decoction of the seed is antidotal [13]. It is also used in the treatment of dysentery and to relieve thirst [13]. The plant is anthelmintic and vulnerary [13], [17], [18]. It is used in the treatment of cancer [13].

Agricultural conditioner and substrate: The plant has phytotoxic properties that allow it to inhibit the growth of other plants nearby and therefore to become dominant. This gives it a potential for the natural control of invasive water weeds [19].

Further reading: Cultivation [7], [20]

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Pictures: USFWS Mountain-Prairie

Calamagrostis canadensis (Michx.) P.Beauv.

Bluejoint, marsh reedgrass, Canadian reedgrass

Family: Poaceae
Life form: graminoid
Main use category: fodder
Used part: aboveground biomass

General information

Morphology: Perennial. Height: 60-180 cm. Stems stout, with 3-8 prominent nodes. Leaves ribbed, lax, rough to the touch, 3-8 mm wide. Hermaphrodite. Panicle rather narrow to open and loosely branched, upright to drooping when mature, 10-20(-30) cm long. Flowering June to July. Fruiting in August. Seeds tiny, with fine hairs attached at one end of their hull. They remain viable in the soil for up to 5-7 years. Spreading slowly by rhizomes, forming a sod [1].

Geographic distribution: N. America [1].

Natural habitat: Bluejoint can be found in a wide variety of environments including meadows, open woods, wet thickets or swamps, marshes, bogs, ditches, and the margins of streams and lakes [1].

Site specific properties

Water regime: moist-wet
Trophic conditions: mesotrophic-eutrophic
pH: acid-alkaline
Light conditions: shade intolerant
Salinity: low tolerance

Cultivation

Paludiculture is unknown from this species. It is used possibly in a traditional paludicultural way in the USA. The broad ecological amplitude suggests that paludiculture is possible. This species thrives in more nutrient rich, saturated soils, peat, or deep, fine textured substrates that are moist-wet all summer. Reportedly, bluejoint only withstands seasonal inundation and temporary spring flooding up to 15 cm deep. However, stands have maintained themselves for several years in permanent standing water at similar depths [1].

Propagation and establishment: Generative or vegetative. The seed is very small, has no dormancy and germinates when sown in fall or spring. It requires specialized processing after harvest: the basal hairs on the seed should be removed with a debearder to improve seed flow. Hulls may be removed in the process, resulting in approximately 8 million seeds/kg. A seeding rate of 1 kg/ha will result in about 1,000 seeds/m². Rates as low as 0.03-0.06 kg/ha are suggested [1]. Their small size results in generally poor seedling vigour, thus requiring very shallow seeding and effective weed control during establishment [1].
Vegetative propagation via rhizomes and plugs is more successful but expensive and laborious. One source recommends a spacing of 0.15, 0.3 or 0.45 m for a uniform aerial coverage in 1, 2 or 3 years, respectively. The planting density should be 8,750-17,500 plants/ha [1].

Management: The statements about grazing and cutting tolerance are heterogenous. In wet, disclimax bluejoint stands (e.g., after clear cutting of a forest) heavy grazing maintained bluejoint in an early phenologic condition, causing it to retain good nutritional quality. Maintenance of forage quality supported uniform utilization of bluejoint through the entire growing season [2]. Bluejoint is sensitive to overgrazing in some regions and multiple cuttings can reduce forage yields [1]. After another report, the yield increases by 10-15 % in heavily grazed paddock [2]. Aboveground biomass is most palatable when young, prior to seed head maturation. Fertilized stands produced crude leaf protein of 12-20 % dry weight during mid-June harvests. Unfertilized forage was found to have marginal calcium and magnesium content and its digestibility was reduced. Clipping can improve late season forage quality [1].

Harvest: Unfertilized bluejoint seems to be intolerant of heavy grazing or repeated harvests, so harvesting should be restricted to a single event per year (or only in alternate years) before flowering.

Productivity: Fertilized stands (2.5-5 t DM/ha) of bluejoint produced three times more forage than did unfertilized stands (1.25 t DM/ha) [1]. Forage production of 1.5-2.3 t DM/ha were measured in wet birch-spruce sites that had been clear-cut logged and then heavily grazed by livestock for 4 years [2].

Cultivation experiences: Known from USA and Canada.

Utilisation

Animal fodder: Stands have been hayed for forage in the Midwestern states of the USA. Forage value varies widely by region with ratings from poor to good for all classes of livestock. Palatability is considered fair at best, regardless of livestock type. It is highest in the spring prior to maturity [1]. A nutritional analysis is available [3].

Fuel: Unknown but imaginable.

Raw material: The plant was used to make mattresses when nothing else was available [4]. Grass was used to line and cover winter storage pits for potatoes [4].

Co-benefits: Bluejoint is useful for wetland restoration and enhancement as well as shoreline and stream bank stabilization. Creeping underground shoots (rhizomes) improve the plant's ability to bind soil, especially along higher gradient streams and waterways. It is included in hydroseeding mixtures for drainage ditches designed to filter storm water [1].

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Picture: Frank Mayfield

Carex spp.

sedges (Seggen)

Family: Cyperaceae
Life form: graminoid
Main use category: fuel, raw material, fodder
Used part: aboveground biomass

General information

Morphology: Perennial. Height: up to 150 cm. Culms usually trigonous. Leaves basal and cauline, sometimes all basal; ligules present; blades flat, V-shaped or M-shaped in cross section, involute, or rounded, usually less than 20 mm wide. Monoecious. Terminal inflorescences consisting of spikelets borne in spikes, racemes, or panicles; spikelets 1-flowered. Fruit achenes, biconvex, plano-convex or trigonous, rarely 4-angled. Specifics: caespitose or not, rhizomatous, rarely stoloniferous.

Geographic distribution: Almost worldwide distributed, absent from tropical lowlands except for a few species in SE Asia [1].

Natural habitat: Most (but not all) sedges are found in wetlands, usually with water not more than 50 cm deep in the growing season [1], such as marshes, calcareous fens, bogs and other peatlands, pond and stream banks, riparian zones, and ditches.

Site specific properties

Depend on species. See table below.

Cultivation

Carex is one of the largest genera of vascular plants and most commonly associated with moist to wet habitats. Among them there are several species that are acceptable or good fodder plants, or well suitable as raw material for the bioeconomy. The large sedges especially have a good potential for paludiculture because of their higher productivity. Wet sedge meadows are used traditionally in a paludicultural way in N.

America and Europe for fodder, bedding material and thatching [2], [3], in Poland and Germany the biomass is used on a small scale for combustion [4], [43].

Sedges are also important peat forming species [5]. After peatland rewetting and stand establishment, new peat formation can be induced given constant high water tables [6]. New research results assume that potentially peat-forming biomass (roots) of fen sedges increases with increasing nutrient levels [21], which are prevalent after rewetting. *Carex* meadows also hold a high importance for biodiversity, e.g., in the form of calcareous fens that are among the most species-rich ecosystems of the temperate zone and harbour many endangered species [2], [7]. Mowing and grazing has been successful in maintaining or increasing species richness, particularly in fens that have been mowed annually for centuries [7], [8]. The management is used to control the dominance of tall woody and herbaceous species [9] [47], while overgrazing or multiple mowing results in a permanent reduction in biodiversity [7]. More information on biodiversity enhancing management recommendations: [47].

After rewetting, sedge stands can develop spontaneously when propagules are available. They can also develop in succession after *Phalaris arundinaceae* or *Typha* spp. [6], [10], [11], but the natural re-colonization of sedges can be very slow [12].

Propagation and establishment: Vegetative: via rhizome divisions, for example. Rhizomes are best planted in spring or summer with a water table close to the surface [13], [14]. Inundation reduces the establishment rate in the first growing season. One study [15] suggests that planting of seedlings is a more appropriate method of establishing this species than the use of transplanted rhizomes. Soil preparation is necessary before planting or seeding to reduce weeds and competition pressure. Direct seeding is possible in spring in a moist soil with light shade [16]. If water tables are too high in spring, seeding in late summer is recommended. If seeds are in short supply it can be sown in a cold frame and be planted out in the summer. Three factors generally favour germination in *Carex*: cold moist stratification, alternating soil temperature after sowing, and perigynium exposure to light after sowing [17], [18], [19]. The magnitude of the effects varied among species.

Control of water-level conditions and competition is most crucial during the first growing season to ensure appropriate conditions for successful stand establishment [12]. Immature sedges are very sensitive during the first year. Seedling and juvenile growth were slowed by non-sedge colonizers during the first two growing seasons, but by the third growing season *C. stricta* was able to out-grow all annual and perennial weeds, except the aggressive perennial *Phalaris arundinacea* [15]. Once established, plants tolerate a broad range of seasonal drying and flooding conditions, although lowering the groundwater level appears to negatively affect regeneration, growth and biomass development of *C. cinerascens* [20], [21].

Management: The development of peat forming sedge stands after rewetting are predominantly restricted to long-term shallow inundated sites with a water level median in winter of 0-30 cm above surface [6]. These water levels should be targeted in fen peatlands. The growth is favoured by low inundation levels and hampered by high ones [22].

Most *Carex* species are tolerant of regular mowing and moderate grazing in summer or winter, while multiple cuttings will reduce vigour. Sedge stands are grazing tolerant given an adequate regrowth period, e.g., *C. utriculata* (beaked sedge) is tolerant of moderate to heavy, controlled early summer and fall grazing [23]. The removal of standing material and the increase of soil insolation and soil temperatures stimulates the initiation of new shoots and leaf growth particularly of rhizomatous sedges [23]. Two mowing's or one single cut of a nearly pure *C. atherodes* stand in Alberta/Canada seemed to be optimal regarding yield and chemical composition [24]. Fertilization of this stand showed no effect on productivity [24]. It was concluded that the fertilizer may have been lost in the surface water or that the response was delayed and not measured.

Without nutrient resupply, there may be medium-term effects of oligotrophication and associated yield declines.

Harvest: Mowing is possible with adapted machinery. Mowing in late summer or autumn is best for conservation targets but the harvested biomass can only be used for bedding or combustion, not for fodder [9]. Double harvest or single harvest were optimal in a *C. atherodes* stand considering both yield and chemical composition for hay use [24].

Productivity: Sedges are generally low to moderate productive species. The productivity of sedge stands is very variable and differs with species and site [25]. Large sedges' biomass range generally between 5 and 12 t DM/ha [11]. A sedge fen in Belarus harvested in spring for bioenergy yielded 7 t DM/ha [26]. Some examples of high yielding large sedges that are suitable for paludiculture with corresponding productivity values are provided in the table below.

Cultivation experiences: Known from restoration projects [12], [13], [14], [27] and paludiculture trials in Bavaria, Germany [44].

Tab. Overview of different *Carex* species, their distribution, and productivities from different study sites.

Scientific name	**Vernacular name (German name)**	**Distribution**	**Productivity in t DM /ha**	**Study site**	**Characteristic site properties**
Carex acuta	acute sedge (Schlank-Segge)	central and northern Europe, western Asia	3.8	wet sedge meadow of a river valley in Poland [4]	wet-flooded, meso-eutrophic, subneutral (weak acid to weak alkaline)
Carex acuta / C. riparia			8	fen in the Netherlands dominated by *C. acuta / C. riparia* [28]	
Carex acutiformis	lesser pond sedge (Sumpf-Segge)	Europe and western and central Asia	4.2	wet sedge meadow of a river valley in Poland [4]	flooded, eutrophic, subneutral-weak alkaline
			5.4-7.6	values from several studies on peatlands in Germany [10]	
Carex atherodes	wheat sedge (Grannen-Segge)	Eurasia and N. America	6-8 / 5.6	on clay or peat soil in Alberta/Canada [24]	flooded, eutrophic, subneutral-alkaline
Carex nebrascensis	Nebraska sedge	western and central N. America	4.5-8.9	wet sedge stand in a river valley in Oregon/U.S. [29]	wet-flooded, subneutral-alkaline
			4.1 / 7	grazed/ ungrazed wet meadow in Oregon/U.S. [30]	
Carex riparia	greater pond sedge (Ufer-Segge)	Europe and western and central Asia,	5.3-11.1	rewetted fen grassland in a river valley [31]	flooded, meso-eutrophic, subneutral-weak alkaline

Carex rostrata	beaked sedge (Schnabel-Segge)	Europe, N. Asia and N. America	4.9	England [29]	flooded, oligo-mesotrophic, acid-subneutral
			3-5	peatland in Sweden [33]	
			6.4	moderately rich fens in western Canada [34]	

Utilisation

Human food: Young stems and the tuberous base of stem are edible. Seeds can be ground, cooked into a mush and eaten. *Carex rostrata*: root is edible when cooked [35], [36]. *Carex aquatilis*: stem bases are edible raw [36]. *Carex utriculata:* the pith of the stem can be eaten raw or cooked. It has a sugary taste [37]. Root and tuberous stem bases are edible when cooked [37], [35].

Ornament: *Carex* species are often grown as ornamental grasses.

Animal fodder: There are several tall sedges that can be mown or used as a pasture grass. The aboveground biomass of the species *Carex divulsa, C. spicata* and *C. muricata* has a very valuable chemical composition and provides a valuable fodder. The most remarkable features are: high concentration of proteins and a high proportion of C:N [38]. In western N. America, sedges provide forage for domestic livestock and wildlife. In some areas sedges are among the major forage items found in cattle diets [39]. In Canada and the U.S., *C. atherodes*, *C. rostrata* and *C. nebrascensis* are valuable forage plants if cut early [24], [40]. Crude protein percentages of *C. atherodes* decline throughout the season from 18.7 % in May to 14.4 % in June to 7.5 % in September [24]. According to another report, the sedge fen vegetation is less attractive for cattle due to high levels of fibres, tannins, and a low nutrient content [9].

Fuel: The winter harvest can be used as a bioenergy-crop for direct combustion (also in condensed form of pellets and briquettes) [4]. Calorific value from sedge biomass from polish river valleys is 18.7 MJ per kg. Pellets from sedges hold 18.2 MJ per kg [4]; after Dahms et al. the range is between 17.6 and 17.9 MJ per kg with an ash content of 5 % (more information, cf. [47]). The biomass harvested in summer could be used for biogas production, preferably when it is used as bedding material beforehand [48].

Raw material for industry: The roots were formerly used to make rope and the leaves are woven into mats and baskets [36]. The straw and hay can be used for bedding [41], [16]. *Carex* species might be usable for new pathways in the bioeconomy, since they offer multiple utilisation options from bioplastics (HMF), building materials to fibre-based packaging or paper.

Co-benefits: *Carex* species can be used for wastewater treatment in natural and constructed wetlands [40], [42] or efficient wetland buffer zones for nutrient retention [45], [46]. *Carex* biomass harvest has the potential to counteract eutrophication in fens [20]. Several species can be used for erosion control, soil stabilization and wetland restoration [40].

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Pictures: John B.

Chamaecyparis thyoides (L.) Britton, Sterns & Poggenb.

Atlantic white cedar = AWC (Weiße Scheinzypresse)

Family: Cupressaceae
Life form: tree
Main use category: raw material, energy
Used part: wood

General information

Morphology: Perennial, up to 20(-28) m. Trunk to 0.8(-1.5) m in diameter. Bark dark brownish red, irregularly furrowed and ridged. Branchlet sprays fan-shaped. Leaves of branchlets up to 2 mm, apex acute to acuminate. Monoecious. Pollen cones 2-4 mm, dark brown; pollen sacs yellow. Seed cones maturing and opening the first year, 4-9 mm broad, glaucous, bluish purple to reddish brown; scales 5-7. Seeds 1-2 per scale, 2-3 mm, wing narrower than body [1]. Natural reproduction in open stands. Starts bearing seeds after 4 or 5 years, in dense stands after 10-20 years [2]. Potentially peat forming [3].

Geographic distribution: Eastern N. America: Maine, south to Florida and west to Mississippi.

Natural habitat: Grows on cold, swampy often inundated ground, frequently forming dense pure forests or as an overstory dominant in peaty swamps [4]. Atlantic white cedar is an obligate wetland plant in its natural habitat. The best specimens are found in acid peat beds [5]. AWC forests occur on peatlands throughout the Coastal Plain (USA) [6]. Highest elevation found 457 m.

Site specific properties

Water regime: moist-wet
Trophic conditions: mesotrophic
pH: acid-subneutral
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

The primary Atlantic white cedar (AWC) swamp forests in south-eastern USA were extensively used and cut over in the 1800s and 1900s until the mid-2000s [7], [8], [27]. As with many other plentiful resources in the early days of development, the supply of cedar seemed endless. When all cedar that was easy to remove was gone, the operators moved on. Later, the secondary forest was used. But most of the natural area was subsequently drained and transformed for forestry, where fast-growing hardwoods often replaced cedar, and agriculture was implemented, e.g., for cranberry bogs. A paludiculture with AWC is not established in the USA. The wet cultivation is somewhat known from restoration [9].

Propagation and establishment: Under natural conditions the generative establishment from seeds is the dominant mode of reproduction. The natural regeneration of white cedar depends on a source of seed and the factors influencing its presence, germination, and subsequent survival. The main abiotic factors influencing seed germination are moisture, light, and temperature [10]. Seedlings occur on hummocks that rise ca. 30 cm above the water filled hollows [11]. Bare peat or mosses and adequate moisture are usually required for good seedling establishment [4], [12], while flooding and salt water is detrimental [13]. AWC can germinate and grow on more mesic (wet) sites as long as climatic conditions allow early establishment of seedling root systems to greater depths during the first few years. Relatively open conditions are essential for good survival and growth of AWC seedlings [12].

Planting or direct seeding are possible measures to establish AWC forests. The latter shows mixed results [10]. Seeds are known for delayed germination, highly variable viability, and relatively slow production [14]. Plantings can be carried out with seedlings or rooted cuttings. Cuttings are easy to collect (in late autumn), easy to root, and the supply does not depend on variable pollination, seed production, and viability [10]. They can be planted out after 2 years. Seedlings are relatively inexpensive compared to cuttings. There are substantial variations among populations from different provenances [15]. The selection of appropriate geographic sources for white-cedar establishment is therefore important. Cuttings allow for the selection of desirable individuals. Today, commercial production of AWC is mostly conducted through rooted cuttings [14].

Site preparation prior to planting is recommended to reduce competing vegetation. Planting on ridges reduces the risk of inundation. Newly planted AWC individuals are susceptible to high water levels and flooding. Plantings should not be exposed to inundation for more than 3 continuous weeks. Mature stands in contrast are less susceptible to flooding [16], [17].

Management: Because of the shallow root system, AWC trees are susceptible to windthrow [3], [18]. Water levels in natural AWC stands are typically within 10-20 cm below soil surface during the growing season [17]. Long inundation periods during the growing season have a negative effect on survival rates and should be avoided. It tolerates neither inundation nor drought [10].

Information about best management practices of cedar wetlands is available [14]. Stands should be managed in even-aged tracts carried out by clear cutting in patches or strips, because AWC requires relatively open conditions for adequate establishment [14], [3]. The size of the harvested patches depends on the swamp size, existing vegetation, and adjacent stand composition [14]. Successful regeneration of an existing stand is influenced by several factors: the size, shape, and orientation of the cut; size, shape, age, condition, and species composition of the previous stand; hydrology of the site; adjacent forest type and the prevalent white-tailed deer population [14].

Thinning can lead to several problems which often discourage its use, because thinning can promote both cedar windthrow and the development of competing underbrush and hardwoods [3]. But there are also successful and encouraging experiences with thinning [14] to promote rapid growth and the quality of the wood. A commercial thinning of the smallest individuals is recommended.

Harvest: AWC reaches merchantable age in 50-70 years [3]. A rotation of 40-50 years is recommended to produce cordwood, and 60-

80 years for sawtimber [19]. It is suggested that with a comparatively high water table the wood increment will be slower, but the so-called "tight grain" wood thus produced is also desired [20].
The low carrying capacity of the wet peat soil makes the wood harvest difficult. Harvesting should be done with adapted machinery, cable way technique, helicopters or on frozen ground to minimize peat disturbance and its possible harmful effect on water quality. Large-scale harvest, as practiced in North Carolina, New Jersey, and Virginia where the great majority of cedar is cut, is done with a gigantic amphibian feller-buncher, a machine specifically developed for harvesting wetland cedars [3].
Harvesting of the timber from peatlands can create severe forest renewal problems, unacceptable increases in the ground water levels, and competition by fast growing ground vegetation, and these problems are magnified when the final fellings are carried out as large clear cuts [21]. Fences can be necessary to keep deer and browsing animals out. The greatest natural reproduction was achieved in North Carolina when cutting was done on frozen ground [3]. Dense logging slashs left after lumbering can reduce cedar seedling establishment [3].

Productivity: AWC is a long-lived tree in the wild with specimens more than 1,000 years old [5]. It is slow growing in cultivation [22]. Under favourable conditions AWC grows 0.3-0.5 m in height and 0.25-0.40 cm in d.b.h. each year until trees are 40-50 years old [2]. After 50 years, height growth slows, while diameter growth continues at about the same rate for an additional 50 years. Height growth essentially ceases at 100 years [2]. According to yield tables, basal areas may reach more than 69 m^2/ha. References and yield tables for different site indices are available [12], [14].

Cultivation experiences: Known from the USA [9]. There has been much recent interest in restoring white cedar swamps along the Atlantic coast [10]. There are major restoration efforts in numerous areas in the USA, e.g., in New Jersey, North Carolina, Virginia.

Utilisation

Medicine: A decoction of the leaves has been used as herbal steam for treating headaches and backaches [23]. A poultice made from the crushed leaves and bark has been applied to the head to treat headaches [22].
Ornament: Plants can be grown as a tall hedge [21]. They are very tolerant of clipping as long as this does not extend into the brown barked wood, since trees cannot regenerate from it [22].

Fuel: Wood can be used as fuel.

Raw material for industry: The wood is soft, not strong, close-grained, very durable, easily worked, light, slightly fragrant with a weight of 336 kg/m^3. Wood found buried in swamps for hundreds of years is perfectly sound and not water-logged [24]. The most important use is for lumber [8]. Further common uses include: woodenware, cooperage, fence posts, interior finish of houses, boat building, molding, shingles etc. [8], [25].

Co-benefits: AWC is used for restoration of wetlands and for recreating cedar swamps.

Further reading: [3], [8], [10], [12], [14], [20], [26]

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Cladium mariscus (L.) Pohl

sawgrass, great fen sedge (Schneide)

Family: Cyperaceae
Life form: graminoid
Main use category: raw material, energy
Used part: leaves

Pictures: Kristian Peters

General information

Morphology: Perennial. Height 1.2-2.5 m. Rhizome creeping or stoloniferous, sturdy. Stem 6 mm in diameter, hollow, smooth, grey green. Leaves up to 2 m long, 5-9 mm wide, flat or folded, evergreen, grey-green, arranged spirally along whole stem length, persistent; with sharp leave margins. Hermaphrodite (mostly). Inflorescence a terminal panicle (30-70 x 5-12 cm) of 1- to 3-flowered spikelets (3-4 mm) in dense clusters. Species forming large pure evergreen stands [1], [2]. Peat forming [3].

Geographic distribution: South, central, and northern parts of Europe (throughout Europe south of lat. 60°); E. Asia (Orient) [3]. Cannot withstand mean temperatures below -10° C.

Habitat: Shallow-water zones in lakes, ponds and alkaline fens that may adjoin these or develop from them [4]. When it occurs in oligotrophic bog-communities, it indicates the position of former open water [3].

Site specific properties

Water regime: wet-flooded
Trophic conditions: meso-eutrophic
pH: subneutral-alkaline
Light conditions: shade intolerant
Salinity: no (to low) tolerance

Cultivation

Paludiculture is known from traditional utilisation for thatching in the UK and southern Sweden (Gotland). In Poland, calcareous fens with *C. mariscus* are mown as a nature conservation practice. The biomass is used as a fuel. As *C. mariscus* stands are rare and threatened, paludiculture with it should be treated carefully.

Propagation and establishment: After rewetting of a peatland, *C. mariscus* can spread out spontaneously from remnants in the ditches and viable diaspora in the peat. It has been noted that an area after peat extraction often spontaneously produced a profitable crop of sedge soon afterwards, depending on the local available diaspora [4], [17]. The knowledge of artificial establishment is rare and most likely difficult because it is not easy to make seeds germinate [3]. Establishment from seed is probably only successful on bare soil or open water as it is severely inhibited by the presence of a canopy of vegetation [4]. A restoration project in southern Germany observed delayed germination of *C. mariscus* after topsoil removal and spreading hay from donor fen meadows [5]. The seeds have a strong dormancy. Even after stratification and fluctuating temperatures germination failed in a germination trial [5]. *Cladium mariscus* produces sometimes unviable seeds, which, however, appear viable from the outside [5]. The production of fruits appears to depend on a high summer water table, which also facilitates the distribution of the floating nuts by water [4]. Fruits are matured and shed from September to December [3].
Artificial vegetative propagation by clumps seems also promising but is expensive and laborious.

Management: Depending on the type of peatland, a *Cladium*-swamp can be a well-defined phase of succession to either woodland or acid bog; regular mowing of the sedge can prevent succession to woodland by curbing the establishment and growth of woody species [4]. As a natural crop, sawgrass traditionally receives no management other than harvesting by cutting. Today, however, some control may be exercised over the water table [4]. For an adequate production the water table should range between +40 cm above and -15 cm below surface [4]. A depth of more than 40 cm of water above the soil level is unfavourable [3]. Sawsedge photosynthesis is optimal in waterlogged conditions [16].
Mowing should be allowed only at locations with low water level (max up to 10 cm above surface) [Jarosław Krogulec, pers. comm.]. A study about the impact of tracked mowers on a fen ecosystem in a *C. mariscus*-dominated fen indicated a slow shift to semi-aquatic communities, due to compaction of the sward and the upper peat layer induced by considerable soil damage caused by the mowing machine [6].

Harvesting: For thatching, the *C. mariscus* stand is cut every four years in mid to late summer [7]. More frequent cutting reduces its length and suitability for ridging and the plant vigour will be reduced too, which would finally lead to its dieback [3]. After the 'Chelm Calcareous Marshes SPA Natura 2000 Management Plan' a rotation of 5 years is recommended [Jarosław Krogulec, pers. comm.]. So, only 20 % of an area can be mown every year. From the conservation perspective it is best to harvest as late as possible. Therefore, a harvest in autumn is recommended.
For thatching: the modern 'standard bunch' measures 71 cm in circumference at the band when the sedge is first cut; the measurement decreases as the material dries. Modern thatchers prefer to use partially green sedge of about 105 cm in length [4]. Adapted machinery from reed harvesting is available.

Productivity: Even under optimal conditions *C. mariscus* is a rather slow growing species, but its leaves have an active meristem for approx. two years (evergreen species) and the standing crop is therefore a result of more than one season's growth [8]. Total standing crop (aboveground biomass) varies in an unmanaged stand from 27 to 49 t/ha and in the managed stand from 9 to 19 t/ha (air-dried weight) [8]. Low productivities of 1-1.9 t/ha were obtained in calcareous fens dominated by *C. mariscus* in Poland [9].

Productivity research of herbaceous rich fen vegetation of lowland England and Wales showed high total standing crop mass with stands dominated by *C. mariscus* yielded 9 t/ha, but a lower standing crop increment of 6 t/ha (air-dried weight) was also observed [10]. This reflects the winter-green, long-lived character of *C. mariscus*. Aboveground biomass ranged from 22 to 47 t DM/ha in an unmanaged floodplain wetland in central Spain [11].

Cultivation experiences: Known from restoration projects [5].

Utilisation

Human food: The young shoots may be edible [12].

Energy: Sawgrass has a good potential to be used for bioenergy production (similar to sedges). It was used as a fuel in the UK in the last centuries [4]. In Poland, *C. mariscus* biomass from conservation measures was shredded and used for direct combustion or used as a pellets substrate [9].
The high water content can be problematic. Extra drying and/or higher straw admixture can be necessary.

Raw material for industry: The stems are still used for thatching the ridges of the roof in Norfolk, UK and the roofs in Gotland, Sweden [13], [7]. As a ridging material, sedge is much more flexible than reed, and more durable [5]. The roots have been used to make small baskets [14].

Co-benefits: As to aspects of biodiversity, the species richness is higher in managed stands than in unmanaged *C. mariscus* stands [8].

Further reading: [3], [4], [8]

Similar species:
Cladium mariscus subsp. *californicum* (S.Watson) Govaerts (Syn: *Cladium californicum*), California sawgrass:
Grows naturally in western N. America in alkaline marshes, swamps, springs [15]. The leaves have similar capabilities as *C. mariscus*.

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Cyperus esculentus L.

chufa, earth almond, tiger nut
(Erdmandel)

Family: Cyperaceae
Life form: graminoid
Main use category: food
Used part: tuber

Picture: Blahedo

General information

Morphology: Perennial. Height: 5-60(-90) cm. Culms solitary, trigonous, glabrous. Leaves 3-7, flat to V-shaped, 20-40 cm × 2-4 mm. Hermaphrodite. Inflorescence a simple or compound umbel. Fruit: achenes (seldom maturing), brown, sessile, ellipsoid. Stoloniferous or rhizomatous growth; stolons soft, spongy, bearing tubers. The cultivated plant is *Cyperus esculentus* var. *sativus* with larger, more elongate tubers marked with conspicuous bands, and seldom with flowers [1], [2], [3].

Geographic distribution: Original range is probably the eastern Mediterranean [4]; the plant is now widespread from the tropics to the temperate zone and boreal zone [5].

Natural habitat: Muddy soil and shallow water, also as a weed of cultivated ground in southern and central Europe [1]. It grows on low, frequently flooded ground, moist fields, the margins of riverbanks, ponds, and lakes, bogs, marshes, swamps, in irrigated and dryland crop fields, gardens, pastures, turfgrass, ornamental landscapes, along roadsides and in ditches [4].

Site specific properties

Water regime: moist-wet
Trophic conditions: eutrophic
pH: acid-subneutral
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

Cyperus esculentus is widely cultivated as a food crop for its edible tubers, e.g., in Nigeria, Ghana, Togo and the Spanish Mediterranean region [7]. Because the plant's mechanical cultivation has not been refined, chufa is little used as a food plant in most developed

countries. Paludiculture is unknown but seems promising because the plant grows naturally in wetlands [4]. Since the harvest of the underground organs will disturb the peat soil, it is unknown if a paludiculture with chufa can be peat conserving in spite of a high water table. Nevertheless, constant high water tables will reduce high CO_2 emissions compared with drained peatlands.
This plant can be weedy or invasive [8]. It causes yield reductions and can hardly be eradicated [9]. The cultivated variety *Cyperus esculentus* var. *sativus*, known as chufa, has a less aggressive growth habit and tubers with higher oil and starch content. It rarely flowers and is not frost tolerant [10].

Propagation and establishment: The plant is naturally reproduced by seeds, creeping rhizomes, stolons, and tubers. Chufa is planted in late spring to midsummer by dropping the dried tubers 15-30 cm apart in rows spaced 60-90 cm apart [11]. Planting rate is 20-45 kg/ha. The tuber develops into a plant with several tubers bunched together directly beneath the plant and a few stragglers some distance away. Although bunched together, each tuber is attached to a thin underground stem (rhizome) that connects the single tuber to the growing shoot. The plants mature within 100-125 days, and the tubers mature approximately 110-120 days post-emergence [12]. Commercial chufa varieties cannot successfully overwinter in most central and northern states (USA) and require replanting. Tubers survive soil temperatures as cold as -5°C and require a period of chilling to break dormancy and germinate. Tubers germinate when soil temperatures remain above 6°C. Under field conditions, tubers typically survive approximately 3-4 years [13]. The plant dries during September/October and is ready for being harvested in November/December.

Management: It is a species with a considerable nutritional demand, the NPK demand is approximately 240-35-300 kg/ha respectively [7]. A fertilization study showed that fertilization of N in the range of 250-400 kg/ha had no effect on tuber production, and higher amounts (520-780 kg/ha) led to a reduction in production [7]. In soils with an average fertility, fertilization is not necessary and can even be counterproductive.
One study [14] found that tuber sprouting was greatly reduced when the soil was compacted and that plants grown at 100 % moisture produced significantly more tubers and vegetative material than those grown at 50 % moisture [15]. Tubers planted in peat produced the most shoots per tuber [16].
Prolonged flooding during the late summer to early fall impacted the growth and survival of the plants [17].

Harvest: Harvest usually occurs in November or December and the leaves are scorched during the harvest. With a combine harvester, the tubers are pulled out of the ground. Then they are washed immediately and dried for 3 months. Within this process the tubers have to be turned every day to ensure uniform drying.
The present lack of a mechanical harvesting technology may limit the potential of developing markets.
If used for wildlife or livestock feed, the tubers usually are not harvested and are left in the ground for animal forage.

Productivity: Tuber yield differs between cultivars and different site conditions, like substrate and fertilization. The range is between 10 and 20 t/ha [7]. The tubers weigh about 44 pounds per bushel with oil yields of 0.5-1.5 t/ha [12].

Cultivation experiences: Spain [18], Nigeria, Ghana, Togo [7]. Unknown if plantations on peat soil exist.

Utilisation

Human food: Tubers are used raw, cooked or dried and soaked in water or ground into a powder (= horchata) [19], [20], [21], [22], [23], [24], [25]. They are also used in confectionery [25]. A delicious nut-like flavour is obtained [25], [26], [27] which is, however, rather chewy and has a tough skin [5]. They taste best when dried [28]. They can also be cooked in barley water to give them a sweet flavour and then be used as a dessert nut [25]. A refreshing beverage is made by mixing the ground tubers with water, cinnamon, sugar, vanilla, and ice [25]. The ground up tuber can also be made into plant milk with water, wheat, and sugar (aqua de horchata) [25]. Edible oil is obtained from the tuber. It is considered to be superior oil that compares favourably with olive oil [25]. It is a potential supplement to, or substitute for, olive oil given its fatty acid composition and other physico-chemical properties [7]. The roasted tubers provide a substitute for coffee [19], [22], [25]. In addition, the base of the plant can be used in salads [25].

Medicine: Tiger nuts are regarded as a digestive tonic, having a heating and drying effect on the digestive system and alleviating flatulence [29]. They also promote urine production and menstruation [29].
The tubers are said to be aphrodisiac, carminative, diuretic, emmenagogue, stimulant and tonic [29], [30]. In Ayurvedic medicine they are used in the treatment of flatulence, indigestion, colic, diarrhoea, dysentery, debility, and excessive thirst [29].

Animal fodder: It is sometimes grown as hog pasture, livestock feed and a winter food source for wild turkeys and waterfowl. It is said that this fodder leads to especially tasty pork [12]. In the U.S. the primary use of chufa as a crop is to attract and feed game, particularly wild turkeys, since they love chufa tubers [13]. The residues of chufa production can also be used as fodder [31]. Leaves are a meagre forager due to the high fibre content [32].

Fuel: The oil of the tubers has physical properties similar to other vegetable oils. It is suggested that this oil may also be used as biodiesel fuel [7].

Raw material for industry: The tubers contain up to 30 % of a non-drying oil which is used in cooking and in making soap [33], [34], [35], [36]. It does not solidify at 0°C and stores well without going rancid [34].
The leaves can be used for weaving hats and matting etc. [37].

Co-benefits: The plant can be used in constructed wetlands for phytoremediation of wastewater (especially of Cd, Cr, Cu, Mn, Fe, Ni, Pb and Zn) [38].

Further reading: [6], [17], [18], [39]

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Drosera rotundifolia L.

Round-leaved sundew (Sonnentau)

Family: Droseraceae
Life form: forb/herb
Main use category: medicine, ornamental, food
Used part: leave, stem, flower

Pictures: DymphieH; Detail: Kristian Peters

General information

Morphology: Perennial. Height small. Leaves are all basal, inclined or almost erect; upper surface of lamina covered with long, red, motile hairs, which entrap and digest insects. Leaves usually spreading horizontally, sometimes semi-erect. Lamina 5-8 mm. Hermaphrodite. Inflorescence scape slender, bearing a few-flowered ebracteate cyme. 6-10 flowers. Petals white, persistent, 5 mm. Fruit capsule smooth, testa reticulate. Plants solitary, insectivorous [1].

Geographic distribution: Europe (excluding the Mediterranean), N. Asia, N. America [2], [3].

Habitat: Wet and moist places in poor peaty soils, in *Sphagnum* bogs on hummocks [3].

Site specific properties

Water regime: moist-wet
Trophic conditions: oligotrophic
pH: acid-subneutral
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Today the commercial need of sundew biomass for pharmaceutical industry is satisfied by the collection of natural populations, mainly in Finland. Until now only few cultivation trials with *Drosera* have been conducted. Promising cultivation trials were reached in Finland in artificial peat beds filled with 40 cm non-fertilized peat [4]. In Germany, *Drosera* spp. are cultivated experimentally alongside sphagnum [3], [5]. Thus, *Drosera* cultivation could be a possibility for rewetted peatlands after peat extraction or in combination with *Sphagnum* farming. There *D. rotundifolia* appears to be a weed that could be used as a co-benefit.

Propagation and establishment: *Drosera rotundifolia* can be propagated vegetatively by plant division, and in larger scale generatively via seeds. The seeds can be sown on the surface of the moist peat. It requires stratification for 2 months at 1-5°C in moist conditions [6]. Afterwards the seed usually germinates in 1-2 months at 20°C [7]. The plants should be grown up in the pots for their first growing season, making sure that the soil does not become dry. The initial growth is very

slow [4]. Direct autumn sowing is probably also possible and simpler and less laborious than transplantation of seedlings [4]. Up to now, there are no experiences with direct sowing. Long term sowing experiments should be carried out with different seed quantities.
A critical factor is the sufficiently high number of seeds that is necessary for direct sowing. The artificial peat bed experiment in Finland was established with 0.2-0.3 g seeds/m² (with an average 1,000 seed weight of 0.02 [6] = 10,000 to 15,000 seeds) that were sown equally mixed with sand in a ratio of 1:10. For establishing a larger area, significant quantities of seeds are necessary. Currently there are no seeds commercially available, so they have to be collected from natural populations.
A wet (not flooded) weed free peat soil is definitely necessary for the first 2 years of establishment.
Vegetative propagation: the plants are divided in autumn, grown up in the greenhouse for the first winter and planted out into their permanent positions in late spring [2].

Management: Permanent moist-wet conditions are substantial. It is probably necessary to weed the cultivated field and to avoid shading [4]. On natural peatlands, the average plant number is 20-55/m², the plant density in cultivated peat beds is about 45 times higher, ranging from 920 to 2,710 plants/m² [4], [7]. Greenhouse experiments were carried out with different N-containing feeding preparations used for aquarium fishes. Some of them effected the growth of *Drosera* highly, but they seem to be too costly [B. Galambosi, pers. comm.]. Feeding with cheap milk powder can increase the plant growth significantly [8].

Harvest: The plants are harvested by hand in midsummer when the plant is flowering [11]. During the first year the plant develops a leaf rosette. In the second or third year, the flower is developed, and the plant can be harvested. The plant size is very variable and strongly affected by the local growing conditions (shadow, water) [4].

Productivity: Fresh yield in an experimental cultivation in plastic houses with high plant density varied between 1.1-1.4 kg/m² and 0.6-0.9 kg/m² in the second and third growing year [3]. The fresh yields in the outdoor peat beds cultivation in Finland (total area 50 m²) were picked regularly. During the 6-year experimental period the fresh yields in the 3rd, 4th, 5th, and 6th years were: 75 g/m², 489 g/m², 212 g/m², and 69 g/m², respectively, yielding in total 836 g/m² in 4 years [3], [12]. Due to the high plant density in the artificial peat bed cultivation, the flowering plants could be harvested during the 3rd and 6th year, but the regular picking decreased the number of harvestable flowering plants over the years. The average fresh yield from natural peatlands is only 6.7 g/m² [3]. Highest concentration of plumbagin were detected in the roots, with maximum concentrations usually reached in September or October, and remaining relatively high even in early Winter [13] (see also [14]).

Cultivation experiences: Cultivation experiments were carried out in southern Finland [3], [4], [7] and in N Germany on *Sphagnum* farming fields [3], [5].

Utilisation

Medicine: Sundew has a long history of herbal use, having been popular for its fortifying and aphrodisiac effects [15], [16]. It relaxes the muscles of the respiratory tract, easing breathing and relieving wheezing and is thus of great value in the treatment of various respiratory complaints [9]. The flowering plant is antibacterial, antibiotic, antispasmodic,

antitussive, demulcent, expectorant and hypoglycaemic [17], [18], [19], [20], [21], [22], [23], [24], [25], [26].
Sundew as *Droserae herba* was administered formerly to remedy respiratory diseases such as regular coughs and pertussis [27], [28], [29]. Nowadays, extracts of it are still used against convulsive and whooping cough [17], [30]. In Russia, medicaments of *Drosera* spp. are applied to treat pertussis, laryngitis, tracheobronchitis, and bronchial asthma [31]. Water decoctions of *D. rotundifolia* shall moreover be effective against colds, warts, and nervous diseases [32]. Amerindians of Vancouver Island, N. America, make use of *D. rotundifolia* for the treatment of warts, corns, and bunions [33], [34]. Generally, sundew can be used internally as a diuretic, spasmolytic, remedy for arteriosclerosis and ailments of the liver [35], while externally the sap can counteract warts and freckles [16], [35] or other skin issues [36]. Furthermore, the plant is used in the treatment of incipient phthisis and chronic bronchitis [17]. It is harvested in the summer and can be dried for later use [18]. However, one should use it with caution [21]. Internal use of this herb causes a harmless colouring of the urine [19]. An extract of the plant contains plumbagin, which is antibiotic against a wide range of pathogens [25], [15]. Because of their protein digesting enzymes, the leaf juice has been used in the treatment of warts and corns [17], [25].
The entire fresh plant, harvested when it is starting to flower, is used to make a homeopathic remedy [37]. It is used mainly in the treatment of coughs [37] and is specific for whooping cough [18].

Ornamental: The living plant is traded commercially for decorative purposes.

Human Food: The juice of the plant is used to curdle milk [38], [39]. Milk and leaves are heated together in order to make the milk curdle [18].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Kristian Peters

Echinochloa crus-galli (L.) P.Beauv.

Cockspur, barnyard millet (Hühnerhirse)

Family: Poaceae
Life form: graminoid
Main use category: fodder
Used part: aboveground biomass, seeds

General information

Morphology: Annual. 30-100 cm high. Culm caespitose. Leaf blade linear, 10-40 cm x 2-15 mm; sheath slightly keeled; ligule absent. Hermaphrodite. Panicle 10-20 cm long, axis often papillose-hisped, racemes 2-7 cm long [1]. It is a very variable species having many forms [2]. C4 metabolism.

Geographic distribution: *Echinochloa crus-galli* is widespread throughout the tropics, e.g., Africa, S. Asia, and SE. Asia - India, Burma, Thailand, Indo-China, Malaysia, and Australia. It extends to the subtropics and some warm temperate regions such as Italy [3].

Natural habitat: Freshwater swamps [4]. *Echinochloa crus-galli* is adapted to wet places and waterlogged land and grows very vigorously in hot wet conditions from sea-level to 2,500 m altitude [3].

Site specific properties
Water regime: moist-wet-flooded
Trophic conditions: eutrophic
pH: acid-alkaline
Light conditions: shade intolerant
Salinity: medium tolerance [5]

Cultivation

The ecological amplitude of the plant suggests that cultivation in wet peatlands could be possible. The high palatability makes it a good candidate for forage production. Since it is an annual plant, it is not certain if the annual yield profits can cover the establishment cost. It is the world's worst weed in paddy rice cultivation [4]. The success of *E. crus-galli* as a weed is attributed to rapid development to reproductive maturity, high phenotypic plasticity, production of large numbers of small easily dispersed seeds and seed dormancy [2], [6]. These characteristics could be beneficial for paludiculture.

Propagation and establishment: Propagation is via seeds. In India it is best sown from February to April. Optimum temperature for germination is 35°C, with maximum of 40°C, and minimum of 5-10°C [7]. Some forms of *E. crus-galli* can germinate under water but most cannot. Emergence and growth are increasingly suppressed by increased depth of submergence. The water level should be close to the surface during the establishment phase. When the water depth reaches 15 cm, *E. crus-galli* stops growing and most of the plant dies [8].

It is self-pollinating and a prolific seed producer. A healthy plant can produce from 750,000 to one million seeds. The seed is water dispersed and the viability is variable [8]. Solitary plants may develop up to 80 shoots. The seed matures from August to October [7].

Management: Generally, seed yields from barnyard grass stands are reduced in 2-3 years because of competition with other weeds [9]. Alternate moisture regime favours the growth of the plant.

Harvest: When it is used for fodder, the grass is ready for cutting 1.5-3 months after growth has started [7].

Productivity: The production of green material may be up to 4-11 t DM/ha [10]. According to the phytomass files, annual productivity of *E. crus-galli* is 10 t/ha [7]. Yields of 3.9-11 t/ha were obtained from a rice field [4].

Cultivation experiences: Barnyard grass is extensively cultivated in Japan, Korea, and northern China [11].

Utilisation

Human food: In times of scarcity the grain is eaten by people [3]. Young leaves can be eaten as vegetables [10].

Medicine: It can be used to treat carbuncle, hemorrhage, sore, spleen, and splenitis [12].

Animal fodder: Barnyard millet is used as fodder. It is a palatable and succulent feed which produces copious quantities of seed [3], [4]. Barnyard grass produces fair pasture when grazed during early growth stages but becomes harsh and unpalatable at maturity [13]. It is palatable to sheep in Minnesota [14].

Fuel: It is a highly productive species, making it a possible candidate as a bioenergy crop.

Co-benefits: In Egypt, the grass is used for reclaiming saline areas [10].

Further reading: [4]

Similar species:

Echinochloa crus-galli subsp. *utilis* (Ohwi & Yabuno) T. Koyama:

Japanese millet is cultivated in warm-temperate regions of Asia and Africa; introduced in America, both for grain and forage production [15]. It can be grown throughout the United States, and its range extends from Canada to northern Mexico [16]. *Echinochloa crus-galli* subsp. *utilis* is thought to be a cultivated derivative of *E. crus-galli* that arose in China, Japan, and Korea [15]. It grows along rivers and ponds, is abundant in freshwater marshes, and can be a weed in rice fields. Japanese millet can grow in flooded soils and standing water as long as a portion of the plant remains above the water’s surface [16].

Echinochloa frumentacea Link:

White panicum or billion dollar grass occurs widely in the tropics. It is cultivated in tropical Asia, Africa, Australia, and the western United

States and Canada as a fodder grass and cereal. This annual plant is widely adapted also to the temperate zone as it matures in 60-90 days. It grows well in wet soils but will also grow on well-drained upland soils [16]. It is sown in spring to late summer, depending on frost incidence, at 8 kg/ha drilled seeds and 10 kg/ha broadcasted. Yields of up to 35 t/ha of green material can be obtained [4].

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Picture: Kristian Peters

Eupatorium cannabinum L.

hemp-agrimony (Wasserdost)

Family: Asteraceae
Life form: forb/herb
Main use category: medicine
Used part: leaves, roots

General information

Morphology: Perennial. Height 30-175 cm. Stem erect. Most leaves palmately 3- to 5-fingered lobes, lanceolate to ovate, acuminate, coarsely serrate. Hermaphrodite. Flower capitula 2-5 mm in diameter, in terminal corymbs or panicles. Involucre cylindrical to campanulate. All florets tubular, white, pink, or purplish. Achenes ca. 3 mm, black; pappus-hairs in 1 row, numerous [1].

Geographic distribution: Most of Europe, to N. Africa, W. and C. Asia [2].

Natural habitat: By streams, in low damp sites and in woods, avoiding acid soils [3], [4].

Site specific properties
Water regime: moist-wet
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: intermediate shade tolerant
Salinity: medium tolerance

Cultivation

Paludiculture is unknown, but the ecological amplitude of the plant suggests that a wet cultivation is possible. It is unknown if the demand is sufficient for an economically beneficiary cultivation.

Propagation and establishment: Vegetatively or generatively. Via seeds: sow in spring in a cold frame and cover only the seed. Prick out the seedlings into individual pots when they are large enough to handle and plant them out into their permanent positions in the summer. If sufficient seed is available, it can be sown outdoors in situ [2]. Vegetative propagation via division is best in spring or autumn [5]. The clumps can be replanted directly into their permanent positions [2].

Management: No information found.

Harvest: The plant (aboveground parts) is harvested in the summer and dried for later use [3]. Roots are harvested in autumn and dried for later use [6].

Productivity: No information found.

Cultivation experiences: No information found, probably harvested from the wild. Cultivation known from gardening.

Utilisation

Medicine: Hemp agrimony has been employed chiefly as a detoxifying herb for fevers, colds, flu, and other viral conditions. It also stimulates the removal of waste products via the kidneys [7]. Due to its content of alkaloids, the plant should only be used under professional supervision [7].
The leaves and flowering tops are alterative, cholagogue, depurative, diuretic, emetic, expectorant, febrifuge, purgative, and tonic [3], [6], [8], [9], [10], [11]. The plant has a long history of use as a gentle laxative that does not provoke irritation [3], albeit excessive doses cause purging and vomiting [6]. A tea made from the dried leaves will give prompt relief if taken at the onset of influenza [8]. Recent research has shown that the plant might have anti-tumour activity, though the plant also contains pyrrolizidine alkaloids that can cause damage or cancer to the liver [6]. The roots are diaphoretic, laxative and tonic [3].
Recently the plant has been found to be of use as an immune system stimulant, helping to maintain resistance to acute viral and other infections [7]. In addition, a homeopathic remedy is made from the leaves [8]. It is used in the treatment of influenza and feverish chills [8], also for disorders of the liver, spleen, and gall bladder [9].

Ornament: Used as an ornamental plant. There are several cultivated forms available [12].

Raw material for industry: No information found.

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Picture: Christian Fischer

Filipendula ulmaria (L.) Maxim.

meadowsweet (Mädesüß)

Family: Rosaceae
Life form: forb/herb
Main use category: medicine, food
Used part: leaves, flowers, roots

General information

Morphology: Perennial. Height 80-100(-180) cm. Deep roots and scaly horizontal rhizome. Stems sulcate, glabrous. Stipules green, semicordate or ovate-lanceolate, herbaceous, margin sharply serrate; petiole glabrous; leaf blade pinnate, with 2-5 pairs of leaflets, abaxially white tomentose, adaxially glabrous; margin doubly serrate. Hermaphrodite. Inflorescence terminal, paniculate. Flowers ca. 5 mm in diameter. Sepals ovate, densely pubescent abaxially. Petals white, obovate. Flowering and fruiting June to September. Achenes attached to receptacle adaxially near base, subsessile, spirally contorted and appearing united [1], [2].

Geographic distribution: Europe, from Iceland south and east to Spain, temperate Asia, and Mongolia [3]. Introduced to western N. America.

Natural habitat: Wet ground in swamps, marshes, fens, wet woods and meadows, wet rock ledges and close to rivers and lakes, not on acid peats [4].

Site specific properties

Water regime: moist soil
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Paludiculture with *Filipendula ulmaria* is unknown, but the ecological amplitude suggests that a moist or wet cultivation is possible. Cultivation instructions are rare and only available from cultivation on mineral soil. Information on propagation and establishment are probably transferable to paludiculture, but a peat conserving paludiculture with constant high water tables is probably not tolerated. Furthermore, the harvest of the valuable roots could harm the peat soil and probably lead to further degradation, similar to the necessity of the new installation of the field after root harvest. A peat conserving paludiculture with *F. ulmaria* would exclude the harvest of belowground biomass. The cultivation is recommended in eu- or polytrophic rewetted fen peatlands.

Propagation and establishment: *Filipendula ulmaria* can be propagated via seeds or vegetatively via division. The seeds can be sown in autumn or spring in a cold frame or directly in the field in early spring [2], [5]; germination is best at a temperature of 10-13°C [6]. Seedlings should be planted in the field in May [2]. The plant divisions for a vegetative propagation should be taken in autumn or winter [6]. Larger rhizome divisions can be planted directly into the field in autumn or spring with a row spacing of 30 cm [2]. Soil preparation is necessary to reduce competition losses.

Management: The plant is probably resistant to temporary floods, but permanent flooded conditions are not tolerated. A four-year cultivation period is assumed [2].

Harvest: Currently the plant material for drug use comes exclusively from wild collections of natural stands in south-eastern Europe [2]. The plant should be harvested in July to August when it is in flower. The flowering stalks should be cut 20 cm below the inflorescence and should be dried for later use [2]. The plant is sensitive to cutting and should be harvested only once per year to sustain the stand [2].
Tray drying at low temperatures may reduce drying time without having a significant effect on the phenolic content and colour of the extracts (for incorporation into functional beverages with potential anti-inflammatory properties) [7].
The rhizome can be harvested in September/October [2].

Productivity: No information available.

Cultivation experiences: Successful cultivation trials in a rewetted fen in NE Germany [8]. Unknown if other cultivation fields with meadowsweet exist.

Utilisation

Human food: The root is edible when cooked [9], [10]. Young leaves are used as a flavouring in soups [11], while dried leaves serve also as a flavouring [13], [14], especially as a sweetener in herb teas [12], [15]. Young leaves, flowers, and roots are brewed into a tea [12]. The flowers are used as a flavouring in various alcoholic beverages and in stewed fruits [12]. Adding them to wine or beer is said to make a very heady brew [16]. They are also made into syrup which can be used in cooling drinks and fruit salads [12].

Medicine: Meadowsweet has a very long history of herbal use [2], [3]. The leaves and flowering stems are alterative, anti-inflammatory, antiseptic, aromatic, astringent, diaphoretic, diuretic, stomachic and tonic [17], [18], [19], [20]. The flower head contains salicylic acid [6], [21]. Unlike the extracted aspirin from the salicylic acid, which can cause gastric ulceration at high doses, the combination of constituents in meadowsweet act to protect the inner lining of the stomach and intestines whilst still providing the anti-inflammatory benefits of aspirin [22]. The herb is a valuable medicine in the treatment of diarrhoea [17]. It is also considered to be a useful stomachic, being used to treat hyperacidity, heartburn, gastritis, and peptic ulcers for which it is one of the most effective plant remedies [17], [21]. It is also frequently used in the treatment of afflictions of the blood [17]. Meadowsweet is also effective against organisms causing diphtheria, dysentery, and pneumonia [21]. Meadowsweet remedies should not be given to people who are hypersensitive to aspirin [21]. A strong decoction of the boiled root is said to be effective in the external treatment of sores and ulcers [16]. A homeopathic remedy is used against joint rheumatism and gastritis [2].

Ornament: The plant is used as an ornamental plant [23]. An essential oil obtained from the flower buds is used in perfumery [24], [25]. The whole plant, but especially the leaves [26], was formerly used as a strewing herb, imparting an almond-like fragrance [17], [27]. Strongly aromatic, its delightful perfume would completely fill the room [16]. Both flowers and leaves have been used in pot-pourri, retaining their scent for several months [26].

Raw material for industry: A black dye is obtained from the roots [10], while a yellow dye is obtained from the plant tops [28].

Further reading: [2], [8]

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Frank Vincentz

Frangula alnus Mill.

alder buckthorn (Faulbaum)

Family: Rhamnaceae
Life form: shrub
Main use category: medicine, raw material, ornamental
Used part: bark, wood

General information

Morphology: Perennial. Height: 3-6 m. Usually multi-stemmed, rarely a small tree with trunk diameter of up to 20 cm. Leaves deciduous; arranged alternately, ovate, 3-7 x 2.5-4 cm. Hermaphrodite. Flower 3-5 mm in diameter, star-shaped with five greenish-white acute triangular petals in clusters of 2-10 in leaf axils. Flowering May to June. Fruit small black berry 6-10 mm in diameter, dark purple or black in early autumn, containing 2-3 pale brown 5 mm seeds. Bark is blackish-brown, with bright yellow inner bark exposed if cut [1].

Geographic distribution: Native to Europe, from Scandinavia south and east to N. Africa, and central Asia - the Urals and Siberia. Introduced to N. America [2], [3].

Natural habitat: Bogs, fens, marshes, and other damp places, usually on moist heaths and damp open woods, preferring a peaty soil [4], [5], [6]. Occurs in calcareous wetlands [3].

Site specific properties

Water regime: moist-wet
Trophic conditions: meso-eutrophic
pH: acid-subneutral-alkaline
Light conditions: intermediate shade tolerant
Salinity: medium tolerance [7], after [8] no tolerance

Cultivation

Paludiculture is unknown, but the ecological amplitude of *Frangula alnus* suggests that a wet cultivation is possible since there is no permanent waterlogging or inundation. It is uncertain if peat conservation is possible, so cultivation is recommended for peatlands that are not properly rewettable with moist to wet conditions. Information on propagation and establishment are probably transferable.

In North America, *F. alnus* is an aggressive invader in wetland habitats [9], [10].

Propagation and establishment: *Frangula alnus* can be propagated with seeds or vegetatively with cuttings. The seed can be sown in autumn. Stored seed will require 1-2 months cold stratification at about 5°C and should be sown as early in the year as possible

in a cold frame or outdoor seedbed [11]. Germination is usually good, at least 75-80 % by late spring [2], [12]. Plant them out in late spring or early summer of the following year [2]. If the permanent position is too wet, plant them on ridges to avoid permanent flooding.
Vegetative propagation is possible with cuttings of half-ripe wood, taken in July/August [13]. Cuttings of mature wood of the current year's growth should be taken in autumn.
Frangula alnus rapidly forms dense, even-aged thickets. In an open site, buckthorn establishment is followed by lateral crown spread [14].

Management: Although it is somewhat adapted to wet conditions, the plants will probably not survive permanent waterlogging [12].
Glossy buckthorn grew tallest and most rapidly where depth to the water table was intermediate and water table fluctuations were lowest on a mined peat bog in Delafield, Wisconsin [15].

Harvest: The bark is harvested in early summer from the young trunk and moderately sized branches. It must then be dried and stored for at least 12 months before being used medically [16], [17].

Productivity: *Frangula alnus* has a long growing season, rapid growth rate, and resprouts vigorously following top removal [14]. Plants of 0.7 m in height are capable of growing about 4 m in five years. Mature plants, cut near the base early in the season, can send up sprouts up to 2 m in the same year [18].

Cultivation experiences: Cultivated as a medicinal plant in S. Europe [19]. It was once often grown for its wood which was used in making charcoal [12], [20].

Utilisation

Medicine: *Frangula alnus* has been used medicinally as a gentle laxative since at least the Middle Ages [21]. The bark contains 3-7 % anthraquinones, which act on the wall of the colon stimulating a bowel movement approximately 8-12 hours after ingestion [22]. The treatment is so gentle and effective when prescribed in the correct dosage that it is completely safe for children and pregnant women. Their effect is greatly reduced after the bark has been dried and stored for a long time [22]. The inner bark is cathartic, cholagogue, laxative (the fresh bark is violently purgative), tonic, ermifuge [4], [6], [16], [23], [24]. It is taken internally as a laxative for chronic atonic constipation and is also used to treat abdominal bloating, hepatitis, cirrhosis, jaundice, and liver and gall bladder complaints [17]. It should be used with caution since excess doses or using the bark before it is cured can cause violent purging [4], [6]. Externally, the bark is used to treat gum diseases and scalp infestations [17], or as a lotion for minor skin irritations [21]. The fruit is occasionally used, being aperient without irritating [16]. It is also used in homeopathy.

Ornament: *Frangula alnus* is used as an ornamental plant. Plants can be grown as an informal (untrimmed) hedge, though they are also amenable to trimming [11]. *Frangula alnus* was introduced to N. America prior to the 1900s for horticultural purposes as hedges and specimens for landscaping because of its hardiness and absence of pests [25].

Raw material for industry: A yellow dye is obtained from the leaves and bark [16], [26]. It is much used in Russia and turns black when mixed with salts of iron [16]. In addition, a green dye is obtained from the unripe fruit [16], [26], and a blue or grey dye is obtained from the ripe berries [16], [26].

The wood is used to make wooden nails, shoe lasts, veneer etc. [27], [28]. It is the source of a high-quality charcoal that is used by artists [5], [16], [20], [23], [26], [29], [30], [31].

Further reading: [12], [14]

Similar species:
Rhamnus cathartica L.
The bark and the fruits have been used medicinally due to their purgative effect. With its variable phenology, *R. cathartica* is highly adaptive to a range of ecological conditions. It is dioecious and rather vigorous in growth. While being even extremely shade tolerant, it grows much quicker in open conditions and is able to benefit from canopy openings. Reproduction may commence between the age of 4 and 20 years, subsequently reproducing every year with fruits becoming larger under optimal light conditions. On wetlands, shrubs of *R. cathartica* bear already fruit when still being seedling-sized. The seeds are zoochorous (insects) and have a high germination rate, being highest if fresh (not dried) ones are planted. Stratification at low temperatures may increase slightly the germination rate. If the seeds are immersed in water for more than 2 weeks, germination might be prevented [32], [33].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Pictures: Siedbrand

Fraxinus excelsior L.

common ash (Gemeine Esche)

Family: Oleaceae
Life form: tree
Main use category: raw material
Used part: wood

General information

Morphology: Perennial. Height: 20-40 m. Leaves deciduous; 20-35 cm long, pinnate compound, with 7-13 leaflets, 3-12 x 0.8-3 cm, sessile, serrated margin. Dioecious, monoecious, or hermaphrodite, they can also change sex from year to year. Flowers open before leaves, female flowers somewhat longer than male; dark purple without petals. Fruit a samara, 2.5-4.5 cm x 5-8 mm, often hanging in bunches through the winter, and regularly called 'ash keys'. Crown tall, domed. Shoots are stout, greenish-grey, with jet black buds. Bark smooth and pale grey on young trees, becoming thick and vertically fissured on old trees [1], [2]. Trees take 30-40 years to flower from seed [3].

Geographic distribution: Europe, south of latitude 64°, to N. Africa and W. Asia [4].

Natural habitat: Forming woods on calcareous soils, also in oakwoods, scrub, hedges etc. [5]. It is also often found on acid soils [5]. In carrs (forested wetlands) and alluvial forests [6]. Site specific properties after [6].

Site specific properties

Water regime: moist-wet
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: intermediate shade tolerant
Salinity: low tolerance

Cultivation

European ash is a fast-growing hardwood with outstanding wood properties high economic value and a wide ecological amplitude, except for acid soils. Ash rarely occurs in pure stands, which probably explains why silviculture of the species has received little attention in the past. If managed carefully, ash stands can produce a valuable timber on relatively short rotations. Ash tolerates short-term flooding but is intolerant of stagnant water [7]. There is no growth reduction due to prolonged flooding according to one report [8]. Another study, however, indicates that prolonged waterlogging is detrimental to growth [9]. Ash cultivation is recommended for peatlands that are not properly rewettable with moist to wet conditions. Since the 1990s, a large-scale ash dieback caused by a fungal disease has been observed in countries around the Baltic Sea and recently spreading to other regions of Europe. An invasive ascomycete was identified as the cause [10]. The symptoms include wilting of leaves, cankers on young shoots and stem bark necroses.

Propagation and establishment: Regeneration and establishment of ash can be either through natural seed fall or by planting [9]. The seed is best harvested green - as soon as it is fully developed but before it has fully dried on the tree - and can then be sown immediately [11]. Ash is deeply dormant; the germination is generally delayed by one year [9]. After a cold stratification the seeds can be directly sown into an outdoor seedbed, preferably in autumn. Grow the seedlings up in the seedbed for 2 years before transplanting either to their permanent positions or to nursery beds. Ash is planted at an initial stocking of 3,000 to 5,000 2-year old seedlings per ha at a spacing of 2 x 1.5 or 1.5 x 1.5 m, respectively [9]. High density favours height growth in the first years; however, wider spacing results in faster diameter growth [9]. Vegetation control is extremely important in ash plantations as it is a species very sensitive to competition from weeds for nutrients, light and moisture. Vegetative propagation with cuttings of mature wood is semi-successful [4]. Ash is often planted in mixtures with other species (e.g., alder or larch), because it has a low volume production in pure stands, decreasing frost risk and quality defects [12], [13]. The trees are susceptible to frost and therefore are not suited to sites where frosts occur regularly.

Management: When grown up, ash is a strong light demander and must be thinned heavily and regularly (every 5 or 7 years). Thinning promotes the development of large crowns which in turn stimulate diameter growth. Long clear boles are obtained by natural pruning with late and light thinning during an extended rotation, while short clear boles are produced with early and heavy thinning combined with artificial pruning over a shorter rotation [9].
The tree is very tolerant of cutting; ash was once also frequently coppiced for its wood [3].
Several borers often infest the trunk and cause the tree to decline.
Longer periods of flooding seem detrimental to growth and should be avoided entirely when the goal is timber production.

Harvest: The low load-bearing capacity of wet peat soil makes harvesting difficult. Harvesting should be done in winter after the ground is frozen and snow-covered or with machinery adapted for wet conditions, use of the cable way technique, or use of helicopters to minimize peat disturbance and its harmful effect on water quality.

Productivity: Several yield tables are available; a good overview is given by [9]. Diameter growth and also the length of the branch free bole are strongly affected by initial spacing and subsequent thinning practices. The number of potential crop trees per hectare, radial increment and pruning height are main determinants for the length of rotation period, which can vary considerably [9].
For northern Germany, the cumulative volume production (CVP) at 80 yrs is 504 m^3/yr for the best and 352 m^3/yr for the poorest yield class [14]. Volume growth culminates at relatively young ages and shows large variation across Europe [9].

Cultivation experiences: *Fraxinus excelsior* is widely cultivated in Europe.

Utilisation

Human food: The immature seed is edible, usually pickled by steeping in salt and vinegar, and then used as a condiment for other foods [15], [16], [17], [18]. The leaves are sometimes used as an adulterant for tea [15], [18], [19].

An edible oil similar to sunflower oil can be obtained from the seed [20].

Medicine: The leaves are astringent, cathartic, diaphoretic, mildly diuretic, laxative and purgative [20], [21], [22], [23], [24], [25], [26]. The bark is antiperiodic, astringent and a bitter tonic [21], [27]. Being rarely used in modern herbalism, it is occasionally taken in the treatment of fevers [26]. The seeds, including their wings, have been used as a carminative [21].

Ornament: There are many named varieties, selected for their ornamental value [2]. Trees have a light canopy and cast little shade [3].

Fuel: The wood is an excellent fuel with a high calorific value.

Raw material for industry: The wood is hard, light, flexible, strong, resilient. A very valuable wood, it is much used for tool handles, oars, furniture, posts, veneer etc. [17], [20], [21], [23], [28], [29]. Ash has been traditionally used to produce hurleys. A green dye is obtained from the leaves [20].
The bark is a source of tannin [21]. A tying material can be obtained from the wood [28].

Co-benefits: The ash tree has also a cultural importance. In the Nordic mythology, Yggdrasil, the world tree holding the universe together with its mighty roots and branches, is a majestic ash tree [32].

Further reading: [9], [13]

Similar species:

Fraxinus latifolia Benth.
Oregon ash is native to the Pacific Northwest of N. America. The wood is mostly used as fuel, splits easily and has a high heating value. It is commonly found in riparian habitats, poorly drained and seasonally flooded, but not managed for timber production.

Fraxinus nigra Marshall
Black ash is native to eastern N. America. It grows on sites and soils with generally poor drainage (including peat) in bogs, streambanks, and other low spots. It is a medium sized tree and slow-growing. Many aspects are unknown because the tree has never been commercially important [30]. The wood is used mainly for indoor furnishings.

Fraxinus pennsylvanica Marshall
Green ash or red ash is native to eastern N. America and is the most widely distributed of all the American ashes. Green ash is widely adapted to soils, moisture conditions, pH and will tolerate seasonal flooding. The tree is fast growing on moist bottomlands and is extremely hardy to climatic extremes once established.

Fraxinus profunda (Bush) Bush
Pumpkin ash is native to the south-eastern N. America. It is a large tree of swamps and bottomlands where it often develops a swollen or pumpkin-shaped butt. Pumpkin ash is found on wet to very wet sites where surface water stands well into the growing season [30]. Yet, there is no published growth or yield data, and in practice it has not been practical to distinguish it from green ash either for management purposes or in its utilization [31].

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Pictures: Rasbak

Glyceria maxima (Hartm.) Holmb.

great manna grass, reed sweet grass (Wasser-Schwaden)

Family: Poaceae
Life form: graminoid
Main use category: fodder, energy
Used part: aboveground biomass

General information

Morphology: Perennial. Height 80-200 cm. Stem unbranched. Leaves 30-60 cm x 8-20 mm, grass-green, scabrid beneath, cross-veined, sheaths scabridulous. Hermaphrodite. Inflorescence a rather dense open panicle, 10-40 cm, with 4-10 branches at central panicle-nodes. Flowering from June to August. Shallow root system, no deep penetration. Long and robust rhizome [1], [2], [3].

Geographic distribution: Native to Europe, except the southwest, and to C. Asia [4]. *Glyceria maxima* has been intentionally introduced as livestock forage in seasonally inundated pastures to temperate N. America, New Zealand, and Australia [5].

Natural habitat: Lakes, fens, freshwater wetlands, and shallow water sites [6]. Optimum on nutrient rich alluvial or peat soils, tolerates a large range of soil pH [4].

Site specific properties

Water regime: wet-flooded
Trophic conditions: eutrophic
pH: acid-subneutral-alkaline
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

Glyceria maxima, as an obligate wetland plant, has a good potential for paludiculture. Naturally grown *G. maxima* in fen meadows, as well as successional stands developed after peatland rewetting, can be used for biomass production. It can spread rapidly: in N. America and Australia it is even considered as an invasive weed species. The artificial cultivation is known from wastewater treatment. Its methods are probably transferable to paludiculture.

Propagation and establishment: Naturally mainly vegetative reproduction, but also low generative propagation [5]. The most promising vegetative propagation methods are rhizome cuttings (19 cm section of terminal rhizome with 1-2 root-bearing nodes) and aerial shoots trimmed to 20 cm length [7]. They can be planted out in spring but are probably expensive and laborious. Direct seed-sowing in late summer is also possible. *Glyceria maxima* spreads vigorously from rhizomes and seedlings that produce numerous vegetative and flowering shoots. A single plant may produce up to 100 shoots and 30 m of rhizome in its first 2 years of growth [9].

Management: Constant flooding conditions and high nutrient inputs favour the competitiveness of *G. maxima* [8]. Harvesting of *G. maxima* either two or three times per season will cause a decrease in shoot biomass even in highly productive stands [8]. Cutting height must be some centimetres above the water table because flooding of the stubble is detrimental [10]. *Glyceria maxima* is sensitive to grazing and moderately tolerant to mowing [11]. Another report says that grazing and harvesting can lead to the emergence of other species and in the long term to the disappearance of the *G. maxima* stands [12]. Cutting with low frequency is clearly recommended for a long-term use.

Harvest: Summer harvest is best done once a year with adapted machinery that can work in wet conditions.

Productivity: Moderate to high. The primary productivity is severely limited by nutrient supply [8]. Range of annual biomass production: 9-28.6 t DM/ha [2], [13]. Aboveground biomass stock in a cold/boreal climate: 6-11.6 t DM/ha [14]. In a floodplain in S-Sweden 5.9 t/ha were obtained [8].

Cultivation experiences: In constructed wetlands for wastewater nutrient removal in Sweden [10].

Utilisation

Animal fodder: It has an intermediate forage value [11]. The net energy content depends on the harvest time. It differs from 7.3 MJ NEL/kg DM (dry matter) in May to 5.5 MJ NEL/kg in July [15] (NEL = net energy content lactation according to the German feed evaluation system). *Glyceria maxima* supplied with wastewater hold a metabolizable energy of 10.6 MJ/kg DM [10]. It has a high fibre content [4]. Hay is only eaten if cut at a young stage [4].

Food: Since the Middle Ages, manna-grass (*Glyceria* spp.) has been gathered and processed for its nutritional benefits, for which reason it was also sold on markets [18]. It appears, however, that *G. fluitans* was more relied upon for this purpose (see below).

Energy: *Glyceria maxima* has a good potential as a renewable energy source, e.g., for biogas production [2].

Co-benefits: *Glyceria maxima* is used for wastewater treatment in constructed wetlands [2], [10]. It is the commonly used plant species for horizontal sub-surface flow systems in C. and N. Europe.

Similar species:

Glyceria grandis S.Watson, American manna grass.

Glyceria fluitans (L.) R.Br.: called floating manna grass (*Flutender Schwaden*). It is quite a good pasture herb on wet fen meadows. Native to temperate Europe, western Asia, and eastern N. America [4].

In Central Europe – especially NE-Germany through eastern Poland –, the use of *G. fluitans* (German *Mannagrütze* or *Schwaden*) as food crop was known since around the late Middle Ages [16], [18]. Generally, the harvestable plant parts were collected and then processed, but collecting and processing was said to be quite time-consuming and complicated, which is why the market prices for it were relatively high [16], [17], [18]. The dishes prepared with it are said to have been tasty; recipes for manna-soup (*Schwadensuppe*) and manna-cake (*Schwadenkuchen*) can be found in [17]. Ascherson [16] described in 1896 succinctly how the seeds were to be extracted:

> When collecting, ordinary grain sieves are used to drain off the water that accumulates, which are then emptied into linen sacks. The fruit, which is naturally still very wet, must be dried as soon as possible in order not to spoil. During this process, the brown skin of the fruit turns into a pitch-black skin, which is then removed by pounding with heavy wooden clubs, so that the yellowish-white kernel is revealed. (p. 43, translated)

With the then ever-increasing drainage of peatlands and the focus on other crops, however, these uses fell into oblivion at around the beginning of the twentieth century [18].

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Pictures: H. Zell

Gratiola officinalis L.

common hedgehyssop, herb of grace (Gottes-Gnadenkraut)

Family: Plantaginaceae
Life form: forb/herb
Main use category: medicine, ornamental
Used part: plant, root

General information

Morphology: Perennial. Height 10-50(-80) cm. Stem terete, branched, erect, glabrous throughout. Rhizomes short, horizontal. Leaves opposite, sessile, linear to lanceolate, 1.5-4 cm x 2-8 cm, narrower on branches, margin sparsely and minutely serrate. Hermaphrodite. Pedicels shorter than subtending leaves. Flowers solitary. Corolla 1-1.3 cm, white, usually veined and tinged with purplish-red, calyx-lobes unequal. Flowering from June to October. Capsule globose, ca. 5 x 4 mm, 4-valved; seeds numerous [1], [2].

Geographic distribution: C. Europe and S. Europe [3]. Temperate E. Asia.

Natural habitat: Wet grassland, fens, river banks, ditches etc. [1], [4].

Site specific properties

Water regime: moist-wet
Trophic conditions: mesotrophic
pH: subneutral-alkaline
Light conditions: intermediate shade tolerant
Salinity: low tolerance

Cultivation

Paludiculture of *Gratiola officinalis* is unknown but the ecological amplitude of the plant suggests that it is possible. It is also unknown whether the demand is sufficient for an economically beneficiary cultivation or not. In many European countries it is a threatened species. Reasons for the decline are eutrophication, land use change and interventions in hydrology [5].

Propagation and establishment: Naturally, hedgehyssop reproduces mainly vegetatively. Generative reproduction is rare due to lack of suitable germination places (bare soil).
Generative: seed sowing in spring in a cold frame. Pricking out the seedlings when they are large enough to handle and planting them out in the summer.
Vegetative: division in spring [6]. Larger clumps can be replanted directly into their permanent positions, though it is best to pot up smaller clumps and grow them up in a cold frame until they are rooting well. Planting them out in the spring.

The plant has a low competitiveness, especially in the early phase of establishment. Shallow peatlands are more suitable for cultivation with *G. officinalis* [5].

Management: No information found.

Harvest: The plant is harvested whilst in flower in the summer and dried for later use [4], [7].

Productivity: No information found.

Cultivation experiences: There is only a very small market for homeopathic remedies. Large cultivation is probably not necessary, and hence unknown. Some information from conservation measures is available [5].

Utilisation

Medicine: Hedgehyssop was once widely used as a medicinal herb but it is now considered to be obsolete because of its strong toxicity in all parts [4], [7], [8], [9]. All parts are poisonous [4], [8], [9].
The root and the flowering herb are cardiac, diuretic, violently purgative and vermifuge [4], [10], [11]. The plant has been used in the treatment of liver problems, enlargement of the spleen, dropsy, jaundice, intestinal worms etc. [7], [10]. It should be used with caution, since the plant causes abortion, kidney damage and bowel haemorrhage when applied excessively [7]. Nowadays it is used as a homeopathic remedy, made from the flowering plant [4]. It is used in the treatment of cystitis, colic, and certain stomach disorders [4].

Ornament: It is used as an ornamental plant.

Further reading: [5]

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Picture: Kenraiz

Hierochloë odorata (L.) P.Beauv.

sweet grass (Mariengras)

Family: Poaceae
Life form: graminoid
Main use category: food, raw material
Used part: leaves

General information

Morphology: Perennial. Height: 25-60 cm. Rhizomatous; stem hollow and hairless with open sheaths. Leaf blades flat at maturity, usually glabrous, 10-30 cm x 3-6 mm, green. Hermaphrodite. Inflorescence a pyramidal panicle 4-9 cm. Spikelets 3-flowered, the 2 lowest florets staminate (male), the uppermost is perfect. Flowering May to July. Plant is fragrant (coumarin) [1], [2].

Geographic distribution: C. and N. Europe, to N. Asia and N. America [3].

Natural habitat: Sweetgrass grows in wet meadows, low prairies, and the edges of sloughs and marshes [2] and in the upper zone of salt marshes [4].

Site specific properties

Water regime: moist-wet
Trophic conditions: oligo-mesotrophic
pH: subneutral
Light conditions: intermediate shade tolerant
Salinity: low tolerance

Cultivation

Hierochloë odorata is used in a traditional way and still harvested by hand from peatlands. The ecological amplitude suggests that its cultivation in moist to wet peatlands is possible, but high water tables will probably reduce growth. Sweet grass is capable of growing with water tables ranging from 7 to 56 cm below the surface [4]. A good water management of the peatland is a precondition to avoid long periods of flooding.

Natural sweetgrass populations are declining due to harvesting for both personal and commercial use. The species is subject to over-collecting and is sensitive to grazing. Today sweetgrass has become scarce and is hard to find [2]. Wild harvests should be restricted to salvage sites with appropriate approvals or permits.

Propagation and establishment: *Hierochloë odorata* can be propagated generatively via seeds and vegetatively via divisions. The seeds should be sown in spring in situ and just cover the seed with soil [5]. Germination usually takes place within 2 weeks. If the seed is in short supply, it can be sown in the cold frame in spring and planted out in early summer [3]. The recommended planting density is 30 cm or 11 plants per m².

Plant divisions should be taken in spring or summer [5]. Virtually any part of the root will regrow to make a new plant [3]. The plant shows a strong vegetative reproduction by tillers arising from rhizomes [4].

Management: Fertilization increases the height and yield [4], but it is not considered as a viable method for improving either quality or quantity of sweet grass due to the possible environmental damage and it would also lead to the stimulation of more competitive species. Shading has a positive effect on plant growth. In one study, shading resulted in a 30 % increase in height [4].

Harvest: The plants should be cut in late July to September, after they have gone to seed. They are dried for later use. It is probably difficult to harvest in a larger scale because the plant topples down when it becomes larger. The harvest by hand is still common, e.g., for the Żubrówka vodka.

Productivity: Sweetgrass is a high-yielding grass. When fertilized, cultivated, and managed, it can produce up to 40,000 dried braids or 4.5 t/ha [6].

Cultivation experiences: It is cultivated in North America mostly on very small scales [4], [6].

Utilisation

Human food: The seeds are edible when cooked [7]. An essential oil from the leaves is used as food flavouring in sweets and soft drinks. It has a strong vanilla-like flavour [8]. The leaves are added to vodka as flavouring [9]. The plant is said to be used as a colouring agent [8] but no more details are given.

Medicine: A tea made from the leaves is used in the treatment of fevers, coughs, sore throats, chafing and venereal infections [10], [11]. It is also used to stop vaginal bleeding and to expel afterbirth [10]. The stems can be soaked in water and used to treat windburn, chapping and as an eyewash [11]. Smoke from the burning leaves has been inhaled in the treatment of colds [11].

Ornament: The dried leaves are used as an incense [12], [13], [14]. An essential oil distilled from the leaves is used in perfumery where it acts as an excitant and fixative for other aromas [9].

Animal fodder: Rodents and small mammals (such as pika) browse on sweetgrass [2].

Raw material for industry: The leaves were formerly also used as a strewing herb [9], [12], [15] and have been used as a stuffing in pillows and mattresses [11]. Moreover, aromatic baskets are made with the leaves [12], [13], [14], [16], [17]. They have also been used as an insect repellent in the clothes-cupboard where they impart a nice smell to the clothes [9], [14]. The leaves can be soaked in water to make a tonic hair wash [11].

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Pictures: Marshman

Ipomoea aquatica Forssk.

water spinach (Wasser-Spinat)

Family: Convolvulaceae
Life form: vine
Main use category: food, fodder
Used part: aboveground biomass

General information

Morphology: Annual, sometimes biennial or perennial, terrestrial and repent or floating. Stems terete, thick, hollow, rooting at nodes. Petiole 3-14 cm; leaf blade variable, ovate to lanceolate, 3.5-17 x 0.9-8.5 cm, margin entire or undulate. Hermaphrodite. Inflorescences 1-3(-5)-flowered; peduncle 1.5-9 cm. Corolla white, pink, or lilac, with a darker center, funnelform, 3.5-5 cm. Capsule ovoid to globose, ca. 1 cm in diameter, woody, 2-4 seeds. Seeds densely grayish pubescent, sometimes glabrous. It can produce 175-245 fruits per plant [1], [2], [3].

Geographic distribution: Originated in tropical Asia (possibly India). Widely distributed in tropical and subtropical zones: S. and SE. Asia, Africa, Australia, Pacific Islands, S. America, N. America - USA (California, Florida) [2].

Natural habitat: Occurs in waterways, such as canals, lakes, ponds, rivers, in marshes and in paddies with rice [3].

Site specific properties

Water regime: moist-wet-flooded
Trophic conditions: eutrophic
pH: acid-subneutral
Light conditions: shade tolerant
Salinity: no information found

Cultivation

Asiatic farmers favour water spinach because it is easy to grow, has relatively low labour requirements, needs no weeding and can be harvested irregularly to meet the demand [4]. It is unknown if *Ipomoea aquatica* is already grown in peatlands, although the ecological amplitude suggests that paludiculture may be feasible. It thrives well in marshy soils rich in organic matter [2]. Water control is essential for cultivation and probably best done in paddies. In the U.S., it is listed as a federal noxious weed (especially in Florida).

Propagation and establishment: *Ipomoea aquatica* can be propagated generatively via seeds or vegetatively via divisions. The seeds are either broadcasted or sown in well prepared fields [2]. Since seedling growth is poor under water, the seed is usually germinated and the plants grown on a dry portion of the field or in the cold frame during the first six weeks [4]. Vegetative propagation is mostly done by fragmentation, but it can easily be propagated by stem cuttings taken by apical nodes exhibiting more mature morphology than those from more basal cuttings [2]. The cuttings or seedlings are planted at a spacing of 40 cm in the slightly flooded field that has been trampled to liquid mud [4]. They root quickly and need little attention except for fertilization. As the crop grows, the water depth can be increased to 15-20 cm.

Management: Fertilization is common in the conventional cultivation. It is considered as a shade loving plant and the provision of shade favourably influences the yield [2]. It is probably a good companion plant in agroforestry.

Harvest: Harvesting is done by cutting the floating shoots 1-2 months after planting. Short harvesting intervals are beneficial for the yield. Harvesting from near ground level should be avoided as it causes mortality [2]. The field is conventionally drained after the final harvest to induce flowering and seed-setting [4].

Productivity: Under fertile and wet conditions, *I. aquatica* produces 190 t/ha fresh weight biomass in nine months [3]. Yield of water spinach greatly depends on varieties, growing conditions and span or harvesting season. Under upland (i.e., drier) conditions, the yield is generally around 7.3 t/ha, whereas under wet conditions it ranges from 24 to 100 t/ha per year [2].

Cultivation experiences: Widely cultivated in E. and SE. Asia [5], [6]. Unknown if it is already grown on wet peatlands.

Utilisation

Human food: Throughout much of tropical Asia it is a common vegetable eaten by all social groups. There are several ways people consume this herb, although the most frequent is as a cooked vegetable [3]. Nutrient values are available [7].

Medicine: *Ipomoea aquatica* is considered a laxative, is recommended for piles, and in certain nervous conditions with sleeplessness and headache. Eating a lot of the plant has a nerve-calming effect in cases of sleeplessness, stress, headache, general weakness and leukorrhoea [3]. It is recommended for treating hemorrhoids, most likely applied directly as a poultice. People in Borneo, Cambodia, and Malaysia use it as a poultice to treat fever with delirium and put buds on ringworm lesions or on boils. In Burma, India, and Indonesia the juice is used as an emetic to treat poisoning from opium, arsenic, and from drinking polluted water [3]. In much of southeastern Asia, *I. aquatica* is considered a tonic. The species contains several vitamins and is used to treat gastric and intestinal disorders [3]. The species also contains aliphatic pyrrolidine amides, carotenoids, hentriacontane, β-sitosterol and its glycosides, prostaglandin, leukotrine, N-trans- and N-cis feruloyltyramines. Fresh plants have from 1.9 to 4.6 % proteins; carbohydrates average ca. 4.3 %. In the Philippines, a mouthwash made of water spinach was experimentally shown to be effective against *Escherichia coli* and *Staphylococcus aureus* [3]. In Africa, *I. aquatica* is used to treat diabetes as it is in Sri Lanka. Plants contain insulin-like compounds clinically shown to be effective. Elsewhere the species is used to treat abscesses, mental illness (Tanzania), and intestinal problems (Somalia) [3].

Animal fodder: *Ipomoea aquatica* is used as fodder for animals, but in limited quantity as it is somewhat laxative. In China it is often grown in fish ponds particularly as food for pigs; it is also fed to cattle and fish. In Vietnam, it is moreover fed to chickens, ducks, and pigs [3].

Agricultural conditioner and substrate: The seeds are a strong pesticide killing earthworms, leeches, pig tapeworm and other intestinal parasites. This trait has not been located elsewhere but is not surprising since there are many poisonous compounds found in the family [3].

Further reading: [2], [3], [4], [5]

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Kristian Peters

Iris pseudacorus L.

Yellow flag (Sumpf-Schwertlilie)

Family: Iridaceae
Life form: forb/herb
Main use category: ornamental, food, medicine
Used part: plant, flower, seed, root

General information

Morphology: Perennial. Height: 60-120 cm. Stem slightly compressed, bearing several leaves. Basal leaves 50-90 cm x 10-30 mm, rather glaucous, with conspicuous midrib. Hermaphrodite. Flowers 4-12, bright yellow, 7-10 cm across, the lower on long, suberect peduncles. Fruit capsule 40-80 mm, cylindrical, with short beak. Smooth, dark brown seeds. Thick rhizome. The seasonal accumulation of storage materials in the rhizomes results in annual segments that can be counted to determine their age [1], [2].

Geographic distribution: Native to Europe, from Norway south and east to N. Africa, the Caucasus, and W. Asia. Introduced to N. America, New Zealand, and S. America [3], [4].

Natural habitat: Damp marshy areas, swampy woods and in shallow water or wet ground on the edges of rivers and ditches [5].

Site specific properties

Water regime: moist-wet-flooded
Trophic conditions: eutrophic
pH: acid-alkaline
Light conditions: shade tolerant
Salinity: no tolerance

Cultivation

Iris pseudacorus is widely cultivated as an ornamental plant and the ecological amplitude suggests that cultivation in wet peatlands could be possible. The harvest of the underground biomass probably harms the peat soil and lead to further degradation, similar to the necessity of the new installation of the field after root harvest. Propagation methods are known from gardening and probably transferable. The actual cultivation under wet conditions is, however, not known to the authors. This iris is listed as an invasive and/or noxious weed in several states in N. America.

Propagation and establishment: *Iris pseudacorus* can be reproduced both vegetatively and generatively by seed. The seeds should be sown as soon as it is ripe in a cold frame [6]. Scarification as well as a period of cold stratification improves germination time and rates [3], [7]. Germination and establishment are best in moist but not waterlogged conditions [8], since submerged seeds fail to germinate. The seedlings can be planted out in late spring or early summer [3].

Vegetative propagation is possible with rhizome fragments. Dry rhizomes remain viable for more than 3 months and may establish themselves if they encounter moisture [7].

Management: *Iris pseudacorus* has a high nitrogen demand [9]. Yellow flag rhizomes can withstand long periods of flooding, so the cultivation can be recommended for very wet to temporarily flooded rewetted peatlands.

Harvest: No information found.

Productivity: In a test trial with slurry, *I. pseudacorus* had a productivity of 6.17 t/ha [10]. The production in southern Poland is estimated to be 7-8 t/ha [11].

Cultivation experiences: It is often cultivated as an ornamental plant in water gardens or near ponds.

Utilisation

Human food: The seed is said to make an excellent coffee substitute as long as it is well roasted [12], [13], [14], [15], [16], [17]. Caution is advised since it might be poisonous [18].

Medicine: The fresh root is astringent, cathartic, emetic, emmenagogue and odontalgic [6], [13], [14]. A slice of the root held against an aching tooth is said to bring immediate relief [17]. It was once widely used as a powerful cathartic but is seldom used nowadays because of its extremely acrid nature [6]. It can also cause violent vomiting and diarrhoea [17]. When dried, the root loses its acridity and then only acts as an astringent [6].

Ornament: Used widely as an ornamental plant in water gardens or flower arrangements. There are several varieties available [7].

Raw material for industry: A beautiful yellow dye is obtained from the flowers [6]. A good black dye is obtained from the root if it is mixed with iron sulphate [6], [16]; it is brown otherwise [19]. The root is a source of tannin [14] and has been used in making ink [6].

Co-benefits: It has been used as a rehabilitation plant to reduce bacterial loads, absorb heavy metals from contaminated water and provide erosion control [7].

Further reading: [7], [20]

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Pictures: Alberto Salguero

Juncus acutus L.

Spiny rush (Stechende Binse)

Family: Juncaceae
Life form: graminoid
Main use category: raw material, ornamental
Used part: stems, flowers

General information

Morphology: Perennial. Height 50-150 cm. Stem 2-4 mm in diameter, rigid, with 2-5 leaves. Leaves basal, terete, pungent. Hermaphrodite. Inflorescence many-flowered, usually dense, globose; lowest 2 bracts strongly pungent. Fruit capsule 4-6 mm, obovoid to ovoid. Plant densely caespitose; intravaginal shoots present. Tussock-forming [1].

Geographic distribution: S. Europe, south and east from France to N. Africa, Asia and Macaronesia [2]. Found also in California, Argentina, Uruguay, Chile and Cape Province in South Africa [3].

Natural habitat: Sandy sea shores and dune slacks, occasionally in salt marshes [4]. The plant can form peat near the sea [5].

Site specific properties

Water regime: moist-wet
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: shade intolerant
Salinity: medium tolerance [6]

Cultivation

Natural stands of *Juncus acutus* are traditionally harvested in the Kizilirmak Delta, Turkey. It is an important part of the livelihood of the people living around wetlands [7]. Cultivation is unknown to the authors. The ecological amplitude suggests that cultivation of *J. acutus* in moist-wet peatlands (paludiculture) might be possible.

Propagation and establishment: *Juncus acutus* can be propagated vegetatively by plant division, and generatively via seeds. The seeds can be sown on the surface in moist pots in a cold frame in early spring. They can be planted out in the summer [2]. Direct seed sowing in the field is probably also possible. Plants spread naturally mostly by seed and germinate at almost any time of the year. Water and wind are the main dispersal agents. Each capsule can hold up to 150 seeds and each fruiting head contains approximately 200 capsules, which amounts to 30,000 seeds per fruiting head per year [3]. Seeds hold high germination rates (75 %) and they may persist for many years in the soil. Availability of light is a major limiting factor for germination, so wet and open substrates are favoured sites for establishment of new populations.

Vegetative propagation can be done with division, planted in spring. Larger clumps can be replanted directly into their permanent positions [2].

Management: *Juncus acutus* appears to be intolerant of permanent high water tables [3], so permanent high flooding should be avoided. The traditional harvesting in Turkey seems beneficial for *J. acutus*. The main clump is strengthened by taking away dead shoots and opening space for new ones to emerge. This provides space for thicker shoots in the next year [8].

Harvest: In Turkey, *J. acutus* is harvested by hand until all the longest and thickest stems in each clump are pulled out [8]. Harvest time is from June to August. Each clump amounts to 10-50 stems. A bundle weighs 20 kg, numbering 1,000 stems. One person can collect up to 100 kg a day [8]. The wet biomass must be dried before sale.

Productivity: No information found.

Cultivation experiences: Unknown to the authors.

Utilisation

Ornament: The stems are used in making large commercial flower arrangements in Turkey [8]. Cut flowers are bound to stems and then mounted on a base through the hard stem of *J. acutus*.

Raw material for industry: The stems are used in making hand woven baskets, thatching, mats, spikes for frying mussels, shish kebabs, and for drying a kind of pasta (kuskus) and tarhana, a preparation of yogurt and flour dried in the sun to make soup (in Turkey) [8], [9], [10], [11]. The culms can be used for paper making [12]. The aerial parts have a good potential to be used to produce natural products with use as algicides [13].

Co-benefits: The plant can be used for wastewater treatment in constructed wetlands [14].

Further reading: [3], [7]

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Picture: Christian Fischer

Juncus effusus L.

soft rush (Flatter-Binse)

Family: Juncaceae
Life form: graminoid
Main use category: raw material
Used part: stems

General information

Morphology: Perennial. Height 50-150 cm. Stout but soft stem, 1.5-3 mm wide; rhizomatous. Stems and leaves with 10-20 ridges. Basal sheaths are bladeless or the inner ones tipped with a short awn, usually reddish-brown. Flowering and sterile shoots grow from buds on the rhizome. Remains green in winter. Hermaphrodite. Inflorescence is a many-flowered, lax panicle, 2-10 cm long. Perianth-segments 2.5-4 mm. Stamens 6. Fruit capsule 0.5 mm. The seeds are reticulate, small (2-2.5 mm) capsules. Tussock-forming [1], [2].

Geographic distribution: Native to Europe and N. America [2], [3]. Distributed throughout the cold and temperate zones of both hemispheres, but also E. and S. Africa, Asia, and Australia [2], [3].

Natural habitat: Wet pastures, bogs - especially in lagg zones, damp woods, ditches, clearings etc., usually on acid soils [4]. It is often found in disturbed habitats.

Site specific properties

Water regime: moist-wet
Trophic conditions: oligo-meso-eutrophic
pH: acid-subneutral (less common above pH 7.0)
Light conditions: shade intolerant
Salinity: low tolerance

Cultivation

Paludiculture is unknown, apart from collecting stems from natural sites for traditional uses, like weaving. Cultivation is known from China and Japan and is probably transferable to wet peatlands. *Juncus effusus* is potentially peat forming [5].

The plant is particularly well adapted to colonising and spreading over bare cutaway peatlands [5]. These sites are rapidly invaded and overgrown with *J. effusus* [6]. It is considered as a weed, e.g., as a seed contaminant, on forested cutaway peatlands, and on Sphagnum farming sites. The plant can be invasive.

Propagation and establishment: *Juncus effusus* is easily propagated from bare root stock or seedlings, from container stalk, or directly seeded into the soil [2].

Generative: seeds germinate easily. Collect seeds when mature inflorescences are brown and tiny seeds are dark reddish brown (June to September). There is a large seed production. One study calculated a distribution of 4 million seeds per m² [7]. Essential for germination is a cold stratification (one winter) [8] and bare moist soil with direct sun light. Seedlings are extremely susceptible to competition from other species.

Seeds are dispersed naturally mainly by wind and by floodwaters probably also very effectively [5]. Seeds remain viable for up to 60 years [9] and can form a persistent seed bank.

Rhizome cuttings and divisions of mature clumps are also effective. Division occurs generally in spring. Larger clumps can be replanted directly into their permanent positions, although it is best to pot up smaller clumps and grow them up in a cold frame until they are rooting well. A planting unit should contain 3-5 culms [2], [3]. Spacing of 25-30 cm is recommended [2]. Best time of planting depends on climate.

Management: *Juncus effusus* is tolerant of a wide range of ecological conditions. It shows generally a good tolerance to wet and dry conditions and can be inundated regularly to permanently up to 0.3 m [10]. Another report states that it rarely occurs on permanently submerged habitats [11]. *Juncus effusus* shows a low competitiveness in mixed plantings with other wetland species [12].

The soil fertility has probably no effect on the initial establishment of *J. effusus* seedlings but it could indirectly increase total germination and establishment [13].

Harvest: With adapted machinery (e.g., tracked vehicles) or by hand.

Juncus is most susceptible to weakening in summer (mid-July), in the main growing period [14]. There are several studies for eliminating this "weed" [5]. No information about sustainable cutting frequencies was found, but probably a harvesting regime every second year, outside the main growing season, will not reduce the *Juncus* cover. Even single cuts were unlikely to have any long-term effect on the rushes' regrowing as soon as the annual cutting ceased [15].

Productivity: Slow to moderate growth habit [10]. Another report concludes that *J. effusus* exhibited extremely high production rates and this resulted in continuous growth throughout the year [12]. In general, a range of annual biomass production for *Juncus* species is as follows: 7.96-53.3 t/ha*yr dry weight [16] (note from the authors: numbers seem very high). For a sub-temperate riparian wetland of west-central Alabama, estimates of total annual net productivity were ~9.8 kg ash-free dry mass/m² [17].

Cultivation experiences: Soft rush has long been a wetland crop in Taiwan, China, Korea and Japan. It is known to have been cultivated in Japan as early as the 19th century A.D. In 1970, the Japanese harvest amounted to 120 million kg of the dried stems, which were used for floor matting (Tatami) [18], [19]. It is unknown to the authors, if it is grown in peat soil.

Utilisation

Human food: The early sprouts of soft rush were sometimes eaten raw by the natives of Washington state. *Juncus* shoots were eaten raw, roasted in ashes, or boiled by Maidu, Luiseño, and others. Owens Valley Paiute ate the seeds. Soft rush stalks were gathered in wetlands and eaten on occasion by the Nlaka'pamux and Lillooet people of British Columbia [2]. In hui sup tea, *J. effusus* is listed as one of the seven ingredients.

Medicine: The pith of the stem is antiphlogistic, depurative, discutient, diuretic, febrifuge, lenitive, lithontripic, pectoral and sedative [20], [21], [22], [23], [24]. It is used in the treatment of sore throats, jaundice, oedema, acute urinary tract infection and morbid crying of babies [21].

Ornament: The cultivar *Juncus effusus* f. *spiralis* is a popular ornamental water plant due to its tortuous spiral like foliage.

Animal fodder: The metabolizable energy (ME) ranges from 6-4.5 MJ per kg dry matter [25]. After [25] it has a german forage value (Futterwertzahl) of 1 (= worthless).
Cattle will graze *J. effusus* late in the season after more palatable plants are eaten. Rushes tend to be resistant to grazing pressure and fairly unpalatable to cattle, so they tend to increase in species composition in pastures [2].

Raw material for industry: Stems are used in basket making, thatching, weaving mats etc. [26], [27], [28], [29], [30], [31]. The famous Japanese tatami mats are woven with soft rush. The stems can also be dried then twisted or braided into ropes for tying or binding [32].
Stems can be peeled (except for a small spine which is left to keep them upright) and soaked in oil and then used as a candle [27], [30], [33], [34]. The Dutch name "pitrus" is derived from using the aerenchym of the species as wick (dutch "pit") in oil lamps. A fibre obtained from the stems is used for making paper [35]. The stems are harvested in late summer or autumn, they are split and cut into usable pieces and then soaked for 24 hours in clear water. They are then cooked for 2 hours with lye and beaten in a blender. The fibres make an off-white paper [35]. When mixed with mulberry fibres they can be used for making stencil paper [35]. The whole plant was formerly used as a strewing herb [28], [30], [36].

Energy: *Juncus effusus* is recommended as a biomass for bioenergy production, having a net calorific value of 15.06 MJ kg FM_{w15}^{-1} [37].

Co-benefits: Can be used for wastewater treatment in constructed wetlands [38]. *Juncus effusus* is, among other species, typically used in the second stage (horizontal flow bed) in the Krefeld process and Haider/Rausch process [16].

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Picture: Kristian Peters

Juncus gerardii Loisel.

saltmarsh rush (Salz-Binse)

Family: Juncaceae
Life form: graminoid
Main use category: fodder
Used part: aboveground biomass

General information

Morphology: Perennial. Height 15-30(-90) cm. Leaves basal, 2-4, auriculate; 10-40 cm x 0.4-0.7 mm, margins entire. Hermaphrodite. Inflorescences 10- to 30-flowered, usually loose and somewhat lax, 2-16 cm. Rhizomes long-creeping [1], [2].

Geographic distribution: N. America, Europe, Asia [1].

Natural habitat: Forming extensive colonies in exposed coastal estuary meadows and salt marshes just above high-tide line; also occurring inland [1].

Site specific properties

Water regime: moist-wet
Trophic conditions: mesotrophic
pH: subneutral-alkaline
Light conditions: shade intolerant
Salinity: high tolerance

Cultivation

The species is a component of the diverse and valuable wet salt grassland that is traditionally used as pasture in the Baltic Sea region [2], [3]. The root biomass of *Juncus gerardii* is the main material for peat formation in coastal flood peatlands (= coastal transgression mires) in the Baltic coasts, where trampling by cattle favoured the formation of salt grassland peat through compaction of the organic material

[4], [5]. Paludiculture is therefore conceivable.

Propagation and establishment: Propagation can be done via seeds and divisions. Germination experiments showed higher survival rates under flooding. Salinity reduced the germination rates but was less pronounced under waterlogging [6]. *Juncus gerardii* is a prolific seed producer in the salt marsh with a seed viability of 84 % [7]. *Juncus* forms a persistent seed bank [8]. Thus, the physical conditions on salt marshes may not normally favour the accumulation of persistent, buried seed banks [7].

Management: It is tolerant towards grazing or mowing. A management is even necessary to inhibit an invasion of more competitive plants like *Phragmites* or *Spartina* into the sites [5], [9], [10]. Fertilization with nitrogen leads to a decrease of abundance of *J. gerardii* because of competition pressure [11].

Harvest: Grazing is possible in the whole vegetation period. Mowing seems unprofitable because of the low vegetation height.

Productivity: The yield of typical salt marsh rush meadows in Germany is specified with 3.5 t DM/ha [2]. The hay yield was measured with 0.63 t DM/ha in the plant association dominated by *J. gerardii* in coastal meadows in western Estonia [3]. Annual net aboveground primary productivity was estimated for *J. gerardii* in selected east coast salt marshes in the U.S. with 6 t/ha [12].

Cultivation experiences: Unknown.

Utilisation

Animal fodder: *Juncus gerardii* is eaten by cattle and sheep. It has a metabolizable energy of 9.4-8.7 MJ/kg DM. It has a German forage value (Futterwertzahl) of 2 [2]. An Estonian study provides values for metabolizable energy of 10.8 MJ/kg and satisfactory digestibility rates of 68 % [3].

Co-benefits: The plant was tested for Cadmium accumulation as a cleansing method for heavy metal contaminated soil and ground water [13].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Kosteletzkya pentacarpos (L.) Ledeb.

seashore-mallow, saltmarsh-mallow

Picture: Magnus Manske

Family: Malvaceae
Life form: forb
Main use category: energy, raw material
Used part: seed, aboveground biomass

General information

Morphology: Perennial. Height 90-150 cm. Stem much-branched and angular. Leaf blades triangular-ovate with triangular lobes at the base. Hermaphrodite. Flowers light pink, hibiscus-like, 7.5 cm across, terminal or axillary, stalked with central column of yellow stamens. 5 seeds per flower, 4 mm, 20 mg. Flowering June to July, fruiting July to August. Fleshy tuberous root system [1], [2], [3].

Geographic distribution: Europe - Italy to the Caspian Sea [4]. South-eastern N. America [1].

Natural habitat: A non-dominant species in plant communities of seaside bogs of the Caspian littoral [5] and brackish marshes along the Atlantic and Gulf Coasts of N. America [6]. Warm-temperate areas, cannot withstand cold winters [3].

Site specific properties

Water regime: moist-wet
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: shade intolerant
Salinity: medium tolerance

Cultivation

Paludiculture is unknown from this species. The plant has been suggested and tested as a grain crop in seawater-based agricultural systems or on saline soils (e.g., on tidal flats). Information on propagation and establishment are available and probably transferable to paludiculture, because the ecological amplitude of the plant suggests that its growth in wet peatlands is possible. A paludiculture seems promising because the aboveground biomass has versatile utilisation options.

Propagation and establishment: *Kosteletzkya pentacarpos* can be propagated via seeds or cuttings. Seeds are dormant at harvest in September to October. Scarified seeds can germinate to 100 % [7]. They can be sown directly into the field in spring since they will germinate after 5-10 days [8]. Soak the seeds in water the night before planting. The plant is salt-tolerant in its mature state, but less tolerant during germination, since the presence of NaCl inhibits germination [7]. Seeds are commercially available. Seedlings are sensitive to long-term flooding, but waterlogging up to 20 days can be managed by adaptation mechanisms [9].

The seeds can be broadcasted with a disk planter in rows that are 4 to 5 m apart [10].

Vegetative propagation can be done via tip cuttings. They should be taken before flowering.

Soil preparation before planting is recommended to reduce competition in the young establishment stage.

In the first year one stem is produced per plant, which will increase to about 13 in the next 5 years [10].

Management: The plant is tolerant toward drought and flooded conditions, so alternate water tables can be tolerated. It is a short-lived perennial, only to about 5 years, so allow seedlings to establish as the plant seeds out [1] or a new field has to be established after a couple of years. Some seedlings are added to the crop stand each spring from the seeds shattered during harvesting. Replanting after five years in a no-till mode - planting the new rows at right angles to the initial planting will rejuvenate the stand.

Kosteletzkya pentacarpos is recommended as a low-cost nurse crop in salinized agro-ecosystems to facilitate the establishment of desirable wetland species [11].

Harvest: Harvesting is already possible in the first year after plantation, when seeds are mature in September [8]. Either by direct combining or by cutting and wind-rowing the plants. After about five days of drying, the plant material can be combined. Direct combining results in more shattering loss [JG, pers. comm.]. The stems are then baled. Harvesting is possible either with conventional heavy machinery, but in doing so the field must be dry. Drainage may be necessary for wet sites. Using adapted light machinery like caterpillars or Seigas with a swathing mower and an adapted combine could also be possible, even without drainage of wet soil.

Productivity: In field trials in the U.S., seed yield ranged between 800 and 1,500 kg seeds/ha [10], [11], with a maximum seed oil yield of 330 kg/ha [10]. In China, the seed yield ranged between 603 and 957 kg seeds/ha with an oil content from 17.4 and 20.6 % [8]. Older plants are more productive than the young ones, because the number of stems is increasing with age.

The stem yields are variable depending on salinity, drainage, and genotype of the plant. Stem yields for first year plants range from 0.8 to 2.4 t/ha and the leaf standing crop at fruit set was 0.8 t/ha [John Gallagher, pers. comm.].

Cultivation experiences: Cultivation trials are known from the USA, Egypt [10], [11] and China [3], [8], [12]. It was introduced to China as a potential species to improve tideland and develop ecologically sound saline agriculture.

Utilisation

Human food: The leaves can be used for food, raw or cooked [13], [14], [15]. They are used as a potherb or to thicken soups [16], [17]. The leaves can be eaten raw but are rather fibrous and somewhat hairy, though the taste is pleasant [4]. The flowers can be eaten raw or added to salads [18]. The oil from the seeds is edible [2].

Fodder: Seeds or residuals from seed oil production can be used as cattle or fish feed [2].

Ornament: The plant has beautiful flowers with a relatively long flowering period. It can be used as a landscape plant for coastal areas [19].

Fuel: It can be used as a feedstock for production of biodiesel from seeds [8], [10] and ethanol from residual stem biomass. The seeds contain 19.3 mass % oil, which after extraction with hexane and pre-treatment with catalytic sulfuric acid can be converted into methyl esters in 94 mass % yield, utilizing homogenous base catalysis. The principal components are methyl linoleate (48.9 %), palmitate (24.4 %), and oleate (18.3 %). The stems and other residuals can be converted into sugars and ethanol [10]. Stem biomass provided ethanol and xylose yields of 104 g/kg and 47.8 g/kg, respectively [10].

Raw material for industry: A strong fibre can be obtained from the stems. It is used for making string, nets, clothes etc. [5]. *Kosteletzkya pentacarpos* bast fibres have good mechanical properties and excellent hygroscopicity, making it an ideal candidate for new textile materials [20].
Other uses could be: kitty litter, bedding for small mammals (e.g., rabbits), hydromulch for grass seeding or bioabsorbent for organic liquids [21]. Mucilage from seeds is possibly suitable for industrial use as candy or gum [2], [22].

Co-benefits: The flowers provide nectar for honey. The plant is used for wetland restoration and soil improvement [3], [12].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Pictures: Jason Sturner; Tim & Selena Middleton (detail)

Larix laricina (Du Roi) K.Koch

tamarack (Ostamerikanische Lärche)

Family: Pinaceae
Life form: tree
Main use category: raw material, fuel
Used part: wood

General information

Morphology: Perennial. 15-20 m high. Trunk up to 60 cm in diameter. Bark is tight and flaky, pink, but under the flaking bark it can appear reddish. Leaves needle-like (coniferous), 2-3 cm, light blue-green, turning bright yellow before falling in autumn (deciduous). Needles spirally on long shoots and in dense clusters on short woody spur shoots. Monoecious. Cones 1-2.3 cm long (smallest of any larch), 12-25 seed scales, bright red. Cones turning brown and opening to release the seeds when mature [1]. Potentially peat forming [2].

Geographic distribution: Northern N. America - Alaska to Labrador, south to West Virginia [3]. Forms the tree line to the north alone or with *Picea mariana* [4].

Natural habitat: Often forming pure forests in the south of its range on mires (fens and bogs) and on wet soils [5], [6], [7], [9] sometimes also on dry plateau or slopes in the north of its range [6], [8].

Site specific properties

Water regime: moist-wet
Trophic conditions: meso-, eutrophic
pH: subneutral
Light conditions: shade intolerant
Salinity: low tolerance

Cultivation

Natural stands of tamarack are widely used in boreal N. America, where they occur on a wide range of peatlands. Plantations are unusual due to the difficult propagation and establishment. Stimulation and improvement of natural regeneration can lead to the preservation of a sustained yield of wood. Paludiculture with this species is not known to the authors, however.

Propagation and establishment: The establishment of *Larix laricina* is quite difficult.

The seeds germinate poorly, even under greenhouse conditions [9]. Cold stratification for one month favours germination [10]. Natural seed establishment is hindered by strong rodent predation, damage by fungi or bacteria and shading [11]. The best seedbed is warm, moist mineral or organic soil with no brush but a light cover of grass or other herbaceous vegetation. Hummocks of slow-growing sphagnum moss often make a good seedbed, but some sphagnum mosses may offer too much competition [12]. The seed can be sown in an outdoor seedbed in late winter and transplanted into their permanent position when they are a few centimetres tall [3]. Tamarack seedlings are very small and easily killed during the first 6-8 weeks after germination, caused by damping-off; in the second and third years, drought, drowning, and inadequate light sometimes cause considerable loss [12]. The seed remains viable for 3 years [10]. Open-grown trees, 50-150 years old, produce the best cone crops. Good seed crops are produced at intervals of 3-6 years [11].
Vegetative reproduction is uncommon. However, layering occurs when branches are covered by sphagnum mosses and roots are known to produce shoots [12]. An experiment in Ontario shows that tamarack can be easily propagated from cuttings taken in early July from young trees (probably less than 5-7 years old) [13]. Site preparation is necessary to reduce competitors. Trees should be planted at wide spacings [11]. Tamarack is susceptible to damage from long-term flooding, so it is best to plant the young trees on ridges.

Management: Tamarack is shade intolerant, even-aged management is therefore recommended to maintain the stand, otherwise tamarack will be suppressed by more competitive species [9]. Little information is available on intermediate cutting methods. Thinning is probably economically feasible only on productive sites when the objective is to grow high quality products. Periodic thinning is recommended up to 20 years prior to the end of rotation [9].
A combination of clear-cut and seed-tree strips is recommended to rejuvenate the stand. Strips in sets of three are suggested: the first two would be clear cut progressively and the last strip would leave the seed trees that provide the seed crops for the natural regeneration [9].

Harvest: Rotations of 70-100 years are recommended [9]. Harvesting should be done in winter after the ground is frozen and snow-covered to minimize peat disturbance and its harmful effect on water quality. Harvesting of the timber from peatlands can create severe forest renewal problems, unacceptable increases in the ground water levels, fast growing ground vegetation competition, and these problems are magnified when the final fellings are carried out as clear cuts [14].

Productivity: Growth differs strongly between sites, with much slower growth on nutrient poor sites. Little is known about the growth and yield of tamarack. No yield tables have been published [9]. Limited data indicates exemplary yields as follows:
- annual growth of pole-size stands in Minnesota: 1.9-2.5 m^3/ha;
- annual growth of a 70- to 100-year-old stand: 3.8 m^3/ha;
- the basal area ranges from 12.6 to 23.4 m^2/ha on medium to poor peatland sites in Minnesota [9], [12].

Cultivation experiences: Known from N. America [15].

Utilisation

Human food: The young shoots are used as an emergency food [16]. A tea is made from the roots [17], or from the branches and needles [18].

Medicine: Tamarack was employed medicinally by a number of North American indigenous groups to treat a variety of complaints [18]. It is little used in modern herbalism. A tea made from the bark is alterative, diuretic, laxative and tonic [7], [19]. It is used in the treatment of jaundice, anaemia, rheumatism, colds, and skin ailments [7], [18]. Gargled, it may give relieve from sore throats, and with a poultice of it, sores, swellings, and burns can be treated [7], [18]. A tea made from the leaves is astringent [7], [19]. It is used in the treatment of piles, diarrhoea etc. [7]. An infusion of the buds and bark is used as an expectorant [18]. The needles and inner bark are disinfectant and laxative [18]. A tea is used in the treatment of coughs [18]. A poultice made from the warm, boiled inner bark is applied to wounds to draw out infections, to burns, frostbite and deep cuts [18]. The resin is chewed as a cure for indigestion [7]. It has also been used in the treatment of kidney and lung disorders, and as a dressing for ulcers and burns [8].

Ornament: The tree has been infrequently planted for ornamental purposes [13].

Fuel: The wood is used as fuel wood [13].

Raw material for industry: The wood is very strong, heavy, hard, and durable even in water. It weighs 625 kg/m^3 and is used for telegraph poles, fence posts etc. [8], [20], [21], [22], [23], or for pulpwood. The diameter is usually too small for saw timber [13]. The roots have been used as a sewing material in canoes and to make durable bags [18]. The roots are often curved by as much as 90° and are used by builders of small ships [8].

Resin is extracted by tapping the trunk. It is obtained from near the centre of the trunk [22], one properly made borehole can be used for 20-30 years [24]. The resin has a wide range of uses including wood preservatives, medicinal etc. The hole is made in the spring and the resin extracted in the autumn [24]. The bark contains tannin [25].

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Picture: Stephen Lea

Liquidambar styraciflua L.

sweet amber, sweetgum (Amerikanischer Amberbaum)

Family: Altingiaceae
Life form: tree
Main use category: raw material, energy, ornamental
Used part: wood, plant, resin

General information

Morphology: Perennial. Height up to 41 m. Leaf stipules linear-lanceolate, 3-4 mm, early deciduous, leaving 2 stipular scars adaxially near base of petiole. Leaf blade palmately lobed, 7-19 × 4.4-16 cm, surfaces glabrous. Monoecious. Staminate flowers in pedunculate clusters, 3-6 cm; perianth absent; stamens 4-8, falling after anthesis. Pistillate flowers without perianth; hypanthium disc-like. Capsular heads brown at maturity, globose, 2.5-4 cm in diameter. Seeds apically winged, 8-10 mm [1].

Geographic distribution: Eastern N. America - Connecticut to Florida, west to Texas and Illinois; Mexico; C. America - Belize and Honduras to Nicaragua [1].

Natural habitat: Occurs in moist or wet woods, tidal swamps, along streambanks, in drier areas, clearings and old fields, and in low swampy bottomlands where they often form pure stands [2].

Site specific properties

Water regime: moist
Trophic conditions: eutrophic
pH: acid-subneutral
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

Liquidambar styraciflua is a fast-growing and long-lived tree that is fairly free from pests and diseases [3], and one of the most important commercial hardwoods in the south-eastern U.S. Cultivation instructions are available, since it is a popular ornamental tree. The ecological amplitude suggests that the cultivation in moist peatlands is possible, most likely with weaker productivities. Peat conservation is doubtful. It should be cultivated in peatlands that are not completely rewettable. The tree cannot tolerate long periods of flooding [4]. According to an ecological study in Florida, sweetgum achieved greater net heights on muck (peat) soils than on other, e.g. sandy soils, but the net height was greater under moist than inundated conditions; total biomass was maximum on moist organic soils [5].

Propagation and establishment: *Liquidambar styraciflua* can be propagated via seeds. Natural regeneration may occur also from stump and root sprouts [6]. Seeds may be sown in fall in a nursery or may be stratified over winter and sown in spring. Germination rates are often poor. The seedlings can be planted into their permanent positions in early summer of their second year [7]. Results of early plantation establishment and development have been quite variable. This variability in growth has been attributed to seedling quality. Seedlings with a large root-collar diameter achieve the best growth, and planting seedlings with a root-collar diameter of less than 6 mm is not recommended [8]. Sweetgum has a slow early growth rate and needs weeding to reduce competitors. The tree is not tolerant of constant flooding, thus planting on ridges is recommended to reduce the risk of flooding. Mature trees withstand winter flooding and should survive standing water for half of an occasional growing season. Established seedlings usually will not tolerate more than a couple of months of inundation in the growing season [9].

Plantation design depends on the utilisation goal. Generally, spacings of 2-3 m are used. Maximum stocking for saw timber production should be no more than 5,000 trees per ha and the minimum should be no less than 1,250 [9]. Sweetgum is also able to reproduce through coppice [10]. The tree can be managed in short rotation with higher densities (1,800 trees/ha) that may be more suited to biomass harvests on rotations of 12-14 years. Slightly lower densities (1,050-1,350 trees/ha) could offer more flexibility and similar yields at slightly longer rotations of 15 years [11]. Trees smaller than 40 cm d.b.h. will reproduce readily from stump and root sprouts. For best results, trees have to be cut as low as possible, preferably no higher than 30 cm above the ground [9].

Management: Moderate thinning stimulates epicormic branches, primarily on trees with light to moderate crown development [12]. Since sweetgum shows a slow early growth rate, commercial thinning should be done at 20-25 years [13]. From then to final harvest, a thinning schedule is recommended as presented in [9], [14].

Harvest: The low load-bearing capacity of wet peat soil makes harvesting difficult. Harvesting should be done with machinery adapted for wet conditions, use of the cable way technique, or use of helicopters to minimize peat disturbance and its possible harmful effect on water quality. When the tree is grown for short rotation coppice, the biomass is harvested after 12-15 years [11]. Pulpwood can be harvested after 20-30 years; saw logs for lumber and veneer after (40)60-80 years.

The aromatic resin 'Storax' can be obtained from the trunk of this tree [15], [16], [17], [18]. It forms in cavities of the bark and exudes naturally. It is harvested in autumn [19], [20]. Production can be stimulated by beating the trunk in the spring [20], [21].

Productivity: Sweetgum has a slow to medium height growth rate of 30-60 cm per year [22]. The average 10-year diameter growth for overmature sweetgum in the southern region of the U.S. was reported to be 4.8 cm, and for immature trees of medium to high vigour 8.9 cm [23]. In the Mississippi Delta, pure stands of sweetgum average 84-112 m^3/ha. Very good stands have 210 to 280 m^3/ha with up to 420,560 m^3/ha on small, selected areas [4]. The growth rate declines markedly with increasing age [13].

Cultivation experiences: Sweetgum is used in N. America for pulpwood and saw timber, and in Europe it is cultivated for ornamental purposes.

Utilisation

Human food: A chewing gum and a stabilizer for cakes is obtained from the resin [24], [25], [26], [27]. It can also be chewed to sweeten the breath [28].

Medicine: A resin obtained from the trunk of the tree is antiseptic, carminative, diuretic, expectorant, sedative, stimulant, vulnerary, and can be used as a parasiticide, poultice and salve [15], [16], [17], [21], [26], [29], [30], [31], [32], [33]. It is chewed in the treatment of sore throats, coughs, asthma, cystitis, dysentery etc. [20], [32], [34]. Externally, it is applied to sores, wounds, piles, ringworm, and scabies [20], [32].
The resin is an ingredient of 'Friar's Balsam' (also known as copal balsam), a commercial preparation based on Styrax benzoin that is used to treat colds and skin problems [20].
The mildly astringent inner bark is used in the treatment of diarrhoea and childhood cholera [32].

Ornament: *Liquidambar styraciflua* is valued as a cultivated ornamental tree for its dramatically colored fall foliage. The resin has a wide range of uses including incense, perfumery, and soap [26].

Fuel: The wood can be used as a fuel. Sweetgum has a good potential to be used as a bioenergy crop in short rotation [11], [35].

Raw material for industry: The wood is heavy, fairly hard, fine-grained, not strong, light, tough and resilient. It weighs about 593 kg/m^3 [3]. The wood takes a high polish, can be stained, and then used as a cherry, mahogany, or walnut substitute [21]. It is also used for furniture, flooring, fruit dishes, veneer, plywood etc. [3], [15], [17], [26], [36]. The resin has a wide range of uses including incense [37], perfumery, soap and as an adhesive [26].

Co-benefits: Used for wetland restoration.

Further reading: [9], [14]

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Picture: Kristian Peters

Lotus pedunculatus Cav.

Lotus uliginosus Schkuhr (Syn.)
marsh bird's-foot trefoil
(Sumpf-Hornklee)

Family: Fabaceae
Life form: forb/herb
Main use category: fodder
Used part: aboveground biomass

General information

Morphology: Perennial. Height 15-60 cm. Stoloniferous and shallowly rhizomatous plant. Stems herbaceous, hollow, erect or ascending, scrambling. Leaves glabrous to pubescent, pentafoliolate (3+2), leaflets 10-25 mm long. Hermaphrodite. Inflorescence umbel-like, comprising 5-12(-15) flowers, yellow, often with reddish veins. Growth habit: tall in leniently managed stands, or prostrate, mat-forming in intensively managed stands [1].

Geographic distribution: Primary distribution in W. Europe and the Mediterranean coast of N. Africa; secondarily in New Zealand, coastal SE. Australia, and to a lesser extent in NW. USA and S. America [2].

Natural habitat: Common in wet meadows and woodland, marshes, freshwater margins and ditches, at altitudes up to 1,500 m [1].

Site specific properties

Water regime: moist-wet
Trophic conditions: meso-eutrophic
pH: acid-subneutral
Light conditions: shade intolerant
Salinity: low tolerance

Cultivation

Lotus pedunculatus is a common forage legume, usually grown in acid and wet situations (poorly drained or high rainfall), where other legumes have difficulty in establishing themselves or persisting [3]. It can withstand long periods of surface flooding by fresh or slightly salty water [1]. It has been successfully cultivated on acidic, waterlogged peatlands in Scotland [4]. Therefore, its utility in paludiculture elsewhere appears possible as well.

Propagation and establishment: Vegetative or generative propagation is possible. It can be established using 10-20 cm long stem sections, planted on a 25-50 cm grid, or from seed, sown at 1-3 kg/ha [1]. Best sown in spring, but it can also be sown in spring or autumn when the climate is warm temperate. Germination rate and percentage increases above 5°C, but generally it shows a slow germination and seedling growth. Normally sown when temperatures exceed about 10°C [1]. The optimum depth is 10-15 mm with a light but firm soil cover [2]. The seed usually germinates in 2-4 weeks at 15°C [5]. If sown in autumn in cold temperate climates, diploid cultivars are sown at 1-3 kg/ha and tetraploids (e.g., Grassland Maku) at 1-5 kg/ha, the higher rates being used for difficult conditions or when surface-seeded [2]. Seeds can also be oversown into existing grassland following stock trampling in the pre-sowing situation to create bare soil spaces and then trampling again post-sowing to encourage soil-seed contact [2]. Natural reseeding and spread by rhizomes aid its persistence [2].

Management: After the plants are well established, they can withstand long periods of surface flooding during winter or dormant season. Summer flooding is not acceptable because no growth is made during the time it is submerged [6]. To achieve good yields, the water table must be near, but not above, the surface in the growing season [6]. It shows slow regrowth after grazing. Specialized grazing management to quickly re-establish an active shoot population is necessary [3].

It is adapted to infertile soil conditions but responds well to improved fertility [2]. Application of P and K to infertile soils benefits the yield [2]. In a pilot experiment in Scotland, *L. pedunculatus* was successfully grown on wet acid peat with the application of 5 t/ha of limestone (52 % CaO) and 2.5 t/ha of basic slag (9 % P_2O_5) in a two year interval [4]. A growth comparison of different cultivars is available [4].

Harvest: Lax, rotational grazing is needed in late summer and autumn in order to encourage rhizome growth and spread, and hence aid stand persistence and yield [3]. Mowing is also possible, making it a suitable species for conservation as hay or silage [2].

Productivity: Under ideal conditions yields can reach 12 t DM/ha, although yields are more commonly around the order of 3-8 t DM/ha [1]. In a pilot experiment in a wet acid peatland in Scotland the annual yield was 2.1 t DM/ha (harvest in July and September) [4].

Cultivation experiences: Its use for acid, wet peatlands has been advocated in New Zealand [3], [6], [7] and in Scotland (UK) [4].

Utilisation

Animal fodder: *Lotus pedunculatus* is used as a pasture for cattle and sheep. It is also suitable for conservation as hay or silage. It is a fair pasture herb on wet fen meadows. The energy content depends on harvest time. It differs from 6.2 MJ NEL/kg DM in May to 4.2 MJ NEL/kg in July [8].
Condensed tannins (CT) are present in *Lotus* spp., depending on their concentration in the plant, and can prevent bloating and improve protein absorption in ruminants [9]. Low levels of CT in the feed improve the utilization of protein by ruminants without affecting the consumption or the digestibility of carbohydrates [10]. *Lotus pedunculatus* has a high genotypic variability in CT, but tends to overcharged CT production which has the potential to limit the use in feeding rations [11].

Ornament & Co-benefits: Used as a ground cover under fruit trees and in agroforestry [1].

Further reading: [4], [3], [6]

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Kristian Peters

Lotus tenuis Waldst. & Kit.

Lotus glaber Mill. (Syn.)
narrow-leaf bird's-foot trefoil, slender trefoil (Schmalblättriger Hornklee)

Family: Fabaceae
Life form: forb/herb
Main use category: fodder
Used part: aboveground biomass

General information

Morphology: Perennial. Height: 20-100 cm. Stem slender, erect or ascending. Leaflets 5, obovate-oblanceolate to linear, 1-4 mm wide. Hermaphrodite. Inflorescence in umbels (1-)2-5-flowered; peduncle 3-12 cm. Corolla yellow. Flowering May to August; fruits July to September. Taproot [1].

Geographic distribution: Primary distribution in NW., E. and central Europe, Mediterranean basin, SW. and E. Asia; secondarily in Argentina and parts of the USA, mainly W. and NE. states [2].

Natural habitat: Saline, poorly drained grasslands of lake or swamp shores [1], forest glades and felled areas, wet sandy seashores [3], coastal flooding peatlands [12].

Site specific properties
Water regime: moist-wet
Trophic conditions: meso-eutrophic
pH: subneutral-alkaline
Light conditions: shade intolerant
Salinity: medium tolerance

Cultivation

Lotus tenuis grows on coastal flood peatlands that are used traditionally as wet grasslands. Highly acceptable to livestock whether at leafy grazing stage or as conserved hay or silage. Cultivation is common in the flooding Pampa, Argentina, and probably transferable to paludiculture. However, no cultivation reports are known to the authors, probably because of lower productivity.

Propagation and establishment: Generative propagation via seeds with a poor to medium seedling vigour [4]. It is used in seed mixtures for pasture and for soil stabilisation in the USA, sown at 5-8 kg/ha (circa 900,000 to 1,000,000 seeds per kg) [4]. The plant does not compete well with weeds because of slow germination and seedling development [4]. Flooding is probably destructive during the establishment phase, but can be tolerated for some time [5]. *L. tenuis* has two strategies either to escape from partial submergence by elongating its shoot more vigorously to avoid becoming totally submerged or to adopt a non-elongating quiescent strategy when completely immersed that is based on utilizing stored reserves [6].

Management: *Lotus tenuis* seedling recruitment can be increased by controlled extensive grazing. Continuous and heavy grazing can negatively affect seed production and plant survival [7], [8]. Thus, the soil seed bank can be significantly reduced and affect the persistence of plant population [9]. Seed limitation can be minimized through seed additions or the exclusion of grazing during the reproductive period [10].

Harvest: In the United States it can be harvested for hay in June. It flowers from June to July and can be grazed until September [11].

Productivity: Yields of 4-6 t DM/ha in the first year and 5-9 t/ha in subsequent years have been obtained in central Chile [11]. In general, it is less yielding than other trefoil species.

Cultivation experiences: Argentina; USA, mainly W. and NE. states, where 8,000 ha and 4,500 ha, respectively, are sown annually [2].

Utilisation

Animal fodder: *Lotus tenuis* is used for pasture and as hay [11]. Its utility as such is largely determined by the stage of growth, since its value decreases with plant maturity. It represents an acceptable forage for grazing at vegetative stage [4], [12]. It is protein-rich, and contains condensed tannins, often in concentrations suitable to enhance protein utilisation [13]. After [12] it has a German forage value (Futterwertzahl) of 7.

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Kristian Peters

Lycopus europaeus L.

gypsywort, European bugleweed (Ufer-Wolfstrapp)

Family: Lamiaceae
Life form: forb/herb
Main use category: medicine
Used part: aboveground green parts

General information

Morphology: Perennial. Height 15-80 cm. Rhizomes transverse, producing long stolons enlarged at apex, with scale-like leaves. Stems erect, unbranched or apically branched. Leaf blade oblong-elliptic to lanceolate-elliptic, 3-9 × 1-4 cm or more, apex acuminate; lower and mid stem leaves coarsely dentate. Hermaphrodite. Calyx ca. 3 mm, ± conspicuously 10- to 15-veined; teeth 4 or 5. Corolla white, red spotted on lower lip, tube ca. 2.5 mm, intricately white villous inside. Flowering June to August. Nutlets 4-sided, ca. 1.5 × 1 mm, areolae basal, white. Fruiting August to September [1].

Geographic distribution: Europe, throughout the Mediterranean, N., W. and C. Asia [2]. Introduced to N. America [3].

Natural habitat: Close to rivers, streams and in ditches; also in marshes and fens [4], [5].

Site specific properties

Water regime: wet-flooded
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: intermediate shade tolerance
Salinity: no tolerance

Cultivation

Paludiculture is unknown with *Lycopus europaeus*. Propagation methods are available and may be applicable to peatlands. Paludiculture looks promising as long as the demand for biomass is sufficient for an economic benefit.

Propagation and establishment: *Lycopus europaeus* can be propagated generatively via fruits or vegetatively via division. The seeds should be sown in spring or autumn in a cold frame [6]. The seedlings can be planted out into their permanent positions in early summer of the next year [2].

Vegetative propagation is possible with divisions that can be taken in spring or autumn [6]. Larger clumps can be replanted directly into their permanent positions, although it is best to grow smaller clumps in a cold frame for their first winter until they are rooting well [2]. *Lycopus europaeus* tolerates most soil types as long as they are wet.

Management: No information found.

Harvest: The plant is harvested as flowering begins and can be used fresh or dried, in an infusion or as a tincture [7], [6]. Most likely it is currently harvested by hand from wild stocks.

Productivity: No information found.

Cultivation experiences: Unknown to the authors.

Utilisation

Human food: The root is edible raw or cooked. Being considered a famine food, it is used in times of scarcity only [8].

Medicine: The fresh or dried flowering herb is astringent and sedative [7]. It inhibits iodine conversion in the thyroid gland and is used in the treatment of hyperthyroidism and related disorders [4], [6]. The whole plant is used as an astringent, hypoglycaemic, mild narcotic and mild sedative [7], [6]. It also slows and strengthens heart contractions [6]. In addition, it is used in the treatment of coughs, bleeding from the lungs and consumption, excessive menstruation etc. [7], [6]. The leaves are applied as a poultice to cleanse foul wounds [9]. This remedy should not be prescribed for pregnant women or patients with hypothyroidism [6]. *L. europaeus* shows endocrine effects following oral application [10].

Ornament: *Lycopus europaeus* is sold as an ornamental plant in specific nurseries.

Raw material for industry: A black dye is obtained from the plant [7], [11]. It is said to give a permanent colour and was also used by gypsies in order to darken the skin [7].

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Picture: Keisotyo

Marsilea quadrifolia L.

water clover (Klee-Farn)

Family: Marsileaceae
Life form: fern
Main use category: medicine
Used part: leaves

General information

Morphology: Perennial. 7-20 cm high. Rhizomes slender, creeping, bearing leaves and roots at each node. Leaves glabrous, long-petiolate; lamina cruciformly 4-foliate, consisting of 2 contiguous pairs of opposite, sessile, obdeltate leaflets, 7-21 × 6-19 mm. Sporocarp 3-5 mm, ellipsoid, pedicellate, brown to blackish with brown hairs, 2-chambered, dehiscent into 2 valves, stalked or sessile. Sori 10-17 within a delicate indusium. Roots arising at nodes; 1-3 also on internodes. Plants forming diffuse clones [1], [2].

Geographic distribution: C. and S. Europe, Caucasia, western Siberia, Afghanistan, SW. India, China, Japan, Australia and N. America. Considered a weed in some parts of the United States where it has been introduced in the north eastern states. Threatened in Europe [3].

Natural habitat: It can be found in shallow waters of lakes, ponds or quiet sections of rivers and streams and on wet shores. It is tolerant to a range of water conditions and requires a permanently moist or wet soil and thrives on muddy ground, loam or peat [4], [5].

Site specific properties

Water regime: moist-wet-flooded
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Paludiculture with *Marsilea quadrifolia* is unknown. The ecological amplitude suggests that a wet cultivation in peatlands is possible. Propagation methods are available from the use as an ornamental plant and probably transferable to peatlands. Paludiculture looks promising as long as the demand for biomass is sufficient for economic benefits.

Propagation and establishment: Generative propagation via spores. The plant produces sporocarps, which need to be lightly abraded and then immersed in water. The sporocarps will then swell and burst to release the spores. The spores germinate immediately, while the highly developed prothallus remains inside the large seed-like spores [6]. The gametophyte generation is completed in 24 hours and the first roots and shoots appear in 2-3 days. Mature plants bearing sporocarps can develop in as little as 3 months [7]. It can also be propagated vegetatively via divisions [6].

Management: No information found.

Harvest: Unknown, but most likely gathered by hand.

Productivity: Net primary productivity in a sewage-sullage mixture system is 7.2 t/ha*yr [8].

Cultivation experiences: Unknown, except for for ornamental use.

Utilisation

Human food: Young stems and leaves are edible [9], [10]. Being a famine food, it is used in times of scarcity only [11]. In Cambodia, however, it seems to be used as food beyond times of scarcity [4]. Data about the nutritional composition are available [12]. The spores are produced in a sporocarp which in allied species is ground up and mixed with flour etc. and used in making bread and other baked goods. Rich in starch [13].

Medicine: A juice made from the leaves is diuretic and febrifuge [11]. It is also used to treat snakebites and applied to abscesses etc. [11]. The plant is anti-inflammatory, diuretic, depurative, febrifuge and refrigerant [14], [15], [11]. A crude extract of *M. quadrifolia* shows antibacterial, cytotoxic and antioxidant activity [16].

Ornament: Used as an ornamental plant for water gardens or aquariums [4].

Animal fodder: In Australia it is much relished by livestock [4].

Co-benefits: It can be used for wastewater treatment [8].

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Picture: Kristian Peters

Mentha aquatica L.

water mint (Wasser-Minze)

Family: Lamiaceae
Life form: herb
Main use category: medicine, food
Used part: leaves

General information

Morphology: Perennial, 20-90 cm high. Stem square in cross section, green or purple. Leaves ovate to ovate-lanceolate, 2-6 x 1-4 cm, green (sometimes purplish), opposite, petiolate, toothed, hairy to nearly hairless. Hermaphrodite. Inflorescence 2-3 congested vertical lasters with inconspicuous bracts, forming a terminal head. Corolla lilac. Flowering mid to late summer. Rhizomes wide-spreading, fleshy. Root fibrous. Plant spreads by underground rhizomes [1], [2].

Geographic distribution: S. and E. Europe to N. Africa, SW. Asia, and S. Africa [3].

Natural habitat: Swamp, fen, marsh, near rivers, streams and ponds, in wet woods (carrs), wet meadows and nutrient rich waters [4], [5].

Site specific properties

Water regime: wet-flooded
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Mentha aquatica is a mint species adapted to wet conditions. It has similar properties and utilisation options like the economically used (hybrid) mint species. Breeding techniques could improve properties of *Mentha aquatica*. Paludiculture is unknown. Propagation methods are known from gardening and are probably transferable. The ecological amplitude suggests that cultivation in wet peatlands could be possible.

Propagation and establishment: *Mentha aquatica* can be propagated generatively via fruits or vegetatively via division. The seeds can be sown in spring in a cold frame [3]. Germination is usually fairly quick and the seedlings can be planted out in the summer [3]. *Mentha* species are very prone to hybridisation. Even without hybridisation, seedlings will not be uniform and so the chemical make-up (including its medicinal oils) will vary. When growing plants with a particular

aroma it is best to propagate them by division [3]. Vegetative propagation is done via division that can be taken in spring or autumn. Larger divisions can be planted out directly into their permanent positions. But for maximum increase it is possible to divide the roots up into sections, no longer than 3 cm, and pot these up in light shade in a cold frame. They will quickly become established and can be planted out in the summer [3].
The cultivation site should be weed free before seeding or planting. Control of invading weeds is important within the whole establishment phase. High water tables will probably help to out-compete weeds.

Management: No specific information found.

Harvest: The leaves are harvested as the plant comes into flower and can be dried for later use [6]. The plant, harvested before flowering, yields about 0.8 % essential oil [7].

Productivity: No information found.

Cultivation experiences: Cultivation is only known from gardening. In general, the economic use and cultivation is done with other *Mentha* species.

Utilisation

Human food: Leaves are edible raw or cooked. They have a strong distinctive peppermint-like fragrance [8]. They can be used as a flavouring in salads or cooked foods [9]. The leaves are too pungent for most people to use as flavouring [10]. A herb tea is made from the leaves [11], [8].

Medicine: The leaves are anodyne, antiseptic, antispasmodic, astringent, carminative, cholagogue, diaphoretic, emetic, refrigerant, stimulant, stomachic, tonic and a vasodilator [12], [4], [11]. A tea made from the leaves has traditionally been used in the treatment of fevers, headaches, digestive disorders and various minor ailments [13]. It is also used as a mouth-wash and a gargle for treating sore throats, ulcers, bad breath etc. [4]. The essential oil in the leaves is antiseptic, though it is toxic in large doses [13]. Mild psychoactive constituents are reported [14].

Ornament: The plant is used as an ornamental plant in water gardens.

Animal fodder: It provides a good additive in animal fodder from wet meadows or reed beds [anonymous farmers, pers. comm.].

Raw material for industry: The plant repels flies, mice and rats [15], [16], [10]. It has a pleasant, fresh scent and was formerly used as a strewing herb in granaries to keep mice and rats off the grain [15], [10]. The fresh or dried plant is used in herbal baths and in herb pillows [10].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Anneli Salo

Menyanthes trifoliata L.

bog-bean, buckbean (Fieberklee)

Family: Menyanthaceae
Life form: forb/herb
Main use category: medicine
Used part: leaves

General information

Morphology: Perennial, 12-35 cm high. Stem glabrous with a stout, creeping rhizome. Leaf blades erect, long-petiolate; leaflets shortly petiolate, elliptic, up to 10 cm, margin entire or crenulate, apex obtuse. Hermaphrodite. Inflorescences 10- to 20-flowered racemes, 30-35 cm including scape. Corolla pink outside, paler or white inside, tubular, ca. 15 mm in diameter. Fruit a capsule (up to 10 mm long). Flowering and fruiting May to July [1], [2], [3].

Geographic distribution: Europe, from Scandinavia south and west to Spain, N. and C. Asia, Morocco (N. Africa) [4] and N. America, except the south [5].

Natural habitat: Grows in or on the edges of lakes, slow flowing rivers, and in mesotrophic peatlands [6], [3].

Site specific properties

Water regime: wet-flooded
Trophic conditions: mesotrophic
pH: acid-subneutral
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

Menyanthes trifoliata grows naturally in wet peatlands. Paludiculture is unknown. It is a threatened species in many countries of Central Europe where its collection from the wild has been restricted. Cultivation in rewetted peatlands could help to conserve wild stands.

Propagation and establishment: *Menyanthes trifoliata* can be propagated generatively via seeds or vegetatively via divisions. The seeds can be sown in late winter to early spring in a cold frame. Scarification can be necessary, since the seed coat is very thick, otherwise it can take at least 6 months until germination [3]. The seed should not dry out. The seedlings can be planted out in late spring or early summer after the last expected frosts [4]. Plant divisions can be planted straight out into their permanent positions or cuttings taken in summer can be inserted directly into wet soil [4]. Plants can be very invasive, spreading by means of long-creeping thick surface rhizomes [7]. The side should be weed free before seeding or planting. Control of invading weeds is important within the whole growing phase.

Management: The peat must be kept wet because drought greatly affects the survival of plants [8].

Harvest: The leaves are best harvested in late spring or early summer and dried before use [9], [10]. For economic use they are currently harvested by hand from the wild [11]. *Menyanthes trifoliata* plants can live indefinitely in the wild; while the older plant parts die, new growth is added by vegetative spread from the apex of the rhizome throughout the growing season [3]. A careful partial harvest of leaves could most likely sustain the plant stand and a rotational use over years is possible. It is unknown how much one is allowed to harvest to sustain a stand.

Productivity: In a biomass study in a "rich fen" in Sweden the annual net production was estimated to be only 14-26 % of the total phytomass. The annual leave mass ranged from 10 to 40 g/m² DM, and the stem mass from 9 to 29 g/m² DM [12].

Cultivation experiences: *Menyanthes trifoliata* is grown on a small scale [11]. Cultivation trials have been done in a rewetted fen peatland in NE. Germany [13], and on an artificial peat bed in Finland [8].

Utilisation

Human food: The root is edible when cooked [14], [15]. It must be treated to get rid of an acrid taste [16], [17]. This can be done by drying the root, grinding it into a powder and then washing it in running water [14]. Unfortunately, this treatment will also destroy many of the vitamins and minerals contained in the root [4]. The powder can be used for making 'missen bread' (famine bread) [18]. The root is an emergency food that is used in times of scarcity [19]. The intensely bitter leaves are used as a substitute for hops in making beer [14], [20], [21], [22], [18].

Fodder: It has been used as cattle feed [8], probably in a mixture with various grasses.

Medicine: The plant is anti-inflammatory, astringent, carminative, cathartic, deobstruent, digestive, diuretic, emetic, emmenagogue, febrifuge, hypnotic, stomachic, and tonic [23], [20], [9], [21], [24], [25], [17], [26], [27], [10], [28]. All parts of the plant are medically active, but the leaves are most commonly used [23], [29]. The fresh plant causes vomiting [10]. An infusion is given in the treatment of muscular weakness, chronic infections with debility and exhaustion, indigestion, anorexia, and rheumatism [28]. Given in small doses of about 10 grains it imparts vigour to the stomach and aids digestion [27], [10]. Using the plant helps a person to gain weight [30]. It is also believed to be an effective remedy for rheumatoid arthritis, especially when this condition is associated with weakness, weight loss and lack of vitality [30]. It is used in anti-wrinkle creams.

Ornament: Often used as an ornamental plant.

Further reading: Biomass allocation: [12]; ecology: [3]

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Pictures: Kristian Peters

Metasequoia glyptostroboides Hu & Cheng

dawn redwood, water fir, shui shan (Urweltmammutbaum)

Family: Cupressaceae
Life form: tree
Main use category: raw material, energy, ornamental
Used part: wood, plant

General information

Morphology: Perennial. Height up to 50 m. Trunk buttressed at base up to 2.5 m d.b.h. Leaves deciduous, bluish green or yellowish green adaxially, linear, 0.8-1.5 × 1.2-2 cm. Monoecious. Seed cones purplish black when young; ca. 2 × 2 cm when mature. Seeds ca. 5 × 4 mm. Bark of young trees pale orange-brown with darker flakes and exfoliating, finally dark reddish brown to gray, fissured. Crown narrowly conical or pyramidal, finally broadly conical; branches ascending [1].

Geographic distribution: Naturally only in Sichuan and Hubei provinces in west-central China. This small population is a relic of a former worldwide distribution [2]. Today it is widely planted as an ornamental tree. It has a large geographical distribution under cultivation, e.g., in N. America from Sitka, Alaska south to New Orleans [3]. In colder climates it has a shrub-like growth form [3].

Natural habitat: Riparian habitats on valley floors and in moist ravine bottoms, on acidic, montane yellow-earth soils in regions with moderate climate [1]. Confined to slightly waterlogged areas of open forest [4]. It copes well with normal, well-drained upland soils and also in wet, soggy soils [2].

Site specific properties

Water regime: moist-wet
Trophic conditions: meso-eutrophic
pH: subneutral
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

Dawn redwood is a very fast-growing softwood tree [5] that can grow on wet soil. The tree does not grow on peat soils under natural conditions (within this small valley in China) [3]. The prehistoric distribution and the distribution under cultivation is much larger [3], so it is not unlikely that the tree can grow in wet peat soils, probably given a flow with aerated water.
After one study in Poland, a 25-year-old *M. glyptostroboides* growing on moist peat soil performed better than trees growing on a dry sandy soil [6].

Propagation and establishment: *M. glyptostroboides* is easy to propagate from seed or cuttings (either hard- or softwood cuttings), taken in late summer [7], [8]. Germination takes 5-7 days; the mortality of germinants is high in the first 5-6 weeks [3]. Young specimens are easy to transplant. Once established, they can survive in standing water [2]. Initial planting densities should range between 2,000 and 3,000 trees/ha [9].

Management: In monospecific stands canopy closure occurs rapidly, usually in 10-14 years depending on stem density. Thinning is necessary as *M. glyptostroboides* is a shade intolerant plant [3], [8]. Since much light passes through the crown, plantations require constant weeding [8].

The plants are sometimes damaged by early freezes, so they are best not planted in a depression that collects cold air [2]. At present *Metasequoia* plantations remain free of serious diseases and insect pests [8].

Harvest: The low carrying capacity of wet peat soil makes harvesting difficult. Harvesting should be done with machinery adapted for wet conditions, use of the cable way technique, or others to minimize peat disturbance and its possible harmful effect on water quality.

Productivity: Dawn redwood is a fast-growing softwood tree when grown in good conditions with lots of water. Within 26 years many trees are over 30 m tall and more than 90 cm in diameter [5]. Other studies show that the tree can attain average stem lengths greater than 30 m in less than 50 years [9]. Most of the height growth occurs early in stand development with vertical extension slowing through time [3]. The largest diameter trees can occur in the lowest density stands [9]. An average stem wood estimate for a 40-year-old stand in Japan is 294 Mg/ha [9].

Cultivation experiences: Experiences are available from N. America, Europe and Asia [9], [8], but no detailed information was found for peat or wet soils.

Utilisation

Medicine: The oil and the methanol extract from the floral cones show a great potential of anti-fungal activity, possibly useful as a mycelial growth inhibitor against phytopathogenic fungi [10].

Ornament: *M. glyptostroboides* is a fine, stately specimen for large landscapes such as parks or golf courses. They make excellent avenue trees. Fast growing, with a dense, feathery texture, a stand of *M. glyptostroboides* creates an effective summertime visual screen and windbreak in just a few years. Fall colour is excellent and even the winter silhouette is very attractive with its massive, fluted trunk and strong horizontal branches [2].

Fuel: It has a good potential to be a short-rotation crop tree [5].

Raw material for industry: The wood is soft with pinkish heartwood and white sapwood, is fairly weak and has an excellent resistance to decaying fungi. Although the wood is probably too soft for decking material, it could be used for house siding and shakes, boat houses, outdoor furniture, garden trellises and similar items not requiring strong wood [5].

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Picture: Rosarinagazo

Miscanthus x giganteus J. M. Greef, Deuter ex Hodk. & Renvoize

Giant Miscanthus
(Riesen-Chinaschilf)

Family: Poaceae
Life form: graminoid
Main use category: energy, raw material
Used part: aboveground biomass

General information

Morphology: Perennial. Height up to 4 m high. Culms slender to robust, erect, solid. Leaves basal or cauline; blades large, linear, flat, broad or narrow, white mid-rip. Hermaphrodite. Inflorescence a large panicle of racemes. Sterile. Growth habit tufted or rhizomatous [1], [2], [3], [4].

Geographic distribution: Originally from E. Asia (e.g., China, Japan, Korea, Taiwan). Cultivated in Europe, Africa, S. and N. America [2].

Natural habitat: *M. sacchariflorus*: grows in flood plains and river banks, along streams or ponds [4]. *Miscanthus x giganteus* is only known from cultivation.

Site specific properties

Water regime: moist-wet soil
Trophic conditions: meso-eutrophic
pH: subneutral
Light conditions: intermediate shade-tolerant
Salinity: low tolerance

Cultivation

The perennial grass *Miscanthus x giganteus* is a promising renewable bioenergy feedstock in the United States and Europe. Originating from eastern Asia, this species is a sterile hybrid cross between *M. sinensis* and *M. sacchariflorus*. Cultivation in rewetted peatlands seems feasible since *Miscanthus* has a remarkable adaptability to different environments [5]. It has been successfully cultivated in a rewetted peatland in Tuscany, Italy [6], [7] and [8] reported no reduction of productivity under temporal flooded conditions, even though other references state that stagnant water or wet sites are unsuitable for *Miscanthus x giganteus* [9]. In some cases it is argued that high water tables in the winter or early spring should be avoided because harvest with large equipment is not possible [10]. More research is necessary to demonstrate successful long-term cultivation in wet peatlands and peat conservation. Until now, paludiculture has not been successfully demonstrated. Key disadvantages of *Miscanthus* cultivation are the relatively high establishment costs, narrow genetic base and low hardiness in the first winter after establishment [1].

Propagation and establishment: Since *Miscanthus x giganteus* is sterile and cannot form fertile seeds, it has to be propagated vegetatively by rhizome divisions or plantlets that were micro-propagated in tissue culture (by in vitro tillering) [8]. Propagation by stem divisions is also possible but uncommon [11]. Rhizome division is favoured because it is less expensive and generally produces more vigorous plants [12]. The divisions are produced in nursery fields. Pieces must not dry out after harvest, and storage should be as short as possible. The divisions should be planted in spring after the last expected frost in densities of at least 1 plant/m² [1]. In the first winter following planting, the rather shallow and under-developed rhizomes can easily be destroyed by cold and or wet conditions [13]. It is thus recommended to keep the water tables low in the first winter. Larger rhizome pieces planted more deeply or a covering with straw can increase over-winter survival [14]. Weed control is normally required during the establishment phase [10].

Management: *Miscanthus x giganteus* requires 2-3 years to reach full production potential and has a stand life of about 15 years. *Miscanthus* has a high water demand but also good water-use efficiency [15]. So, plant the crop only in areas where enough water is available to keep constant high water tables. The salt concentration of 150 mM limits *Miscanthus* growth [16].
Miscanthus has in general a low fertilizer demand. The storage of nutrients in the rhizome makes the plant partly independent of the actual N supply from the soil. N fertilization showed no effect at locations with sufficient N mineralization from soil organic matter [17]. Fertilization seems not necessary in eutrophic peatlands.

Harvest: The normal production cycle is a single harvest late in the fall/winter or early spring before new shoots emerge. The later - the better. This allows the nutrients to return to the overwintering organs (rhizome) and the plant material to dry to a moisture content of less than 15 % prior to harvest. Disadvantage of a late harvest is that the yield is reduced because the leaves fall off in winter and the translocation of matter to the rhizome. The harvest equipment needs to be adapted to the typical height (2.5-3.5 m) and stiffness of the stems. Single or multi-phase methods can be implemented. Multi-phase consists of mowing, swathing, picking up, baling or bundling, or chopping with or without further compaction. The plant tolerates low cutting heights [1]. If full drying is not possible in the field, drying is necessary after harvest.

Productivity: Typical range of biomass yield for *M. x giganteus* under temperate conditions in southern Europe is 20-30 t DM/ha [2]. In central and northern Europe where global radiation and average temperatures are lower yields range typically between 10-25 t DM/ha [1]. It has been shown that the total biomass under flooded conditions is not different from the control [8]. Unpublished data for a peatland are available from a pilot site in Tuscany, Italy [7]: one year after establishment, *Miscanthus* already produced 22.4 t DM/ha

[18].

Cultivation experiences: Miscanthus is widely cultivated on mineral soil. The successful cultivation on moist-wet peat soil is known from a pilot site in Italy [6], [7].

Utilisation

Ornament: The flower heads are used in floral arrangements.

Animal fodder: Not recommended in general since digestibility is even lower than that of corn stover (straw from *Zea mays* ssp. *mays)* [19]. *Miscanthus x giganteus* shows some potential as a reserve forage crop in times of scarce hay [20].

Fuel: It is a commercial energy crop, as a source of heat and electricity, or converted into biofuel products such as ethanol. The dried biomass can be used as a solid fuel with a very good combustion quality. The quality increases when the harvest date in spring is delayed [21]. It can be compacted into pellets. The calorific value varies between sites and harvest time; it generally ranges from 17-18.5 MJ/kg.

Agricultural conditioner and substrate: It can serve as raw material for agricultural purposes, e.g., composting [2].

Raw material for industry: The fibres can be used for pulp and paper production due to the relatively high lignin and cellulose content and for building, insulation and packing material [2]. *Miscanthus* biomass can be used for construction materials, like incorporation in manufacture of medium density fibre board (MDF); for thatching - as an alternative to straw as a roofing material and as a raw material for the production of plant pots [12]. The *M. x giganteus* genotypes compared to other *Miscanthus* genotypes were identified as the best ones to be used for lightweight concrete production [22]. The cellulose content and the permanent binding of water in concrete are the most important factors for a good pressure stability of lightweight concrete made out of *Miscanthus*. It is also used as high-quality bedding typically for equine applications.

Co-benefits: The plant can be used for wastewater treatment. Also discussed as a bedding material in husbandry.

Further reading: [2], [12], [1]

Similar species:

M. sacchariflorus (Maxim.) Hack. (Amur silver grass) is native to temperate Asia and is cultivated elsewhere. This plant is capable of producing high yields, has a poor cold tolerance and can be invasive. It has abundant and aggressively spreading rhizomes, which underscores its invasive risk [23].

M. sinensis Andersson (Chinese silver grass): native to eastern Asia throughout most of China, Japan, Taiwan and Korea and invasive in the United States. Tufted growth. Highly productive with improved winter hardiness.

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Hajotthu

Myrica gale L.

sweet gale (Gagelstrauch)

Family: Myricaceae
Life form: shrub
Main use category: medicine, raw material
Used part: leaves, fruits

General information

Morphology: Perennial. Height up to 1.5(-2) m. Stem much branched. Leaves deciduous; blade oblanceolate to obovate, 1.5-6.5 × 0.5-1.5 cm, ± leathery, margins usually minutely serrate; surfaces abaxially pale green, adaxially dark green. Dioecious, rarely monoecious. Inflorescences: staminate flowers ca. 1-1.5 cm. Fruits ovoid, flattened, 2.5-3 mm; fruit wall smooth, with glandular deposit [1]. A suckering shrub, it can form thickets when well sited [2].

Geographic distribution: W. Europe, from Scandinavia to Portugal, east to NW. Russia [3]; N. America [4].

Natural habitat: Bogs, marshes, fens and wet heathland in acid soils, occasionally found in calcareous fens [5], [6], [2], [7].

Site specific properties

Water regime: moist-wet
Trophic conditions: oligo-mesotrophic
pH: acid-subneutral (-alkaline)
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Bog myrtle is harvested from natural stands on peatlands in Scotland and Finland [8], [9]. The cultivation of *Myrica gale* is suitable on normal mineral garden soils and for moderately rewetted peatland areas. Under such moist to wet conditions peat degradation is reduced substantially (compared with deeply drained use) or stopped completely. It might be useful for paludiculture, although its use as such is unknown to the authors.

This species has a symbiotic relationship with certain soil micro-organisms (*Frankia*) which form nodules on the roots of the plants and fix atmospheric nitrogen. Some of this nitrogen is utilized by the growing plant itself, while it can also be used by other plants (e. g., softwood trees [10]) growing nearby [11]. This habit also allows the plant to succeed in water-logged soils [2]. Nitrogen fixation and consequent plant growth is greatest in wet but well-aerated soil [10].

Propagation and establishment: *Myrica gale* can be propagated vegetatively by plant division and generatively via seeds. The seeds are best sown in the autumn in a cold frame. Seeds should be barely covered and kept moist. Germination is improved by 3 months cold stratification [3]. Planting out is to be recommended in late spring to early summer [4].

Vegetative propagation: cuttings of 5-8 cm long half-ripe wood should be taken with a heel in July/August. Cuttings of mature wood are best taken in November/December. In Finland cuttings were taken in the beginning of May, the rooting percentage was 85 % and the potted, well-rooted seedlings were transplanted into mineral soil the next year in April [12], [13]. Division of suckers in the dormant season is also possible. They should be planted out directly into their permanent positions [4].

Populations can be highly variable in productivity (especially in oil yield) depending on the locality. It is therefore advisable to analyse individual plants before cultivation [9].

Management: In an experiment on natural stands in Scotland, fertilizers had no significant effect on productivity [8]. A study in Massachusetts showed that nitrogen fixation provided 43 % of the estimated annual N requirement [14]. Plant growth would be enhanced by the prevention of grazing and could be combined with softwood forestry since the trees would benefit from soil nitrogen enrichment thanks to the symbiotic association of *M. gale* and *Frankia*. [10]. An experiment on a peatland in Finland showed that fertilization (NPK = 75-90-30 kg/ha) and liming (15 t/ha) increased growth in the first year by 40 % and in the second year by 13 %. During the third year, the yield was very low due to iced standing water [13].

A field experiment in Scotland showed that cutting stimulated new shoot growth, the best regeneration was achieved when all stems where cut around at mid-height. For a sustainable harvesting a cutting regime of 8 years is recommended [8].

Harvest: It is harvested by hand or with adapted machinery, such as tracked vehicles with a mowing device. Cutting all stems to mid-height produced the most rapid regeneration. Stems could take 8 years to regenerate to a harvestable size if this cutting method is employed [8]. According to non-published experimental results from Finland, the regeneration of plants, harvested at 20 cm height, was very low [15]. The stems must be longer than 45 cm to be suitable for ornamental purposes; 12 or more suitable stems per m² provide a good yield [8].

Productivity: In a dense natural stand in a peatland in Massachusetts the aboveground biomass was 6 t/ha with stems contributing 75 % and leaves 24 %; the annual aboveground net production was 3.9 t/ha [14]. Annual shoot yield of bog myrtle in an experiment on a peat field in Finland during 2000-2002 with no treatment was 2.7 and 3.0 t/ha in the 1st and 2nd years, and with NPK fertilisation: 3.7 and 3.4 t/ha [12], [13]. When only the young stems are harvested, the percentage of leaf dry weight from total dry weight can be much higher (60-85 %) [9]. A targeted cultivation could improve total productivity [9].

The calculated final commercial dry leaf yield for essential oil production of natural stands is 2.5 t/ha and 0.8 t/ha for Scotland and Finland, respectively [9]. During the 1st and 2nd years the average dry leave yield in the peat field in Finland was 921 kg/ha*year [16], [13]. A more efficient oil production could result from an understanding of the relationship between leaf biomass production and seasonal changes in oil content and quality [10]. A study in Finland and Scotland showed that the oil yield of the leaves was highest at the beginning of the summer season (0.29-0.69 %) and decreased over the following months [9]. The oil yield from flowers was much higher (0.97-1.46 %) [9].

The plant must have 12 or more suitable stems (longer than 45 cm) per m² to provide a good yield for ornamental purposes [8]. In a study in Scotland, *M. gale* had a stem density of 38 ± 65 stems/m² [9].

Cultivation experiences: Known from Finland [16], [12], [13].

Utilisation

Human food: The aromatic fruits and leaves are used either fresh or dried to flavour soups, stews etc. [17], [18], [19], [20], [21], [36]. They are sometimes put in beer and ale to improve the flavour and increase foaming [22], [23], [24]. The dried leaves make a delicate and palatable tea [18], [19], [25], [21].

Medicine: The leaves are abortifacient, aromatic, astringent, emmenagogue and stomachic [18], [26], [25], [27]. It may be administered to remedy inflammations and headaches [28]. An extract of the aboveground parts can be used to treat skin diseases and dysentery [29]. The leaves are normally used as a tea, but they do contain a poisonous aromatic oil, so some caution is advised in their use [18].

Ornamental: Stems are bunched with cut flowers. The catkins are retained on the stems long after harvesting and give a long-lasting menthol-like aroma to bouquets [8].

Raw material for industry: The plant repels insects [30], [31], [32], [29]. In Finland an oil-base mosquito repellent prototype was prepared. In the test effective repellent activity was demonstrated for 3 hours [13]. The fragrant leaves and catkins are used to produce such an insect repellent, especially against midges [18], [20], [10], [9]. A strong decoction of the leaves can be used as a parasiticide to kill external body parasites [25]. A fragrant essential oil is obtained from the fruits [32].

A wax covering on the fruit and leaves is extracted by scalding the fruit with boiling water and immersing them for a few minutes, the wax floats to the surface and is then skimmed off. The fruit is then boiled in water to extract the wax from the pulp and once more the wax is skimmed off. It is then strained through a muslin cloth and can be used to make aromatic candles [18], [33], [34]. These candles diffuse a delightful odour when burnt [34]. Unfortunately, this species does not produce enough wax to make it commercially viable [32].

A yellow dye is obtained from the stem tips [30], [32], [25] - brown according to another report [35] - and the seeds [35]. The bark contains tannin and can be gathered in the autumn and used as a yellow dye [18].

Further reading: [10], [8], [9], [3]

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Pictures: Stefan.lefnaer (large picture), Stickpen (detail)

Nasturtium officinale R. Br.

water cress (Brunnenkresse)

Family: Brassicaceae
Life form: forb/herb
Main use category: food, medicine
Used part: plant (green parts), leaves

General information

Morphology: Perennial, 10-70 cm high. Stem decumbent or prostrate, erect in emergent plants, branched above, rooting at proximal nodes; rhizomatous. Leaves all cauline, pinnately compound, 3- to 9-foliolate; leaflet suborbicular or oblong, 1-4 cm, margin entire or repand; lateral leaflets smaller, usually sessile. Hermaphrodite. Sepals oblong, 2-3.5 mm. Petals white or pink, spatulate or obovate, 2.8-4.5 × 1.5-25 mm. Florescence April to September. Fruit cylindric, 1-1.5 cm × 2-2.5 mm. Seeds biseriate, ovoid, 1 mm, reddish brown. Fruiting May to September [1].

Geographic distribution: Europe, from Sweden and Denmark south and east to N. Africa and W. Asia [2].

Natural habitat: *N. officinale* grows at the edges of slow-flowing water in lakes, reservoirs, springs, streams, rivers, either just below or above the water level [3], usually in chalk or limestone areas [4].

Site specific properties

Water regime: wet-flooded
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Paludiculture with *Nasturtium officinale* is unknown. Cultivation is well known and probably transferable to paludiculture with its preferred conditions of slowly flowing clean water, preferably coming from chalky or limestone soils [5], [6]. The cultivation demands a high water quality and uncontaminated soil because the plant can easily accumulate heavy metals from soil and water [7].

Propagation and establishment: *Nasturtium officinale* can be propagated generatively via seeds or vegetatively via division. The seed can be sown in spring in a pot slightly submerged with water in a cold frame. The seedlings can be planted out in summer [2]. Direct seeding is also possible. The seeds will germinate immediately after shedding and remain viable for about five years when stored dry [8]. The directly sown crop requires less labour input than the vegetative propagation or breeding in a nursery [9].

The vegetative propagation is very successful, virtually any part of the plant, including a single leaf, will form roots if detached from the parent plant [10]. The division can be put in a container of water until the roots are well formed and then planted out in shallow inundated sites [2]. The stems of the harvested crop obtained from cuttings are often too thick and of lower quality [9].

Unfortunately, virus diseases have become more common in cultivated plants and so most propagation is carried out by seed [6].

Most suitable growth substrate is a mixture of poorly decomposed peat and intensely decomposed peat [9].

Management: The depth of water in commercial watercress beds is about 7-15 cm. Under natural conditions it is usually absent from stagnant water [3]. Flowing water induces the vegetative growth of the plant [11]. Watercress can presumably obtain mineral nutrients from either the water or the soil, or both [8]. Phosphate fertilizers are the only ones used by watercress growers [8]. Nitrate must be obtained from the water, not from the soil.

Harvest: Cuttings can be taken at any time in the growing season and can give 10 pickings annually [12], [2]. Harvested cut-ware is susceptible to withering and loses quality soon after cutting, so the production chain must be very short to the consumer.

Productivity: It is a high yielding crop with 15-20 t/ha (yield of fresh green leaves) [11].

Cultivation experiences: It is cultivated mostly in artificial water beds, e.g., in the UK. Paludiculture is unknown to the authors.

Utilisation

Human food: The leaves can be eaten raw or cooked [13], [14], [15], [16], [17], [18]. Watercress is mainly used as a garnish or as an addition to salads for its strong flavor with a characteristic mustard-like hotness [19], [2]. It has a reputation as a spring tonic, and this is its main season of use [12]. The leaves are exceptionally rich in vitamins and minerals, especially iron [5]. A nutritional analysis is available [20]. The seed can be sprouted and eaten in salads [19]. The seed is ground into a powder and used as a mustard [21], [19], [12].

Medicine: *N. officinale* is very rich in vitamins and minerals, and has long been valued as a medicinal plant [22]. Considered a cleansing herb, its high content of vitamin C makes it a remedy that is particularly valuable for chronic illnesses [22]. The leaves are antiscorbutic, depurative, diuretic, expectorant, purgative, hypoglycaemic, odontalgic, stimulant and stomachic [23], [15], [16], [24], [21], [25], [12]. The freshly pressed juice has been used internally and externally in the treatment of chest and kidney complaints, chronic irritations and inflammations of the skin [16]. Applied externally, it has a long-standing reputation as an effective hair tonic, helping to promote the growth of thick hair [26]. A poultice of the leaves is said to be an effective treatment for healing glandular tumours or lymphatic swellings [26]. Some caution is advised, since excessive use of the plant can lead to stomach upsets [16], [24].

Co-benefits: It can accumulate heavy metals and could be used for phytosanitation [7].

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Picture: Lord Koxinga

Nelumbo nucifera Gaertn.

Indian lotus (Lotosblume)

Family: Nelumbonaceae
Life form: forb/herb
Main use category: food, ornamental, medicine
Used part: leaves, flowers, roots

General information

Morphology: Perennial, up to 1.5 m high. Leaf petiole to 2 m long or more. Blade to 6 dm or more, peltate, with water-repellent surface. Hermaphrodite. Tepals normally all caducous, pink, pink-tinged, or fading to white, 1-13 cm. Fruits ovoid, 10-20 × 7-13 mm; receptacle to 10 cm diameter at maturity, gradually tapered or rounded from flattened top to base [1], [2].

Geographic distribution: In the wild the Indian lotus occurs in warm-temperate to tropical regions of Asia (Iran to China, Japan and New Guinea) and NE. Australia [3]. Introduced to N. America, S. Europe, and other parts of Asia [1].

Natural habitat: Ponds and lakes, with altitudes of 0-400 m [1].

Site specific properties

Water regime: flooded
Trophic conditions: no information found
pH: acid-alkaline
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

Indian lotus is widely used: an estimated 0.2 million ha are cultivated with it in China [4] and it is the national flower of India [5]. Paludiculture is unknown but the cultivation method is probably transferable. It is recommended for peatlands where flooding of partial areas is unavoidable after rewetting. The harvest of the valuable rhizome will harm the peat soil and probably lead to further degradation, but the extent is unknown. Cultivation could lead to high methane emissions. Further research is necessary.

Propagation and establishment: Generative: the long-lived seeds [6] have extremely hard coats, one end of which could be filed away to expose the endosperm before germination. The seedling will then begin to emerge 24 hours later when placed at 25-30°C. The seedlings require high light levels in order to form a tuber that is large enough to survive its first winter. For one ha planting 10-12 kg of seeds are required to raise the seedlings [5]. Propagation can also be carried out by division in late winter, just before the growing season. The rhizomes are cut into small pieces and are planted to allow a small portion to stick above the soil at the bottom of the pond. The material for propagation should consist of 3 connected tubers with at least 2 growing tips. Best planting time is in March [7]. The rhizomes grow and shoot upwards to form new plants [8].

Management: Succeeds in water up to 2.5 m deep [9]. In cooler climates, however, it should be grown in shallower water (though no less than 30 cm deep) since it will warm up more quickly and encourage better growth and flowering [9]. The plant grows best with water temperatures of 23-27°C in the growing season [10] and requires a five months growing season [11]. Plants are resentful of root disturbance and should therefore be planted into their permanent positions as soon as possible [9].
In the conventional practice the field is drained for harvesting the rhizomes. Either the field is constructed like a paddy with a pumping system or a more conserving harvesting technique must be developed for a wet harvest.

Harvest: The rhizomes can be harvested after 120 days in warm climates and after 150-180 days or after the leaves die in cold weather in cool climates in fall or early winter. In the conventional harvest practice, the water is drained and the fragile rhizomes are dug carefully [12]. In some farms in Japan, high pressure water stream is used to wash away the mud and expose the storage rhizomes [12]. Water lotuses bloom in their second summer and can then be harvested.

Productivity: Rhizome yields vary from 3.5 to 4.5 t/ha [12]. Higher yields can be obtained when flowers are removed [12].
With an intercropping system in China 30-52 t/ha of lotus can be achieved [5].

Cultivation experiences: *N. nucifera* is much cultivated as an aquatic food plant in S. and SE. Asia.

Utilisation

Human food: Young leaves, petioles, flowers and the fleshy rhizomes are eaten as vegetables. Fresh rhizomes are eaten after boiling and fried slices are used in a curry or fried as chips [5]. In India, China and Japan the Indian lotus is the most important aquatic vegetable [5].
<u>More detailed information:</u>
<u>Root</u> - cooked as a vegetable [13], [14], [15], [16]. It is also a source of starch or arrowroot [17], [15]. Much used and relished in Chinese cooking, the root has a mild flavour [18] and a crisp texture [19]. It can be cooked with other vegetables, soaked in syrup or pickled in vinegar [11]. The root contains about 1.7 % protein, 0.1 % fat, 9.7 % carbohydrate, and 1.1 % ash [20].
<u>Young leaves</u> - cooked or raw [14], [15], [21], [22]. Used as a vegetable [16]. The leaves can also be used to wrap small parcels of food before cooking them [11].
<u>Stem</u> - cooked. A taste reminiscent of beet [17], [23]. They are usually peeled before use [24].
<u>Seed</u> - raw or cooked [13], [14], [25], [22], [16]. A delicate flavour [17]. The seeds can be popped like popcorn, ground into a powder and used in making bread or eaten dry [22]. The bitter tasting embryo is often removed [26], [21]. The seeds contain about 15.9 % protein, 2.8 % fat, 70 % carbohydrate, and 3.9 % ash [20]. The roasted seed is a coffee substitute [22].
<u>Petals</u> - can be floated in soups or used as a garnish [22]. The stamens are used as a herbal tea or to flavour tea [22], [2].

Medicine: *N. nucifera* is used as a traditional Chinese medicine in the treatment of hyperlipidaemia. It is reported that a decoction of its leaves significantly reduces the serum triglyceride and cholesterol level.

Seed extracts have antioxidant properties. The rhizome of lotus is known for its hypoglycemic, antipyretic, anti-diarrheal, anti-bacterial and anti-fungal activity. The lotus embryo is a good source of higenamie - a cardio tonic principle. Crude alcoholic and aqueous extracts of decorticated seeds of lotus possess anti-emetic properties [5]. Lotus has been used in the Orient as a medicinal herb for well over 1,500 years [27]. All parts of the plant are used; they are astringent, cardiotonic, febrifuge, hypotensive, resolvent, stomachic, styptic, tonic and a vasodilator [26], [28], [29], [30], [27], [31]. The leaf juice is used in the treatment of diarrhoea and is decocted with liquorice (*Glycyrrhiza* spp.) for the treatment of sunstroke [32]. A decoction of the flowers is used in the treatment of premature ejaculation [32]. The flowers are recommended as a cardiac tonic [31]. A decoction of the floral receptacle is used in the treatment of abdominal cramps, bloody discharges etc. [32]. The flower stalk is haemostatic [30]. It is used in treating bleeding gastric ulcers, excessive menstruation, and post-partum haemorrhage [27]. The stamens are used in treating urinary frequency, premature ejaculation, haemolysis, epistasis, and uterine bleeding [30], [27]. A decoction of the fruit is used in the treatment of agitation, fever, heart complaints etc. [32]. The seed contains several medically active constituents, including alkaloids and flavonoids [33]. It is hypotensive, sedative and a vasodilator [30], [33]. The seed has been shown to lower cholesterol levels and to relax the smooth muscle of the uterus [33]. It is used in the treatment of poor digestion, enteritis, chronic diarrhoea, spermatorrhoea, leukorrhoea, insomnia, palpitations etc. [30], [32], [27], [33]. The plumule and radicle are used to treat thirst in high febrile disease, hypertension, insomnia, and restlessness [30], [27]. The root is tonic [32]. The root starch is used in the treatment of diarrhoea and dysentery, and a paste is applied to ringworm and other skin ailments [32]. It is also taken internally in the treatment of haemorrhages, excessive menstruation, and nosebleeds [27]. The roots are harvested in autumn or winter and dried for later use [27]. The root nodes are used in the treatment of nasal bleeding, haemoptysis, haematuria, and functional bleeding of the uterus [30]. The plant has a folk history in the treatment of cancer; and indeed, modern research has isolated certain compounds from the plant that show anticancer activity [32].

Ornament: Lotus is the national flower of India. It is considered to be the most auspicious flower in Indian rituals. The flowers are used for ornamental purposes and for offerings in temples. There are several varieties available.
The flowers are also a source of perfume [5]. The dried seed cup is commonly used in flower arrangements [3].

Raw material for industry: A fibre can be produced of the isolated secondary wall of the leafstalk (tracheary elements which has a unique shape) and has a good potential to be used for textile production [34].
A unique fabric from the lotus plant fibers is produced only at Inle lake, Union of Myanmar and is used for weaving special robes for Buddha images called kya thingahn (lotus robe) [3].

Co-benefits: Lotus can be used in aquatic systems for domestic wastewater treatments [34].

Further reading: [4], [7]; a good review of the medicinal and culinary use of different plant parts and their phytochemical properties and substances can be found here: [35], [36].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Valley Nature Center

Nyssa aquatica L.

Water tupelo (Wasser-Tupelobaum)

Family: Cornaceae
Life form: tree
Main use category: raw material, energy
Used part: wood

General information

Morphology: Perennial. Height up to 30 m. Deciduous. Leaves simple, alternate, 12-20 cm long, ovate, entire or smooth margins, sometimes serrated. Thick leaves, shiny dark green on topside, paler and pubescent on backside. Polygamo-dioecious. Flowers minute, greenish-white, appearing March to April. Fruits are drupes 1-4 cm long, epicarp thick, mesocarp fleshy, dark purple with conspicuous pale dots. Stone boney, ribbed, one-seeded, ranging in colour from white to dark brown or gray. Buttressed stems (swollen base). Seed production is started at age 30 [1], [2], [3], [4].

Geographic distribution: South-eastern U.S.A. - Virginia to Florida, west to Illinois and Texas [1].

Natural habitat: Water tupelo grows in low, wet flats or sloughs and in deep swamps. On some sites water may reach a depth of 6 m during rainy seasons and may remain as high as 4 m for long periods [5]. Soil moisture can remain at or near saturation level throughout most of the growing season [3]. Soils that commonly support water tupelo range from muck (peat) and clay to silt and sand. Most are moderately to strongly acidic [3].

Site specific properties

Water regime: moist-wet-flooded
Trophic conditions: eutrophic
pH: acid-subneutral
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

The majority of the virgin tupelo forests were cut over and used for timber production during the late 1800s and early 1900s. Although there has been a general trend of land loss of these forested wetlands during the past 100 years, there are still vast areas of second-growth timber existing today [6], [7]. Afforestation is known from restoration measures, but probably transferable to a managed wet forestry on peatlands (paludiculture). A good mature tree will produce commercial lumber that can be used for crates, boxes, pallets, baskets, veneer and furniture [3], [8].

Propagation and establishment: *Nyssa aquatica* can be propagated generatively and vegetatively including coppice regeneration as the best way for its establishment [9]. Under natural conditions the generative establishment from seeds is the dominant mode of reproduction. Germination is epigeal. Seeds do not germinate until water recedes, which may be midway to late in the growing season [10]. Partially shaded, wet, poorly-drained soils provide the best seedbed. Seeds buried 1-3 cm deep in the soil show higher germination rates [11]. Seedling development is better in saturated than in well-drained soil, in moving and aerated rather than stagnant water, and in shallow rather than deep water [3]. Provided their tops are above water, seedlings can generally survive continuous flooding even if it persists throughout the growing season. Because of the exacting requirements for germination and establishment, planting seedlings is most likely the preferred generative propagation method. Seeds may be sown in fall in a nursery or may be stratified over winter and sown in the spring. Three months stratification at 5°C improves germination [12]. Nursery-sown seeds may be drilled 13-25 mm deep, or they may be broadcasted and rolled into the soil. A seedbed density of 110-165 seedlings/m² is recommended [3]. Seedlings should be planted out into their permanent positions in late spring or early summer, after the last expected frosts. Planting on ridges may reduce the risk of high flooding. In general, there has been little success in planting tupelo [13]. Seedlings may need to be protected from herbivory to advance establishment [14].

Innovative planting methods may be required because of standing water and unconsolidated sediments. One method of planting that has been tested extensively in the southern U.S. is to heavily prune seedlings down to the root, so that they may be planted by grasping the seedling at the root collar and simply inserting them into the soil or sediment, without digging a hole [15].

Water tupelo is a prolific stump sprouter [3], making coppicing the best way for regeneration of an existing stand. Stump height should be 60 cm, depending on the inundation level [16]. Flooding of stumps is probably detrimental. There are no practical techniques available for reproducing water tupelo through cuttings or layering [3]. Coppicing of water tupelo in a permanently flooded swamp in Louisiana (U.S.) does not appear to be a satisfactory method of regeneration. The surviving sprouts within one study were too few to fully utilize the site, since only 9-18 % of the stumps had live sprouts after six growing seasons [7]. In contrast, a study in the Mobile-Tensaw River Delta reported high survival of water tupelo coppice [17], [18].

Management: Tupelo stands should be managed on an even-aged basis. Because of the exacting requirements for germination and establishment and the variable success of stump sprouting, planting of tupelo could be necessary in many areas to ensure adequate stocking of future stands [19]. If hydrologic conditions have been changed, natural regeneration may be hampered and recovery rates may be much slower or even non-existent [20], [21].

Reproduction is usually sparse in natural swamp stands because of the extremely dense canopy allowing little sunlight to reach the forest floor and the standing water that is often present [22]. In very dense stands a light thinning to reduce basal area may be necessary during a dry cycle to allow sufficient sunlight to reach the forest floor to encourage establishment and development of an advanced regeneration [22].

The results of thinning in tupelo stands are variable, but it apparently leads to an increased productivity [19], [23]. Thinning mature water tupelo stands in Louisiana did not increase diameter growth [8]. A study in a 60-year-old swamp forest showed increased growth of individual trees after thinning, but higher volume growth in the unthinned plots [23]. Another report states that although thinning

might decrease the basal area, the increase in quadratic mean diameter is sufficient to bring about an insignificant effect of thinning on total volume, so that thinned stands will have greater standing volumes of water tupelo than unthinned stands [18]. Thinning might not increase biomass production in total but less will be lost to mortality and more will be harvestable [18].
One report [24] recommends a series of periodic cuts beginning with a commercial thinning when dominant trees reach 20-25 cm in diameter. A second thinning should be done when dominant trees average 35-40 cm in diameter and a third cut when they average 50-55 cm. Generally, thinning is not easy to do in areas where standing water for most or all of the year is common [15]. As commercial thinning may not be practical (and even uneconomical) in these stands, precommercial thinning and cleaning could be conducted to achieve a merchantable size at an earlier age (with 8 cm top diameter for pulp use), thereby reducing rotation length as well as minimizing losses of growth to mortality [18].
Thinning sprout clumps has the ability to reduce rotation age considerably [18].
Cleaning of undesirable willow species after coppicing can be necessary since they might have adverse effects on tupelo growth [18].
A soil moisture that remains at or near saturation level throughout most of the growing season may provide near-optimum soil moisture for growth of water tupelo. Any drastic change in normal water levels can decrease growth [2]. Also, old water tupelo trees slowly die when exposed to prolonged, deep flooding [15].

Harvest: The low carrying capacity of the wet peat soil makes the wood harvest difficult. Harvesting should be done in winter in drier seasons with adapted machinery, the cable way technique or the use of helicopters to minimize peat disturbance and its possible harmful effect on water quality [16], [25].
It is common practice to harvest water tupelo before reaching 100 years, e.g., at age 60-80 for pulp use [26], [18]. Clear-cutting is the recommended method [15]. Most of the reports and studies state that there is a rapid recovery following clear-cutting. A few others report regeneration is insufficient mainly owing to altered hydrology [19]. Clear-cut harvesting with ground-based skidder or helicopter transport results in stands similar to the original ones [27]. Skidder disturbances even favoured the establishment of *Nyssa aquatica* because of its ability to grow under anaerobic conditions and less competition [27].

Productivity: Average annual growth of water tupelo should be 0.7 cm in diameter and 60 cm in height [28]. Plants in the wild are fast-growing in well-drained lowlands, but slower in swampy sites. An enclosure experiment found greater aboveground biomass three years after harvesting on a site that was continuously flooded as compared to a site that was periodically flooded [29]. In poorly drained swamps in the south-eastern U.S., average annual production of water tupelo stands was found to reach between 6.3 and 7.0 m^3/ha, with a ten-year average diameter growth for trees free to grow in unmanaged stands on an average site of about 8 cm [3]. Under management, a pure even-aged stand with a d.b.h. (above bottleneck) of 107 cm is estimated to have an accumulative total yield of 676 m^3/ha [3]. Yield tables are available [3].

Cultivation experiences: Known from restoration from south-eastern U.S. [13], [14].

Utilisation

Human food: The fruits are occasionally eaten raw but more often used in preserves [30], [31]. The fruit has a thick, tough skin with a thin acid flesh surrounding a large seed [32], [33].

Fuel: Wood can be used for combustion.

Raw material for industry: The wood is light, close-grained, soft and difficult to split [32], [33], [34]. Tough according to one report [34], weak according to another [33]. It has an intricately contorted and twisted grain [32]. It weighs 141.6 kg/m^3 [34], and is used as lumber for various things such as panelling, broom handles, woodenware and crates [32], [33], but also as pulp for paper production [18]. Water tupelo has been valued because of its white colour, lack of odour or taste, and good staining quality. The swollen buttress of the tree weighs less than the wood of the bole and is commonly used for pulp or for making duck decoys because it is both buoyant and easily carved. Additionally, a cork substitute is sometimes made of the roots and is used for various things such as floats for fish nets [32], [4]. A red dye can be obtained from the burnt bark mixed with water and the ash of *Quercus rubra* [35].

Co-benefits: The tree is used for wetland restoration to minimize storm impacts [14]. Tupelos are well known for their smooth, sweet-tasting honey, produced by bees that have been drawn to the sweet nectar of the small flowers [4].

Similar species: *Nyssa sylvatica* Marshall

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Pictures: Christian Fischer (big picture), H. Zell (detail)

Oenanthe aquatica (L.) Poir.

waterfennel (Wasserfenchel)

Family: Apiaceae
Life form: forb/herb
Main use category: medicine
Used part: fruit

General information

Morphology: Winter annual or biennial, up to 150 cm high. Stem hollow, much-branched, stout, striate and grooved, often very short. Leaves 3- to 4-pinnate; aerial leaf lobes ovate, acute. Submerged or winter leaf lobes linear to filiform. Hermaphrodite. Umbels terminal or leaf-opposed. Sepals conspicuous, persistent; petals white. Rays 5-15, not thickened in fruit. Fruit 3.5-4.5 mm, one seed - achene. Roots entirely fibrous [1], [2].

Geographic distribution: Europe (excluding the far north) to temperate W. Asia [3].

Natural habitat: In slow moving or stagnant water [4], and close to streams, avoiding acid conditions [5].

Site specific properties

Water regime: wet-flooded
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

It is an obligate wetland plant, but paludiculture is unknown. The ecological amplitude suggests that cultivation in wet peatlands could be possible. Paludiculture looks promising as long as the demand for biomass is sufficient for economic benefits.

Seed crops are probably expensive because cultivation is unknown. It is an annual or biennial plant, so reseeding is necessary.

Propagation and establishment: *Oenanthe aquatica* reproduces only generatively [6]. Seed sowing appears best in August/September under moist, light conditions. Stratification in water can improve germination rates, but stratification is not essential. When sown in spring (annual plant) it displays low competitiveness and lower production.

Management: *Oenanthe aquatica* is not very competitive, so weed control could be necessary. However, no more information was found.

Fluctuating water tables are necessary for a natural reseeding when fruits are retained on the plant. Under flooded conditions the germination is poor. Plants can tolerate water levels up to 1 m (or more) [6].

Harvest: In August/September, when fruits are ripe.

Productivity: Seed production fluctuates depending on habitat and life cycle. The highest seed production is in biennial plants originating from autumn seedlings. Very tall plants can produce up to 40,000 seeds, while smaller plants produce only 800 seed [6].

Cultivation experiences: Unknown to the authors.

Utilisation

Medicine: The fruit is antiperiodic, diaphoretic, diuretic, expectorant and pectoral. It is used in the treatment of chronic pectoral affections, dyspepsia, intermittent fevers, obstinate ulcers etc. [5], [7], [8]. This plant should be used with great caution, and only under the supervision of an experienced practitioner. Consumed in excess, the fruits can cause vertigo, intoxication and other narcotic effects. A homeopathic remedy is made from the fruits. It is used in the treatment of bronchitis, coughs, and gastritis. [7].

Ornament: It is sometimes used as an ornamental plant in water gardens.

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Pictures: Charlie fong (big picture), Dalgial (detail)

Oryza sativa L.

rice (Reis)

Family: Poaceae
Life form: graminoid
Main use category: food
Used part: seed

General information

Morphology: Annual. Height: 0.5-1.5 m, tufted. Fibrous root system. Forms multiple tillers, with culm and leaves, with or without panicle. Culms erect, glabrous, rooting at lower submerged nodes. Leaf blades 25-60 × 0.5-2 cm, glabrous, margins scabrid, apex acuminate. Hermaphrodite. Panicle up to 30 cm, nodding after anthesis. Spikelets up to 12 mm. Glumes ca. 0.25 mm. Fruit – caryopsis, ovate or elliptic to cylindrical, 5-7 mm, whitish yellow to brown or blackish [1], [2]. Diploid genome (2n = 24).

Geographic distribution: *Oryza sativa* evolved along the foothills of the Himalayas [3]. Rice is planted throughout the humid tropics and in many subtropical and warm temperate areas with a frost-free period longer than 130 days [3].

Natural habitat: Swampy areas [4]. The water regime in which rice is growing and the water requirements are variable. Upland rice, grown as a rain fed crop, requires an assured rainfall of at least 750 mm over a period of 3-4 months and does not tolerate desiccation. Lowland rice is concentrated in flat lowlands, river basins, deltas [3], and in regions where the flooding can be guaranteed during the rice growing season.

Site specific properties

Water regime: moist-wet-flooded
Trophic conditions: eutrophic
pH: acid-subneutral-alkaline
Light conditions: intermediate shade tolerant to shade intolerant (depending on variety)
Salinity: none-low (depending on variety)

Cultivation

Rice is cultivated throughout the world, almost exclusively on mineral soil. The peatland areas suitable for rice production are small: they are shallow and/or with clay, within lagoonal peat formations or among valley peats [5]. Deep, oligotrophic peatlands (bogs) are unsuitable. Bog peat is invariably associated with sterility problems in lowland rice, since two third of the panicles remain empty (Lignin-related phenolic acids have been implicated [6], but are probably not the only reason for sterility [7]). Also, natural soil fertility decreases rapidly and severe acidity may develop.

Common conventional rice cultivation requires at least a periodic lowering of the water table (drainage) for harvest or planting which will lead to the oxidation of the peat and subsidence [5]. Maintaining a permanent high-water table is the best way to minimize subsidence of peatlands. Rice thrives under prolonged waterlogging and has a shallow, fibrous root system that anchors it even on loosely packed peat [5]. If peatlands must be used for agriculture, rice monocropping on a larger scale or mixed cultures, e.g., agroforestry systems can be attractive possibilities. Compared with other conventional crops, which require deep drainage of the peat soil, rice cultivation can decrease subsidence rates and net CO_2 emissions due to peat oxidation substantially. However, a complete prevention or reversion of peat oxidation and subsidence seems not possible with the conventional rice cultivation practices [8], [9]. This means that rice cultivation on peatlands cannot be called paludiculture. Furthermore, rice fields emit high amounts of the greenhouse gases CH_4 and N_2O [10], [9].

Rice cultivation can be classified according to the water source as rain-fed, flood-fed, or irrigated. Based on land management practices, rice lands can be grouped as: lowland (fields are flooded most of the season) or upland (fields are never flooded). In some parts of the world the traditional surjan system is introduced and used for lowland rice cultivation on a small scale, e.g., on peat in Indonesia [11]. It consists of sunken, wet beds planted with rice (or other wetland crops) surrounded by ridges that are dry raised beds planted with dry land crops.

Propagation and establishment: Rice is propagated by caryopses, which may either be broadcasted or drilled directly in the field, or the seedlings may be grown in nurseries and transplanted later [3]. Seeds are capable of germination under soil or under water, but not under both (i.e., mud). So direct seeding is done in dry or puddled soil. For this type of sowing, weeding is necessary and herbicides are applied. In dry soil, the seeds are sown after land preparation and are then covered lightly with soil by a tooth harrow. Germination occurs after heavy continuous rains.

For lowland (wet) rice cultivation, a nursery is necessary or the seeds are broadcasted in flooded soil where the seeds germinate at the soil-water interface; then it grows up through the water column. When grown in the nursery, the seedlings are transplanted after 20-35 days after emergence into the wet field. The weeds are suppressed by constant high water tables. Paddy rice fields are usually ploughed and harrowed several times in the wet state as a "mudding-up" operation which incorporates organic matter and levels the land [12].

There are many varieties available, such as flood tolerant, drought tolerant or salt tolerant rice. The japonica or paddy varieties are aquatic and grow in water at various depths and are grown predominately in temperate-subtropical regions. Deep water varieties will grow in up to 6 m of water. Upland or indica (tropical and sub-tropical distribution) varieties are not adapted to flooding [12].

Management: Rice grows best in fertile heavy soils. It can be planted in dry or puddled soil and grown like an upland crop, or in inundated soils. The soils on which rice grows vary considerably: from sand to clay, organic matter content varies from 1 to 50 %, pH from 3 to 10, salt content from 0 to 1 %, and nutrient availability from acute deficiencies to surplus. The optimum pH for flooded soil is 6.5-7.0 [3]. The common practice includes fertilization (N-P-K) and the application of herbicides before permanent flooding. In some countries, the use of herbicides is prohibited, and seems not necessary, when the water management is apllied correctly [pers. comm., Yvonne Fabian]. Silicon fertilization is applied occasionally in peat soils [13]. The organic carbon content of the soil can predict the indigenous nitrogen supply of rice [14]. Peat soils with soil organic C from about 10-15 % had no positive response to N fertilization. Thus, the organic matter was oxidized and released nitrogen. Here N fertilization is not necessary but at the expense of the oxidised peat. Another study showed that N fertilization at rates up to 160 kg N ha^{-1} in rewetted degraded peat soils does not affect annual CH_4 and N_2O emissions [24]. Fertilization with micronutrients, especially Cu, can reduce sterility of rice when grown in peat soil [15].

The rice fields are drained at least twice annually (spring for planting, fall for harvest and application of fertilizers or herbicides) but the depth of drainage varies. Each drainage event might be about 2-3 months as it takes a while for the soil to dry enough to be workable. In peatlands in the Sacramento-San Joaquin Delta (U.S.) the water table is within 1 m below the surface even during peak drainage times, and often quite shallower than this. The estimated subsidence rates were 0.7-1.1 mm per year determined by a nitrogen budget method [16]. According to one study [9], subsidence rates vary from 1 to 1.4 mm per year in the rice paddy.

It might be recommended to minimize drainage time and depth when the crop is grown on peat and to stimulate the development of light machinery that is adapted for wet soils. On the other hand, alternate wetting and drying of the soil will probably reduce the otherwise high CH_4 emissions [17], [18], but might be problematic for the supression of weeds. So it is necessary to have a fine balanced water regime to achieve high yields, low CH_4 emissions and low subsidence. More research is necessary to develop the best strategy.

Harvest: The grain is harvested 4-6 months after planting when the entire plant begins to become yellow and dry out. In SE. Asia it is harvested by hand and later threshed or the harvest is done mechanically with heavy machinery. In Europe and N. America all harvest is done mechanically after drainage. Drainage is carried out to allow the use of effective heavy equipment on the field.

The rice straw can be left on the field, it may compensate minimally for mineralisation losses [5], but will probably increase CH_4 emissions.

Productivity: Yields in temperate areas are generally higher than in SE. Asia. Average grain yields in t/ha are: 4.3 in Indonesia, 3.1 in Malaysia, 2.2 in Thailand, 3.5 in Vietnam, 5.8 in Korea, 6.0 in China, and 6.2 in the U.S. [3]. The average yields in California are about 9.3 t/ha [19] and 7.9-10.7 t/ha in a peatland in the Sacramento-San Joaquin Delta [16]. The average world yield is 4.5 t/ha (paddy rice, 2013) [8]. The grain yield of upland rice is around 0.5-2.0 t/ha in Asia but may reach 4 t/ha in Latin America. Rain-fed lowland rice is higher yielding than upland rice but may suffer a drastic reduction in years with drought or floods. Although yields in the deep-water rice areas are generally low, they are more stable than in the upland rice areas of SE. Asia [3]. In Indonesia good yields were achieved (up to 3 t/ha) on 60-cm-deep wood peat over pyritic sediments [5].

Cultivation experiences: On peatlands with deep drainage systems in Kalimantan

(Indonesia: Ex-Mega-Rice-Project, which failed dramatically) [20], small scale cultivation on peat in Indonesia [11], in the Everglades, Florida [21], [22], in California (U.S.) in the Sacramento-San Joaquin Delta [25] and in wet cropland areas in Switzerland [26].

Utilisation

Human food: Rice is the main staple food of 40 % of the world population and the main food throughout SE. Asia. The rice grain is cooked by boiling in water or by steaming, and is eaten mostly with pulses, vegetables, fish or meat. It is often the main source of energy. Flour from rice is used for breakfast foods, meat products, baby foods, bread and cake mixes, and cosmetics. The waxy rice flour has superior qualities as a thickening agent for white sauces, puddings and oriental snacks. Glutinous rice is used for making sweetmeats. Starch is made from broken rice, and used as laundry starch, in foods, and textile manufacture. Beers, wines and spirits are manufactured from rice [3].

Medicine: Processed bran oil is used in medicine [3]. Several traditional medicinal applications of rice have been reported from tropical Africa [23]: leaf dressings are applied to ulcers and grain decoctions are drunk to treat diarrhoea, as a diuretic and as an emollient. Rice powder is applied against itch in Senegal. In the Democratic Republic of Congo, a decoction of the roots, leaves and husks is taken against madness and beriberi.

Animal fodder: Rice straw is used for animal feed, but is nutritionally inferior to other cereal straws unless ensiled [3]. The rice bran or meal obtained in pearling and polishing is a valuable livestock and poultry food [3].

Fuel: The husk or hull is used as fuel [3].

Agricultural conditioner and substrate: Rice straw is used for mushroom growing medium, for the production of organic manure and for mulching crops such as onions, garlic and cucurbits [3].

Raw material for industry: [3] The husk or hull is used as bedding, absorbent, building board, and carrier for vitamins, drugs, toxicants, etc. The charred rice hull is used for filtration of impurities in water, as a medium for hydroponics and in the manufacture of charcoal briquettes. The rice bran consists of the pericarp, the aleurone layer, the embryo and some of the endosperm. The rice bran contains 14-17 % oil. Crude rice bran oils are used for producing solidified oil, stearic and oleic acids, glycerine and soap. Processed bran oil is used for cooking, antirust and anticorrosive agents, textile and leather finishers. China, India, Japan, Vietnam and Thailand are the main producers of rice-bran oil. Rice straw is used for bedding. It is used for the manufacture of straw boards and pulp for paper and only rarely for rope and roof thatch.

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: SEWilco

Panicum virgatum L.

switchgrass (Rutenhirse)

Family: Poaceae
Life form: graminoid
Main use category: energy, fodder
Used part: aboveground biomass

General information

Morphology: Perennial. Height: 90-150 cm. Culms round, tough, erect, usually unbranched, nodes glabrous or pubescent. Leaves basal and cauline; leaf sheaths rounded, glabrous; leaf blades linear, flat, 20-40 × 0.3-1.5 cm. Hermaphrodite. Inflorescence is an open, spreading panicle, 15-55 cm. Florescence and fruiting July to October. May - spread from short, stout, scaly rhizomes [1], [2].

Geographic distribution: It is native to N. America, where it occurs naturally from 55° N latitude in Canada southwards into the United States and Mexico [3].

Natural habitat: Switchgrass occurs naturally on prairies, open oak and pine woodlands, shores, riverbanks, wet lowlands and high brackish marshes along maritime forest ecotones [2].

Site specific properties

Water regime: moist-wet
Trophic conditions: eutrophic
pH: acid-alkaline
Light conditions: shade intolerant
Salinity: medium tolerance

Cultivation

Switchgrass is a perennial warm-season C4 grass that received much attention in the last decades because it can be established with low costs, low impacts and its capacity to produce sustainable yields over reasonably long periods (over 10 years). There are numerous varieties available, belonging either to the lowland (e.g., Alamo, Kanlow) or upland varieties. Also winter hardy ones are available [4]. The lowland ecotype grows taller and is adapted to wet conditions [5], making it probably suitable for paludiculture. Greenhouse experiments showed that flooded conditions had no negative effects on germination, establishment and flowering on the tested lowland ecotypes [6]. A newly formed peat accumulating floating marsh dominated by *Panicum virgatum* in the Mississippi River delta [7] suggests that cultivation in wet peatlands is possible.

Propagation and establishment: Only generative propagation is possible. Switchgrass is established by fruits, typically at a seeding rate of 7-13 kg seeds/ha. Mixed plantings may

be seeded at a lower rate. Seeding rates and dates vary according to cultivar, region of adaptation, and purpose. One challenge in establishing switchgrass is its seed dormancy. Recommendations for breaking seed dormancy differ; specific protocols are available [8]. The seed can be planted using seed drills or broadcast spreaders. Seedbeds should be firmed prior to seeding. When using the broadcast method, the area should be rolled after seeding to increase the seed-to-soil contact. No-till seedings in closely grazed or burned sod have been successful but will require higher seeding rates. [2], [9].
It will take 2-4 years after seeding to reach maximum yield potential of the stand.

Management: Managing switchgrass for biomass (energy) production is quite different compared to its management for fodder production [9]. When growing switchgrass for biomass, the crop is established for 10-20 years before reseeding is required, generally due to reduced yield mainly caused by stand loss. In general, one harvest is optimal. Yields may be slightly higher in a twice-per-year cutting system (summer and winter); however, the extra cost, extra fertilizer need and reduced biomass quality, especially for combustion purposes, will not make this an attractive option. The twice-per-year cutting system may also reduce stand maintenance and require earlier need for reseeding and thus increase biomass cost [9]. For fodder production 2 cuts per year are desired. Cutting at 20-30 cm in early June can maximize the amount of high quality fodder biomass and promote a better growth in the following year [4]. Switchgrass breaks winter dormancy in late April and can provide some grazing in late May, but makes the most of its growth in June, July, and August [8]. More information for a sustainable grazing management can be found here: [8].
Switchgrass is most susceptible to weed competition [10], so weed control can be necessary in the establishment phase, e.g., by mowing to 10-15 cm in the early summer or by sowing a grain crop in the previous year; also herbicides are frequently used [2], [10], [9].
Switchgrass makes very efficient use of nutrients. It is not recommended to use fertilizers in the first year as this would only benefit weeds. In the following years a fertilization equal to the nutrients removed is generally sufficient. The removal of nutrients is lower when the crop is harvested as late as possible (in winter or early spring) due to translocation of nutrients to the below-ground parts [9].

Harvest: For biomass production switchgrass is best harvested after a killing frost or later in winter or early spring. This will maximize biomass quality (low moisture, low nutrients, low ash, low K, low Cl) and will reduce nutrient removal from the site [11]. The delay in harvest, however, reduces the biomass yield considerably.
In general, switchgrass will be mowed, baled and then processed into pellets or other products. The moisture content is often below 15 % and preferably 10 % when harvested in winter or early fall. If the moisture content is above 15 %, field drying will be necessary [9].

Productivity: In a newly formed floating marsh in the subtropical Mississippi Delta, switchgrass was supplied with high nutrient loads which has led to very high values for NAPP (net annual aerial primary productivity) = 27 t/ha [7]. On mineral soil in the U.S., it yields 9.4-22.9 t DM/ha, with an average yield of 14.6 t DM/ha [10]; the reference gives a good overview about productivities on different sites. A delayed harvest in winter/spring leads to a loss of 30-40 % compared to maximum yields in early fall. So the harvested biomass is generally much lower than its potential [12].

Cultivation experiences: Switchgrass is widely cultivated in the U.S. [10]. It was introduced and tested in most west and southern European countries and more recently in central and eastern Europe including Poland and Ukraine, respectively. So far no large scale commercial production is known and no locally adapted varieties have been developed [13], [9].

Utilisation

Ornamental: Switchgrass is a well-known ornamental grass used in gardens and the inflorescence is used in bouquets. Varieties such as 'Heavy Metal' and 'Rehbraun' are well-known ornamental varieties sold in Europe [9].

Animal fodder: It provides good pasture and high quality hay for livestock [2], [9]. Switchgrass is palatable to cattle, horses, and sheep during the spring and early summer before the leaves become coarse and tough. By midsummer, when the seedheads begin to mature, nutrient content and palatability decline rapidly. Nutritional values are available [14].

Fuel: Switchgrass is used in several bioenergy conversion processes, including cellulosic ethanol production, biogas, and direct combustion for thermal energy applications [2].

Agricultural conditioner and substrate: It is used as a substrate for mushroom culture [9].

Raw material for industry: Switchgrass has been tested for paper pulp production mainly in Canada with positive results. No commercial use is known at this moment [9]. It is also used as livestock bedding material and straw bale housing.

Co-benefits: Switchgrass is used for erosion control. It stabilizes soil on strip-mine spoils, sand dunes, dikes, gullies and other critical areas [2]. It is also used for phytoremediation [9].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Pictures: Harry Rose

Paspalum vaginatum Sw.

seashore paspalum, salt-water couch

Family: Poaceae
Life form: graminoid
Main use category: ornamental, fodder
Used part: aboveground biomass

General information

Morphology: Perennial. Height: 10-50 cm. Creeping with short rhizome and long stolons. Culms solitary or tufted, many-noded. Leaf sheaths imbricate, often keeled, margins membranous; leaf blades distichous, 2.5-15 × 0.3-0.8 cm. Hermaphrodite. Inflorescence of (1-)2(-3) racemes arising together at culm apex; racemes 2-5 cm. Florescence and fruiting June to September [1], [2].

Geographic distribution: Worldwide distribution in tropic, subtropic and warm-temperate areas. Some botanists have considered it indigenous to southern and eastern Africa. It has become widely distributed, because it was used as bedding in slave ships and as a salt-tolerant forage crop [2].

Natural habitat: Grows on sandy seashores, saline swamps, along the margins of slow-moving streams, tidal marshes, coastal flats and mangrove swamps [2]. It will tolerate waterlogged conditions, periodic flooding and also drought [2]. It is considered as the most salt-tolerant warm-season turf-grass with ecotypes tolerant to ocean water [2].

Site specific properties

Water regime: moist-wet
Trophic conditions: meso-eutrophic
pH: acid-alkaline
Light conditions: shade intolerant
Salinity: high tolerance

Cultivation

Seashore paspalum has multiple stress resistances. For instance, it is tolerant to waterlogging and salinity which makes it suitable for paludiculture on salt-influenced rewetted peatlands. It must be handled with care since it can be an invasive weed of wetlands. Cultivation is well-known from its use in landscaping and golf courses, where it is usually applied for minor sites.

Propagation and establishment: Seashore paspalum must be propagated vegetatively using stolons and rhizomes, since seed production has not been reliable [2]. It is commercially available in sprigs, plugs and sod. Minimum planting rates of 500-1,000-1,500 bushels per ha are recommended [2]. The lower volume will take at least 3 months for grow-in. It should be mowed after the first 60-90 days after planting when it will be used as turf grass to avoid vertical growth and to promote horizontal growth [3], [2].

Management: Seashore paspalum can be grazed from March to November and the green stolons are eaten during the winter months [3]. The species generally persists with heavy grazing because it grows flat on the ground. In managing seashore paspalum for forage, it is recommended that less than 50 % of the present years production by weight be grazed. In addition, a 90-day suspension of grazing is implemented to improve the strength of the crop and to obtain a forage reserve [3]. Fertilization is generally applied when it is used for fodder. When it is used as turfgrass, only minor additions are used; high nitrogen levels promote succulent growth which encourages scalping when closely mowed as a turf grass [3].

Harvest: It is probably rarely cut for biomass production because of its low growing height. In wet peatlands it could be harvested with adapted machinery (e.g., tracked machinery).

Productivity: Production can range from 1.3 to 7 t DM/ha*yr for the coarse types on saline fields; adding fertilizer can enhance yields to 23 t DM/ha [4], [2].

Cultivation experiences: It is widely cultivated as turfgrass, especially for golf courses [2]. An experimental mesocosm study in Italy cultivated *Paspalum vaginatum* successfully in saturated peat. The results indicate a good potential for removing N and P by harvesting biomass to reduce nutrient release in a Mediterranean drained peatland [5].

Utilisation

Ornamental: *Paspalum vaginatum* is used in commercial and residential landscaping. This turfgrass has been very successful for golf courses all around the world [3], [2].

Animal fodder: It is used as a forage food for cattle and horses [3]. Its use as forage has been documented in Africa, Australia, S. America and the U.S. [2]. The metabolizable energy of *Paspalum* biomass in an experiment in the San Joaquin Valley (California) is ca. 10 % DM for non-saline and moderately saline areas with a crude protein content of 15-16 % DM [6].

Co-benefits: *Paspalum vaginatum* is used for erosion control and wetland restoration [3]. It has a long history of use for bioremediation of contaminated soils [2]. It shows, for example, a proven ability for heavy metal phyto-extraction from marine dredged sediments.

Further reading: [2]

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GREIFSWALD
MIRE
CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Kristian Peters

Persicaria hydropiper (L.) Delarbre

Polygonum hydropiper L. (Syn.)
water pepper, smartweed
(Wasserpfeffer)

Family: Polygonaceae
Life form: forb/herb
Main use category: food, medicine
Used part: leaves, stems

General information

Morphology: Annual, 20-70 cm high. Stem straight or ascending, usually branched, reddish. Leaves oblong-lanceolate or lanceolate, sharp, short-petiolate, often with translucent gland-dots and dark spots, having bitter pepper taste. Ocreae reddish. Hermaphrodite. Inflorescence a slender, spike-shaped, loose raceme, interrupted in lower part, with nodding top. Perianth pink or white, densely covered with indented yellow glandula-dots. Florescence May to August. Nutlet dihedral, convexo-plane or nearly trihedral, dark-fulvous, 300-400 seeds per plant. Fruiting July to September [1], [2].

Geographic distribution: Native to Europe, from Norway south and east to N. Africa and temperate Asia. Distributed cosmopolitan, found in Australia, New Zealand, temperate Asia, Europe and N. America [1].

Natural habitat: *P. hydropiper* grows along shorelines of lakes and ponds, banks of streams and rivers, fens, forested wetlands, pastures and occasionally on waste ground [3].

Site specific properties

Water regime: wet-flooded
Trophic conditions: eutrophic
pH: acid-subneutral
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

Paludiculture with *Persicaria hydropiper* is unknown, but the ecological amplitude suggests that cultivation in wet peatlands could be possible. A paludiculture with *P. hydropiper* seems promising as long as the demand for biomass is sufficient for economic benefits. The species has three edible varieties, all cultivated in Japan: beni-tade, ao-tade and ayu-tade [4].
The species is assigned as a weed in Russia because it may infest grain, tilled and flax crops, that is growing on wetter soils, mainly in zones of the middle and southern taiga and broad-leaf-coniferous forests [1]. In the south, it may occur in irrigated crops. Admixture of *Persicaria hydropiper* seeds to the grain decreases the quality of flour.

Propagation and establishment: *Persicaria hydropiper* can be propagated only generatively via fruits. There is no natural vegetative reproduction [2]. Seeds showed no viability after 6 months of stratification in peat. The highest germination rates were observed when the nuts were stored 12 months under water at 2-4°C [2]. The seeds germinate after 5-10 days. Young seedlings establish themselves readily in damp soils [2].
Seeds are reproduced and distributed by a limited number of seed companies in Japan [4]. Every plant produces 300-500 seeds on average [1].

Management: *Persicaria hydropiper* is an obligate wetland plant and dies rapidly under dry conditions [2], so the peatland must be constantly wet during the growth period in summer. Weed control is necessary because the plant is not very competitive, preferring rather open habitat or closed pure stands [2].
It is a summer annual plant and must be reseeded every year. Natural reseeding seems not possible because the plant is harvested before flowering. Only when the stand is partially harvested, rows of flowering plants are left behind.

Harvest: The fresh aboveground parts are harvested in a young stage. Under favourable conditions this occurs after 6-10 weeks after germination (= age of first flowering [2]).

Productivity: No information found.

Cultivation experiences: *P. hydropiper* is cultivated for its edible leaves in Japan [5].

Utilisation

Human food: The leaves and stems are edible, raw or cooked. They can also be made into an acid peppery condiment [6]. They are very spicy [5]. The leaves contain about 7.5 % protein, 1.9 % fat, 8 % carbohydrate, and 2 % ash [7]. The leaves are said to contain rutin [8]. The seed can be used raw or cooked. It is rather small and fiddly to utilize. The seed is used as a condiment to substitute pepper [9]. The sprouted seeds or young seedlings can be used as a garnish or added to salads, they are commonly sold in Japanese markets [6], and are very hot [5], [7].

Medicine: *P. hydropiper* has a long history of herbal use, both in Eastern and Western herbalism. It is not used very often, and is seen more as a domestic remedy being valued especially for its astringent properties which makes it useful in treating bleeding, skin problems, diarrhoea etc. [10]. It serves as a promising candidate as a multipurpose herbal medicinal agent owing to its economic viability and its being a reservoir of many significant medicinal properties in treating diseases and ailments related to microbial infections, inflammation, pain, allergy, uterine disorders, fertility, obesity, and improvement of memory [11].

The leaves are anti-inflammatory, astringent, carminative, diaphoretic, diuretic, emmenagogue, stimulant, stomachic, and styptic [12], [13], [14], [15], [16]. They contain rutin, which helps strengthen fragile capillaries and thus helps prevent bleeding [17]. It should be used with caution [14]. The seed is carminative, diuretic and stimulant [8].
The whole plant, either on its own or mixed with other herbs, is decocted and used in the treatment of a wide range of ailments including diarrhoea, dyspepsia, itching skin, excessive menstrual bleeding, and haemorrhoids [8], [18]. A poultice of the plant is used in treating swollen and inflamed areas [19]. In Chinese tests, the plant was ranked 20th in a survey of 250 potential antifertility drugs [8].
A homeopathic remedy is made from the leaves [13]. It is used in the treatment of piles, menstrual pains and other menstrual complaints [13].

Raw material for industry: A yellow-gold dye can be obtained from the stalks [20].

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Picture: TeunSpaans, Richard Bartz (detail)

Petasites hybridus (L.) G. Gaertn., B. Mey. et Scherb.

butterbur, bog rhubarb (Gemeine Pestwurz)

Family: Asteraceae
Life form: forb/herb
Main use category: medicine
Used part: leaves, roots

General information

Morphology: Perennial, 80-120 cm high. Stems stout, erect. Leaves orbicular-cordate, margin irregularly toothed; diameter of 40-70 cm. Dioecious. Capitula 16-55 in the male, 32-130 in the female. Bracts purplish. Florets pale lilac-pink or yellowish, all tubular. Flowers appear before leaves in March. Achenes cylindrical; pappus-hairs numerous in female, few in male florets, simple. Strong rhizome: 4 cm thick [1], [2].

Geographic distribution: Europe - from Scandinavia south and east to Spain, N. Asia and W. Asia; naturalized in north-eastern N. America [3], [4].

Natural habitat: Nutrient-rich, wet forb meadows and copses by streams to 1,500 m [5], [6].

Site specific properties

Water regime: moist-wet
Trophic conditions: eutrophic
pH: subneutral
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Paludiculture with *Petasites hybridus* is unknown, but the ecological amplitude suggests that a wet cultivation is possible. A successful test cultivation in a rewetted fen peatland showed that cultivation in moist to wet peatlands is possible. Cultivation instructions are rare and only available from cultivation on mineral soil. Information on propagation and establishment are probably transferable to paludiculture. The harvest of the valuable roots could harm the peat soil and probably lead to further degradation, just like the necessity of the new installation of the field after root harvest. A peat conserving paludiculture with *Petasites hybridus* would therefore exclude the harvest of below-ground biomass.

Propagation and establishment: *Petasites hybridus* can be propagated generatively via fruits (achenes) or vegetatively with divisions. The seed should be sown in a cold frame as soon as it is ripe or in early spring and planted out in the next summer [3]. The viability of the seed is low and the growth is very slow, for which reasons the vegetative propagation is recommended. A division succeeds at almost any time of the year. Larger divisions can be planted out directly into the field in autumn [3], [2]. A successful cultivation in mineral soil used divided stolons of 10 cm length minimum, planted 6 cm deep with a density of 6-7 divisions per m² [7]. Rhizome division can be used as well [2]. Weeding is necessary before planting. After 1 year a closed stand has established and weeding is unnecessary.

Management: The plant has a high N demand [7], so cultivation in fertile peatlands is recommended. Long-term high water tables will lead to lower root biomass. Also, very consolidated soils will lead to cuts in yields [2].

Harvest: Most of the plant material for drug use comes from wild collections from natural stands [2]. The aboveground biomass can be harvested one year after planting, the roots after 3 years. The leaves can be harvested in summer (June to August) after flowering when the plant is withered; thus, 2 cuts per year are possible [2]. The roots are harvested in late summer to autumn [7]. Both can be dried for later use [8].

Productivity: The productivity depends strongly on nutrient conditions: 0.44-5.7 t/ha are possible after one reference (aboveground biomass with a moisture of 8-10 %) [7]. The first cut in the first year after planting will yield up to 1.8 t/ha DM (= 9 t fresh material), the 2nd around 8 t/ha DM (= 400 t fresh material) and the 3rd up to 10 t/ha (= 500 t fresh material) from 2 cuts per year, respectively [2]. The root drug biomass reaches values of > 12 t/ha after the 2nd year of growth. Information on ingredients of roots and leaves are available [7], [2].

Cultivation experiences: One pilot study is known from a rewetted fen peatland in NE. Germany [9]. It was grown on mineral soil [7], e.g., in Germany or Switzerland [2]. In 2003 the permission for the use of the root drug in Germany was revoked. Since then it is unknown if there are still cultivation fields in Germany [2].

Utilisation

Medicine: *P. hybridus* is widely considered to be an effective cough remedy and recent experiments have shown it to have remarkable antispasmodic and pain-relieving properties [10]. It acts specifically on the bile ducts, stomach and duodenum [11]. The plant contains pyrrolizidine alkaloids, which are in isolation toxic to the liver [11]. Thus, the direct internal use cannot be recommended. But the alkaloids are extractable [2].

The root and the leaves are analgesic, antispasmodic, cardiotonic, diaphoretic and diuretic [12], [8]. A decoction is taken as a remedy for various respiratory problems such as asthma, colds, bronchitis and whooping cough and also other complaints such as fevers and urinary complaints [12], [11]. It is also very effective in the treatment of gastrointestinal complaints and biliary dyskinesia [10], [11]. Externally it can be used as a poultice to speed the healing of wounds and skin eruptions [11]. A homeopathic remedy is made from the leaves and roots. It is used in the treatment of severe and obstinate neuralgia [12].

Ornament: Butterbur is used as an ornamental garden plant.

Further reading: [7], [2]

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Phalaris arundinacea L.

reed canary grass (Rohr-Glanzgras)

Family: Poaceae
Life form: graminoid
Main use category: energy, fodder
Used part: aboveground biomass

Picture: James K. Lindsey, Kristian Peters (left detail), Rasbak (right detail)

General information

Morphology: Perennial. Height up to 2.5 m. Stem hairless and erect, persistent. Leaf flat, rough-textured. Tapering leaves 9-25 cm long. Hermaphrodite. Inflorescence a compact panicle, 7.5-40 cm long, erect or slightly spreading. Flowers green to purple, changing to beige over time. One of the first grasses to sprout in the spring. Thick rhizome system that quickly dominates the soil [1], [2], [3].

Geographic distribution: Throughout the northern hemisphere: native to Europe, W. and N. Asia, N. America and N. Africa [4].

Natural habitat: Marshy grassland, river and lake margins, mainly at nutrient-enriched sites in riparian habitats [5], [3].

Site specific properties

Water regime: moist-wet
(groundwater rich in oxygen preferred)
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Phalaris arundinacea is well suited for paludiculture. Reed canary grass is suitable for moderately rewettable peatland areas [8]. Under such moist to wet conditions, peat oxidation is retarded substantially or stopped completely. Most likely, there will be no new peat formation with *Phalaris*. Existing stands of reed canary grass spread in the course of natural succession in rewetted fens. After several years of utilization, they are often replaced by sedges, reeds or giant manna grass [9], caused by increased wetness or it disappears through inadequate use (e.g., cut too early, too deep or too often). In this case, a transitionary use would be possible or a specific stand conserving management is necessary to achieve long term use of reed canary grass. There are several studies on GHG emissions on peatland sites with reed canary grass available [29] or pilot studies are currently implemented (e.g., MoorUse project in Bavaria, Germany [31]). The results show that a reduction in total GHG emission can be achieved without losing the productivity of newly established reed canary grass when the water level is maintained close to the surface [29].

Propagation and establishment: It is propagated generatively via fruits (achenes). Tillage and seeding are done as for normal forage grasses. Direct seeding from spring to late summer with a density of 10 to 25 kg seeds per ha that are about 1-2 cm deeply placed with a row spacing of 12.5 cm [10], [11], [12]. Flooding is destructive during the establishment phase. Weeds could be problematic during establishment phase.

Management: Growth is favoured by fertile soils. Reed canary grass has a high nutrient demand to express its full potential [10]. It is resistant to temporary flooding and drought. An alternate moisture regime with a mean water level of 0 to -20 cm favours growth and competition. Permanent flooding will not be tolerated, except with groundwater rich in oxygen. Adapted to infrequent cutting regimes (2-3 cuts per year). Disappears when grazed, because it is sensitive to trampling [10].

Harvest: The harvest can be done with adapted machinery or in drier periods with adapted and light conventional technique (e.g., double and low pressure tires). Harvest time depends on utilisation purpose. In winter harvested reed canary grass is suitable both as a loose solid fuel for direct combustion, but also for the production of pellets and briquettes. The harvest for combustion should be done as late as possible, but due to snow and heavy weather conditions the stand may collapse and the biomass will be procumbent in the proceeding winter, which is why harvest should be conducted in November/December. A report from Sweden says the crop is harvested in spring until March/April [7]. Apart from that, a report from Estonia suggests harvesting in late autumn [6]. The content of critical chemical elements for combustion is decreasing from summer to autumn without any significant differences between autumn and spring. The ash concentration in autumn is higher than that in spring, but its value is not higher than that of peat commonly used in distant heating boilers. The additional energy yield gained from the reed canary grass fields in autumn compared with that in spring is more than 30 % [6]. Values for ash content, critical elements and heating values are available [33]. The summer harvested hay can also be utilized for direct combustion or for biogas production. Before flowering, reed canary grass yields a good fodder for horses. It is used for silage, hay or bedding.

Productivity: Annual productivity for N. America from cultivated stands range from 1.6 to 12.2 t DM/ha, and for Europe 7-13 t DM/ha [13]. The annual fall yield of harvested reed canary grass from peatlands in Estonia amounted to about 7 t DM/ha and in spring 5.5

t DM/ha [6]. Paludiculture trials in Denmark achieved 6 t DM/ha [29]. Natural stands on rewetted fens in northeast Germany achieved the following yields: 5-10 t DM/ha*yr in summer, and in winter 3-5 t DM/ha*yr [14].
Biomass production is exceedingly high but it requires a tremendous amount of nutrients to sustain this growth. Riparian soils tend to be very rich in nutrients, allowing reed canary grass to thrive. There are stands that are hayed every year and a large amount of nutrients is thus subsequently removed. Yet these stands continue to proliferate for decades [2].

Cultivation experiences: In northern Europe, it is grown successfully on cutover moist peatlands for several decades [6], [7]. It is also cultivated in Estonia [6], Canada [15], Denmark [29], and Germany [31].

Utilisation

Medicine: *Phalaris* contains DMT (N,N-Dimethyltryptamine) that is and was used for spiritual and medicinal purposes [16], [17]. Nowadays it is listed as a so-called ayahuasca-analogue, because it can cause effects similar to the South American brew ayahuasca, but can be cultivated in temperate regions [18]. When ingested, DMT acts as a psychedelic drug. The DMT content in *Phalaris* is highly variable [19]. A comprehensive review and bibliography about this special topic is available [20].

Animal fodder: It can be used as pasture grass and for production of silage and hay [10]. It also provides good fodder for horses, because high feeding values are not desired [21], [22]. The nutritional value of reed canary grass differs strongly between different sites - from 4.5 to 7.1 MJ/kg DM [23]. Highest productivity can be found on the wetter sites, in contrast to the higher nutritional value that can be found on the drier sites [23]. Growth of grazing animals is often low and diarrhoea may occur in lambs. However, varieties bred with lower alkaloid content are much better accepted and less toxic [10].

Fuel: The winter and also the summer harvested biomass can be used for direct combustion due to new special oven technology ([28], see also information in section "Harvest” therein). Another option for the summer harvested biomass is the production of biogas [12]. The specific biogas yield potential is highest for juvenile plants and decreased with increasing plant maturity [30], [27]. A small proportion (~20%) of maize (or others) could be replaced by *Phalaris* biomass as substrate for biogas plants [27].

Agricultural conditioner and substrate: Reed canary grass biomass can be used to produce growing media as an alternative for peat or compost [35], [36].

Raw material for industry: The aboveground biomass was traditionally used for bedding [10]. The leaves have been woven into hats and mats [24]. Reed canary grass is also suitable for paper production [25].
It may be useful for new pathways in the bioeconomy, offering multiple utilisation options from bioplastics (HMF), building materials to fibre-based packaging or paper.

Co-benefits: This is one of the main species used in the reed bed system for the water purification treatment of grey water and for irrigation with pollution control sewage effluent from municipal and industrial sources [26], [3].

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Pictures: Isidre blanc, Rasbak (detail)

Phragmites australis (Cav.) Trin. ex Steud.

common reed (Schilf, Reet)

Family: Poaceae
Life form: graminoid
Main use category: raw material, energy
Used part: aboveground biomass

General information

Morphology: Perennial. Height 1.5-5 m. Stem is rhizomatous, stoloniferous. Leaf blade flat, smooth; 2-3 x 20-50 cm. Hermaphrodite. Inflorescence a dense, dark purple panicle, about 20-50 cm long. In maturing the numerous long, narrow, sharp pointed spikelets appear greyer due to the growth of long, silky hairs. Extensive stands (known as reed beds) formed, which may be as much as 1 km² or more in extent. It can spread at 5 m or more per year by horizontal runners, which put down roots at regular intervals [1].

Geographic distribution: Nearly cosmopolitan. Native to Europe, Asia and Africa. It does not occur in polar/arctic regions, Iceland and some certain tropical areas (Amazon basin, Indonesia) [2].

Natural habitat: The common reed is able to grow in a very wide array of habitats: brackish to freshwater marshes and swamps, shallow lakes, ponds margins and wet wastelands. Shallow water and wet soil, avoiding extremely poor soils and very acid habitats [3].

Site specific properties

Water regime: moist-wet-flooded
Trophic conditions: meso-eutrophic
pH: subneutral-alkaline
Light conditions: intermediate shade tolerant
Salinity: high tolerance

Cultivation

Phragmites australis is well suited for paludiculture. It can be productive and there is a variety of utilisation options available. The artificial cultivation is well known and studied from wastewater treatment and restoration measures. The traditional reed paludiculture is known for its use for roof thatching, e.g., in Poland or Germany. Nowadays thatch is a globally traded commodity. Germany and other major reed importing countries such as the Netherlands, the United Kingdom, and Denmark rely on high import rates to meet their national consumption [65]. For Germany import rates of 83 % were calculated for 2018 [65], although thatchers would prefer regional reed.

In China large reed beds are harvested for paper production [4]. *Phragmites australis* is an aggressive colonizer. In parts of N. America it is considered as an invasive weed species.

Reeds and reedbeds are variable for several causes, e.g., its genetic variation. In Europe diploid (2n=24) as well as tetraploid (4n=48) genotypes dominate [5]. While in Asia and North Africa the number is higher, many are octoploid (8n=96) types [6]. Higher, lower and non-standard numbers are recorded as well.

Phragmites is a well-described and important peat-forming plant species [6].

Propagation and establishment: Reed propagates naturally mainly by vegetative reproduction; seedlings are rare [6]. After rewetting of a peatland, reed can spread out spontaneously, e.g., from remnants in ditches or diaspores [7]. For a generative propagation, seeds must be harvested in winter from high quality sites in the nearby area or a site with similar growing conditions [7], [8]. Germination is increased by frost. Germination rates about 80 % can be achieved with good seeds [9].

Planting reed can be done with seedlings grown from seed, stem cuttings and rhizome cuttings. The most promising way seems to be the cultivation of seedlings from seed in the greenhouse. In the greenhouse or nursery it should be sown on the surface in spring in a light position. The soil should be kept moist [2], [7], but flooding is detrimental during germination. When the seedlings have formed about ten culms that are at least 20 cm high, they can be planted out. The peatland areas should be mowed before planting, the mown material removed and then scarified [59]. After planting, shallow flooding for a short period is recommended to ensure good plant establishment and to suppress emerging competitor species [8]. Planting out should occur in early or mid-summer. Even at planting densities of less than one plant per square metre, it rapidly forms closed beds [8]. Recommended planting densities vary between 0.25 to 4 plants per m^2 [59], more plants per m^2 will shorten the stand establishment time. Young reed plants cannot tolerate high floodings, so a water level of maximum 5 cm above ground is recommended [10]. After 2-3 years of growth the reed stand is ready for the first harvest. For thatching reed, a preceding care-cut is recommended to get rid of old plant material [9].

Vegetative propagation can be done with rhizomes or stem cuttings. Rhizomes should be divided in spring. Any part of the root that has a growth bud will grow into a new plant. Larger divisions can be planted out directly into their permanent positions. A good overview about different rhizome planting technique is provided by [7]. The use of stem cuttings is a simple and inexpensive technique for establishing a reedbed, but it requires considerable labour input [7].

Direct seeding is possible but difficult due to the high sensitivity of young seedlings towards flooding, frost and competition [11], [12]. Seeds germinate only on wet soil, and flooding must be avoided at all costs. Aerial sowing has been done in the Netherlands, but it is expensive and only cost-effective on very large homogeneous areas with good water management [7].

Management: Water is the most important life factor for common reed [6]: for a long term establishment and growth, water tables should be between -0.5 and +1.5 m above the surface. The utilisation of the biomass determines the harvesting time (cf. harvest) which in turn determines the nutrient storage in the underground parts. Annual mowing in winter can – especially on nutrient-poor sites – lead to a decrease in yields [59]. Others report that the annual winter harvest can even lead to an increase of the productivity [17], probably only when lots of additional nutrients are supplied. Due to sufficient nutrient availability of rewetted peatlands, stable yields can be expected, at least over the first few years [59]. Annual summer mowing reduces the vitality of the plants and can completely displace them. Many authors reported a depressive effect of the summer harvest, since the beds have not yet translocated all resources to rhizomes to guarantee a vigorous resprout in the next vegetative season [17], [57]. As a result, the reed plants become weakened and may be outcompeted entirely because fewer nutrients are stored in the rhizomes to support the emergence of shoots in the following growing season. It should be mowed only every 3-5 years in summer [15], to avoid complete displacement with other vegetation.

Harvest: Harvest time depends on utilisation purpose and the quality demands. Reed for thatching is harvested in winter, from January until March (-April) when stems are dry and have shed most of the leaves. For pulp, direct combustion or construction materials, the aboveground biomass is also harvested in late winter. Many nutrients that may frustrate biomass use for these purposes are relocated to the rhizomes or leached out by precipitation during autumn and winter [13].
Average cut height of 30 cm is recommended to avoid destructive flooding of the stubbles [6]. If stubbles from last year's cut become flooded in spring the reed plants do not receive sufficient oxygen and the plants become weakened. Harvest can be conducted on frozen ground and in summer or winter with adapted machinery like caterpillars or Seigas [14].
Summer mowed reed can be used for biogas production [15]. It is important that the reed is not harvested too late in the growing season, since increased lignin content will decrease the gas yield.
Especially summer mowing of reed fosters biodiversity by suppressing reed, for which reason it is often applied in nature conservation to support certain animal and plant species.
Grazing, e.g., with water buffaloes is used in nature conservation (e.g., for the restoration of species rich salt marshes) for reed control and will suppress reed growth and reed bed encroachment [62].

Productivity: The annual productivity depends on site properties and the genetic characteristics. The highest productivity can be reached under polytrophic conditions with water tables between 30 and 150 cm above ground. Summer harvested reed from peatlands in Germany ranges from 4 and 23.8 t DM/ha*yr [5]. In winter approximately 75 % of the biomass (mainly leaves and stems leftover) remain on the site, on average 11-15 t DM/ha*yr [5].

Cultivation experiences: e.g., UK [7], Germany [8], [9], [60], Italy [57], Russia [18]

Utilisation

Human food: The rhizome is edible, raw or cooked like potatoes [19], [20], [21], [22], [23], [24]. It contains up to 5 % sugar. The flavour and texture are best when the rhizome is young and still growing [23]. It can be dried, ground coarsely and used as porridge [26], [27], [28]. In Russia they are sometimes harvested and processed into starch [29]. The young shoots are edible raw or cooked [30], [28], [22], [31]. They are best if used before the leaves form

[25]. They can be used like bamboo shoots [24]. The partly unfolded leaves can be used as a potherb and the Japanese dry young leaves, grind them into a powder and mix them with cereal flour when making dumplings [24]. The stems are reported to contain 4.8 g protein, 0.8 g fat, 90.0 g total carbohydrate, 41.2 g fibre, and 4.4 g ash [29]. The seed is edible raw or cooked [32]. It can be ground into a powder and used as flour [33], [28], [22], [23]. The seed is rather small and difficult to remove from the husk but it is said to be very nutritious [24]. A sugar is extracted from the stalks or wounded stems [19], [34], [28], [35]. Having a sweet liquorice-like taste [33], it can be eaten raw or cooked [28]. The stems can be boiled in water, after which the water is boiled off in order to obtain the sugar [36]. A sugary gum that exudes from the stems can be rolled into balls and eaten as sweets [24]. A powder extracted from the dried stems can be moistened and roasted like marshmallow [28], [35], [22], [24].

Medicine: The leaves are used in the treatment of bronchitis and cholera; the ash of the leaves is applied to foul sores [37]. A decoction of the flowers is used in the treatment of cholera and food poisoning [37]. The ashes are styptic [37]. The stem is antidote, antiemetic, antipyretic and refrigerant [37]. The root and rhizome is antiasthmatic, antiemetic, antipyretic, antitussive, depurative, diuretic, febrifuge, lithontripic, sedative, sialogogue and stomachic [38], [39], [37], [40]. It is taken internally in the treatment of diarrhoea, fevers, vomiting, coughs with thick dark phlegm, lung abscesses, urinary tract infections and food poisoning [40], [32].

Animal fodder: Only the young and growing plants can serve as forage for cattle and horses, since after maturity common reed becomes unpalatable for many animals [41]. The metabolizable energy (ME) ranges from 3.6 to 5.7 MJ NEL per kg dry matter [42]. It has a German forage value (Futterwertzahl) of 3 [61]. Water buffaloes also consume reed, especially the young plants or when nothing else is available. Grazing will displace reed beds [62].

Fuel: Reed biomass can be combusted directly as a fuel or can be converted to biogas [43], [44], [56]. Pellets for direct combustion are produced for more convenient handling and for reducing transport costs. The calorific value of *Phragmites* (17.5 MJ/kg dry mass) is only marginally less than that of wood (18.5 MJ/kg dry mass).
The composition of the biomass differs from site to site, depending on site conditions (trophy, pH, water availability, harvest time). In general, it has higher ash content than wood which requires adapted combustion techniques [45].

Agricultural conditioner and substrate: The plant is made into fertilizer [38]. Freshly cut shoots are a good green manure [219], [15] or the biogas by-product (sludge) can be spread as a fertilizer on farmland [15].
In Finland a commercial substrate (growing media) is made from reed biomass [63] and sold by this company [64].

Raw material for industry: The plant is rich in pentosans and may be used for the production of furfural; the nodes and sheaths yield 6.6 %, whilst the underground parts even over 13 % of furfural [29]. The pentosan content increases throughout the growing period and reaches its maximum in the mature reed [29]. The reed can also be used for the preparation of absolute alcohol, feed yeast and lactic acid [29].
Reed contains high concentration of silicon. Silicon is responsible for the water resistance of reed blades and the heavy flammability of reed. Thus, silicon is known for its water repellent property. Silicon, a crystal and semiconductor, is very flame retardant and almost water resistant. The leaves can be used for Li-ion batteries: three-dimensional (3D) porous silicon-based anode materials have been successfully fabricated from natural reed leaves [65].

The stems are useful in the production of homogeneous boards [27]. They can also be processed into a fine fibrous material suitable as a filler in upholstery [29], or into fireproof walls [5].

The stems have many uses. They are used traditionally for thatching roofs [46], [27], [21], [23]. It can last for 45 to 100 years [47], which mainly depends on the slope of the roof. The stems and leaves are also used for building dwellings, lattices, fences, arrows by indigenous groups, and for weaving mats, carrying nets, basket making, insulation, as a cork substitute etc. [20], [21], [48], [22], [49], [32], [29]. The stem contains over 50 % cellulose and is useful in the manufacture of pulps for rayon and paper [29], e.g., in China [4]. For one ton of pulp, 2.7 t of raw material (dried reed biomass) is needed [4]. In China the reed is harvested in winter for pulp production [4]. The fibre from the leaves and stems is used for making paper [50]. The fibre is 0.8-3.0 mm long and 5.0-30.5 µm in diameter. The fibre makes a khaki paper [50] or could be used for manifold purposes, like packaging or molded products. A fibre obtained from the plant is used for making string [35], [23]. The flowering stalks yield a fibre suitable for rope making [29]. The leaves are used in basket making and for weaving mats [47], [40]. In Romania, reeds are also harvested in winter, but sometimes until March, and yield up to 60 % unbleached pulp from 125,000 t of dry reeds [51], [52]. A light green dye is obtained from the flowers [53], [49]. The inflorescences are used as brooms [21]. The plant is mixed with mud to make a plaster for walls [54]. The plant has a very vigorous and running rootstock; it is useful for binding the soil along the sides of streams [49].

Co-benefits: It is planted for flood control since it stabilizes the banks and gradually builds up soil depth, thus raising the level of the bank [2]. Plants are widely used for wastewater treatment.

Further reading: General information on reed: [6], [55]. A good review on the utilisation of reed biomass is provided by [43].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Ivar Leidus

Picea abies (L.) H. Karst.

Norway spruce (Gemeine Fichte)

Family: Pinaceae
Life form: tree
Main use category: raw material, fuel
Used part: wood

General information

Morphology: Perennial. Height: 35-55 m. Trunk up to 1-1.5 m in diameter; shoots orange-brown and glabrous. Evergreen leaves needle-like, 12-24 mm long, quadrangular in cross-section, dark green with inconspicuous stomatal lines. Monoecious. Cones 9-17 cm long, bluntly to sharply triangular-pointed scale tips; in early stage green or reddish, maturing into brown 5-7 months after pollination. Shallow root system [1].

Geographic distribution: Norway spruce is native to the mountainous region of Central Europe and the boreal zone of Eurasia. Introduced to N. America.

Natural habitat: *Picea abies* is widespread and dominant in boreal conifer forests of N. and NE. Europe, and occurs on nutrient-rich mineral soils and fens. Minerotrophic forested mires are usually dominated by *Picea abies* in Fennoscandia (with proportions of *Betula pubescens*) [2].

Site specific properties

Water regime: moist(-wet) (only oxygen rich water)
Trophic conditions: (oligo-)meso-eutrophic
pH: acid-subneutral
Light conditions: shade tolerant
Salinity: no tolerance

Cultivation

Picea abies is the most abundant, if not widespread, conifer in Europe and an important timber tree. In the boreal zone, commercial timber is harvested from managed forests from drained peatlands and mineral soil sites and nowadays even from plantations. In general, the tree growth of pristine mires dominated by *Picea abies* is low and is conventionally increased by drainage [2], which leads to peat degradation. The ecological amplitude suggests that cultivation in moist rich peatlands could be possible. Long term flooding is detrimental, so Norway spruce can only used in moderately rewetted peatland areas. Peat conserving paludiculture is impossible.

Propagation and establishment: Generative establishment from seeds is the dominant mode of reproduction of *Picea abies* forests. Peatlands with a *Sphagnum* cover provide ideal conditions for germination. Under natural unmanaged conditions spruce forests are characterized by a multi-layered tree canopy with most individuals in the youngest age classes. Seedlings survive in an extremely stunted condition for many years. This reservoir of seedlings functions in a way analogous to soil seed banks [3]. Direct seeding, however, appears not to be successful. Natural regeneration and planting are mostly applied for propagation. To enhance the natural regeneration after harvest, seed trees and short-term shelter wood systems are recommended. Shelter woods at densities of 200 trees/ha are suggested [4]. The trees should not be removed until the spruce seedlings have reached 10-20 cm in height (around 10 years) [5]. Because of avoiding spring frost damage, too heavy exposure to sun light and ground vegetation competition, the shelter trees should be harvested in two phases.

Bare root or containerized seedlings can be used, planted with 1.5-2 x 1.5-2 m spacing [6], [7]. It is recommended to plant the trees on ridges to reduce the risk of detrimental flooding in rewetted peatlands. Planting without site preparation after clear-cuts is not recommended. Site preparation by mounding, followed by planting in the mounds in combination with shelter trees showed the best results in terms of survival, avoiding damage and height increment [4]. Scots pine or downy birch can be used as a nurse tree for Norway spruce to avoid spring frost damage; such mixtures result in a net gain in production higher than monocultures of either species [2], [8].

Management: Norway spruce is conventionally managed with even-aged systems such as patch clear cutting and strip-cutting [9], but also uneven aged silviculture appears to be applicable to boreal *Picea abies* with selective cuttings [10], [11], [12]. The idea behind continuous cover forestry is to retain an all-sized (uneven-aged) stand structure, where the only treatment is repeated single-tree harvesting.

Thinning models and rotation recommendations are available for mineral soils [13]. Fertilizers (P and K) are used in drained peatlands to increase the productivity. Under wet conditions fertilization is usually forbidden.

Norway spruce cannot cope with stagnant (standing) high water levels and anaerobic conditions; water has to be moving to become oxygen-rich and thus suitable for Norway spruce.

Harvest: In an even-aged system, rotations of 80-100 years are common (depending on site and use). Harvesting of the timber from peatlands can create severe forest renewal problems, unacceptable increases in the ground water levels, fast growing ground vegetation (and thereby competition), frost and wildlife damage; all problems being magnified when the final fellings are carried

out as clear-cuts [4]. So clear-cutting should be avoided.
Harvesting should be done in winter after the ground is frozen and snow-covered to minimize peat disturbance and its possible harmful effect on water quality.

Productivity: The wood production of *Picea abies* is heavily depending on site conditions, especially on the mean water table (which should not be too high), fertility, climatic region and silvicultural measures. The post-drainage average forest productivity of mature Norway spruce forests on mires in Sweden was estimated with 8.5 m^3/ha*yr [4]. A fertilized stand on a drained peatland in southern Norway yielded from 9.5 to 11.9 MT DM/ha*yr [14].

Cultivation experiences: In Fennoscandia, Norway spruce is widely grown on drained peatlands (rarely planted). Cutaway peatlands in Ireland have been afforested with Norway spruce, partly in trials [15], [7]. It is planted in N. America as a timber tree [16].

Utilisation

Human food: Young male catkins are edible, raw or cooked. They are used as a flavouring [17]. Immature female cones can be eaten when cooked. The central portion, when roasted, is sweet and syrupy [17]. The dried inner bark is edible, and can be ground into a powder and used as a thickener in soups etc. or added to cereals when making bread [17]. It is considered an emergency food, and therefore used in times of scarcity. The seed is edible. Rich in oil and with a pleasant slightly resinous flavour, but too small and fiddly to be worthwhile unless in desperate circumstances [17]. A refreshing tea, rich in vitamin C, can be made from the young shoot tips [17]. These tips are also used in making spruce beer [18].

Medicine: The buds, leaves and resin are antibiotic, antiseptic, balsamic, expectorant, sedative [19]. A pitch, or resin, obtained from the trunk is rubefacient and stimulant [20]. It is used externally in plasters etc. for its healing and antiseptic properties [19]. A poultice of the sap or gum has been used in the treatment of boil and abscess pain [21]. Home-made resin salve from Norway spruce is traditionally and widely used in folk medicine to heal various skin infections and wounds in northern Finland [22]. Studies indicate that the resin may have antimicrobial properties [35], [36].

Ornament: Norway spruce has been the most common traditional Christmas tree taken from forests in Finland and in Scandinavian countries. Nowadays it is also planted for that particular purpose. However, the real Christmas tree growers prefer *Picea omorica* and *Abies balsamea*, because they keep the needles longer. *Picea abies* tree fences are also common, although they have to be sheared every year to control the height and branch growth. An essential oil from the leaves is used in perfumery [23], [24].

Fuel: The wood can be used as fuel wood. When burning the wood, it emits sparks, so in open fireplaces one has to be careful.

Raw material for industry: The wood is medium hard, fairly elastic, durable under water, light in weight and colour. Used for saw logs, general carpentry, joinery, musical instruments etc. Valued for its use in the pulp industry to make paper [25], [26], [27], [23], [28].
The tree is a source of pitch and turpentine [25], [19], [23], [29]. Burgundy pitch is used as a varnish [30]. It is a strong adhesive [24], [29]. The turpentine is a waterproofer and wood preservative. They are obtained by incisions in the trunk, the resin is scraped out some months later [29].

The seed contains 30 % of fatty oil. This is used in the production of a varnish [31]. The bark contains some tannin [32]. Both the bark and bark extract have been widely used in Europe as a source of tannin; the bark contains up to 13 % tannin [33]. Yields of tannin have been doubled by heating or steaming the bark as soon as possible after the tree has been felled [33].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Franzi (big picture), MPF (detail)

Picea mariana (Mill.) Britton, Sterns & Poggenb.

black spruce (Schwarz-Fichte)

Family: Pinaceae
Life form: tree
Main use category: raw material, fuel
Used part: wood

General information

Morphology: Perennial. Height up to 25 m, often smaller. Trunk up to 0.25 m in diameter. Leaves 0.6-1.5(-2) cm, 4-angled in cross section, rigid, pale blue-green, glaucous, stomates on all surfaces. Monoecious. Seed cones 1.5-2.5(-3.5) cm; scales fan-shaped, broadest near apex, 8-12 x 8-12 mm, rigid, margin at apex irregularly toothed. Crown narrowly conic to spirelike. Bark gray-brown [1]. Potentially peat forming [2], [3].

Geographic distribution: Northern N. America - Alaska to Newfoundland and south to British Columbia and W. Virginia [4].

Natural habitat: Forested peatlands (mainly bogs and moderately rich fens), mesic uplands to shallow soils over bedrock [5]. Can grow on permafrost [6], [7].

Site specific properties

Water regime: moist-wet
Trophic conditions: oligo- to eutrophic
pH: acid-subneutral
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Black spruce is the most important forest tree species growing on peatlands in N. America [7], [8]. Natural stands of black spruce are widely used in boreal N. America, where they can be found on a large extent on peatlands. There the tree occurs in pure stands or with components of, e.g., *Larix laricina* or *Thuja occidentalis*. Cultivation experiences are available and probably transferable to paludiculture.

Propagation and establishment: Natural seeding is the most important mode of reproduction. Black spruce produces huge seed crops. Artificial reproduction is done by direct seeding and planting [9]; direct seeding is recommended for poorer sites. *Sphagnum* mosses provide a continuously moist seedbed, although they may also overgrow black spruce seedlings and slow down their development. Feather mosses may provide a suitable seedbed during wet years, but they are unreliable and the substrate may dry out before penetration by the seedling root occurs [10]. Planting is often used on richer sites where associated vegetation is very competitive [9]. Seedlings can be planted out into their permanent positions in early summer of the following year after seeding, or be placed in an outdoor nursery bed for a year to increase in size. Flooding is only tolerated to a limited extent by seedlings [15].

Preservation of advance-regeneration is a low-cost and reliable method of re-establishing black spruce forests after harvesting [11]. The cones persist on trees and the viability of seeds in unopened cones is preserved for several years [12].

Black spruce can readily develop adventitious roots in humid peatland conditions. As such, layering is an important mode of reproduction and in many natural stands the abundant advance growth is predominantly of layer origin [13]. However, a high number of layers may have a negative effect on dominant parent tree growth [14].

Management: Black spruce forests can be managed for a sustained yield of pulpwood. For this purpose it is usually grown in even-aged stands. Uneven or all-aged management is recommended for poor sites where stands are windfirm and have abundant layering, and where only the largest trees produce pulpwood anyway [16]. A study in peatlands in Ontario showed that uneven-aged silviculture is biologically and technically feasible in a peatland black spruce stand [11]. The uneven-aged system is an alternative where the stand is managed by high grading, or a combination of high and intermediate level of thinning, and regenerated by an understory of continuous natural regeneration [17]. Mechanized harvest with regeneration protection may sufficiently preserve residual trees and subsequently produce stands that are heterogeneous with respect to the size structure. The management can be implemented via minimum diameter limits based on stand structure and cut-to-length harvesting [18]. The merchantable size will be reached more quickly compared to planted or naturally regenerated trees. The rotation period for an even-aged stand is estimated with 85-105 years, while an uneven aged stand may only attain 60-80 years [19].

Harvest: Clear-cutting in strips or patches is generally considered to be the best silvicultural system for managing black spruce. Clear-cutting on peatlands may affect the annual water table through evapo-transpiration and interception loss, so that the water table might increase. Harvesting should be done in winter after the ground is frozen and snow-covered to minimize peat disturbance and its possible effect on water quality [9].

Satisfactory re-establishment of black spruce after clear-cutting requires an adequate source of reproduction and often some kind of site preparation, such as slash disposal. Rotation age ranges from (60-)95 to 130 for good and poor sites, respectively [6], [9].

Productivity: Productivity is dependent on the nutrient availability. The most productive black spruce stands are on rich fens. Stands of low productivity are usually found in ombrotrophic raised bogs [6]. Under unmanaged conditions, black spruce at maturity averages 12-20 m in height and about 23 cm in d.b.h. on good sites; 8-12 m and about 13 cm in d.b.h. on poor sites [6]. Volumes of 196 m^3/ha are common in 80- to 100-year-old stands on the nutrient-rich peatlands and good upland sites in southern Canada and the Lake States [20].

Yield tables are available [6]. Merchantable volume ranges from 101 to 218 m^3/ha for poor and good sites, respectively, and the mean annual increment from 0.8 to 2.3 m^3/ha [6].

A 70-year-old stand, growing on a well-drained mineral soil with an adequate supply of nutrients, is 30 m high, has a basal area of 40 m^2/ha and a gross merchantable volume approaching 300 m²/ha. Typical 100- to 200-year-old stands growing on (probably pristine) peatland sites often have three times the stem density, but have only one-half of the basal area and one-third the merchantable volume per hectare as compared to average upland stands [13].

Little is known about the growth and yield of uneven-aged stands, but they apparently grow more slowly and have lower volumes than even-aged stands [21].

Cultivation experiences: N. America. Trees have been planted experimentally as a timber crop in N. Europe [22], [14].

Utilisation

Human food: Young male catkins can be eaten raw or cooked, or used as a flavouring [20]. Immature female cones are edible when cooked. The central portion, when roasted, is sweet and syrupy [23]. The inner bark is edible when cooked [24]. A refreshing tea, rich in vitamin C, can be made from the young shoot tips [23], [25], or from the needles and the bark [26], [27]. A gum obtained from the bark is collected in considerable quantities and used for chewing [28], [29]. Hardened blobs make an excellent chewing gum [30]. A source of 'spruce oil' used commercially for flavouring can be harvested [31]. The young twigs are boiled with molasses, sugar etc. and then fermented to produce 'Spruce beer' [31], [24]. The beer is ready to drink in a week and is considered to be a good source of minerals and vitamins [30].

Medicine: A poultice of the inner bark has been applied to inflammations [32], [24]. A tea made from the inner bark is a folk remedy for kidney stones, stomach problems and rheumatism [32]. An infusion of the roots and bark has been used in the treatment of stomach pains, trembling and fits [24]. A resin from the trunk is used as a poultice and salve on sores to promote healing [32], [24]. The resin can also be mixed with oil and used as a dressing on purulent wounds, bad burns, skin rashes, scabies and persistent scabs [24]. The resin can be chewed as an aid to digestion [24]. A decoction of the gum or leaves has been used in treating respiratory infections and kidney problems [24]. An infusion of the leaves has been used as a bath or a rub in treating dry skin or sores [24]. A decoction of the young twigs has been used in the treatment of coughs [24]. To treat diarrhoea, a decoction of the cones has been employed [24]. which is also a remedy (gargle) for sore throats [24]. For the latter purpose, and against toothaches, cones have also been chewed [24].

Ornament: The tree is used as a Christmas tree. In Minnesota Christmas tree harvesting may take place in 20 years intervals: the stump may develop one or two new trees from the upper-most branches left to the stem.

Fuel: The wood can be used as a fuel [33], [34]. It is light, soft and not strong [28], [33]. Because of its small size, it has a low importance as a lumber source, e.g., for construction [30]. However, it is widely used for making boxes, crates etc. [30], and is valued for its use in the pulp industry [33], [34]. The principal commercial use of black spruce both in Canada and the United States is for making high quality pulp with balanced strength properties [6].

A yellow-orange dye is obtained from the cones [35]. Various North American indigenous groups made a string from the long roots of this species and used it to stitch the bark of their canoes, to sew baskets etc. [30], [24]. The pitch obtained from the trunk has been used as a sealing material on the hulls of canoes [24].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Pictures: Peter Mulligan, Pleple2000 (detail)

Pinus sylvestris L.

Scots or Scotch pine
(Gemeine Kiefer)

Family: Pinaceae
Life form: tree
Main use category: raw material, fuel, ornamental
Used part: wood, tree

General information

Morphology: Perennial. Height: 25-35 m. Stems often crooked in early years. Evergreen needles in bunches of 2, stout and usually twisted, 3-8 cm long, bluish-green in colour. Monoecious. Clusters of flowers are yellow, minute, male and female. Female cones tawny-yellow, oblong, symmetrical, 2-5 cm long. Root system widespread, moderately deep, and wind-firm. Spreading tree, pyramidal when young, becoming round topped and irregular in age. Bark orange, thin and smooth on upper trunk, dark and fissured below [1], [2], [3].

Geographic distribution: Grows naturally in continental to sub-maritime regions of Europe, from Scandinavia and Scotland south and east to Spain, Albania and temperate Asia [4], [5]. Introduced to N. America and Asia.

Natural habitat: Grows naturally in oligo-mesotrophic mires and on rather dry mineral soils [6].

Site specific properties

Water regime: moist-wet
Trophic conditions: oligo-meso-eutrophic
pH: acid-subneutral
Light conditions: shade intolerant [7]
Salinity: low tolerance

Cultivation

Scots pine is the most widely distributed pine in the world and one of the most important Eurasian forest trees [5]. Scots pine grows naturally on nutrient poor peatlands (raised bogs) where it may be stunted but there are also forested mire site types dominated by *Pinus sylvestris* that support commercial-size tree stands [8]. The tree is widely growing on mineral soil or on drained peatlands, where it is used for high quality softwood production. The ecological amplitude is wide and suggests that cultivation in moist to wet peatlands is possible. Propagation methods are probably transferable. Long term flooding is detrimental, so Scots pine is recommended for moderately rewetted peatland areas. Also light competition with other tree species (e.g., birch) and the specific targets of one particular rewetting project must be taken into account on a case-by-case basis. The productivity in wet peatlands is probably lower, but there are other benefits resulting of the rewetting of the peatland that should be taken into consideration. Whether a peat conserving paludiculture with Scots pine is possible, needs to be evaluated in pilot projects. But it may be considered potentially peat forming [2], [3], i.e., sphagnum-wood peat.

Propagation and establishment: Natural seeding is the most important mode of reproduction. Artificial reproduction is done by direct seeding and planting. To enhance natural reproduction, various silvicultural systems are applied, the main being clear felling with seed trees and short-term shelterwood [7].
The seeds can be sown without any pre-sowing preparation. Cold stratification for 1-3 months stimulates germination. Sowing the seeds after 12-24 h in fresh water and 3-6 h drying at room temperature without stratification is a common nursery practice [7]. Field germination is best under full or partial sunlight. Sphagnum mosses form a favourable seedbed for germination [8], but the seedlings are easily bogged down due to the rapid height growths of sphagnum under wet conditions [9]. Seedlings may achieve a plantable size in 7-8 months. Two-year-old stock averages from 8 and 20 cm in height. For the installation of a plantation both bare-root and containerized stocks are used [7]. Site preparation is beneficial and weed control is required during the establishment phase. It is recommended to plant the trees on ridges to reduce the risk of detrimental flooding. Almost all the Scotch pine plantations in N. America are from planted nursery stocks.
Planting densities and thinning schedules depend on the management objective. For sawtimber with a rotation of 80-100 years, the optimum initial planting density is 2,500-3,200 trees/her, for pulpwood 3,200-4,800 trees/ha [7], [10].
Scots pine is susceptible to mammal damage during winter time in the early growing stages [8].

Management: Thinning models and rotation recommendations are available for drained peatlands [11], [10]. Fertilizers (P and K) are commonly used in ombrotrophic drained peatlands to increase the productivity [12], [13]. Under wet conditions fertilization is usually forbidden. If Scots pine needs N addition, the site would probably be too poor for growing trees.

Harvest: Harvesting of the timber from peatlands can create severe forest renewal problems, unacceptable increases in the ground water levels, fast growing ground vegetation competition, frost and wildlife damage, and these problems are magnified when the final fellings are carried out as clear-cuts [14]. So clear-cutting should be avoided altogether. Harvesting should be done in winter after the ground is frozen and snow-covered to minimize peat disturbance and its possible harmful effect on water quality.
Tree stands on pristine mires are characterized by their highly uneven age structure. Silviculture should promote this uneven-aged structure with a kind of continuous single tree selection to retain an all-sized mixed stand structure and develop it further in this direction [8]. The cuttings should be light, otherwise there is danger that the site will become wetter due to the rise in groundwater level, and the growing conditions for trees will become worse [15]. On drained peatlands harvesting is done to enhance the natural regeneration via seed tree cutting, shelterwood cutting and small-sized clear-cutting.
In Poland and Russia resin is tapped on a very small scale 3-7 years before clear felling of mature stands [7].

Productivity: The wood production of *Pinus sylvestris* is heavily depending on site conditions, especially on the mean water table (which should not be too high), climatic region and silvicultural measures. Scots pine can reach final yields of 600 m^3/ha on good sites. Mean annual increments peak at about 14 m^3/ha at an age of 65-70 years in the UK [7]. The aboveground biomass is generally lower on wet bogs. A pristine bog in southern Finland (dwarf shrub pine bog) has 19 t/ha (aboveground biomass with increment rates of 2.3 t/ha*yr), while a drained bog in southern Finland (50 years after drainage) has 77 t/ha (4.4 t/ha*yr), and yet another drained bog in southern Finland 74 years after drainage showed biomass values of 118 t/ha (6.6 t/ha*yr) ([8] after Reinikainen 1981, in Finnish).

Cultivation experiences: Known from drained peatlands [8], [16], [17] and mineral soil.

Utilisation

Human food: The inner bark is edible when dried and ground into a powder and used in making bread [18], [19], [20], [21]. It is often mixed with oatmeal [22]. A famine food, it is used in times of scarcity only [22]. A vanillin flavouring is obtained as a by-product of other resins that are released from the pulpwood [23].

Medicine: The turpentine obtained from the resin is antirheumatic, antiseptic, balsamic, diuretic, expectorant, rubefacient and vermifuge [24], [25], [26]. It is a valuable remedy in the treatment of kidney, bladder and rheumatic affections, and also in diseases of the mucous membranes and the treatment of respiratory complaints [24]. Externally it is used in the form of liniment plasters and inhalers [24].

The leaves and young shoots are antiseptic, diuretic and expectorant [27]. They are used internally for their mildly antiseptic effect within the chest and are also used to treat rheumatism and arthritis [28]. They can be added to the bath water for treating fatigue, nervous exhaustion, sleeplessness, and skin irritations [27]. They can also be used as an incense in the treatment of various chest complaints [27]. The essential oil from the leaves is used in the treatment of asthma, bronchitis and other respiratory infections, and also for digestive disorders such as wind [28]. An essential oil obtained from the seed has diuretic and respiratory-stimulant properties [28]. The seeds are used in the treatment of bronchitis, tuberculosis and bladder infections [28].

Ornament: Scots pine is a highly preferred Christmas tree in the USA, accounting for 30 % of all trees planted for that purpose [29].

Fuel: The wood provides a good fuel.

Agricultural conditioner and substrate: The needles contain a substance called terpene which is released when rain washes over the needles. It has a negative effect on the germination of some plants, including wheat [30].

Raw material for industry: The wood is light, soft, not strong, elastic, durable and rich in resin. It has a density of 510 kg/m^3 at 15 % moisture content [7]. It is used in construction, furniture, pulp industry etc. [25], [26], [31].

A tan or green dye is obtained from the needles [32], and a reddish yellow dye is obtained from the cones [33]. Scots pine yields resin and turpentine [34], [19], [31], [35]. Oleo-resins are present in the tissues of all species of pines, but these are often not present in sufficient quantity to make their extraction economically worthwhile [34]. The resins are obtained by tapping the trunk or by destructive distillation of the wood [24], [34]. In general, trees from warmer areas of distribution give higher yields [34]. Turpentine consists of an average of 20 % of the oleo-resin [34] and is separated by distillation [24], [34]. Turpentine has a wide range of uses including as a solvent for waxes etc., for making varnish, medicinals etc. [24]. Rosin is the substance left after turpentine is removed. This is used by violinists on their bows and also in making sealing wax, varnish etc. [24]. Pitch can also be obtained from the resin and is used for waterproofing and as a wood preservative. An essential oil obtained from the leaves is used in perfumery and in medicinal products [26], [36]. A fibre from the inner bark is used to make ropes [22]. The roots are very resinous and burn well. They can be used as a candle substitute [22]. The leaves are used as a packing material [26]. The fibrous material is stripped out of the leaves and is used to fill pillows, cushions and as a packing material [37].

Co-benefits: The trees are very wind resistant and quite fast growing. They are planted as a shelterbelt, succeeding in maritime exposure and for erosion control [38], [23], [7].

Other pine species:

Pinus contorta Douglas ex Loudon

Lodgepole pine is native to western N. America - Alaska to California [4], and cultivated in Europe for forestry both successfully and unsuccessfully [39]. It is a valuable timber tree and used for pulp. It grows naturally in coastal dunes, sphagnum covered bogs, and montane dry or moist areas [40], [41]. The species has been divided geographically into four varieties, where *P. contorta* var. *contorta* is the coastal form (known as beach pine) that grows also on mires and peatlands [29].

Pinus serotina Michx.

Pond pine is a medium-sized tree native to south-eastern N. America that grows on soils with a high water table. Pond pine is frequently found as the major overstory species in pocosins (special peatland type of the south-east of the U.S.). The wood is coarse-grained, resinous, and of a fair quality [42].

Pinus taeda L.

Loblolly pine is the most commercially important forest species in the south-east of the U.S. It is native to south-eastern N. America, where it grows on a variety of soil types from low, poorly drained areas to well drained soils, but usually on poor upland soils [43]. It shows a poor performance on very wet or waterlogged sites [44].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Pictures: Mundhenk, Lambique (detail)

Platanus occidentalis L.

American sycamore
(Nordamerikanische Amerikanische Platane)

Family: Platanaceae
Life form: tree
Main use category: raw material, energy, ornamental
Used part: wood, living tree

General information

Morphology: Perennial, up to 50 m or more. Trunk straight and unbranched to great heights or low-branching or multitrunked, to 4 m or more in diameter. Leaf blade light green, shallowly 3- to 5-lobed, 6-20 × 6-25 cm; margins entire to coarsely serrate; surfaces glabrate, abaxially often persistently tomentose along veins. Monoecious. Pistillate inflorescences: heads 1(-2); fruiting heads 25-30 mm in diameter; peduncle to 15 cm. Fruit is an achene, 7-10 mm. Flowering in March to May. Fruits ripen in September to October, remaining on trees over winter. Seed production in the age of 6-7 years, natural stands with 25 years [1], [2].

Geographic distribution: Eastern N. America - southern Ontario, New England to Florida, west to Texas and Nebraska [3].

Natural habitat: Grows on rich alluvial soils along streams and in bottom lands, sometimes on uplands, sometimes on limestone soils, cultivated in parks and gardens and as a street tree [1]. The tree is tolerant of wet soil conditions, and in the northern part of its range it grows on the edge of streams and lakes and small depressions having slow drainage, as well as on wet muck land, shallow peat soils, and soils associated with river bottoms and flood plains [2].

Site specific properties

Water regime: moist-wet
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

P. occidentalis is a fast-growing and long-lived species. It is valuable for timber, as an ornamental tree and it is grown in short-rotation plantations primarily for pulp [4]. Paludiculture with sycamore is unknown and needs to be investigated, especially if peat conservation is possible. The ecological amplitude of the tree suggests that cultivation in moist to wet peatlands could be possible. Propagation methods are probably transferable. Long term flooding is not tolerated, especially not in summer. So it is recommended for moderately rewetted peatland areas.

Propagation and establishment: *P. occidentalis* can be propagated via seeds or cuttings. Seeds require 2 months of cold stratification [5]. Germination is epigeal and affected by light. The seedlings are intolerant of shading [2], which makes weeding necessary in the early growth's stage. *P. occidentalis* can tolerate weeks of flooding, even complete submersion of seedlings, provided that the water is aerated [4]. Long term flooding reduces the rate of height and diameter growth, leaf initiation and expansion, and dry weight increment and relative growth rates of leaves, stems, and roots [6].
Cuttings of young fast-growing stems should be planted in fall [7]. Sycamore sprouts readily from the stump when young. It is used in short rotation coppice (SRC) with very short harvest cycles of 3-5 year, with a high planting density of ca. 15,000 stems/ha [8]. In the traditional planting system it is planted with 1,100 stems/ha with harvest intervals of 15-25 year [8]. The best coppice regeneration has been obtained by late dormant-season March harvesting [9].

Management: Flooding during the growing season should be avoided; it is destructive if the tree is inundated for more than 2 weeks [2]. The establishment of SRC plantations has been characterized by intensive site preparation, high initial costs and fertilization for several years after planting. Nutrient drain on the site is greater than with conventional long rotation management and fertilization is usually necessary, especially with rotations shorter than 5 years [10], [4]. Under wet conditions fertilization is usually forbidden.
Sycamore plantations can be interplanted with legumes or other nitrogen-fixing species to increase productivity [4].

Harvest: The low carrying capacity of wet peat soil makes harvesting difficult. Harvesting should be done in winter after the ground is frozen and snow-covered or with machinery adapted for wet conditions, use of the cable way technique, or use of helicopters to minimize peat disturbance and its harmful effect on water quality. Harvesting is possible every 3-5 years in a short rotation system and every 15-25 years in a traditional system. The young coppice stems have a d.b.h. of 1-9 cm at harvest time, as compared to traditional larger pulpwood stems with ca. 15-25 cm [8].

Productivity: Sycamore has a very fast growth rate: up to 21 m in a 20-year-period [11]. The potential for plantation-grown sycamore seems much higher than the yields for natural stands [2]. A survey conducted by the North Carolina State University found that annual plantation yields ranged from 7.7 m^3/ha at age 5 to 14.3 m^3/ha at age 25 [12]. Most of the plantations in this survey were not cultivated to optimum intensity after establishment and in all likelihood do not represent the ultimate or even the practical maximum attainable yield [2]. The highest yields for sycamore under intensive culture were recorded on a "creek bottom-land site" in the Georgia Piedmont and in the lower Mississippi River Valley for a 4-year coppice rotation following 3 or 4 years in seedling rotation [13], [14]: annual yields range from 24 to 32 m^3/ha.
At rotations of 4-10 years, yields of 11.2-29.1 dry t/ha can be achieved [15].

Cultivation experiences: *P. occidentalis* is widely planted on mineral soils; successful cultivation for restoration of bottomland hardwood forests is done in the southern U.S. [16]. Experiences from wet peatlands are unknown to the authors.

Utilisation

Human food: The sweet sap is tapped in the spring and used in the preparation of syrup and sugar [17], [18], [19].

Medicine: The inner bark is astringent, diuretic, emetic and laxative [20]. It has been used as a tea in the treatment of dysentery, coughs, colds, lung ailments, haemorrhages, measles, milky and difficult urination etc. and also as a blood tonic [20], [21]. Externally, it has been used as a wash on wounds [21]. An infusion of the bark and roots has been used as a foot soak for treating rheumatism [21]. The bark ooze has been used as a wash on infected sores and an infusion has been given in the treatment of infant rash [21]. An infusion of the bark, mixed with bark of *Gleditsia triacanthos*, has been used as a gargle to treat hoarseness and sore throat [21].

Ornament: *P. occidentalis* is cultivated as an ornamental tree in parks and gardens and as a street tree [1].

Fuel: Wood can be used as fuel wood.

Raw material for industry: The wood is coarse-grained, tough, strong, very durable and difficult to split [22], [23], [24]. Rather weak according to other reports [25], [26]. It weighs 0.56 t/m^3 [27], and is used for furniture, chopping boards etc. [22], [23], [24], [26]. Trunks of wild trees can be up to 4.5 m in diameter and these were once hollowed out to make barges capable of carrying several tons of goods [28].
P. occidentalis is grown in short-rotation plantations primarily for pulp and fibre and it also is used for rough lumber [4].

Co-benefits: Being a fairly wind resistant tree, it is grown as part of a shelterbelt planting [29].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Šarūnas Šimkus

Populus spp. L.

poplar, aspen, cottonwood (Pappel)

Family: Salicaceae
Life form: tree (or shrub)
Main use category: raw material, energy
Used part: wood

General information

Morphology: Perennial. Height: 15-50 m. Trunks to 2.5 m in diameter. Leaves arranged spirally, triangular to circular, rarely lobed, long-petiolate. Leaf size very variable even on a single tree, typically small on side shoots and very large on strong-growing lead shoots. The leaves often turn bright gold to yellow before they fall during autumn. Dioecious, rarely monoecious. Inflorescences long, drooping, sessile or pedunculate catkins. Flowers seated in a cup-shaped disk borne on the base of a scale, itself attached to the rachis of the catkin. Fruit a 2- to 4-valved capsule, green to reddish-brown, mature in midsummer, containing numerous minute light brown seeds surrounded by tufts of long, soft, white hairs which aid in wind dispersal. Bark on young trees smooth, white to greenish or dark grey, often with conspicuous lenticels [1].

Geographic distribution: Depends on species, mostly in the temperate zone of the northern hemisphere in Eurasia and N. America.

Natural habitat: Poplars grow in a wide range of habitats (different soil types and degrees of wetness), pH and salinity tolerance; all characteristics differ between the genus' species. It is most often a fast-growing pioneer species.

Site specific properties

Water regime: moist(-wet)
Trophic conditions: eutrophic
pH: acid-alkaline (mainly subneutral)
Light conditions: shade intolerant
Salinity: depends on species

Cultivation

Poplars and aspen are fast growing, easy to propagate and adaptable to different climatic and soil conditions, but more demanding than willows. Intensively cultured poplar and aspen plantations are known from Scandinavia, Italy, France and N. America for producing mainly pulp-wood and rotary cut veneer. Woody biomass from short rotation coppice (SRC) has good combustion properties and can be used as a renewable energy source [2]. Cultivation trials with *Populus* x *canadensis* "Oudenberg" on rewetted peat soil is known from Tuscany, Italy [3]. There are some species that thrive under wet conditions and have a potential for paludiculture. Paludiculture is only recommended in peatland areas that catch enough water to ensure growth and constant high water tables. Poplar plantations use a large amount of water and can thus drain the peatland.

A non-exhaustive list of *Populus* species that have a potential to be used in paludiculture (with data about distribution and habitat):

Populus balsamifera L.: balsam poplar is native to northern N. America. It grows transcontinentally on upland, flood plain sites, moist depressions, and swamps [4]. The light, soft wood is used for pulp and construction.

Populus grandidentata Michx.: big-tooth aspen or Canadian aspen is native to north-eastern N. America. It grows in rich moist sandy soils near streams and the borders of swamps from sea level to 900 metres [5], [6].

Populus heterophylla L.: swamp cottonwood is native to eastern N. America and is found mainly on heavy waterlogged clay soils on the edges of swamps and bottom lands [5], [6]. It is a difficult species to grow from cuttings, a characteristic that limits its commercial value [4].

Populus trichocarpa Torr. & Gray: black cottonwood is the largest of the American poplars and the largest hardwood tree in western N. America. It grows on bottomlands of streams and rivers. Pure stands may grow on alluvial soils. It is harvested and used for lumber, veneer, and fiber products.

There are also many poplar hybrids with different site-specific demands that developed as a result of natural and man-made crosses among poplar species, e.g., *Populus* x *canadensis*: hybrid of *Populus deltoides* and *Populus nigra*.

Propagation and establishment: Poplars can be propagated via seeds or cuttings. Poplar seeds have an extremely short period of viability and need to be sown within a few days of ripening [7]. Germination is epigeal, so burying in the soil is not necessary. Seedlings develop best on moist soils where competing vegetation is minimal for 1-2 years after establishment. Poplar can be propagated vegetatively with root sections from dormant stem cuttings or greenwood cuttings (differs between species). Weed control during establishing phase is essential.

Management: Poplars and aspen are fast growing pioneer species and have the ability to resprout after felling, making them suitable for SRC. Poplars are demanding concerning site characteristics. Sustaining productivity requires an adequate nutrient supply; N is often considered to be the limiting factor [2]. The most problematic quality parameter of woody biomass from *Populus* SRC is its high water content at harvest time (55-60 %). Storing unchipped material on the field during summer is an efficient tool to lower it [2].

Harvest: A harvest in rotations of 7-12 years is recommended for SRC.

The harvest is probably the bottle neck for paludiculture with poplars in short rotation, because of the low carrying capacity of wet peat soils. Conventional machines are very heavy and also the crop itself quickly becomes heavy when it is loaded on it. Poplar harvest is even more difficult compared to willows since the rotations is generally longer with larger stems and high moisture content of the biomass. One possibility is to establish light devices, like caterpillars. But they are likely to have low transport volumes and it is highly questionable if that can be economically feasible. If a water management system is available, another option can be the drainage of the site for a short harvest time. Then, the conventional heavy equipment could be used. This option will probably lead to mineralization and compaction of the peat soil. A peat-

conserving paludiculture is then critical. When the plantation is located in a more northern country with strong winters, the harvest could be done on frozen ground with conventional technique. This option represents the most conservative harvest option for the peat soil.
When rotations are elongated, costs rise also because as of yet no automated (and thus cheap) harvest methods for large stem diameters were developed [2].

Productivity: Rotations should be longer than for willow: at least 6-7 years for poplars and, due to differences in growth pattern, 10-12 years for aspen. Both results in mean annual increments of 10-12 oven dry tons per hectare and year [2]. A pure stand of mature swamp cottonwood would likely yield 280.0 to 350.0 m^3/ha [4]. For *P. trichocarpa*, data from plantations in the lower Fraser River Valley (U.S.) indicate mean annual increments ranging from 10.5 to 15.4 m^3/ha*yr [8]. A plantation established on a deep alluvial soil in coastal Washington has produced more than 500 m^3/ha [9].

Cultivation experiences: Poplars are sometimes cultivated on mineral soil. There are some unsuccessful experiences on drained peatlands [10] and one successful pilot project in a rewetted peatland in Tuscany, Italy [3].

Utilisation

Human food: The inner bark [11], [12], [13], [14] and the buds are edible [11], [12], [13]. The sap can be used for food [14]. The leaves are rich in protein and have a higher amino-acid content than wheat, corn, rice and barley [15]. A concentrate made from them is as nourishing as meat, but can be produced faster and more cheaply [15]. Some people believe that this will become a major food source for humans [15].

Medicine: The bark of most, if not all, members of the genus contain salicin, a glycoside that probably decomposes into acetylsalicyl acid (aspirin) in the body [16], [17]. The bark is therefore anodyne, anti-inflammatory, febrifuge and tonic [18], [17]. It is used especially in treating rheumatism and fevers, and also to relieve the pain of menstrual cramps [17], [14].

Animal fodder: The bark of *P. grandidentata* is pelletized for supplemental cattle feed [19].
Fuel: The biomass from short rotation coppice is used as biofuel [2].

Agricultural conditioner and substrate: An extract of the shoots can be used as a rooting hormone for all types of cuttings [20]. It is extracted by soaking the chopped-up shoots in cold water for a day [21].

Raw material for industry: The wood is often considered as second-rate timber, used for lumber, boxes, crates, house interiors, veneer and pulp.
The wood of *P. grandidentata* is soft, rather woolly in texture, without smell or taste, of low flammability, not durable and very resistant to abrasion [22], [23], [24]. It weighs 29 lb per cubic foot [25]. It is used mainly for pulp, and makes a high-quality paper [22], [23], [26], [24].

Co-benefits: Some species (e.g., *P. deltoides*) are planted for dune fixing in erosion control programmes [27], [28]. They are also good pioneer species, growing quickly to provide a good habitat for other woodland trees and eventually being out-competed by those trees [6]. Some species are fairly wind resistant, so it can be grown as part of a shelterbelt planting [7], [29].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Kristian Peters

Puccinellia maritima (Huds.) Parl.

Seaside alkaligrass, common saltmarsh grass (Andel, Strand-Salzschwaden)

Family: Poaceae
Life form: graminoid
Main use category: fodder
Used part: aboveground biomass

General information

Morphology: Perennial. Height 20-100 cm. Grows caespitose, often stoloniferous, not mat-forming. Culms erect to decumbent. Leaf blades 2-4 mm wide, flat to involute. Inflorescence is a panicle 3-30 cm, compact to diffuse at maturity [1].

Geographic distribution: Europe, N. America, Greenland [2].

Natural habitat: Grows in salt marshes and salt grassland (character species of the so-called "Andelrasen" = Puccinellietum maritima).

Site specific properties
Water regime: moist-wet
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: shade intolerant
Salinity: high tolerance

Cultivation

The species is a component of the diverse and valuable wet salt grassland that is traditionally used as pasture in the Baltic Sea region [3], [4]. The salt grasslands can form with extensive pasture anthropo-zoogenous coastal flood peatlands [11]. Artificial cultivation is unknown, but its traditional use of natural sites suggests that paludiculture as a wet grassland is possible.

Propagation and establishment: Natural propagation is via fruits [5] and flooding dispersal of propagules [6]. *Puccinellia maritima* is a prolific seed producer under natural conditions, especially in the lower parts of the salt marsh, with a high seed viability of 93 % [5]. Just a low amount of fruits could be found in the seed bank in the following year. Germination occurs from October to March (in Sussex, UK) with a low seedling survival under natural conditions. Only 1 % of the seeds produced became established in the growing vegetation within the low site and no survival was recorded on the high marsh site [5].

Management: The salt marshes dominated by *P. maritima* are used for grazing, hay making and cutting for silage since hundreds of years [7]. *P. maritima* is even favoured by cattle and sheep grazing, especially in the lower, moister areas of a salt marsh. Grazing is an important factor in maintaining the dominance of *P. maritima* in salt marshes, which would otherwise suffer from competition [7], [8]. Fertilization is not recommended as tidal flooding may lead to severe loss of fertilizers.

Harvest: Hay was traditionally cut from areas outside the dyke for young cattle breeding. Cutting is rarely applied nowadays because it is too expensive. It is mainly used as pasture grass.

Productivity: The living plant biomass over one year amounts to 6.6 t/ha, with a summer maximum of 8.3 t/ha [9].

Cultivation experiences: Unknown.

Utilisation

Animal fodder: *P. maritima* is used as pasture grass. It is eaten by cattle. The metabolizable energy (ME) ranges from 10.5 to 8.2 MJ per kg dry matter [3]. After [3] it has a German forage value (Futterwertzahl) of 7.

Co-benefits: *Puccinellia maritima* plays a key role in trapping sediments and protection of young soils at the coastal line and it is strongly linked with the installation of hummocks and in the increase of the succession rate in the lower marsh [10]. The salt marsh with *Puccinellia maritima* is a favoured foraging habitat for various wild goose species [8].

Further reading: [5], [8], [10]

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Kristian Peters

Rhododendron tomentosum Harmaja

(formerly *Ledum palustre* L.)
wild rosemary (Sumpf-Porst)

Family: Ericaceae
Life form: shrub
Main use category: medicine, raw material
Used part: leaves

General information

Morphology: Perennial. Height up to 50 cm. Stem erect or creeping. Branches slender; young branches densely covered with rust-colored wool (tomentose). Evergreen, leaves alternate, shortly petiolate, 12-50 x 1.5-12 mm, linear to elliptic-oblong; margins revolute. Hermaphrodite. Inflorescences umbelliferous racemes; numerous 5-petalled flowers. Corolla milky white, 5-25 mm. Flowering June to July. Fruiting July to August [1], [2].

Geographic distribution: N. and NE. Asia, C. and N. Europe, N. America [2].

Natural habitat: Coniferous forests, forest margins, marshes, wet meadows; oligotrophic or forested bogs [2], [3]. Also on permafrost soils [4].

Site specific properties

Water regime: moist-wet
Trophic conditions: oligo-mesotrophic
pH: acid-subneutral
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

This evergreen shrub prefers moist to wet acidic peat soil in shade or semi-shade.

Artificial cultivation for biomass utilisation is rare and done only on a small scale, but a traditional form of paludiculture with *Rhododendron tomentosum* (formerly *Ledum palustre*) exists, because it is harvested from the wild [5]. The biomass is used commercially for several applications. Propagation methods are available and probably transferable to paludiculture. Also a mixed culture with trees (e.g., *Betula pubescens*, *Pinus sylvestris* or *Picea mariana*) is conceivable. However, the effect of wet conditions on growth rate and productivity is not known to the authors and its utility for paludiculture in this respect needs still to be investigated.

Propagation and establishment: *Rhododendron tomentosum* can be propagated vegetatively by plant cuttings, and generatively via seeds. The seeds can be sown on the surface in a shady part of a greenhouse in February or March [6], [7]. Another report says that the seed is best sown in autumn as soon as it is ripe [8]. Germination is variable and can be quite slow. High temperatures, light and cold stratification can improve germination rates [9]. Gibberellic acid (GA3) has been proven to stimulate the germination of *Rhododendron* seeds [9].
Cuttings of either 5-8 cm half-ripe wood in July/August or of mature wood in November/December can be taken for propagation [7]. They should be grown in a frame and planted into their permanent position in the next spring. This method has a fair percentage of survival [6]. Direct outdoor planting is also possible, probably with higher loss rates. Soil preparation is necessary before planting or seeding to reduce competition by weeds.

Management: The plants can be harvested annually, approximately 4 years after they were planted out into their permanent position.

Harvest: Commercial harvest is currently probably done only from natural stands. Only the young shoot apex should be harvested annually. The harvest of whole branches will probably harm the plant and can easily lead to over-harvesting.

Productivity: The plant has a slow growth rate [4]. Highest quantity of essential oil is reached in the first days of flowering and during seed maturation (July/August), while young leaves and shoots contain more active compounds than aged ones [10]. However, productivity is highly volatile and depends on harvest time [11].

Cultivation experiences: On experimental scale with 250 plants in southern Germany planted in an artificial peat bed by the company WELEDA [Michael Straub, pers. comm.].

Utilisation

Human food: A tea is made from the aromatic leaves [12], [13], considered by some to be better than the tea prepared from *R. groenlandicum* [13]. Preferably, the tea is brewed in cold water by leaving it in a sunny place or in an open container for a short period of time. The leaves are used for flavouring, for example as a bayleaf substitute [12]. The plant has also been used to substitute hops in making beer, although this can cause unpleasant effects of drunkenness characterized by headache and dizziness [5], [14], [15].

Medicine: The leaves and young flowering shoots are astringent, diaphoretic, disinfectant, diuretic, laxative, pectoral, stomachic and tonic [12], [16], [18], [19]. The plant is more strongly narcotic than *R. groenlandicum* [16] and should not be used without expert supervision [20]. A tea is taken internally in the treatment of asthma, coughs, colds, stomach aches, kidney ailments etc. [17], [18], [19]. Externally, it is used as a wash for burns, ulcers, stings, and infections [5], [16],

[17]. A homeopathic remedy is made from the whole (dried and powdered) plant [16], used in the treatment of stings, injuries, and joint pains [16]. Also, its benefits in the treatment of various chest or respiratory complaints, asthma, menstrual pain etc. are known [20], [21]. The internal application of herb extracts is increasingly rare because of the toxicity of ledol, a component of the essential oil. Instead, in recent years new directions for research appeared, focusing on the antidiabetic, anticancer and antioxidant properties of *R. tomentosum*. Extractions are part of several preparations that are currently sold [22].

Ornament: Used as an ornamental plant in bog gardens. The extract of the dried flowering plants of *R. tomentosum* is used in cosmetology [22].

Raw material for industry: The leaves contain tannin [17]. It is traditionally used as an insect repellent [23] and to ward off ticks [24], [25]. Nowadays, it is used as an ingredient in several products against mosquitos [22].

Similar species:
Rhododendron groenlandicum (Oeder) Kron & Judd - Bog Labrador Tea
Native to Eastern and Northern N. America where it grows in bogs and montane coniferous woods [1], [17], [26]. The biomass has similar capabilities to *R. tomentosum* and is used medicinally in like manner [15], [27]. The excavation of bog Labrador tea plants in a black spruce/star reindeer lichen woodland near Schefferville, Quebec, revealed that bog Labrador tea dry weight biomass distribution was 112 kg/ha of leaf, 965 kg/ha of stem, and 658,738 kg/ha of root material [28].

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GREIFSWALD
MIRE
CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Christoph Müller, Jörg Hempel (detail)

Rubus chamaemorus L.

cloudberry (Moltebeere)

Family: Rosaceae
Life form: dwarf shrub
Main use category: food
Used part: fruit

General information

Morphology: Perennial. Height 5-25 cm. Stems erect, arising from a creeping rhizome, those on male plants all flowering. Herbaceous. Leaves reniform, rugose, 5-lobed, crenate-serrate, 2-5 x 3-7 cm. Dioecious. Flowers solitary, terminal; petals 5 or more, white, hairy, larger than sepals. Drupelets about 20, large. Plants growing in different habitats express phenotypic variation, such as differences in mean amount of seeds, leaf and rhizome sizes [1], [2].

Geographic distribution: Circumboreal in the northern hemisphere [3].

Habitat: Cloudberries inhabit peaty moors, open sphagnum bogs, forested mires, and wet spruce forests within the boreal zone [1]. In bogs, it grows on sphagnum hummocks, because the plant needs a habitat that is well supplied with water, but not flooded.

Site specific properties

Water regime: moist
Trophic conditions: oligotrophic
pH: acid
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

Cloudberries are currently primarily produced on slightly managed natural *Sphagnum* bogs surrounded by forest providing a natural shelter. Cultivation has been developed but it is still very expensive [4]. Cloudberry plants have proved to be difficult to grow in the field, because of their special environmental requirements and sensitivity toward plant pathogens; wild berries are therefore the main source of the economic crop [5]. Interest increased during the last decade. It can be cultivated in cutover peatlands after re-establishment of a *Sphagnum* vegetation cover [6]. Best growth is obtained with the ground water being 30 cm below the surface [6]. Under these conditions a constant slow peat loss can be expected, however. This crop is therefore only recommended for disturbed bog sites that are not rewettable up to the surface. An additional drainage of natural bogs should be avoided at all costs.

Propagation and establishment: The plant can be propagated from rhizome cuttings or from seeds. The latter is slow and inefficient in nature; germinability varies from 0 to 31 % under experimental conditions [1]. The seeds require scarification and stratification for 6-8 months [7]. They can be sown in early spring or in early autumn in a cold frame. The seedlings are transplanted to their permanent position in late spring of the following year [3]. The propagation via rhizome cuttings (15-20 cm long) is the preferred method; they should be taken between May and August [7], [8]. Survival is best when planted out in autumn at 5 cm depth with a rhizome length of at least 20 cm [9]. Seedlings or cuttings should be planted on ridges or sphagnum hummocks to avoid flooding. Good growth is obtained on slightly decomposed peat (H2-H4), with pH-values between 3.5 and 4.5, and with the ground water 30 cm below the surface [6]. Genereally, peat with higher porosity and lower bulk density is more favourable for cloudberry growth than very compacted one [6].
For growing on cutover peatlands, cloudberry should be planted 2-3 years after peatland restoration (including mulching and moss introduction [10], [6], i.e., once a *Sphagnum* carpet has begun to establish and when straw mulch density has considerably decreased). Cloudberry would then benefit from the improved hydrological conditions under the newly developed moss carpet and avoid the initial negative impact of the straw mulch [6]. The cultivar Fjordgull seems to be suitable for planting as rhizomes in cutover peatlands in Canada [6]. Since the antioxidative activities and the chemical composition of berries are affected both by genotype and environment [11], it is important to find the suitable cultivar for the prevalent site conditions.

Management: In the conventional practice, fertilization is recommended, either with superphosphates or complete fertilizers (300 kg/ha) that can increase yields per hectare by an average of 50 kg when the fertilizer is placed at a depth of 20-25 cm [7]. In paludiculture (i.e., under wet conditions) fertilization is usually forbidden. Cloudberry plants produce more fruits in wooded than in open habitats [1]. In windswept areas, short fences may help settling the snow in the winter which delays the blossoming period and avoids spring frost injury. Windrows also lead to an increase in the activity of pollinating insects which increases yields [12]. As cloudberry is a dioecious species it is dependent upon insects for pollination. Male plants are overabundant in natural bogs (75 %) [14]. In nature there are a few non-stabile hermaphroditic genotypes. There is a need to develop a stable hermaphroditic cultivar to eliminate the pollination problem, to minimize the cultivation costs and ultimately to increase yields considerably [7], [13].
During flowering and ripening, the berries are easily damaged by fluctuating temperatures, hard winds, and rainfalls. Low temperatures are favourable for berry size [15].

Harvesting: The berries are gathered by hand at the end of the summer until autumn or early winter. Mechanized harvesting techniques are unknown to the authors.

Productivity: The berry yield on natural peatlands is low and variable [16]: 0-30 kg/ha, averaging 20 kg/ha [7]; after another report 20-50 kg/ha [1].
Cultivation is rare. Cultivation trials reached exceptional yields of over 200 kg/ha in good years [17]. Almost all cloudberries on the market today come from natural peatlands. The worldwide production of wild collected

cloudberries in 2005 was 58 t fresh fruits from 420,000 ha [18]. It is one of the most valuable berries in Fennoscandia: in Finland the price paid to pickers varied between 4 and 10 €/kg fresh berries, and the retail price was 10-20 € in 2007 [4].

Cultivation experiences: Norway [19], [7], Canada [6], and Finland [20].

Utilisation

Human food: The fruit can be eaten raw or cooked [21], [22]. It is sour but delicious, the fruit can be eaten out of hand or stewed, used in preserves, pies, yogurts, jam, wine, syrup etc. [21]. Rich in vitamin C [22], 0.8 mg/g fresh weight. Contains 50-150 mg of ascorbic acid per 100 g fruit [7]. Cloudberries may be an important raw material for the food and beverage industries [5]. An overview of the ingredients and concentrations of nutritional components is available [17], [1].

Medicine: The root has been used in the treatment of coughs, fevers, and consumption [22]. Cloudberries may also be an important raw material for nutraceutical and cosmetic industries [5]. They are rich in ellagitannins, which are complex phenolic secondary metabolites with various positive bioactivities (anti-inflammatory, antimicrobial, antioxidant, and anticancer activities) for human health [23], [24], [1].

Further reading: [19], [7], [1]

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Salix spp. L.

willow, osier (Weide)

Pictures (*Salix alba*): Willow; MPF (detail)

Family: Salicaceae

Life form: shrub or small tree

Main use category: energy, raw material, medicine

Used part: aboveground biomass, stem, bark

General information

Morphology: Perennial. Leaves variously shaped. Dioecious. Flowers entomophilous, appearing before or after the leaves, in catkins, each flower with one or two small nectaries and subtended by an entire bract. Numerous seeds - very small, each with a tuft of long hairs. Hybridization plays a very important role in *Salix*. Most hybrids are highly fertile and in some regions hybrid-swarms obscure the limits of the species' distribution [1].

Geographic distribution: Depends on species.

Natural habitat: Most species are pioneers that grow on a wide range on soil types and degrees of wetness, including wet, badly-drained or intermittently flooded soils.

Site specific properties

Water regime: moist-wet

Trophic conditions: oligo-meso-eutrophic

pH: acid-alkaline

Light conditions: mostly shade intolerant (light demanding)

Salinity: depends on species

Cultivation

Willows are fast growing, easy to propagate vegetatively, and highly adaptable to different climatic and soil conditions. These characteristics, combined with the wide range of utilisation options, have led to the widespread use of willows around the world. However, willows are rarely used in forestry, they are more recently being used as a source of renewable energy and for soil remediation in contaminated sites. The ability of *Salix* to resprout (coppice) after harvesting makes it possible to use a plantation for about 30 years.

Paludiculture with willow is unknown to the authors, but there are several species that thrive under wet conditions and have a good potential for paludiculture. A short rotation with willows is only recommended on peatland sites that provide enough water to ensure growth and constant high water tables.

An incomplete list of potential willow species for paludiculture (with data about distribution, habitat and growth height), without assurance of feasibility:

Salix alba (white willow - Silber-Weide), native to Europe (except Scandinavia), N. Africa and Central Asia, introduced to N. America, species of the riparian forest, tree up to 30 m.

Salix aurita (eared willow - Ohr-Weide), native to Europe and Siberia. Sometimes cultivated. Shrub to 2.5 m in height.

Salix babylonica (wheeping willow - echte Trauerweide), native to E. Asia, introduced elsewhere; riparian zones, wetlands.

Salix bebbiana (Bebbs willow, beaked willow), native to North America, grows in riparian forest, swamps and marshes. Often cultivated. 3-7 m in height.

Salix candida (sage-leaf willow), northern N. America, growth height is 0.5-3.5 m.

Salix caroliniana (coastal plain willow), south-eastern N. America and Central America.

Salix cinerea (grey willow, pussy willow; Asch-Weide, Grau-Weide), native to Europe and W. Siberia, introduced to N. America, 2-4 m.

Salix daphnoides (violet willow - Reif-Weide), native to Europe and W. Asia, grows in floodplains, up to 8 m.

Salix discolour (pussy willow), native to N. America, grows in fens.

Salix fragilis L. (Bruch-Weide), western and central Europe to Asia Minor, introduced to N. America; grows in riparian forests up to 20 m.

Salix lucida (shining willow – Glanz-Weide), native to N. America, grows in mires, rarely utilised, 3-6 m.

Salix myrsinifolia (syn. *S. nigricans*) native from Europe to Siberia; grows in riparian areas up to 2-5 m.

Salix nigra Marsh. (black willow), eastern N. America; grows in riparian areas and swamps up to 20 m.

Salix phylicifolia (tea leaved willow), northern Europe; grows in a wide habitat range up to 3 m; planted on cutaway peatlands in Finland [2].

Salix pedicellaris (bog willow), N. America; grows up to 0.2-1.5 m.

Salix pentandra (bay willow - Lorbeer-Weide), Europe and Asia; grows on riparian areas and peatlands as shrub or tree up to 14 m.

Salix purpurea (purple osier willow, Purpur-Weide), native to Europe (except Scandinavia); grows on stream banks, riparian forests, swamps, and mires as a shrub up to 6 m.

Salix pyrifolia (balsam willow), N. America, grows naturally in fens and bogs up to 0.4-4 m.

Salix scouleriana (Scouler's willow, mountain willow), western N. America; grows in a wide range, swamps included, up to 2-10 m.

Salix triandra L. s.l. (Mandel-Weide), Europe, northern Africa, Asia Minor and Asia; grows in riparian forests as shrub and tree up to 7 m.

Salix viminalis (osier, basket willow - Korb-Weide) native in central Europe to western Asia, introduced elsewhere; grows by streams up to 3-8 m; widely cultivated [3].

Salix x *aquatica*, Hybrid of *Salix viminalis* x *Salix daphnoides* x *Salix cinerea*, artificial hybrid, fast growing shrub for biomass production.

Salix x *dasyclados* (Bandstockweide), Hybrid of *Salix viminalis* x *Salix caprea* x *Salix cinereal*; artificial hybrid but supposedly native along the southern Baltic Sea.

Salix x *multinervis* (= cinerea x aurita, vielnervige Weide); grows in riparian forests up to 5 m.

Salix x *rubens* Schrank (Fahlweide), Hybrid of *Salix alba* x *Salix fragilis*, in Central Europe more frequent than the parent species; grows in riparian forests up to 20 m.

Propagation and establishment: In general, propagation is done vegetatively with cuttings or planting rods. Planting rods are cut and trimmed willow stems, generally 1.5-3 m long and cuttings are cut fresh from rods and are 18-20 cm long with a minimum diameter of 9 mm. The planting material is taken from one-year-old material that is harvested in winter. They must be either planted immediately or cold stored for later planting. The rods are cut into 18-20 cm cuttings by the planting machine and inserted into the soil, with a density of 15,000 cuttings per ha [4]. For pulpwood or timber production fewer cuttings are used for planting (ca. 2,000 per ha). Willows exhibit vigorous juvenile growth. Young shoots can reach 3 m high in one growing season (for weeping willow) [5]. Seedling plantations grow slowly initially, but have a long life span and eventually produce large-sized timber.
During the winter following planting, the willow is usually cut back to within 10 cm of ground level to encourage the development of the multi-stemmed coppice. The work should be carried out as late as possible in the winter but before bud-break [4].

Management: Weed control is a critical part of the stand establishment. Complete eradication of all invasive perennial weeds is essential prior to planting [4].
On moderate to fertile soils, particularly in the early rotations, there is probably no demand for fertiliser applications. For a productive plantation nutrient rich water is necessary. Fertilisation is usually forbidden in water saturated or flooded soil.

Harvest: A willow short rotation coppice may be harvested six to eight times on a three-year cycle for woodchips giving the plantation a life of 19-25 years [6]. 5- and 7-year-old trees are cut for pulpwood.
Harvesting is done in winter, in the period from leaf fall to bud burst. There are three approaches to harvest in a short rotation: direct chip harvesting, whole rod harvesting and billeting [6]. The harvest is probably the bottle neck for paludiculture with willow in short rotation, because of the low carrying capacity of wet peat soil. Conventional machines are very heavy and also the crop itself quickly becomes heavy when it is loaded on it. One possibility is to use light devices, like caterpillars. But they will likely have low transport volumes and economic feasibility must be shown. If a water management system is available, another option can be a short term drainage of the site for the harvest time. Then the conventional heavy equipment could be used. This option will probably lead to a slight mineralization and compaction of the peat soil. When the plantation is located in a more northern country with strong winters, the harvest could be done on frozen ground with conventional technique. This option represents the most conservative harvest option.

Productivity: After 3 years of growth 30 t DM/ha can be achieved with a potential annual biomass increment of 6-20 t DM/ha [7]. Yield of *Salix phylicifolia* on a drained cutaway peatland in Finland ranged between 6.3 and 8.7 t/ha*yr [2].

Cultivation experiences: On drained cutaway peatlands in Finland [2], and for wetland restoration [8].

Utilisation

Human food (e.g., *Salix alba*, *Salix fragilis*): Inner bark can be eaten raw or cooked. It can be dried, ground into a powder, added to cereal flour, and then used in making bread etc. [9]. Having a very bitter flavour, especially when fresh [9], [10], it is used as a famine food in times of scarcity [11].
Leaves and young shoots can be eaten raw or cooked [9], [12], but are not very palatable [11]. They are used only in times of scarcity [13]. The leaves can be used as a tea substitute [14].

Medicine: The fresh bark of all members of this genus contains salicin [15], which probably decomposes into salicylic acid (closely related to aspirin) in the human body [16]. This is used as an anodyne and febrifuge [15], [16].
For *Salix alba*: The bark is anodyne, anti-inflammatory, antiperiodic, antiseptic, astringent, diaphoretic, diuretic, febrifuge, hypnotic, sedative and tonic [17], [18], [19], [20], [21]. It has been used internally in the treatment of dyspepsia connected with debility of the digestive organs [17], rheumatism, arthritis, gout, inflammatory stages of auto-immune diseases, feverish illnesses, neuralgia and headache [22]. Its tonic and astringent properties render it useful in convalescence from acute diseases, in treating worms, chronic dysentery and diarrhoea [17]. The fresh bark is very bitter and astringent [23].
The bark is harvested in the spring or early autumn from 3- to 6-year-old branches and is dried for later use [18], [19]. The leaves are used internally in the treatment of minor feverish illnesses and colic [22]. An infusion of the leaves has a calming effect and is helpful in the treatment of nervous insomnia [18]. When added to the bath water, the infusion is of real benefit in relieving widespread rheumatism [18]. The leaves can be harvested throughout the growing season and are used fresh or dried [22].

Ornament: Young willow twigs with open or closed buds are collected in early spring for decoration. The dried leaves of *Salix pentandra* have a pleasant aromatic aroma and can be used in pot-pourri [24].

Fuel: The biomass from short rotation forestry can be used for bioenergy production, mainly as wood chips for direct combustion [7], [2]. Willow biomass characteristics [7]: heating value = 19.8 MJ/kg (per kg oven-dried material); moisture at harvest = ca. 50 %; ash content = 1,24 %.

Raw material for industry: The stems are very flexible, for which reason they are used in basket making [25], [26]. The plant is usually coppiced annually when grown for basket making, although it is possible to coppice it every two years if thick poles are required as uprights [27].
The bark of *Salix alba* can be used for tying plants [14]. A fibre obtained from the stems is used in making paper [28]. The stems are harvested in spring or summer, the leaves are removed and the stems steamed until the fibres can be stripped. The fibres are cooked for two hours with lye and then beaten with mallets or put through a blender. The paper is red/brown in colour [28].
The wood (e.g., of *Salix alba*) is elastic, soft, easy to split, and does not splinter. It is used for construction, turnery, poles, tool handles etc. [25], [29], [14]. The wood is also used to make charcoal [25], which has medicinal uses [18]. Moreover, the wood (e.g., of *Salix fragilis*) is tough, withstands friction, and is used for floors, bases of carts etc. [25]. A good quality charcoal is obtained from the wood[14].

Salix bebbiana: The diamond shaped wood is carved into canes, lampposts, furniture, and candleholders. The wood has also been used to make furniture, baskets, baseball bats, charcoal, and gunpowder [30]

Co-benefits: Willows are used for soil phytoremediation [8] and for wastewater purification [31]. *Salix* species are used for biological engineering, based on its ability to provide mechanical functions for water and wind soil erosion, as well as to form protective structures [8]. For example, *Salix alba* can be grown as a shelterbelt [32].

Further reading: [7], [8]

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Pictures: Karelj (big picture), H. Zell (detail)

Sanguisorba officinalis L.

great burnet (Großer Wiesenknopf)

Family: Rosaceae
Life form: forb/herb
Main use category: ornamental, medicine
Used part: plant, root, leave

General information

Morphology: Perennial, 20-100 cm high. Stem erect, branched. Basal and lower cauline leaves with 3-7 pairs of leaflets; leaflets up to 5 cm, ovate. Hermaphrodite. Flower capitula 1-3 cm, subglobose or ellipsoid, erect. Sepals crimson. Fruiting hypanthium with 4 narrow wings [1]. On average 962 seeds per plant [2].

Geographic distribution: Europe, temperate Asia, western N. America [3], [4].

Natural habitat: Meadows and wet grassy places by streams, floodplains [5]. Moist shady sites in grassland, on siliceous soils [6], [7], [8].

Site specific properties

Water regime: moist-wet
Trophic conditions: mesotrophic
pH: subneutral-alkaline
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Paludiculture with great burnet is unknown. The ecological amplitude suggests that cultivation in moist-wet peatlands could be possible. Propagation methods are known from gardening and probably transferable. Long-term flooding is not tolerated, especially not in summer. It is therefore recommended for moderately rewetted peatland areas. Paludiculture may look promising as long as the demand for biomass is sufficient for economic benefits. The harvest of the roots or whole plant could moreover harm the peat soil and probably lead to further degradation, similar to the necessity of the new installation of the field after root and plant harvest. A peat conserving paludiculture with *Sanguisorba officinalis* would exclude the harvest of below-ground biomass.

Propagation and establishment: Generative: seeds of great burnet germinate most rapidly and completely at constant temperatures of around 24-25°C (germination also with temperatures from 5 to 30°C) following 6 months dry storage at 4°C [9]. It can be sown in situ in spring or in a cold frame [10]. Vegetative propagation takes place by division in spring or autumn [10]. Vegetative spread rate is fast. Flooding should be avoided in the establishment phase.

Management: No information found.

Harvest: Leaves for food should be harvested in spring before the plant comes into flower [11]. The root is harvested in autumn as the leaves die down and are dried for later use [10], [12].

Productivity: No information found.

Cultivation experiences: Only known from gardening.

Utilisation

Human food: Young leaves and flower buds are edible, raw or cooked [7], [13], [14]. Having a cucumber-like flavour [6], [15], they can be added to salads or used as a potherb [16]. The fresh or dried leaves are used as a tea substitute [16].

Medicine: *S. officinalis* is employed mainly for its astringent action, being used to slow or arrest blood flow. It is taken both internally and externally; especially internally it is described as a safe and effective treatment. Modern research in China has shown that the whole herb heals burns more effectively than the extracted tannins (the astringent component of the plant) [17]. The leaves are astringent, refrigerant, styptic and tonic [6], [18], [19]. They are used in the treatment of fevers and bleeding [18], [19]. The plant is prevented from flowering and then the leaves are harvested in July and dried for later use [10], [12]. The root is anodyne, astringent, diuretic, febrifuge, haemostatic, tonic and vulnerary [10], [6], [11], [20], [21], [22], [23], [24], [18]. It is used in the treatment of peptic ulcers, haematuria, menorrhagia, bloody stool, dysentery, diarrhoea, haemorrhoids and burns [23]. All parts of the plant are astringent, but the root is most active [10]. *S. officinalis* is an excellent internal treatment for all sorts of abnormal discharges including diarrhoea, dysentery and leucorrhoea [10]. It is used externally in the treatment of burns, scalds, sores and skin diseases [12]. Used in homeopathy.

Ornament: *S. officinalis* is used as an ornamental garden plant. There are several varieties available.

Animal fodder: It is a good and preferred admixture to fodder. Intermediate to high forage value [25].

Similar species: *Sanguisorba canadensis* has similar properties like *S. officinalis* but is less used

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GREIFSWALD
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Potential plants for paludiculture in the Holarctic

Picture: Curtis Clark

Schoenoplectus californicus (C.A. Mey.) Soják

Incl. *Schoenoplectus californicus* ssp. totora

giant bulrush, tule, totora (Totora-Schilf, Teichsimse)

Family: Cyperaceae
Life form: graminoid
Main use category: raw material
Used part: stems, aboveground biomass

General information

Morphology: Perennial. Height: 1-4 m. Triangular or subterete stems. Leaves 3-4, basal, slender, v-shaped blades that are sheathed around the long stem. Hermaphrodite. Inflorescences arranged in spikelets 25-150 or more; solitary and in clusters of 2 or more; scales orange-brown. Stout rootstocks and long, thick, brown rhizomes (10-15 mm in diameter) [1], [2].

Geographic distribution: Native to N. America: Southern U.S. and California - distributed along the Atlantic and Pacific coasts of America, C. America and temperate areas of S. America (Argentina, Bolivia, Chile, Peru and southern Brazil). Introduced to and naturalized on the North Island of New Zealand [3], [4].

Natural habitat: *S. californicus* is restricted to almost permanently flooded areas on estuaries, also in coastal lagoons and fresh water lakes [5]. Giant bulrush will tolerate only slight salinity (0-5 part per thousand), but will tolerate periodic short inflows of more saline water. This species can grow in water depths up to 90 cm or more [2], [5].

Site specific properties

Water regime: wet-flooded
Trophic conditions: eutrophic
pH: acid-alkaline
Light conditions: shade intolerant
Salinity: low tolerance

Cultivation

Schoenoplectus californicus is used traditionally in many countries of the Americas. The cultivation is known from restoration, stream bank stabilization, waste-water treatment and traditional use as a raw material in N. and S. America [2], [6], [5]. Cultivation methods are most likely transferable to paludiculture.

Schoenoplectus californicus is often dominant in its habitat and forms dense monospecific stands in deep water where it can out-compete other species by the dense rhizomatous root system. In New Zealand it is even seen as an invasive weed species.

Propagation and establishment: *S. californicus* is best established with seedlings, plugs or potted plants derived from divisions of the rhizomes. Direct seeding is also possible but difficult due to germination problems. Production of viable fruits has proven unreliable for commercial purposes. Consequently, vital plant collections of this species are recommended [2].

Planting success is optimal in 30 cm deep water but can be successful in 2-60 cm depth as well. Water management is critical during establishment. Spacings of 1.5-3 cm or closer are recommended. Planting in rows parallel to the shore is most effective when planted for shoreline protection. In zones of high wave energy, plantings should be anchored in holes by stakes or pins until the plant establishes itself [2].

Management: In some areas (for example, Ecuador and Peru) the stems are harvested from natural, partly managed populations, while in others it is cultivated as a crop [3], [6]. Plant stands are tended by gathering rhizomes and reducing plant density. Fire was also used to manage *S. californicus* wetlands, but is not recommended due to haze and GHG emissions. Fire eliminates decadent old stems and restores open water areas. This stimulates growth of new shoots from rhizomes and provides a bare soil substrate for seed germination [2]. Regular mowing has probably similar promoting effects.

Harvest: In Ecuador the green aerial stems are harvested for weaving when the inflorescence has matured and the plant has reached maximum development. Length of the harvested stems varies from 1.5 to 4 m [3]. Most harvesting is done during the dry season, i.e., every 6-8 months. Regular harvesting appears to promote growth of the stands and increases stem density [3]. Harvesting is done by hand with serrated sickles from a boat by standing within the stands. Stems are cut 15-20 cm above the water and are left in place in stacks for 1-2 weeks to dry, thereby weight is decreased to facilitate transport. For the use as cattle fodder, it is harvested more often: 3-4 times a year [3]. Machine mowing is not known but probably feasible with balloon tires or tracked vehicles when water levels are close to the surface.

Productivity: Highly productive species [7]. Under higher nutrient conditions of constructed wetlands, the aboveground live biomass of *S. californicus* can reach up to 54 t/ha [5]. In two naturalized stands in New Zealand the aboveground biomass ranged between 16 and 21 t/ha [5]. A study of a fluvial-tidal gradient in the Lower Delta of the Paraná River showed a significantly higher net aboveground primary production (NAPP) of *S. californicus* in the marsh directly affected by the tides (19 t/ha*yr). The more upstream site that is less prone to tidal flooding (and nutrients) showed a lower NAPP (12 t/ha*yr) and the system showed a higher ability to keep the produced biomass within the marsh [8].

Cultivation experiences: It is cultivated in N. and S. America and in New Zealand for restoration, thatching and wastewater treatment. It is unknown to the authors if it is cultivated on peatlands.

Utilisation

Human food: Totora (*S. californicus*) is used by various Amerindian peoples since at least many centuries [9], [10, [11], [12]. Young shoots coming up in the spring can be eaten raw or cooked. The pollen is eaten as flour in bread, mush or pancakes. Later in the season, the seeds can be beaten off into baskets or pails, ground into a similar meal and used as flour. Tea is made from the flowers [13]. The large rhizomes are eaten raw or cooked; sometimes they were dried in the sun, and then pounded into a kind of flour [2]. The stem bases are valued for their high carbohydrate content. It is used as food sources and was sometimes marketed commercially (e.g., in the Lake Titicaca region) [3]. Bulrush is similar to cattail in edibility, although it is purportedly sweeter [2].

Medicine: Totora has medicinal utility. The reed can be wrapped around a sore wound which tends to ease pain. Similarly, it is reportedly used to help deal with hang-overs [13].

Animal fodder: *S. californicus* is used as an excellent cattle fodder [3].

Agricultural conditioner and substrate: It can be used as a soil fertilizer [3].

Fuel: Dried totora is used sometimes as fuel for fire [14].

Raw material for industry: The stems are used as weaving material, e.g., mats, baskets, etc.; totora mats are marketed throughout Ecuador and exported to Colombia, Peru, U.S. and Italy [3]. It is also used as building material, e.g., thatching [10], [11]. The stems have also been used for totora houses in California and in Peru near Lake Titicaca due to their insulating and water-proof properties [2], [10], [11]. For the same reason they have also been used to make reed boats, e.g., at Lake Titicaca [14], [6], [11], as well as mattresses, furniture, and handicrafts [13]. Lake Titicaca reed boats are also called balsas [11], [12] and have intrigued archeologists and others for many years [15]. In fact, the renowned explorer Thor Heyerdahl (famous for his 1947 trans-Pacific voyage on a balsa boat “Kon-Tiki”) had reed boat builders from Lake Titicaca construct RA-II that he used to cross the Atlantic (Morocco to Barbados) in 47 days [13]. A totora boat may last 3-6 months with normal use but if plastic tarps are applied to protect the inside of the boat, its life expectancy is increased to 8-12 months [6].
Totora is also used to build artificial floating islands on Lake Titicaca by the indigenous Uru people [10], [11]. The artificial island is comprised of two layers: the first is a layer of the natural rootmass (= peat block) about 1 m thick; the second layer consists of harvested stems laid in a crisscrossed pattern strung together by ropes [13]. The islands last for about 15-18 years.

Co-benefits: *Scirpus californicus* appears to be a well-suitable species for use in constructed wetlands for treatment of agricultural, nonpoint source pollutions and municipal wastewaters [16]. These plants are especially good for stabilizing or restoring disturbed or degraded (including logged or burned) areas, for erosion and slope control, and for wildlife food and cover [2].

Similar species:

Schoenoplectus tabernaemontani (C.C.Gmel.) Palla - soft-stem bulrush (Salz-Teichsimse): It occurs in deep or shallow water, as well as in muddy or marshy ground around lakes, ponds, streams, and wooded wetlands. The growth is better in saline conditions than in fresh water, and it tolerates a wide range of salinity [32]. Utilisation options are similar to *S. lacustris.*

Bolboschoenus maritimus (L.) Palla (= Syn.: *Scirpus maritimus* L.) – cosmopolitan or alkali bulrush (Gewöhnliche Strandsimse):
It grows at low to mid elevations in marshes, transient wet spots, pond margins, and backwater areas. It forms large dense stands in alkaline or saline sites [2] and occurs almost globally. It is widespread across much of temperate and subtropical Africa, Asia, Europe, N. America, S. America and various islands. It is used for erosion control, restoration and constructed wetlands [2].

Schoenoplectus acutus (Muhl. ex Bigelow) Á.Löve & D.Löve - hardstem bulrush or tule:
It is native to freshwater marshes all over N. America. Tule has a thick, rounded green stem growing to 1 to 3 m tall, with long, grasslike leaves, and radially symmetrical, clustered, pale brownish flowers. There are two varieties: *Schoenoplectus acutus* var. *acutus* occurring in northern and eastern N. America and *Schoenoplectus acutus* var. *occidentalis* growing in southwestern N. America. Dyed and woven, tules are used to make baskets, bowls, mats, hats, clothing, duck decoys by Native American groups. Also, houses (tule houses) and canoes similar to totora boats were made out of the stems. Flour can be made by peeling and cutting up the older roots, crushing and boiling them, removing any fiber, and drying [17]. The seeds can also be ground and mixed with the root flour [17]. It was also tested for peatland restoration to reduce greenhouse gas emissions in California [18].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Kristian Peters

Schoenoplectus lacustris (L.) Palla

common bulrush (Gewöhnliche Teichsimse, Flechtbinse)

Family: Cyperaceae
Life form: graminoid
Main use category: raw material
Used part: stems

General information

Morphology: Perennial, 50-300 cm high. Rhizomatous stems, solitary, terete. Persistent during winter season, stems decay in the beginning of the next growing season. Leafless sheath below, upper sheath often with a short lamina. Hermaphrodite. Spikelets 3-10 mm, ovoid, in fascicles arranged in a head or a simple or compound umbel with unequal rays. Glumes reddish-brown. Nut 2-3 mm, smooth, greyish-brown [1], [2].

Geographic distribution: Nearly cosmopolitan: Europe, south and east from Lapland to Africa and Asia. C. and N. America, Polynesia [3].

Natural habitat: Bogs, shallow pond margins, rivers and lakes, usually there where abundant silt is present, in acid or calcareous conditions [4], [5].

Site specific properties

Water regime: wet-flooded
Trophic conditions: eutrophic
pH: acid-subneutral-alkaline
Light conditions: shade intolerant
Salinity: medium tolerance

Cultivation

Schoenoplectus lacustris is widely harvested from natural stands for thatching. It is a very productive species with a high economic value [2]. It grows naturally in peatlands and is a potentially peat forming species [6], [7]. Successful cultivation experiences are available and probably transferable to paludiculture. However, paludiculture with this species is unknown to the authors.

Propagation and establishment: Under natural conditions generative propagation is rare. The seed can germinate in shallow stagnant water or in wet soil [8]. Stratification improves germination rates (wet/cold storage) [9]. Vegetative propagation seems more effective and secure for dispersal. The divisions should be taken in spring. Larger divisions can be planted out directly into their permanent position [3]. A planting density of 5 plants per

m^2 has given good yields after 2 years [10]. In Manipur (India) 4 cuttings were used per m^2 [11]. During the time of transplantation, the water level should be maintained between 10 and 15 cm. After some weeks the water level can be raised gradually. Young plants can be established in shallow and moderately deep water (5-40 cm deep) [12]. *Schoenoplectus lacustris* is adapted to a wide range of ecological parameters with characteristic ecotypes developed in specific sites. The use of plant material that has originated from a site with similar conditions is more likely to survive than plant material from sites with large differences (e.g., in pH, salt content) [8].

Management: *Schoenoplectus lacustris* can grow in water that is up to 2 m deep, but is more common in wet to 1 m deep water. The deeper the water, the higher the productivity [10], but the harvest is much more problematic in deeper water. Thus, a shallow water table is probably a good trade-off. The plant is tolerant to strongly fluctuating water levels [13], but sensitive to prolonged drought conditions. To achieve high yields, the site should offer eutrophic conditions or should be rewetted with water that contains high nutrient loads.

Harvest: The stems are cut in summer from June to August for thatching and weaving. The bulrush is cut from a punt using a long scythe, enabling the rush stems that are sometimes up to 3 m long to be cut from the bottom. The stems have to be dried afterwards. During the drying process the weight of the rush is reduced to a fifth.

Productivity: Bulrush is a productive species with a moderate to fast growth rate. The range of annual biomass production for *Schoenoplectus* spp. is in general: 7.85-46 t/ha*yr [14]. Maximum net productivity of *S. lacustris* in the cool temperate zone is reported to be 46-59 t/ha*yr [15]. The yield can vary in an unpredictable way due for example to damage by bad climate or heavy waterfowl grazing [16]. A cultivation experiment in a hydroponic system had a stem productivity of 12 t/ha DM after 2 years establishment [17]. The maximum stem productivity of natural stands is reported with 12-30 t/ha [10].

Cultivation experiences: [8], [12]. *S. lacustris* was successfully cultivated in a peatland (bog with acid condition) in the Emsland region in Germany [8].

Utilisation

Human food: The root can be eaten raw or cooked [18], [19], [20], [21]. It is rich in starch and can be dried and ground into a powder or made into a syrup [22], [19], [20], [21]. The buds at the end of the rhizomes are crisp and sweet; they can be eaten raw [21]. The young shoots are edible, raw or cooked [19], [21], [23]. The pollen and the seeds can be ground up into a powder and mixed with flour for use in making cakes etc. [19], [21]. They are small and rather fiddly to harvest and utilize. The base of mature stems is edible, raw or cooked, just like the pollen.

Medicine: The roots are astringent and diuretic [24]. They were formerly employed medicinally but have fallen into disuse [25]. *S. lacustris* is a traditional medicine for cancer [26].

Ornament: Some named varieties have been selected for their ornamental value [27].

Animal fodder: *S. lacustris* can be used as a forage plant; nutritional values are available [28], [8]. Especially the young stems are readily eaten by waterfowl.

Fuel: The dried stems have some potential as an energy source for direct combustion [28].

Agricultural conditioner and substrate: It is a good source for compost or green manure [8].

Raw material for industry: The stems are frequently used for making mats, chair bottoms etc. and thatching [4], [25], [29], [19], [30], [31]. The pith of the stems is used in paper making [30].

Co-benefits: The plant is used for biological wastewater treatment [2], [8], [28], [16]. Bulrushes are also planted for land reclamation, bank management and restoration [16], [8].

Further reading:
[8]; http://www.rushmatters.co.uk/video/

Similar species:
Schoenoplectus tabernaemontani (C.C.Gmel.) Palla - Soft-stem bulrush (Salz-Teichbinse):
It occurs in deep or shallow water, as well as in muddy or marshy ground around lakes, ponds, streams, and wooded wetlands. The growth is better in saline conditions than in fresh water, and it tolerates a wide range of salinity [32]. Utilisation options are similar to *S. lacustris.*

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Krzysztof Ziarnek

Scirpus cyperinus (L.) Kunth.

woolgrass, woolly grass bulrush

Family: Cyperaceae
Life form: graminoid
Main use category: raw material
Used part: stem

General information

Morphology: Perennial. Height: 120-150 cm. Culms slender, erect. Leaves smooth, flat, elongated, up to 1.2 cm wide. Hermaphrodite. Flowers dense rounded terminal clusters of greenish-brown spikelets. Fruit: Achenes yellow-gray to white, surpassed by long red-brown bristles at maturity. Extremely variable [1], [2].

Geographic distribution: Native to Eastern N. America: from Canada to Southern USA. Natural range: from Newfoundland to Florida [3].

Natural habitat: *Scirpus cyperinus* grows in several wetland types including tidal and non-tidal freshwater marshes, sedge meadows, shrub wetlands, edges of swamps, lakes, ponds and ditches [4].

Site specific properties

Water regime: wet
Trophic conditions: eutrophic
pH: acid-alkaline
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Scirpus cyperinus grows naturally in peatlands. It is used traditionally as a raw material, but cultivation is unknown from a larger scale. Since it prefers peat soil for growing, paludiculture seems promising. It grows spontaneously in cutover peatlands, e.g., in Manitoba (Canada) [5]. *Scirpus cyperinus* also displays a good peat-accumulating potential after restoration due to the high biomass production and low decay values of the biomass [6].

Propagation and establishment: As soon as they are ripe, fruits should be sown in a cold frame in a pot standing in 3 cm of water. The seed germinates quickly. Planting out in their permanent positions should occur in early summer. When seeded directly, the water level should be maintained at 30 cm above ground level for two weeks. Thereafter the water level can be raised until 90 cm [1]. Vegetative propagation via division in spring. Larger divisions can be planted out directly into their permanent positions [3]. An exact propagation protocol is available [7].

Management: Woolgrass can tolerate periods of inundation, but best growth is attained in saturated wet soils [4].

Harvest: No information found. The harvest is probably done when the stem is fully established in late summer.

Productivity: Moderate to high productivity under nutrient-enriched and favourable conditions. The annual primary production in a biomass study in Canada was 15 t/ha*yr in a cutover peatland [6].

Cultivation experiences: Unknown to the authors.

Utilisation

Human food: The seed is edible, when cooked. It can be used as a rice substitute [8].

Raw material for industry: The stems are manufactured into matting and ropes [8]. The small rushes have been used in making woven mats and storage bags [9]. The fruiting tops of the plant have been used as a resilient material for stuffing and making pillows [9].

Co-benefits: The plant can be used for biological wastewater treatment [10].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Daderot

Scolochloa festucacea (Willd.) Link

common rivergrass, whitetop (Schwingelschilf)

Family: Poaceae
Life form: graminoid
Main use category: fodder
Used part: aboveground biomass

General information

Morphology: Perennial. Height 0.7-2 m. Culms robust, erect from a decumbent base, rooting at lower nodes; spreading spongy rhizomes. Leaf sheaths smooth, glabrous; leaf blades 15-40 cm × 4-10 mm, margins sharply scabrid. Hermaphrodite. Panicle loose, elliptic to ovate in outline, 15-30 cm; branches 2-4 at each node, naked in lower half, scabrid. Florescence June to August [1].

Geographic distribution: *Scolochloa festucacea* occurs in boreal and sub-boreal regions of N. America and Eurasia. In Europe it occurs mostly in Germany, Poland, the Baltic countries, Sweden, Finland, the Ukraine and Russia; it has an isolated occurrence in the Caucasus [2].

Natural habitat: It occurs in seasonally flooded wetlands including wet depressed meadows, fen peatlands, prairie potholes, and lake and river margins, where it is often stand-forming [3], [2].

Site specific properties

Water regime: wet-flooded
Trophic conditions: meso-eutrophic
pH: subneutral-alkaline
Light conditions: shade intolerant
Salinity: low tolerance

Cultivation

Scolochloa festucacea grows naturally in peatlands and is used traditionally as a fodder plant. In western Canada and the central United States *Scolochloa festucacea* produces excellent forage for livestock [4]. Artificial cultivation is uncommon. Paludiculture experiences with *Scolochloa festucacea* is unknown to the authors.

Propagation and establishment: Generative propagation via fruits. Seed burial, which occurs with inundation, is required for emergence. Anaerobic conditions stimulate fermentation that increases the germination rate. Seeds that have been stimulated by early season anaerobic conditions germinate when light reaches the substrate and the ground is no longer submerged [5], [6]. A seed burial depth of max. 1-5 cm maximizes emergence and seedling length and weight [5], [7]. Stratification does not improve germination [5]. Germination is substantially reduced by soil sodium chloride concentrations of 1,000 ppm and higher [5], [7]. High continuous flooding of 30 cm or more is destructive for seedlings [8], [9]. Only a few seedlings become established after germination. A seedling must have a rhizome to survive the winter. Seedlings produce a rhizome 30-60 days after emergence [6].

Management: There is higher biomass production with high water tables, but biomass declined with water depths greater than 15 cm above surface in a pot experiment [11]. In natural stands a greater depth and duration of spring flooding increased biomass [11], but the plant is not as tolerant of flooding ascattail, hardstem bulrush, softstem bulrush or common reed [10].

Natural *Scolochloa festucacea* areas generally retain surface water during June and July from spring run-off. Often simple earthen dykes are used to impound spring run-off in native stands. The removal of litter by harvesting, spring flooding and periods of undisturbed recover ensure stand persistence and maximum standing stocks over time [4]. Litter removal through harvest caused initial increase in seasonal standing stock. Modelling shows that harvesting for more than 3 consecutive years causes system instability and loss of dominance [12]. *S. festucacea* grows well under extensive mowing regimes but declines with excessive grazing and trampling [13]. Moderate to heavy grazing decreases its productivity. The soft rhizomes which are near the soil surface may be damaged by trampling [13]. If heavily grazed, it may be replaced by bulrush [14].

Scolochloa festucacea biomass increased after 1 year, but decreased after 2 years of fertilization with nitrogen. The second year decrease was attributed to the mat of litter created by the tall weakened culms which resulted from the first fertilizer application. If it had been harvested, regrowth might have been stimulated. Phosphorus had no effect on biomass production [11], [15]. Under wet conditions fertilization is usually forbidden.

Harvest: The optimum time to cut *S. festucacea* would be after the pollen has been shed but before seeds are shattered, because it has good protein and digestibility levels early in the growing season; those levels decline after the seed-fill stage [13]. Harvest can be done with adapted machinery for wet conditions (e.g., light or tracked machines).

Productivity: The total aboveground biomass of a spring-flooded prairie marsh was 9.4 t DM/ha [16]. Biomass modelling in a seasonally flooded prairie marsh showed that leaving the *Scolochloa festucacea* stand undisturbed every fourth year resulted in an average harvested yield of 9.6 t/ha and long term system stability [12]. Some yields exceed 10 t/ha [17].

Cultivation experiences: Unknown to the authors.

Utilisation

Animal fodder: Common river grass is highly palatable to livestock [3]. The biomass shows good protein and digestibility levels early in the season, but levels decline rapidly after seedfill [3].

Further reading: [17]

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Manuel Anastácio

Spartina alterniflora Loisel.

smooth cordgrass, saltmarsh cordgrass

Family: Poaceae
Life form: graminoid
Main use category: wetland restoration, erosion control, fodder
Used part: aboveground biomass

General information

Morphology: Perennial. Height up to 3 m. Culms stout, forming large clumps, erect, ca. 1 cm in diameter, with soft fleshy rhizomes building an extensive underground system. Leaf blades linear-lanceolate, flat, 10-90 × 1-2 cm. Deciduous. Hermaphrodite. Flower: racemes, 10-20 x 5-20 cm, slender, erect or slightly spreading. Forms dense vegetative colonies along shorelines and inter-tidal flats in coastal wetlands [1], [2].

Geographic distribution: Native to S. America and N. America. Introduced to Europe, Asia and New Zealand.

Natural habitat: Brackish coastal saltmarshes, tidal mudflats of coastal areas [2], [1]. It dominates where salinities range from 3 to 5 % and the average water table is 10 cm above the surface [3].

Site specific properties

Water regime: moist-wet-flooded
Trophic conditions: no information found
pH: acid-alkaline
Light conditions: shade intolerant
Salinity: high tolerance

Cultivation

Spartina alterniflora is a pioneer species bordering tidal inlets or lagoons in saline portions of marshes. After organic matter builds up, it is naturally replaced by more dominant species. It is also prone to grow vigorously along mangrove coastlines [4], [5]. There are already several attempts to show the feasibility of the use of natural stands for different utilisation options [6], [7]. Cultivation is known from erosion control, soil stabilization and restoration. Paludiculture with *Spartina alterniflora* is unknown to the authors.

Propagation and establishment: Generative and vegetative reproduction is possible, but smooth cordgrass is a poor seed producer. Although plants appear to produce a significant number of fruits, most of them are empty, damaged or sterile. Consequently, seed fertility is low. For planting purposes, two forms of vegetative plant materials are recommended:

containerized and bare-root plugs. There are no commercially available sources of seed, and seeding is currently not a recommended practice [2].

Management: It is described as a facultative halophyte, since it will tolerate salt; but salt is not a requirement for its growth. It can be established and will persist in areas of elevated salinity (such as salt-flats and tidal lagoons). However, plants in high saline habitats tend to be stubby and less robust, resulting in thinner and more open vegetative stands. The salt-tolerance of cordgrass is directly proportional to water depth [8]. Smooth cordgrass thrives in anoxic, low marsh habitats due to its ability to oxygenate its roots and rhizosphere [9].
It will tolerate fluctuating water levels and can even be established in flooded conditions. It is adapted to a wide range of soils from coarse sands to clays and mucks. Plant establishment and productivity appear to be superior on heavier mineral soils such as mucky clays, silty clays, silty clay loams, and fine sands. Soils with very high levels of organic matter pose structural problems and have proven to be problematic in establishing stands of smooth cordgrass [2]. It is not clear if cultivation in peat soil is feasible. Fertilization is not recommended as tidal flooding may lead to severe loss of fertilizers.

Harvest: Gentle harvest is probably possible with adapted light machinery once or twice a year. Multiple harvests showed disappointing results, since regrowth is minimal. Avoid mid-summer harvests [7]. Also grazing will probably have damaging effects on the stand, because the substrate is soft and fragile, and the below-ground reserves are too scarce to repair the damaged canopy [7]. The high salt content of the biomass is problematic for storage; it is likely to get wet [6]. Further research regarding harvest, transportation and storage techniques is needed.

Productivity: It is a high productive species. Rate of net production of aboveground biomass ranges from 5 to 22 t DM/ha per year [10]. It can produce up to 30 t/ha under natural conditions [11].

Cultivation experiences: It is cultivated in N. America [3] and in China [12], [6] for erosion control, soil stabilization and restoration.

Utilisation

Food: *Spartina alternifolia* contains high amounts of bioactive materials that could be extracted and used as a new functional food additive [13].

Animal fodder: It is recognized as an important forage species for livestock producers along the central gulf coast [2]. A study in China showed that milk cows loved to browse on *S. alterniflora* and that a replacement of up to 2/3 of the conventional food had no negative effect on the quality or quantity of the milk production [6]. Extractions of *S. alterniflora* can be used as a food additive for eels to improve their meat [6]. However, additional inputs of nutrients into water bodies should avoided.

Fuel: It has a good potential for biomass energy systems [10], e. g., as a source for biofuel production [14]. Biogas production by anaerobic digestion may be a promising method [15].

Agricultural conditioner and substrate: Plantations are used for green manure [1]. The grass residue can be used as a substrate for mushroom cultivation [13].

Raw material for industry: Smooth cordgrass provides thatch for roofs [16].

Co-benefits: It is utilized extensively for erosion control along shorelines, canal banks, levees, and other areas of the soil-water interface. It is an effective soil stabilizer used on interior tidal mudflats, dredge-fill sites, and other areas of loose and unconsolidated soils associated with marsh restoration. Under natural conditions on tidal marshes, vigorous stands of this grass will absorb wave energy and screen suspended solids from intertidal waters, while uptaking available nutrients in the sediments. It will tolerate petroleum contaminated soils [2].

Further reading: [3], [6], [7]

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Picture: Dana Filippini

Spartina patens (Aiton.) Muhl.

saltmeadow cordgrass (Schlickgrass)

Family: Poaceae
Life form: graminoid
Main use category: fodder
Used part: aboveground biomass

General information

Morphology: Perennial. Height: 30-122 cm. Dark green stems emerge from rhizomes. Leaf blades rolled, 15-30 x 0.25-0.5 cm, shiny, dark green on upper surface and rough with prominent veins on lower surface. Leaves drooping, wiry. Hermaphrodite. Inflorescence terminal open panicle, 2-10 spikelets, 2.5 cm long. Florescence July to October. Rhizomatous, forming dense turf or sod with fine, matted, decumbent stems. Spreads extensively by long slender rhizomes [1].

Geographic distribution: Native to western and eastern N. America (coastal areas). Introduced elsewhere and often a harmful noxious weed or invasive species.

Natural habitat: Grows in brackish marshes, low dunes, sand flats, beaches, overwash areas, and high salt marshes [2]. It is dominant on peat deposits of varying depths or on mineral soil of outwash material or soils deposited by tidal and wave action [3].

Site specific properties

Water regime: moist-wet-flooded
Trophic conditions: no information found
pH: acid-alkaline
Light conditions: shade intolerant
Salinity: high tolerance

Cultivation

Saltmeadow cordgrass is dominant in the saltmeadow marsh, the third stage of salt marsh succession [2]. Saltmarsh meadows, dominated by saltmeadow cordgrass, served as a natural pasture in the pioneer days in N. America, and are still grazed to a limited extent [4]. Saltmeadow cordgrass is naturally replaced by *Juncus roemerianus* and *Distichlis spicata* in strongly saline areas [5]. In salt marshes of New England, *Spartina alterniflora* monocultures dominate low marsh habitats while the seaward border of high marsh habitats is generally dominated by *Spartina patens* [6]. An artificial cultivation for paludiculture with *Spartina patens* is unknown to the authors.

Propagation and establishment: Generative and vegetative reproduction is possible. Due to sparse fruid production and low vigour of seedlings, saltmeadow cordgrass is usually propagated by vegetative stem divisions. Bare root material should contain 3-5 stems per planting unit, while containers should have at least 5-8 healthy stems. Bare root plugs are generally limited to planting sites that are exposed to little or no wave energy. Since most marsh sites are irregular and difficult to access, hand-planting is normally employed. If site conditions permit, planting can be carried out mechanically. Plant spacing should be between 45 and 90 cm; up to 60 cm of lateral spread can be expected annually [7].

Management: This grass is adapted to a wide range of soils from coarse sands to silty clay and peat soil. It will tolerate irregular inundations with 0-35 ppt salinity. The grass responds well to applications of fertilizers [8]. But fertilization is not recommended as tidal flooding may lead to severe loss of fertilizers.

Harvest: In natural stands the access is probably difficult so that adapted light machinery is recommended. The high salt content of the biomass is probably problematic for storage; it is likely to get wet. Further research regarding a functioning harvest, transportation and storage techniques is needed.

Productivity: Saltmeadow cordgrass yielded 9.7 t DM/ha in one growing season in Georgia, USA (April to September) [9]. A harvest-study in Delaware showed that there is no advantage in multiple harvests compared to a single harvest after July; yields ranged between 11 and 14 t DM/ha [9]. A study in Long Island (NY) revealed annual yields of 4.2-5.4 t DM/ha [10].

Cultivation experiences: Known from N. America [1] where it is cultivated for erosion control and restoration.

Utilisation

Animal fodder: Saltmeadow cordgrass is considered as an important forage species to livestock producers along the gulf coast of N. America [1]. Immature plants provide moderate amounts of digestible protein for livestock (6.9-7.3 %), but as plants mature, protein decreases [11]. Hay harvesting was formerly an important industry in the New England and Middle Atlantic coastal marshes [12].

Fuel: This plant has a good potential to be used as biomass crop for bioenergy systems [13].

Raw material for industry: Saltmeadow cordgrass is the primary component of salt hay, which is utilized in the landscape and vegetable trade industry as weed-seed-free mulch [1]. It could become an excellent raw material for extracting flavonoid compounds by the HPLC method [14].

Co-benefits: Saltmeadow cordgrass is used for shoreline protection and tidal marsh restoration. It is often utilized for levee stabilization and dune stabilization plantings near coastal beaches and on barrier islands. The plant is an effective stabilizer used on interior mud flats, dredge fill sites, and other areas of loose and unconsolidated soils associated with marsh restoration. In its natural state on the tidal marshes, dense stands of this grass cause suspended solids to settle out of floodwaters and take up available nutrients [1].

Similar species: *Spartina cynosuroides* (L.) Roth (big cordgrass, salt reed grass)

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Picture: Susanne Abel

Sphagnum spp. L.

peat moss (Torfmoos)

Family: Sphagnaceae
Life form: moss
Main use category: agricultural conditioner and substrate
Used part: biomass (entire moss plant)

General information

Morphology: Perennial. Individual moss plants typically with upright stems, young branches arranged spirally around the stem at growing apex into a capitulum, branches clustered into fascicles along stem. Along the stem are scattered leaves of various shapes (stem leaves); the shape varies according to species. Stem and branch leaves consist of alternating inflated, S-shaped to rhomboidal hyaline cells and narrow linear chlorophyllous cells. Hyaline cells are typically fibrillose and porose on branch leaves. *Sphagnum* species can be dioecious or monoecious [1].

Geographic distribution: Worldwide, except for Antarctica [56].

Natural habitat: Open and forested bogs as well as fens.

Site specific properties

Varies between species. The following indication is valid for most *Sphagnum* species.
Water regime: wet
Trophic conditions: oligo-mesotrophic
pH: acid-subneutral
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

The cultivation of peat moss on rewetted bogs to produce and harvest *Sphagnum* biomass is called *Sphagnum* paludiculture. It is successfully tested on degraded bogs, i.e., on rewetted bogs formerly used as grassland or on bogs after peat extraction. Additionally, the cultivation of *Sphagnum* was also tested on artificial floating mats on open water bodies resulting from peat, sand and lignite extraction.

So far, material from wild populations of only a few *Sphagnum* species has been tested successfully in field trials in NW-Germany: *S. palustre*, *S. papillosum* and *S. fallax* [2], [5], [37]. Selection of highly productive and more site adapted wild provenances will lead to increased productivity. In general, *Sphagnum* species from the *Acutifolia* and *Sphagnum* subgenus should be targeted in the context of *Sphagnum* paludiculture because of better intrinsic properties (e.g., low decomposition rates) compared to species of the *Cuspidata* subgenus [4].

Propagation and establishment: *Sphagnum* can be propagated via spores or vegetatively via shoots. Although mass propagation from spores in a photo bioreactor is possible [42], [43], its use is not practicable because factors inducing sporulation are unclear, capsules can only be collected manually and the produced moss individuals are genetically diverse (a result of sexual reproduction). However, to get founder material for vegetative propagation *Sphagnum* may be collected from wild populations (depending on the scarcity and conservation status of *Sphagnum* in the country) or existing *Sphagnum* paludiculture sites. Higher multiplication rates can be achieved by cultivation in a sterile tissue culture [44].

Land preparation before seeding: For the installation of a new *Sphagnum* paludiculture site the area must be levelled out to ensure optimal water tables over the entire field. In case of grassland the upper highly mineralized peat layer (~10-30 cm) should be removed. This material can be used to build causeways facilitating the access with machines, e.g., for management and harvest of the *Sphagnum* biomass. Additionally, infrastructure for water management has to be installed.

After site preparation founder material should be applied on the bare peat and can be subsequently covered with straw mulch to provide a suitable microclimate [7]. If the water management provides a constant high water table close below peat surface, the straw mulch is dispensable. Peat moss fragments < 3 cm establish slower than larger ones [5]. Re-sowing some months after the first *Sphagnum* application can be necessary to replenish gaps in the developing moss carpets and to abbreviate the establishment phase. [5].

Management: A high and stable water table (best: a few centimetres below the capitulum) is the most decisive factor for optimal *Sphagnum* growth, whereas fertilization has only minor effects [8]. Dry and flooded conditions must be prevented. In an area surrounded by drained sites, active pumping can be necessary, e.g., with a subsurface [37] or surface irrigation system [2, 6]. A larger area is preferential to minimize ’oasis effect’ [45]. Oligotrophic conditions should to be maintained if possible. Nutrient rich conditions can be tolerated by several peat moss species, but also favour non-target *Sphagnum* species or competitive vascular plant species like *Juncus effusus*. Regular mowing with a grass trimmer or an excavator with a mowing bucket can be used to suppress unwanted vascular plants. After 5 years of management with 2-3 times mowing per year, *Juncus effusus* was repressed successfully on a pilot field in NW Germany [35].

Harvest: The moss biomass can be harvested every 3-5 years [35], depending on the establishment and growth conditions as well as the harvesting method and depth [12]. There are several harvesting methods: cutting the top part, scarifying or total harvest of the biomass (until the peat), manually or mechanically. To harvest with an excavator and a mowing bucket from a causeway [35] necessitates high infrastructural efforts. In Finland and northern USA harvest with excavator or a small crawler tractor is possible by driving on the frozen ground [46], [47], [48]. In Finland a forestry vehicle (‘forwarder’) equipped with bogie tracks and a bucket grapple is also used to gather *Sphagnum* biomass from wild populations in summer [49]. Harvest with adapted machinery on the site (e.g., tracked vehicles with a cut and carry system) is the preferential method, but still in development. The decision on whether to harvest only the upper *Sphagnum* biomass, partly or all of it, is determined by the expected speed of regrowth of the residual *Sphagnum* compared to the speed of new establishment, and by related costs.

Productivity varies between species and depends on site conditions. The natural dry mass productivity of *Sphagnum* species ranges over two orders of magnitude, from 0.08 to 14.5 t/ha*yr with an overall average of 2.6 t/ha*yr [9]. Species of the *S. recurvum*-group grow under higher nutrient availability with a natural productivity with values between 4 and 6 t/ha*yr, while more ombrotrophic carpet and lawn species have lower productivities with mean values ranging between 2 and 3.5 t/ha*yr. Species typically growing in forested habitats and/or in minerotrophic rich fens (i.e., *S. capillifolium*, *S. teres*, *S. girgensohnii*, *S. warnstorfii*) show low productivity values [9].
Dry mass productivity of *Sphagnum* on *Sphagnum* paludiculture sites mainly ranges between 3 and 6 t/ha*yr in Germany [5]. After the establishment phase mean dry mass productivity of *Sphagnum papillosum* reached 3.6 t/ha*yr with highest values (up to 6.9 t/ha*yr) being reached on sites with permanently high water tables [5]. Higher values (4.9 t/ ha*yr in mean during the first five years of growth) where determined at a continuously wet pilot site near Rastede in Northwest Germany [41], which were installed mechanically with *Sphagnum palustre* and *S. papillosum*. In a long-term *Sphagnum* paludiculture experiment in eastern Canada dry mass productivity was lower with values between 0.3 to 2 t/ha*yr [6], probably because of unbalanced water supply as a result of no active irrigation control and shorter growing seasons [37].
Economic calculations and cost-benefit analysis is available [39], [40].

Cultivation experiences For *Sphagnum* paludiculture, gathering or restoration (cf. differentiation in Gaudig et al. 2018 [35])**:** Germany [5], [35]; Canada [7], [6]; UK [44]; Japan, Finland, New Zealand, South Korea, Chile [10], [11], and Georgia [50].

Utilisation

Agricultural conditioner and substrate: Dried *Sphagnum* is used for orchid propagation [21], [22], as growing medium for hanging baskets, vertical “living walls” or roof gardening. Because of similar properties, *Sphagnum* biomass can substitute peat as raw material in growing media, which has been tested successfully on a wide variety of crops summarized in [35]. Growing media from *Sphagnum* biomass can perform equally or better than standard peat-based growing media [27], but with differences between *Sphagnum* species [35], [26].

Ornamental: Living *Sphagnum* mosses are used as ornamental moss (“floral moss”), for green sculptures and as ingredient in turf roofs, which is especially is popular in South Asia. It is also used in miniature models, for urban yard landscaping, to top dress containers and flower beds or making wreath [6], [19].

Medicine: Because the whole fresh moss plant is antiseptic and has a high capacity to absorb and retain fluids [13], [14] it makes an excellent wound dressing and has been widely employed for this purpose in the past [13], [15], [16], [17], [28], [29]. Its use is said to have saved the lives of thousands of soldiers in the First World War [13], [15]. The moss is dried thoroughly before use [13].
Next to wound dressing *Sphagnum* biomass is also used for surgical dressings, sanitary towels, babies’ nappies etc. [13], [18], [16], [17], [30]. Among some Amerindians of western Washington, *Sphagnum* sp. (Makah: pu’u´p; Quinault: tso’otcilminix, ‘berry moss’) is used as sanitary napkin and camp bedding [31].

A tar extracted from the decaying moss is antiseptic and is seen as a valuable external application in the treatment of eczema, psoriasis, pruritus and many other forms of skin diseases [13], [18]. It is very beneficial for allaying irritation from insect bites and can also serve as a preventative to being bitten [13]. Additionally, *Sphagnum* extracts are sources of natural sunscreen [51].

Raw material for industry:
Sphagnum moss is a good packing material and is used for food preservation (e.g. fish) to transport delicate items; it can be used as a cotton wool substitute [21]. It can also be used for vivaria with amphibians, reptiles and spiders to maintain high air humidity. The moss has been and is still used as a traditional insulating material in buildings such as log cabins [54], [55]. Additionally, *Sphagnum* biomass can be used as absorbent material for decontamination of pollutants (e.g. oil, chemicals) and to filter water. *Sphagnum* fibres could be used to manufacture compostable plant pots [6].

Co-benefits: *Sphagnum* cultivation is applied in peatland restoration measures [7], [32], [33], [44]. *Sphagnum* paludiculture on rewetted peatlands provide several positive ecosystem services, like reduction of GHG emissions [38], stop of subsidence and filter nutrients in runoff water [36] [40], as well as promotion of biodiversity [34], [52], [53].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Kristian Peters

Symphytum officinale L.

comfrey (Beinwell)

Family: Boraginaceae
Life form: forb
Main use category: medicine, fodder
Used part: roots, leaves

General information

Morphology: Perennial. Height: 50-120 cm. Stem stout, erect, hollow, often branched. Leaves large, (ovate-)lanceolate, the middle and upper sessile, often decurrent, 20 x 7 cm. Hermaphrodite. Inflorescence a many-flowered cyme. Corolla 12-18 mm, purple-violet, dirty pink or white, lobes deflexed. Nutlets 5-6 mm, black, very smooth, shining. Flowering Mai to July. Root stock stout, vertical, branched, tap-root, inside whitish, outside blackish, 30 cm long and 1-2.5 cm wide [1] [2].

Geographic distribution: Native to Europe, Asia – south-west and east from Scandinavia to Spain, Siberia and Turkey [3]. Introduced elsewhere, including N. America.

Natural habitat: Damp, often shady localities, in meadows, woods etc., especially near streams and rivers [4], [5], [6].

Site specific properties

Water regime: moist
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Paludiculture with *Symphytum officinale* is unknown, but the ecological amplitude suggests that moist-wet cultivation with it could be possible. A successful test cultivation in a rewetted fen peatland showed that cultivation in moist-wet peatlands is indeed possible. Cultivation instructions are rare and only available from cultivation on mineral soil. Information on propagation and establishment are probably transferable to paludiculture. The harvest of the valuable roots could harm the peat soil and probably lead to further degradation, similar to the necessity of the new installation of the field after root harvest. A peat conserving paludiculture with *Symphytum officinale* would exclude the harvest of below-ground biomass or the whole plant. The cultivation is recommended for eu-polytrophic, moderately rewetted peatland areas because long-term flooding will not be tolerated. If peat conservation can be achieved in cultivation needs to be investigated.

Propagation and establishment: *Symphytum officinale* is mostly propagated vegetatively from root cuttings, crown divisions, and transplants [7], but also generatively via seeds which is recommended for larger areas [3], [8]. Direct seeding is possible in autumn or spring with spacing of 25-30 cm and a row distance of 35-50 cm [8]. Seedlings may also be grown in a nursery and planted out with a spacing of 30-50 cm [8]. Root cuttings are the least expensive method of propagation and recommended for small-sized cultivation areas [8]. They are usually 6-10(-20) cm long and 0.6-2 cm in diameter [7], [8]. Smaller cuttings will also generate plants, but plants from longer cuttings emerge and establish more quickly. Wilted cuttings should be soaked in cold water until they become firm before planting. Root cuttings develop buds about 3-6 weeks after planting, while crown divisions emerge in about 10 days. Production during the first year is greatest for a crop started from transplants and lowest for one using root cuttings. The best time to plant is in April, or as early as the soil can be tilled, but the crop can be planted throughout the growing season [7]. Comfrey is planted in rows that are 1 m apart to permit cross cultivation for effective weed control (spacing of 35-50 x 30cm) with a planting depth of 5-10(-15) cm [7], [9], [8]. Weeding is necessary before and after planting.

Plants can even be invasive, often spreading freely by means of self-sown seed or tillering. The root system is very deep and difficult to eradicate, even small fragments of root left in the soil can produce new plants [3].

Management: Long term flooding is detrimental. The plant has a high N demand and should be planted only in fertile sites. When the leaves are harvested, the stands are conventionally fertilized. Fertilization in wet soil is usually forbidden. *Symphytum officinale* is a perennial plant and plantings should last indefinitely (more than 20 years) if proper weed control and soil fertility are maintained [7].

Harvest: The aboveground biomass can be harvested one year after planting and the underground parts after two years. The leaves are harvested in early summer (June to August), the root in autumn or early spring [10], [9]. Both can be dried for later use; the leaves should be dried immediately (max. 35 °C) after harvest or used fresh [4], [8]. The leaves can be harvested 2-5 times per year [8].

Productivity: A comparative study presents values of dry matter yields ranging from 5 to 25 t/ha for different locations [11].

Symphytum officinale could provide average monthly green biomass yields of 2 t DM/ha in a pilot study in Uganda, where the cultivation was tested for forage production [12]. In Germany, the yield of the aboveground biomass of 2 cuts in the first year were 8.5-10 t/ha DM and in the second year 12.8-13.8 t/ha

DM [8]. The root yield can be 8.4-12.2 t/ha DM [8].

Cultivation experiences: A test trial is known from a rewetted fen peatland in NE Germany [13]. It is commonly grown on mineral soil [10], [7].

Hazards: This plant contains small quantities of a toxic alkaloid which can have a cumulative effect upon the liver. Largest concentrations are found in the roots, while leaves contain higher quantities of the alkaloid as they grow older and young leaves contain almost none [3]. There are cultivars available with lower alkaloid content [8].

Utilisation

Medicine and Human food: The young leaves are edible when cooked or raw [14], [15], [16], [4], [17], [18], [19]. The leaf is hairy and the texture is mucilaginous. It may be full of minerals but it is not a pleasant food for most tastes. It can be chopped up finely and added to salads; thus the hairiness is not so obvious [20], [3].

Medicine: Comfrey is a commonly used herbal medicine with a long and proven history in the treatment of various complaints [3], [8], [21]. The root and the leaves are used, the root being more active; both can be taken internally or used externally as a poultice [15], [22]. Comfrey is especially useful in the external treatment of cuts, bruises, sprains, sores, eczema, varicose veins, broken bones etc. Internally it is used in the treatment of a wide range of pulmonary complaints and internal bleeding [15], [23], [3]. The plant contains a substance called 'allantoin', a cell proliferant that speeds up the healing process [15], [24], [25], [26], [22], [23]. This substance is now synthesized in the pharmaceutical industry and used in healing creams [23]. The root and leaves are anodyne, astringent (mild), demulcent, emollient, expectorant, haemostatic, refrigerant, and vulnerary [15], [24], [25], [26], [22]. Some caution is advised, however, especially in the internal use of the herb [3], [21]. External applications and internally taken teas or tinctures of the leaves are considered to be completely safe, but internal applications of tablets or capsules are considered to have too many drawbacks for safe usage [23], [3].

A homeopathic remedy is made from the fresh root; it is harvested before the plant flowers [27]. This has a very limited range of application, but is of great benefit in the treatment of broken bones and eye injuries [27].

Ornament: Comfrey is used as an ornamental garden plant.

Animal fodder: The leafy biomass is used as forage mainly mixed with other silage crops and perennial grasses [28]. It has been successfully tested as a complement to forage legumes, grasses and crop residues for sustainable animal production in Uganda; nutritional values are available [12]. Another report states that the high moisture content and unpalatability for some livestock species make utilization of comfrey as a feed difficult [7].

Agricultural conditioner and substrate: The plant grows very quickly, producing a lot of biomass. It is tolerant to several cuttings per year and can be used to provide 'instant compost' for crops such as potatoes. The wilted leaves can simply be layered at the bottom of the potato trench or can be applied as a mulch in no-dig gardens. A liquid feed can be obtained by soaking the leaves in a small amount of water for a week, which is excellent for potassium demanding crops such as tomatoes. The leaves are also a very valuable addition to the compost heap [25], [29].

Raw material for industry: A gum obtained from the roots was once used in the treatment of wool before it was spun [30].

Further reading: [7], [9], [8], [21]

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Thomas & Dianne Jones

Taxodium distichum (L.) Rich.

bald cypress (Echte Sumpfzypresse)

Family: Cupressaceae
Life form: tree
Main use category: raw material, energy, ornamental
Used part: wood, living tree

General information

Morphology: Perennial. Height 25-40(-44) m. Trunk 2-3(-5) m in diameter. Trunk enlarged basally and often conspicuously buttressed; crown monopodial and conic when young, often becoming irregularly flat-topped or deliquescent with age. Leaves deciduous, up to 20 mm, acute, decurrent, narrowly linear and laterally divergent in 2 rows. Monoecious. Male cones purplish, in pendent panicles to ca. 25 cm, 2-3 mm; female cones 15-30 mm in diameter. 2 irregularly trigonous seeds per fertile scale [1], [2]. Seeds are produced annually and good seed production occurs about every three years, from age 30 onwards [3], [4]. Under flooded conditions the roots develop 'knees', cone-shaped structures adding to stability of the tree [5].

Geographic distribution: South-eastern U.S.A. - New Jersey to Florida and Texas. Cultivated elsewhere in temperate regions.

Natural habitat: Grows on wet sites that are under water for at least part of the year [6]. More commonly found in fresh water areas but can survive in low salinity brackish areas for a while [8], [9].

Site specific properties

Water regime: moist-wet-flooded
Trophic conditions: eutrophic
pH: acid-subneutral
Light conditions: intermediate shade tolerant
Salinity: low tolerance

Cultivation

The majority of the virgin wetland forests with *Taxodium distichum* in south-eastern U.S.A. were cut over during the late 1800s and early 1900s. Although there has been a general trend of land loss of these forested wetlands during the past 100 years, there are still vast areas of second-growth timber existing today, and standing crop volumes have continued to increase since the 1950s [10], [11]. Afforestation is known from restoration measures [12], and are probably transferable to a managed wet forestry on peatlands. *Taxodium distichum* can be planted in wet soils and shallow water, but it thrives in any soil, and trees actually grow faster in unflooded soils [13], [14]. However, trees can reach high d.b.h. on thick peat layers [15]. One report found even a close correlation between the depth of the organic soil and tree size (in d.b.h.) in Florida with increased tree size on deep organic matter [15]. Paludiculture is unknown to the authors but seems very promising.

Propagation and establishment: Under natural conditions the generative establishment from seeds is the dominant mode of reproduction where seeds are dispersed by floodwaters. The natural seedbed is moist and competitors are unable to cope with flooding [10]. In peatlands, the best seed germination generally takes place on a sphagnum moss or a wet muck (peat) seedbed [4], [16]. Germination rates can be increased by a chemical pre-treatment of the seed with 1 % NaOH that neutralize the acidity of the seed resin [17]. Seeds will not germinate under water, but some will remain viable for 30 months under water. On the other hand, seeds usually fail to germinate on better drained soils because of the lack of surface water. Thus, a soil saturated but not flooded for a period of 1-3 months after seeding is required for germination [4], [18]. Seedlings have a very fast early-stage growth rate that is important because they can be killed by four to five weeks of total submergence during the growing season [19]. The seedlings should be grown in a nursery for 1-2 years and then planted out in late fall or winter so that the seedlings become established in low water periods. A 2.4 x 2.4 m spacing is recommended [20]. Planting in standing water areas has been successfully tested [21], [10]. Innovative planting methods may be required because of standing water and unconsolidated sediments. One method of planting that has been tested extensively in the southern U.S. is to heavily root-prune seedlings so that they may be planted by grasping the seedling at the root collar and simply inserting them into the soil or sediment, without digging a hole (reviewed in [12]).

A pilot plantation in a wet peatland in northern Germany with 3-year-old containerized plants showed initially good increment rates; at a later date, however, failures were observed. Replacement plantings and weeding to reduce competitive forb vegetation were carried out [J. Schröder, pers. comm.].

Unlike most conifers, this species responds well to coppicing [13]. Thrifty sprouts are generally produced from stumps of young trees, but trees up to 60 years old also send up healthy sprouts if the trees are cut during the fall or winter. However, survival of these sprouts is often poor and those that live are usually poorly shaped and do not make quality sawtimber trees [21]. But short rotation for bioenergy could be a possible option.

Management: *Taxodium distichum* tends to grow well at high stand densities [23], but there is some evidence that thinning may enhance diameter growth [20], [19]. The stand should be managed on an even-aged basis [20]. Thinning plots within a stand in Florida to various densities at age 60 resulted in faster growth of individual crop trees, but in slower growth per unit area than for the unthinned part of the stand [23]. Others recommended removing approximately 40 % of the original basal area as the best method, since it produced good growth with fewer epicormic branches and increased diameter increment and net volume increment in the first 25 years after thinning [24], [25]. Young stands should be thinned at 15-20 years [15].

Bald cypress is relatively maintenance-free, requiring pruning only to remove dead wood and unwanted lower branches which persist on the tree [26]. It maintains a desirably straight trunk and a moderately dense canopy and does not form double or multiple leaders as do many other large trees [26].

Continuous high water tables can be tolerated by an established bald cypress forest, but then there will be no regeneration. The tree regenerates well where there is ample sunlight and a moist (but not flooded) seedbed during germination and seedling establishment [11]. Herbivory (e.g., nutria, mice) can lead to major losses; several proposals to prevent nutrias from browsing on young bald cypress plants are available [11]. In those areas where flooding prevents or limits the natural regeneration of the forest, artificial regeneration by planting is the only currently viable mechanism [11]. However, also old bald cypress trees slowly die when exposed to prolonged, deep flooding (reviewed in [11]).

Harvest: The low carrying capacity of the wet peat soil makes the wood harvest difficult. Harvesting should be conducted with adapted machinery, the cable way technique, or helicopters to minimize peat disturbance and its possible harmful effect on water quality.
It is common practice to harvest bald cypress before reaching 100 years [27]. Clear-cutting is the recommended method (reviewed in [11]). Harvesting of the timber from peatlands can create severe forest renewal problems, unacceptable increases in the ground water levels, fast growing ground vegetation competition, and these problems are magnified when the final fellings are carried out as clear-cuts [28]. Some reports state that there is a rapid recovery following clear-cutting (reviewed in [20]), while others report that regeneration is insufficient mainly owing to altered hydrology [10]. If hydrologic conditions have been changed, natural regeneration may be hampered and recovery rates may be much slower or even non-existent [29], [30].

Productivity: Values are quite heterogeneous, with hydrology being the most important factor influencing productivity [20]. For example, periodic inundation with riverine waters provides the forest with nutrients and sediments that stimulate plant productivity [31], [32]. Continuous high-water table and acid peat soil sites have lower productivity [33], but one study found greater aboveground biomass three years after harvesting on a site that was continuously flooded as compared to a site that was periodically flooded [34]. In general, *Taxodium distichum* shows medium height growth rates of 30-60 cm/yr for the first 50 years [35]. *Taxodium distichum* can live for hundreds of years, but height growth generally ceases at about 200 years. During some growing seasons, perhaps in response to soil-moisture fluctuations, many *Taxodium distichum* appear to produce more than one ring in the stem. Counting these false rings as annual rings has led to overestimations of ages and consequently to underestimations of growth rates [18].
Taxodium distichum is noted for its high merchantable yields. In the original virgin stands, yields of 112-196 m^3/ha were common, and some stands likely exceeded 1,400 m^3/ha. One tree in Okefenokee Swamp in Georgia scaled 168 m^3 [18]. From age 60 to 70, a bald cypress-hardwood stand in Florida increased from 39 to 43 m^2/ha in basal area and from 359 to 428 m^3/ha in volume, respectively. Bald cypress grew at a faster rate than tupelo and sweetgum [23]. The annual aboveground production of biomass in a bald cypress-ash floodplain forest in Florida was 15.7 t/ha*yr (= 35 m^3/ha*yr) [36].
It appears that plantation-grown bald cypress trees grow better than natural stands and may even grow better than hardwood species [37].

Cultivation experiences: Experiences are available from the south-eastern U.S.A. [37], [12]. It has been planted for its timber in S. Europe, especially on alluvial soils [1].

Utilisation

Medicine and poison: The resin in the cones is used as an analgesic for wounds [38], [5].

Ornament: *Taxodium distichum* is very popular as an ornamental tree [39]. The unusual and pleasing appearance of its knees, buttressed base, massive bole, and irregular crown often festooned with Spanish moss has led to its introduction as an ornamental in many parts of the world [23].

Fuel: Wood can be used as fuel, e.g., as woodchips for short rotation forestry.

Raw material for industry: The wood is light, soft, not strong, moderately hard, easily worked and straight-grained. It weighs 0,45 t/m³ (28 lb per cubic foot) [5]. The wood is not subject to excessive warping or shrinking [5], it is used for construction, water pipes, vats etc. [40], [41], [42], [6], [38], [43], [5]. The wood has long been valued for its water resistance (thus called 'wood eternal'), but only the old growth wood is durable to wet conditions. New wood marketed today has to be treated if exposed to moisture. The old growth wood is extremely resistant against rot and termites because a compound called cypressene (resin) acts as a natural preservative for the heartwood. However, resin takes many decades to build up in the wood, making lumber cut from old-growth trees much more resistant to decay than lumber from younger trees [44]. At what age or size decay resistance develops is unknown, but wood from trees at least 63 years old is susceptible to rot [45]. The bark has been used to make cordage [46].

Co-benefits: It has potential for rehabilitating margins of surface-mined lakes. Cypress domes can serve as tertiary sewage treatment facilities for improving water quality and recharging groundwater [4].

Further reading: [19], [16]

Similar species:
Taxodium distichum var. *nutans*

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Pictures: Harvey Barrison, Joshua Mayer (detail)

Thuja occidentalis L.

northern white-cedar, arborvitae (Abendländischer Lebensbaum, Thuja)

Family: Cupressaceae
Life form: tree
Main use category: raw material, ornamental
Used part: wood, plant

General information

Morphology: Perennial. Height 12-15(-30) m. Leaves evergreen, scale-like and abruptly pointed, 2 mm long, opposite in alternating pairs (in 4 rows), bright green above and pale green below, with a spicy fragrance when crushed. Crown narrowly conic to broadly pyramidal, with spreading, densely crowded branches. Branchlets flattened, in fan-shaped sprays. Bark is reddish-brown, 6-9 mm thick, fibrous, separated into flat, connected ridges. Monoecious. Cones ellipsoid, 9-14 mm long, brown when ripe. Cones ripening in the first year. Seeds ca. 8 per cone, 4-7 mm long, with lateral wings about as wide as the body [1].

Geographic distribution: Eastern N. America - Nova Scotia to Georgia, west to Illinois and Minnesota.

Natural habitat: It usually grows on cool, moist, nutrient-rich sites and calcareous mineral or organic soils, near lakes, streams and river shores, swamps, uplands, cliffs, and talus, at 0-600(-900) meters elevation [1]. Northern white-cedar (NWC) commonly grows in mixed stands but is also found in pure stands on calcareous organic soils [3]. It is usually dominant in forested rich fens that have a strong flow of moderately mineral-rich soil water. (peat-forming [2], [4]). It can also dominate the peat ridges in bog and fen complexes that have a sluggish movement of weakly enriched water [5].

Site specific properties

Water regime: moist-wet
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: intermediate shade tolerant
Salinity: medium tolerance

Cultivation

Natural stands of NWC are traditionally exploited for their timber in eastern N. America. It is a highly variable species that can adapt to a wide range of stresses. Sustainability of NWC resource is a concern in many regions throughout its natural range because of regeneration failures, difficulty recruiting seedlings into sapling and pole classes, and harvesting levels that exceed growth [6]. Although NWC is widely planted as an ornamental, plantation management of cedar swamps has not been adopted.

Afforestation of NWC in peatlands is known from restoration [7], and is probably transferable to a managed wet forestry on peatlands. However, the productivity is generally lower on wet peaty sites than on drier upland sites [8], [9].

Propagation and establishment: Northern white-cedar reproduces naturally via seeds and layering [10]. The seeds germinate readily on a variety of moist substrates, but seedlings become established on only a few. The main requirements for early development seem to be a constant moisture supply and some sunlight [3]. NWC is shade tolerant, but can be shaded out [11]. NWC seedlings can survive on nurse logs in later stages of decay (specifically those with an associated bryophyte mat) that hold moisture through the dry portions of the summer [12], [13] (reviewed in [11]). A low pH negatively affects germination and seedling density [10]. On cutover NWC swamps in Minnesota, seedlings were found only where the pH of the surface soil ranged from 6.6 to 7.2, but are often found in pH > 5.5 [14]. Browsing and desiccation are the most common causes of seedling mortality [11], [15]. The high palatability of NWC foliage to white-tailed deer (*Odocoileus virginianus*) causes extreme browsing pressure on young trees where deer populations are high, making regeneration difficult [15]. The growth and development in the seedling stage is slower than that of competing species. NWC frequently reproduces vegetatively in swamps.

Regeneration after harvest:

Wet lowland stands with numerous hummocks support abundant NWC regeneration when a seed source is present; these sites also have less competing understory vegetation [16], [11]. To enhance NWC establishment, the competition from faster-growing associates should be reduced. Planting or direct seeding of NWC might be necessary on sites without established regeneration or a local seed source [11]. There are several guides for better regeneration results available [11], [8].

Management: Reliable and sustainable management of NWC seems difficult. NWC stands are often affected by browsing, altered hydrology, harvesting, and competition from associated tree and shrub species, which lead to recruitment failures. The current management guides show mixed results. Due to the variability of site conditions, generalisations are hardly practicable. Silvicultural decision guides and recommendations are available [11], [8], [17], [6]. They all stress the need for managers to consider both timber and wildlife implications in any silvicultural treatment.

An established pure NWC stand will benefit from thinning, but stands on poor sites with stagnant water may show little response to thinning [18]. In mixed-species stands, within-stand flexibility of treatment is critical for maintaining NWC, when other, more dominant species are driving silvicultural prescriptions at the stand level; a 'micro-stand' approach in which pockets of NWC trees are identified and managed is suggested [18].

Harvest: The low carrying capacity of the wet peat soil makes the wood harvest difficult. Harvesting should be done in winter on frozen ground to minimize peat disturbance and its possible harmful effect on water quality (or with adapted light machinery, cable way technique or helicopters).

Harvesting of the timber from peatlands can create severe forest renewal problems, unacceptable increases in the ground water levels, replacement by alternative tree and shrub species, fast growing ground vegetation competition, and these problems are magnified when the final fellings are carried out as clear-cuts [19].

Harvesting NWC often results in stand type conversion if well-established advanced regeneration is not present; partial cutting is suggested for regenerating stands with a component of NWC [18]. Clear-cutting in small strips or blocks is often used to take advantage of natural seeding from adjacent stands. Shelterwood or seed tree regeneration systems can be employed [17]. If deer herds are large, it may be better to increase the size of the cuts with isolated residual seed trees or direct artificial seeding to eliminate thermal cover and overwhelm the deer with more food than they can use, thus increasing the chances that enough seedlings will remain to form a new stand [17]. Residual stand damage should be minimized in partial harvesting operations because NWC has a weak wood strength [20].

Productivity: NWC shows medium to slow growth rates, though the range is highly variable [21]. On wet sites the productivity is often low, having a site index of 9 (= 9 m height in 50 years), or lower [8]. Yield tables are available [11], [9]. Radial growth increments were found to be higher in limestone communities than bog communities (3.1 versus 1.5 mm/yr) [6]. On bog and swamp sites, cedar may reach less than 7.6 m (25 ft) in height in 50 years, whereas on upland sites that are wet only a portion of the growing season, they may reach 15 m or greater in height. Basal area in pure and well-stocked maturing stands on wet sites may exceed 28 m² (= 300 ft²) and volumes can exceed 840 m^3/ha (= 12,000 ft^3/ac) [9].

Cultivation experiences: NWC is widely cultivated as ornamental tree or hedge in America, Europe and Asia. Silviculture is known from N. America [18].

Utilisation

Human food: The pith of young shoots is edible when cooked [22]. It can be added to soups [23], and is pleasantly sweet [24]. The inner bark is edible when cooked. It is only used in times of emergency or scarcity [25]. The inner bark can be dried and ground into a powder, then used with wheat or other cereals in making bread, biscuits etc. The leafy branchlets are used as a tea substitute [26], [23], [27]. They have an aromatic flavour [23]. Hazard: An essential oil from the leaves is poisonous if taken in large doses [28], [29].

Medicine: Northern white-cedar was much used by many North American indigenous groups as a medicine to treat fevers, coughs, headaches, swollen hands and rheumatic problems [30], [27]. The plant has an established antiviral activity and is most commonly used in modern herbalism to treat warts and polyps, being prescribed both internally and externally for these conditions [30]. The plant can be used to induce menstruation and should therefore not be prescribed for pregnant women [31].

The recently dried leafy young twigs are alterative, anthelmintic, anti-inflammatory, antiseptic, aromatic, astringent, diaphoretic, diuretic and emmenagogue [32], [28], [33], [34]. The plant is being used internally in the treatment of cancer [30], especially cancer of the uterus [30]. A tea made from the leaves is used in the treatment for bronchitis and other respiratory problems, colds, headaches and as a cough syrup [35], [30]. The plant's diuretic properties make it useful in treating acute cystitis and bed-wetting in children [30]. The leaves are used in steam baths in the treatment of rheumatism, arthritis, colds etc. [35]. Externally, the leaves are used as a wash for

swollen feet and burns [35]. Extracts of the leaves can be used for easing pain and stiffness [30]. A tincture of the leaves has been used in the treatment of warts, piles, bed sores and fungal infections [35].
'Oil of white-cedar', obtained from the leaves, is an essential oil that is antiseptic, expectorant and rubefacient [25], [35]. It is used internally to promote menstruation and relieve rheumatism [25]. This volatile oil is toxic and poisoning from overdoses has occurred [25]. The oil also stimulates the heart and causes convulsions in high doses [25]. A homeopathic remedy is made from the leaves and twigs [36]. It is used as a treatment against warts, but also has a range of other applications [28], [36].

Ornament: *Thuja* is a popular ornamental tree. It can be grown as a hedge [37]. It is often used for border or shelter plantings. The tree is tolerant of regular trimming, though this does not include the old wood. There are many cultivars which differ, primarily in leaf colour, growth habit, cold and heat hardiness.

Fuel: Both wood and spent distillate has been used for fuel.

Raw material for industry: The wood is light, soft, not strong, brittle, coarse-grained, very durable, easily worked and does not warp [38], [39], [40], [37], [41]. It weighs 320 kg/m³ [41], and is used especially where contact with water cannot be avoided, namely for canoes, garden buildings, fences, shingles, log homes, posts etc. [42], [38], [39], [40], [37]. Unfortunately for its value as timber, the tree is commonly hollow and has a curved butt and poor form, especially in swamps. The fresh branches are used as besoms [32]. Their aromatic smell serves to deodorize the house whilst sweeping [37]. The leaves have been kept in clothes cupboards as a perfume, incense and insect repellent [27]. The leaves and stems have been used as an incense [27]. An essential oil is obtained from the leaves and branches; it is used in perfumery and in medicines [43], [44], [38], [37]. The oil also has insect repellent properties [45]. The tough and stringy bark has been used to weave fibre bags [27]. The bark is a source of tannin [27].

Co-benefits: NWC forests provides valuable shelter and browse in deer wintering areas. They are valued for their high biodiversity and potential for long life.

Further reading: [11], [8], [17], [6]

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Georg Schramayr

Trapa natans L.

water caltrop, water chestnut, buffalo nut (Wassernuss, Wasserkastanie)

Family: Lythraceae
Life form: forb/herb
Main use category: food
Used part: seed

General information

Morphology: Annual. Height: up to 60 cm (depending on water depth). Central stem rooted in the hydrosoil. Rosette of leaves around central stem, the spongy inflated leaf petioles enabling the rosette to float. Hermaphrodite. Flowers inconspicuous, born in leaf axils of younger leaves above the water; self-pollinating. Fruit a single-seeded, woody nut, bearing four sharply pointed horns (the variation *T. bicornis* bears 2 horns), falling off the plant when mature and sinking to the bottom of the water. Florescence May to October, fruiting July to November [1], [2], [3], [4].

Geographic distribution: The native area of *T. natans* is from western Europe and Africa to NE. Asia including eastern Russia, China, and SE. Asia, through to Indonesia [4]. Nowadays it is naturalized and cultivated in India, Sri Lanka, countries of SE. Asia, Africa, Australia, and N., Central and S. America [2], [5].

Natural habitat: *T. natans* grows in slow-moving rivers, lakes, swamps, and ponds [1]. Best growth in waters that are nutrient rich and moderately alkaline. It can grow in water up to 5 m deep, but prefers shallow waters (0.3-2.0 m deep) [4].

Site specific properties
Water regime: wet-flooded
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Trapa natans is typically grown for its edible seeds in ponds. Paludiculture is unknown, but it seems promising, since after re-wetting of degraded peatlands open water or flooded parts often arise that could be used for water caltrop cultivation.

It is an invasive weed species, e.g., in the northeastern U.S. where it dominates shallow lakes and river margins, displaces native vegetation and limits navigation and recreation. In some countries of its native range, however, it has become rare and is even under protection [6].

Propagation and establishment: *T. natans* can be propagated generatively either by raising seedlings in the nursery and planting or by direct seeding [2]. Seeds can be harvested in late summer and stored overwinter in a jar of water in a cold but frost-free place. The seed quickly loses its vitality if it is allowed to become dry. It should be sown in spring [3]. A temperature range of 25-30°C has been found most conducive for germination [2]. It has a strong vegetative growth.

Management: Normally it is grown in ponds, where the soil should preferably consist of rich and fine clay. Addition of farm yard manure or ammonium sulfate considerably accelerates the growth. No specific preparation of the land is required, except removing the weeds and ensuring protection from grazing animals [2]. When grown in rewetted peatlands, a constant high water table is important. The construction of polders/dikes to keep the water in the field can be necessary. It is an annual plant and must be reseeded every year.

Harvest: The fruit is mature 22-23 days after development [7]. In China it is traditionally harvested by hand from boats or floating wooden tubs.

Productivity: The average yield is 2-2.5 t fruit/ha, but also yields up to 5 t/ha are possible [2]. Each seed can produce ten to fifteen rosettes and each rosette may produce as many as twenty seeds.

Cultivation experiences: Unknown from peatlands, but widely cultivated in artificial ponds or lakes, e.g., in China and SE. Asia.

Utilisation

Human food: The seeds are eaten raw or boiled [2]. When the fruit has been dried, it is ground into a flour. It has a sweet floury and agreeable flavour [8], similar to sweet chestnuts (*Castanea* spp.) [9]. The seed contains up to 50 % starch according to one report [10], 16 % starch and 3 % protein in another report [11], and 15 % protein and 7.5 % fat in a third [12]. Reportedly, the raw nut contains toxins that are destroyed by cooking the seed [7].

Medicine: The fruit has a weak anti-oxidative effect [13]. An extract of the fruit rind showed a significant antioxidant activity against free radicals [14].

Further reading: [5]

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: Christian Fischer

Trifolium fragiferum L.

strawberry clover (Erdbeer-Klee)

Family: Fabaceae
Life form: forb/herb
Main use category: fodder
Used part: aboveground biomass

General information

Morphology: Perennial. Height 10-30 cm. Plant stoloniferous, glabrous or hairy. Stems prostrate or decumbent, rooting at nodes. Leaves palmately 3-foliolate, long petiolate; leaflets obovate-elliptic, 10-25 × 5-15 mm. Hermaphrodite. Flowers 10-30, in heads, 0.8-2.5 cm; involucral bracts fused. Corolla white or pink, 6-8 mm. Florescence and fruiting May to August [1].

Geographic distribution: Temperate areas of Europe, Asia, N. America, Africa, Australia, and New Zealand. Native to the eastern Mediterranean and southern Asia [2].

Natural habitat: *T. fragiferum* can grow on wet saline and alkaline soils and is adapted to wet meadows, streams and seeps [2].

Site specific properties

Water regime: moist-wet
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: shade intolerant
Salinity: high tolerance

Cultivation

Trifolium fragiferum grows on coastal flood peatlands that are used traditionally as wet grasslands. The biomass is highly acceptable to livestock whether at leafy grazing stage or as hay or silage. It is seldom used for hay, however, because of its low growth height. Cultivation is common and probably transferable to paludiculture.

Propagation and establishment: Direct sowing without a cover crop is recommended. The seedbed should be weed-free. The maximum sowing depth is 10-15 mm with a light but firm soil cover. Spring is a suitable time, though late-summer sowing is a practical alternative provided there is adequate moisture and sufficient time for the clover seedlings to develop well before winter. For areas that are waterlogged or subject to inundation over winter, late winter or early spring sowing is recommended [3]. Strawberry clover has low seedling vigour. It should be sown at 0.5-1 kg/ha in a mixture, or 1-2 kg/ha when sown alone [3]. Other reports recommend higher seeding rates: e.g., 3-6 kg/ha in grass/legume mixtures [4]. All the seeds may be scarified to ensure a good initial germination; alternatively, part of the seed lot may be left unscarified to act as a reservoir for later germination [4]. There are several varieties available.

Management: Except for seed production purposes, strawberry clover is never seeded alone. Better forage and high quality hay is produced if it is mixed with species such as *Alopecurus geniculatus*. The plant is tolerant of mowing and of close continuous grazing on account of its stoloniferous growth habit [5]. Flooding for up to 2 months can be tolerated [2].

Harvest: Highest yielding in spring and summer [4]. The seed crop should be cut when seed envelopes are light brown [5].

Productivity: Aboveground biomass is 1.9 t DM/ha for pure stands; when accompanying plants were included, the productivity was 5.4 t DM/ha [5]. When grown in mixtures, e.g., with *Paspalum dilatatum*, total herbage yields of up to 18 t DM/ha have been noted [4].

Cultivation experiences: N. America (U.S.A.) [5], southern Australia.

Utilisation

Animal fodder: *T. fragiferum* is mainly used for pasture, but also in mixtures with grass for hay and silage [2]. It is rarely used pure for hay because of its low stature [5]. *T. fragiferum* is a useful forage legume for soils that are too saline for *T. repens* [4]. The metabolizable energy (ME) is 6.5 MJ NEL per kg DM [6]. According to [6], it has a German forage value (Futterwertzahl) of 7.

Further reading: [5]

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Pictures: Maksim, Kristian Peters (detail)

Tripolium pannonicum subsp. *tripolium* (L.) Greuter

Aster tripolium L. (Syn.)
sea aster (Strand-Aster)

Family: Asteraceae
Life form: forb/herb
Main use category: fodder, food
Used part: leave, stem

General information

Morphology: Short lived perennial. Height 20-60(-150) cm. Stem erect or ascending, branched from base upwards, often reddish. Leaves lanceolate to linear, moderately to strongly succulent; narrowed into a long petiole. Hermaphrodite. Flower capitula in corymbs or panicles. Ligules 10-30, bright blue or lilac, often absent. Fruit pappus elongating strongly after anthesis; hairs nearly equal [1].

Geographic distribution: Coastal areas of Europe, N. Africa and saline inland areas of Europe and C. Asia [2], [3].

Natural habitat: Brackish reedbeds, wet salt grassland [4], salt marshes with frequent tidal inundations and maritime cliffs [5], [3].

Site specific properties

Water regime: moist-wet
Trophic conditions: eutrophic
pH: subneutral-alkaline
Light conditions: shade intolerant
Salinity: medium tolerance

Cultivation

The species is a component of wet salt grassland that is traditionally used as pasture in the Baltic sea region [4]. Sea aster is cultivated as a sea vegetable in the Netherlands. A cultivation in salt-water influenced peatlands seems promising.

Propagation and establishment: It can be propagated via seeds, for which it is surface-sown in spring. The soil has to be kept moist. Pre-chilling the seed for two weeks can improve germination rates [6]. Germination is inhibited by high salinity; the germination rates are already reduced by NaCl concentration of 1 % [3]. Best germination rates can be achieved with temperatures between 17 and 21°C, and non-saline conditions [7]. Soil preparation is recommended to reduce competition in the young stage.
The seeds ripen in autumn. *T. pannonicum* appears to have a meagre potential to form a sizeable persistent seed bank. On higher sites, however, seedlings seem to have high chances of survival [8].

Management: Iron supply is recommended during repetitive harvesting because iron deficiency, in addition to leaf chlorosis, reduces leaf quality as a vegetable by increasing the leaf nitrate content [9]. It has to be cultivated in saline soils and/or irrigated with brackish or saline water to gain the desired salty taste. Weed control is necessary.

Harvest: Repetitive harvesting of young leaves from spring to late summer is required. Older leaves are fibrous and have a bitter taste [7].

Productivity: The yield of young leaves can reach 35-50 t/ha (fresh weight), harvested in 6-7 cuttings [10]. The mean yields of one harvest in a brackish soil with mean water table of 10 cm below surface are 5 and 8.5 t/ha for a culture in river sand and sandy loam, respectively [7]. The annual yield is much higher through repetitive harvest.

Cultivation experiences: In the Netherlands [10], [7] and Portugal [11], but unknown in peatlands.

Utilisation

Human food: The somewhat fleshy leaves are used to make pickles or are cooked as a vegetable [12], [13], [14]. It is cooked like spinach and may be mixed with common spinach in order to add texture and a salty taste [10]. The stem contains about 8.4 % ash, and the leaf 9 % ash, mainly sodium chloride [15]. Young leaves are rich in protein and amino acids [10]. A concentration of about 6 g sodium chloride per kg fresh leaf weight is required in order to guarantee an acceptable salty taste [11].

Ornament: High ornamental value.

Animal fodder: It is eaten by cattle on salt grasslands [4]. The metabolizable energy (ME) ranges from 9,1 to 7,1 MJ per kg DM [4]. After [4] it has a German forage value (Futterwertzahl) of 4. The fibre content is rather low until the main flowering period in August [4].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Pictures: Petr Filippov

Typha L.

T. angustifolia L., *T. latifolia* L., *T.* x *glauca* Godr. (= hybrid of both)

cattail (Rohrkolben)

Family: Typhaceae
Life form: graminoid
Main use category: raw material, fuel
Used part: aboveground biomass

General information

Morphology: Perennial. Height 1.5-3(-4) m. Leaves basal, stiff, green, with a thick aerenchyma and parallel veins. Bract leaves caducous. Monoecious. Inflorescence spike-like, terminal, cylindric, with staminate flowers above and pistillate flowers below. The spike is medium to dark brown. Seeds 1-1.3 mm. Growth colonial, rhizomatous [1], [2], [3].

Geographic distribution: The genus of cattails is globally distributed. *Typha angustifolia*, *T. latifolia* and *T. x glauca* can be found throughout N. America, Europe, Asia, and northern Africa.

Natural habitat: It grows in dense stands in or near the water, in marshes, ponds, lakes, ditches and depressional areas. It will often form an almost complete monospecific stand and may form floating mats. With influxes of nutrients or freshwater, it is an aggressive invader in both brackish salt marshes and freshwater wetlands [4].

Site specific properties

Water regime: flooded
Trophic conditions: mesotrophic-eutrophic-polytrophic
pH: subneutral-alkaline
Light conditions: shade intolerant
Salinity: medium tolerance

Cultivation

Cattails are highly productive wetland plants. Marshes dominated by cattails have among the highest rates of net primary production (NPP) reported for terrestrial ecosystems [5]. The aboveground biomass has versatile utilisation options, e.g., as a building material (insulation, construction) or for bioenergy. *Typha* biomass is used traditionally almost all over the world for weaving and other purposes.

For paludiculture, natural *Typha* stands that can develop in succession after rewetting or cultivated stands can be used. It can spread rapidly. In N. America and Australia, the dominant *Typha* species is considered as an invasive weed species. The artificial cultivation is known and studied from wastewater treatment. There are several paludiculture trials with *Typha angustifolia* and *T. latifolia* in Germany and the Netherlands. In Manitoba (Canada), natural stands are harvested for nutrient removal and bioenergy production [10].

High water tables and high nutrient supply are preconditions for high growth rates. Hence, rewetted degraded fens with nutrient contamination (polytrophic) are favourable sites for a *Typha* paludiculture.

Peat formation by *Typha angustifolia*, *T. latifolia* or *T.* x *glauca* has not yet been documented. Paludiculture with cattail may be peat conserving, but the formation of new peat is unclear. More research into this matter is necessary.

Propagation and establishment: Cattails can be propagated via seeds and plantings of seedlings or rootstocks. Plantings from seeds are a safe and quick but also costly method. Less than two plants per m² are necessary to achieve a good plant density and a closed stand after one year. Plantings (25-50 cm in lengths) should be planted out in early to mid-summer. The leaves can be shortened to 20-40 cm to reduce evaporation loss in the early growing stage [65]. The vegetative spread is enormous, after 2 months the number of shoots per m² can increase by a factor of 7-10 [6]. Shoot density can reach final numbers of 40-70 stems per m², depending on the nutrient status [6]. Direct seed sowing in June-July is also possible. One spike contains over 100,000 seeds, of which over 80 % are germinable [7]. While seeds can germinate under water, best germination rates are reached with the water table at the surface or some cm above surface. Fluctuating temperatures as occur in shallow water bodies stimulate and accelerate germination [7], [8]. Direct seeding can be used to close stand gaps after planting.

There are different ecotypes with different characteristics in productivity and site adaptation. A reliable way is by planting seedlings grown from seeds that have been collected in winter from donor plants on ecologically similar sites in the near surroundings.

Wet to slightly flooded conditions are best for early stand development. Slowly raising the water level in spring allows seedlings to fill plant cover gaps.

Management: Water tables of 20(-50 and higher) cm above the ground and a high nutrient supply are preconditions for a close plant cover with high growth rates [8], [7]. *Typha* can endure continuous flooding. The eutrophic situation can be intensified by providing the reed stand with water rich in nutrients [6]. Nutrient deficiency leads to a decrease in productivity and a severe weakening of the stand that promotes the vulnerability to parasites and infections (e.g., aphids) [6].

Harvest: Harvesting should be done in winter (November/January), on frozen ground if possible, with specialized machinery (e.g., balloon tyre or tracked machinery) in order to avoid damage to the peat soil and the rhizomes [7], [9]. An average cutting height of 10-20 cm preserves already formed young shoots, facilitating rapid emergence of the stand in spring [8]. Flooding of the stubbles is to be avoided. Annually repeated winter harvest seems to have no negative effect on the productivity in the following year [7]. The removal of accumulated deadfall by winter or early spring harvesting even stimulates further plant growth in spring. It opens the site and removes vermin, shading and competition for light, allowing the ground to thaw earlier in the spring and resulting in plants emerging nearly 2 weeks earlier than unharvested sites [9]. This effect is most likely only detectable if nutrient supply is sufficient. Summer mowing is possible, but not recommended [68]. As a result, the plants become weakened and may be outcompeted entirely because less nutrients are stored in the rhizomes to support the emergence of shoots in the following growing season. Here further research is necessary to find the sustainable mowing regime according to site specific properties depending on the targeted utilisation option.

Productivity: The productivity is very variable, depending on the water table, nutrient availability and time of harvest. Means of aboveground biomass vary between 4.3 and 22.1 t DM/ha*yr [8], [10], [7], [11], [12], with constant yields over time in case of annual winter harvest [7]. *T. angustifolia* seems to be more productive in the long range by building denser and more stable stands [7].

Cultivation experiences: USA [7], Germany [13], [66], [67], and the Netherlands [65]. Several pilot studies are comprehensively summarized in [65] according to experimental setting, species and plant parts used, planting density and method, soil type, soil removal, scale, water level range, water source, and plant performance.

Utilisation

Human food: The rhizome is edible, raw or cooked [14], [15], [16], [17]. It can be boiled and eaten like potatoes or macerated and then boiled to yield a sweet syrup [18]. The rhizome can also be dried, ground into a powder and then used as a thickener in soups etc. or added to cereal flours [19]. Rich in protein, this powder is used to make biscuits and similar treats [18]. The flour would probably contain about 80% carbohydrates and around 6 to 8% protein [20]. Young shoots harvested in spring can be eaten raw or cooked [21], [14], [17], [22], [18]. They are an asparagus substitute [18]. The base of mature stems can be eaten raw or cooked [19]. It is best to remove the outer part of the stem [19]. The young flowering stem can be eaten raw, cooked or made into a soup [23], [17], [18]. It tastes like sweet corn [20]. The seed is edible when cooked [18]. It is very small and fiddly to harvest, but it has a pleasant nutty taste when roasted [14]. An edible oil is obtained from the seed [23]. Due to the small size of the seed, this is probably not a very worthwhile crop. Pollen can be eaten raw or cooked. It is a protein rich additive to flour used in making bread, porridge etc. [14], [24], [18]. It can also be eaten with the young flowers [23], which makes it considerably easier to utilize [20]. A summary of the historical use and importance is available [25].

Typha rhizomes were most extensively used as food among the Iroquios in eastern Canada [28]. Amerindians of the Canadian Northwest Territories dug the rhizomes of *Typha latifolia* in autumn for consumption, either raw or fried in grease [29].

The Maori of New Zealand considered cattail pollen a delicacy, especially the *pua*, pollen mixed with water and steamed to make a kind of bread [30]. Among the Pima of N. America, pollen has been collected by picking buds carefully and position them in baskets, then winnowing the fine parts into a big vessel [31]. Apart from that, the pollen has been treated like flour in the making of bread [32] in eastern Canada [28], the Gran Chaco [33], around Bombay [34], New Zealand [30], and Sind [35].

In Mesopotamia the pollen collection still lingers on, and is sold as *kharet* in the souks and cooperatives of Kuwait [30].

Medicine: The pollen is diuretic, emmenagogue and haemostatic [36]. The dried pollen is said to be anticoagulant, but when roasted with charcoal it becomes haemostatic [37]. It is used internally in the treatment of kidney stones, internal haemorrhage of almost any kind, painful menstruation, abnormal uterine bleeding, post-partum pains, abscesses and cancer of the lymphatic system [38], [37], [39]. Externally, it is used in the treatment of tapeworms, diarrhoea and injuries [37].
Among the Delaware indigenous people, the cattail root is taken to dissolve kidney stones [40]. *Typha angustifolia* or *T. dominguensis* were used among Chaco Amerindians as medicine for urinary retention, and generally as popular sustenance [41], [42]. In Traditional Chinese Medicine, male *Typha* inflorescences (Pollen Typhae) are invariably used to quench bleedings of various origins; the inherent chemical compounds display immuno-suppressive and anticoagulatory activity [43], [44].

Ornament: The plant is widely used as an ornamental in wet gardens or ponds.

Animal fodder: The forage quality of the hay is good if it is utilised before the spikes appear in late spring. Before spike emergence, crude protein concentration in cattail is at least 10% and digestibility is at least 50%. After the plants shed pollen, the nutritional quality quickly declines [45]. Cattails harvested in early summer can be added to feed for dairy cattle. The nitrogen and thus protein content is highest before flowering in June [65]. Cattail harvested in late summer is richer in crude fiber and can be used only proportionately for fodder.
Pollen harvested in summer is food for predatory mites (beneficial in organic farming) and the basis for medicinal tea in China [65].

Fuel: Cattail has high potential as a renewable biomass source as fuel (direct combustion, biogas) due to the high energy content comparable to conventional fuel sources [46], [8] The gross lower calorific heating value (LHV) of cattail briquettes, pellets or bales is on average 18.2 MJ kg-1 [10] with an ash content of 3.7-6.7 % [8]. The high biomass productivity of *T. latifolia* coupled with its ability to cope with low nutrient availability and comparatively good tissue quality for combustion (low tissue concentrations of S and Si, while concentrations of Ca are high) make it a suitable bioenergy feedstock [72]. As to biogas, juvenile plants generally display a higher specific biogas yield than mature plants [70]. When compared with the specific biogas yields of maize silage, however, some suggest to add only small amounts of *Typha* because with higher amounts the poor degradation outweighs the benefits [70].
In addition, cattail biomass can be used for the production of biochar through pyrolysis [71].

Agricultural conditioner and substrate: *Typha* makes an excellent addition to the compost heap [20], [46]. Its use as an admixture in peat substitutes for horticulture is currently being investigated. First results showed that due to high chloride contents only biomass harvested in late winter is suitable for growing media [69].

Raw material for industry: The stems and leaves make a good thatch, can be used in making paper, can be woven into mats, chairs, hats etc. [15], [16], [47], [48], [17]. The hairs of the fruits (seed hairs) are used for stuffing pillows [16], [47], [22]. In the Pacific Northwest, *Typha* furnished as material for matting, roofing, diapers, wound dressings and down, the latter was stuffed into moccasins as insoles [26]. The Chumash of California have employed *Typha domingensis* and *T. latifolia* for making mats, thatching the house, and as food (roots) [27].
Cattail's aboveground biomass is suitable for producing insulation materials (e.g., blow-in),

insulation boards, construction boards and acoustic tiles [49], [50], [51]. The advantage of cattail for building materials is the special leaf texture with a sponge-like tissue (aerenchyma) with low thermal conductivity (λ≈0,032 W*mK-1), a structure with extreme high compressive strength, a high natural microbiological resistance and low inflammability [52].

Typha has been used as material for making mats and mattresses among almost all Amerindians of Western Washington, primarily as screens in winter houses, coverings for temporary houses and in the summer as shelters; pads for the knees, raincoats and capes have also been made of cattail mats, and large rucksacks of cattail are employed by the Quinault [53]. At the end of the 19th century, the Lku'ñgen of British Columbia utilized *Typha* as insulation for their winter abodes, as material for the construction of beds and cradles, for tattooing (Cattail charcoal) and generally to craft mats, like their neighbours the Shushwap and others did [54]. In the north of Venezuela, cattail has been manufactured into table mats, baskets and floor covering [55]. Various Amerindians of the Chaco reposed and/or slept beneath a cover of *Typha* mats [56].

Co-benefits: The extensive root system makes it very suitable for stabilizing wet banks of rivers and lakes [57]. Cattails are used in constructed wetlands for wastewater treatment or for phytosanitation [46], [13], [10], [58]. Up to 83% and 86% of the ammonia- and nitrate-load, respectively, and up to 74% of the phosphate could be absorbed by a *Typha* basin [6], [59], [60]. When *T. latifolia* biomass production was higher than 10 t DM ha^{-1} y^{-1}, 4–14 t C, 100–500 kg N, 20–80 kg P, and 100–450 kg potassium (K) per hectare could be removed by harvesting aboveground biomass [68].

Further reading: [25], [65]

Similar species:

Typha domingensis Pers. (southern cattail, berdi).

It grows nearly cosmopolitan in the subtropical and tropical regions worldwide: S. Europe, S. Asia, Southern N. America to S. America, C. America and Caribbean region, NE. Australia. It is widely used traditionally in similar ways as described above. Specialty: lengths of cattail were plied into rope or other size cordage. This was used in some areas to bind bundles of tule into tule boats (boats made of *Schoenoplectus acutus*) [2], [61]. In the South American Gran Chaco, indigenous people consume the pollen or flower of *T. domingensis* boiled, roasted or sometimes raw, in situ without any preparation [33]. In the traditional Turkey pharmacopoeia, female inflorescences of *Typha domingensis* are widely employed as desiccant against diverse kinds of bleedings [62], [63], the haemostatic virtue of which has been experimentally confirmed [64].

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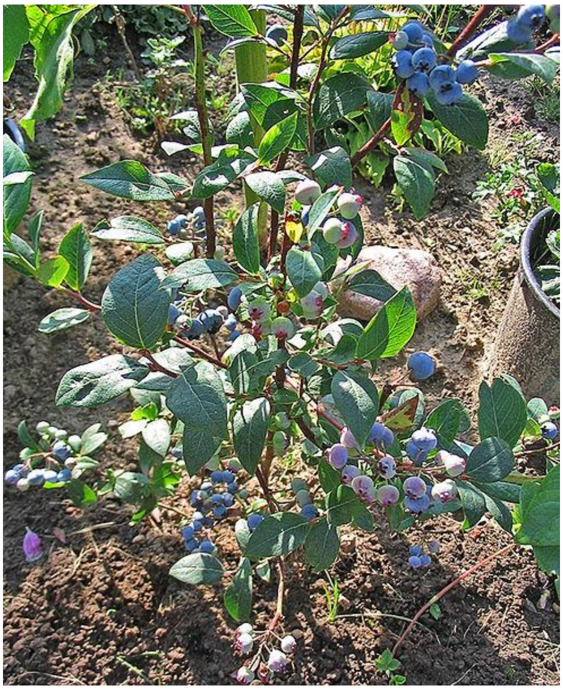

Picture: Darkone

Vaccinium corymbosum L.

highbush blueberry
(Amerikanische Heidelbeere)

Family: Ericaceae
Life form: shrub
Main use category: food
Used part: fruit

General information

Morphology: Perennial. Height: 2-4 m. Many stems arising from a single bole. Leaves alternate, simple, narrow to broadly elliptic or ovate, 3.8-8.2 cm long, deciduous. Hermaphrodite. Flowers 8-10 in a cluster, white to pink, 5-12 mm, with 5 petals. Berries black to blue, 4-12 mm in diameter. Plants erect, not colonial, sometimes suckering, 10-50 dm wide [1].

Geographic distribution: Eastern N. America - Nova Scotia to Quebec and south to Florida. Cultivated elsewhere, e.g., in Europe.

Natural habitat: *Vaccinium corymbosum* grows best and most commonly in moist or wet peat, in and around marshes, swamps, and lakeshores, often with extended flooding, as well as on floodplains, sheltered slopes, ravines and high altitude heath balds. It also occurs in drier areas: dunes and barrier beaches, rocky hillsides, oak woods, and pine woods [2].

Site specific properties

Water regime: moist soil
Trophic conditions: oligo-mesotrophic
pH: acid-subneutral
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Highbush blueberry is one of the most agriculturally important blueberries [3]. There

are many named varieties [4]. Since the 1920s, more than 50 highbush blueberry cultivars have been developed [5].
Paludiculture is unknown. In N. America, it is most typically grown in sandy well-drained soil or mineral soils that have been amended with copious quantities of organic matter. In California, blueberries are being grown in windrows of wood chips with acid injected into the irrigation water to reduce pH. It is rarely cultivated on drained peat. The water table in a blueberry plantation on peat should be kept not lower than necessary to assure adequate root aeration and to minimize mineralisation rates of the peat body. Since it grows naturally in peatlands, a moist to wet cultivation is probably possible. Targeted breeding could enhance tolerance towards water-logging. A study in China showed that the highbush blueberry cultivar 'Aron' has a high flooding tolerance ability (around 30 days) [6].

Propagation and establishment: The plant can be propagated from wood stem cuttings or from seeds. The latter is only used in breeding. Be aware that plants are at least partially self-sterile, thus more than one variety is required in order to obtain good yields of fruit [7]. 2- to 3-year old plants are planted in the permanent position. Long term flooding is not tolerated. To avoid flooding, it is recommended to plant them on ridges. The space between the rows should be 2-3 m and plant-to-plant spacing should be at least 1 m. Spacing depends on the equipment used during management operations. Mulching is extremely beneficial for increasing survival of planted blueberries and encouraging their lateral spread through rhizome growth. The plant needs 3 years of growing in the field until it first bears berries.

Management: Fertilizing, cutting, weeding and harvesting are the common practices in a blueberry field. The plant grows on moderate to low fertile soils. Surface fertilization on a cutover peatland can enable weed infestations which will require a certain control. On the contrary, weak fertilization will probably increase berry yield. In wet and rewetted peatlands fertilization is usually forbidden. Blueberry pruning is done in spring, after strong frosts. The objective of pruning is to maintain plant vitality and productivity, to increase quality and caliper of fruit as well as to prevent diseases and insect pests [8]. Highbush blueberry requires little pruning during the first three to four years. During this period and later on, it is necessary to get rid of broken, sick, dead or unproductive branches. Pruning also removes old large caliper canes to encourage new cane growth and to prevent shading. Insufficient bed height and inadequate attention to surface drainage has resulted in poor growth and plant losses to Phytophthora on some otherwise excellent sites [9]. Here further research and pilot cultivation is necessary to examine the potential (e.g., growth and productivity under wet conditions) of highbush blueberry for paludiculture.

Harvest: Harvest time depends on location. In southern zones in May to June and further north in July and August [3]. The berries can be harvested by hand, with rakes or mechanical harvester. In North America virtually all harvesting is done mechanically.

Productivity: Berry yields in commercial fields often average 4.5-5.5 t/ha [10].

Cultivation experiences: *Vaccinium corymbosum* is widely cultivated on mineral soil, irrigated sandy soils, and on drained peatlands [11], [8]. It may spread easily (transported by birds) into neighbouring conservation sites, behaving like an invasive neophyte in Europe [12].

Utilisation

Human food: The fruit can be eaten raw or cooked [13], [14], [15], [16], [17]. It is usually sweet and juicy, though the flavour can be variable [18]. It can be used in pies, pastries, cereals, and jellies. [4]. The fruit can also be dried and used like raisins [4]. The fruit is rich in vitamin C [19]. A tea is made from the leaves and dried fruit [20].

Medicine: Astringent and pectoral [19].

Ornament: A few selections are used in landscaping [2].

Co-benefits: The plant can be used for wetland restoration and soil stabilization.

Further reading: [11]

Similar species:
Vaccinium angustifolium Aiton:
The lowbush blueberry grows 5-60 cm in height and occurs in mixed conifer and hardwood forests and also in upland bogs. It is the most important commercial blueberry in the northeastern United States and Canada. It is under cultivation and harvested from the wild, mainly from managed wild patches. Cultivation practices are substantially different from highbush blueberries. Lowbush blueberries are cultivated in a biennial system where the vines are burned after fruit harvest, which replaces pruning. Thus only half the acreage is harvested in a given year. Lowbush blueberries are harvested with mechanical rakes, similar to dry cranberry harvest. Lowbush blueberries are suited to reclaimed peatlands, but the lowbush blueberry has a lower flooding tolerance than highbush [6].

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Picture: Sten Porse

Vaccinium macrocarpon Aiton

Oxycoccus macrocarpos (Ait.) Pers (Syn.)

cranberry

(Großfrüchtige Moosbeere)

Family: Ericaceae
Life form: shrub
Main use category: food
Used part: fruit

General information

Morphology: Perennial. Height: 10-30 cm. Stems often ascending. Leaf blade glaucous abaxially, green adaxially, usually narrowly elliptic, 8-18 x 3.5-5 mm, margins entire, slightly revolute. Inflorescences in axils of leaf-like bracts at base of current year's shoots. Corolla white to pink. Berries red to pink, 9-14 mm diameter, smooth. Flowers bloom and produce fruits the following year [1], [2].

Geographic distribution: Native to N. America: Canada and north-eastern USA; introduced and cultivated in Europe; cultivated in Chile [2], [3].

Natural habitat: Grows in bogs, swamps, mires, and wet shores [2]. It grows on peat soils or in acidic mineral soils, such as sand. In bogs it grows on hummocks, since the plant needs a habitat that is well supplied with water, but not flooded, because its growth requires aerated soils [4].

Site specific properties

Water regime: moist
Trophic conditions: oligo-mesotrophic
pH: acid
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Cranberries are cultivated in drained peatlands on a large scale in N. America and Europe; the cultivation in constructed wetlands on mineral soil is also common [4], [5]. There have been several attempts to cultivate cranberries in cutover peatlands, e.g., in Canada and Estonia [4], [6]. A company in the Netherlands grows *V. macrocarpon* successfully on a rewetted polder in a peatland [27]. The production according to current methods requires a significant initial investment and modification of the landscape. Furthermore, fruit prices are low at the moment and there is high competition. With the conventional practice it is more difficult to implement a cranberry field in peat soil, which is why the majority of producers prefer to plant

in sandy soil. The key factor in a successful cranberry plantation on peatlands is a good water management, e.g., drainage possibilities to prevent or initiate flooding [4]. The conventional cranberry cultivation on peatlands is subject to heavy fluctuations in water table that leads to high rates of subsidence and oxidation of the peat soil. It is necessary to find a sustainable balance in water table depth to sustain good yields on the one hand, and prevent/minimize subsidence and oxidation on the other. The water table should be kept not lower than necessary to assure adequate root aeration. A peat-conserving paludiculture is probably difficult to achieve, but, compared with deep drained intensive agriculture on peatlands, subsidence and peat degradation can be reduced significantly.
Natural wetlands in the U.S., where the original cranberry plantations were developed, are now prevented from being put into agricultural use by environmental regulations.

Propagation and establishment: Vegetative propagation is most prominent in the conventional practice. Cranberry cuttings are spread directly on the prepared field (6-10 t/ha [7]) and pushed into the soil with a blunt disk. The cuttings are 0.13-0.25 m long and taken from established stands. Keep the soil moist. Within a few weeks the cuttings produce roots. Other new hybrid cultivars are only available as sticks or plugs and are set by hand or with a vegetable planter. The growth is slow at first, but once a good root system is established they grow more quickly and a dense stand will establish.
Cultivated plants take 3-5 years to come into full bearing but will then crop well for 60-100 years [8], [7].

Management: A good water management is important, with recommended water tables of 25-30 cm below the surface [9], [7]. Lower water tables should be avoided to minimize subsidence. When planted in poorly drained peat, the growth of the seedlings' roots will be limited [10]. Dry conditions cannot be tolerated. Irregular flooding, e.g., for wet harvest, poses no problems. In a sanded cranberry field in a peatland in Quebec the mean monthly water table (during the main growing season) was in June=0.2, July=0.4, August=0.3 and September=0.3 m below the surface [7]; the cranberry yields were 25 t/ha fresh fruit. Although cranberry is a wetland plant, it does not grow under water, the root zone must be aerated in the main growing season. Given that cranberry is a shallow rooted crop (the top 10 cm of the soil) [10], the water table could reach 10-15 cm below surface. Fields are flooded in winter for frost protection. The area must be levelled out to achieve uniform water tables. Normally, basins are constructed with dykes and ditches for water management (1-2.5 ha) [7]. Water to replace water that has been lost through evapotranspiration is applied through solid-set sprinklers.
Cranberry prefers an acid soil with a pH in the range of 4-4.5; hence, plants soon become chlorotic when lime is present. A lack of copper is often recognized on bogs, but can be compensated with copper chelate [9]. Fertilizers are commonly used (ammonium or urea nitrogen, and other major and minor elements) in liquid or granular formulations. Nitrogen management is critical; however, the N requirement is modest (22-67 kg/ha*yr). High N rates lead to an abundance of vegetation at the expense of fruit production [5], [11]. In some fields N application leads to a reduction in crop yield and fruit quality. In the conventional practice huge element outflows (P, N) through periodic flooding are present [12], which is why fertilization is usually forbidden in water saturated soil. A comparison of virgin and cultivated organic soils showed higher amounts of nitrate through an increase in nitrification in the cultivated soils [13]. Nitrate is undesirable in cranberry fields, because the plants use nitrogen in the ammonium form. It is also linked with groundwater contamination. In upland areas

growers commonly apply elemental sulphur to maintain soil pH < 5.5.

In the conventional practice sand is abundantly used for stand maintenance and regeneration, and during the planting process in order to create a suitable environment for the seedlings to take root [4]. Every three to five years the area is treated with a 1 to 4 cm layer of sand, mostly in winter on frozen ground. Sanding is a form of pruning keeping the roots and terminal buds closer together. Sand also buries insect eggs and disease spores reducing pest pressure. Yield is generally slightly reduced in the year following sanding, but increases in the following years. The cranberry farm in the Netherlands did not apply sanding.

After harvest the plants can be pruned to stimulate production of vigorous uprights that will produce more fruits [14]. The cuttings can then be used to establish new fields.

Pest control is a common practice in the conventional cranberry cultivation [14]. It is said that 30-35% of the crop could be lost without the use of the key pesticides [14]. There is also a rising concern regarding distribution of viruses as well as the appearance of new viruses through asexual propagation [15].

Heavy equipment cannot be used on cranberry bogs, because of their fragile nature. No or but light weight equipment can be used on the planted fields.

Harvest: Fruits reach maturity at the end of September, with the exact date depending on variety, season and geographic location [4]. Fruits are harvested in two ways. Wet harvesting requires a flooding with water to a depth of about 30 cm over the vines. A water-reel knocks the berries off the vines and the buoyant berries rise to the surface. The dry harvesting method utilizes small, motorized walk-behind picking machines to 'comb' the berries from the dry vines. 90% of all cranberry growers wet-harvest their bogs, while only 10% dry-harvest because it is more labor intensive and less efficient. Dry-harvested berries are sold as fresh fruit and wet-harvested fruits are used to make juice, sauce and sweetened-dried cranberries.

Productivity: While average yields from conventionally cultivated fields ranges between 20 and 27 t/ha, average yields in peatlands yield from 21 to 22 t/ha [4]. Yields are probably lower with higher water tables. Breeding could help to find better cultivars with a good trade-off between yield and wetness tolerance.

Cultivation experiences: It is widely cultivated for its edible fruit in Chile, N. America and Europe; there are many named varieties [16], [17], [18], [19], [3]. Cultivated in a rewetted peatland in the Netherlands [27].

Utilisation

Human food: The fruit is eaten raw or cooked [20], [16], [21], [22], [23]. It is made into juice. It can also be dried for winter use [24]. Rich in vitamin C [18]. The fruit is very acidic, so it is mainly used in pies, preserves, sauces etc. [17].

Medicine: An infusion of the branches has been used as a treatment for pleurisy [25]. Cranberry is most commonly used as a folk remedy for prevention and treatment of urinary tract infections (UTI). However, clinical trials with cranberry have provided a mixed evidence on behalf of UTI prophylaxis [28]. It is also used for neurogenic bladder, as well as to deodorize urine in people with urinary incontinence.

Ornament: Used as an ornamental plant. Plants can be grown as a ground cover [26].

Further reading: [10], [4], [6], [7].

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GREIFSWALD MIRE CENTRE

Potential plants for paludiculture in the Holarctic

Picture: S URALA

Vaccinium myrtillus L.

bilberry, whortleberry
(Wald-Heidelbeere, Blaubeere)

Family: Ericaceae
Life form: shrub
Main use category: food
Used part: fruit

General information

Morphology: Perennial. Height 15-35(-60) cm. Stems erect, freely branched, arising from a creeping rhizome; twigs 3-angled, green. Leaves 10-30 x 6-18 mm, ovate, acute, serrulate, bright green; deciduous. Hermaphrodite. Inflorescence an axillary raceme, reduced to 1(-2) 4- to 5-merous flowers. Corolla 4-6 mm, pale green tinged with pink. Berry 6-10 mm, globose, bluish-black, sweet [1], [2].

Geographic distribution: Native to Europe, from Iceland south and east to Spain, Macedonia, the Caucasus, N. Asia [3]; also in western N. America and Greenland [4].

Natural habitat: Heaths, bog margins and woods on acid soils to 1,250 metres; shady wet forest [5], [6].

Site specific properties
Water regime: moist
Trophic conditions: oligo-mesotrophic
pH: acid
Light conditions: shade tolerant
Salinity: no tolerance

Cultivation

Bilberries are extensively harvested from wild stands in Europe and Russia. In North America, the fruits were used by indigenous peoples. The small plant and fruit sizes create challenges for commercialization. There is an increasing demand on the market because *V. myrtillus* has a higher content of biological compounds important for human health than the lowbush blueberry [7].
A peatland cultivation with bilberries is suitable for areas of rewetted bogs that are not fully rewettable to the surface (moist), because the roots need to be aerated. The water table in a potential bilberry plantation in a peatland should be kept not lower than necessary to assure adequate root aeration and to minimize mineralisation rates of the peat body. A peat-conserving paludiculture with bilberries seems not feasible, however. Here further research is necessary.
As high yields are achieved in old forest stands [2], [8], *V. myrtillus* is probably suitable for an agroforestry system, combining berry gathering with timber use.

Propagation and establishment: The plant can be propagated from hard wood stem cuttings or from seeds [9]. Germination averages 35-46% following various types of pre-treatment; cold stratification can increase germination rates up to 64% [10]. *Vaccinium* seedlings grown in the greenhouse can be transplanted in their permanent position 6-7 weeks after emergence in late spring or early summer, after the last expected frosts. Seedlings are rarely observed in nature [10].

Root cuttings can be successfully transplanted onto disturbed sites and mature plants can be transplanted during the spring [11]. Cuttings of half-ripe wood, 5-8 cm with a heel, taken in August can be grown in a frame [12]. The growth is slow and difficult. Cuttings of mature wood taken in late autumn have a better performance.

When planting seedlings or cuttings in their permanent position, the soil should be weed free. Growth is slow [10] and regular weeding necessary.

Management: Plants soon become chlorotic when lime is present (when soil pH < 5.5). They succeed also in full sun or light shade, though the fruits are better in a sunny location [5], [13]. The plant can grow on infertile to intermediate fertile sites [14]. Mycorrhiza symbiosis provides access to N and P sources. When fertilizers are added, weeds will start to grow quickly. A Swedish study showed that a fertilization combined with thinning of surrounding trees achieved the best results in fruit productivity [2], [15]. Another study reported no effect of fertilization on growth of bilberry [16]. Forests of medium fertility produce the largest berry yields in the boreal zone [8], [17], [18].

The plant needs aerated soil within the root zone. The top 5 cm is occupied by a mat of short fine adventitious roots. The larger roots grow deeper up to 13 cm, and only some roots up to 17 cm [2]. So, a good trade-off for the mean water table is 15-20 cm below the surface to ensure root zone aeration.

As *Vaccinium myrtillus* is not domesticated yet, there are no management instructions available. Many are probably transferable from the conventional cultivation of *V. angustifolium* [2].

Harvest: Fruits ripen in July [19]. Then the berries are either picked by hand or raked with special instruments ("berry comb").

Productivity: Berry production fluctuates annually with weather conditions because spring frosts and summer droughts can greatly decrease yields [20], [8]. During bad years no fruits are produced over extensive areas. When winter snow cover is less than 20 cm deep, the fruit production is poor [2]. Buds are vulnerable to damage by cold winter temperatures [19], [2]. Berry production may peak at stand ages of 20-70 years, in some areas much earlier [19], [8]. In southern Karelia, the bilberry yield is more stable in natural pine stands with 85-105 kg/ha and fluctuates widely in spruce stands with 35-130 kg/ha, with an increase in yield with higher soil moisture having been observed. On the contrary, moist-wet forests with *Sphagnum* and *Ledum* yielded only 35 kg/ha [8]. In a Russian study the average long term yield was highest in the spruce-*V. myrtillus* forest (415 kg/ha) and lowest in the aspen-*V. myrtillus* forest (215 kg/ha) [2].

Cultivation experiences: Unknown but probably transferable from other *Vaccinium* cultures, especially from *V. angustifolium* [2].

Utilisation

Human food: The fruit is eaten raw or cooked [21]. Sweet and very tasty, they make an excellent preserve, their small seeds make them suitable for jam [22], [23]. Berries are rich in vitamin C and energy content but low in fats [19]. A nutritional analysis is available [2]. The fruit can be dried and used like currants [24]. A tea is made from the leaves [22], [25], [21].

Medicine: A tea made from the green dried leaves is strongly astringent, diuretic, tonic and an antiseptic for the urinary tract [22]. It is also a remedy for diabetes when taken for a prolonged period [22]. Another report says that the leaves can be helpful in pre-diabetic states but that they are not an alternative to the conventional treatment [26]. The leaves contain glucoquinones, which reduces the levels of sugar in the blood [27].
A decoction of the leaves or bark is applied locally in the treatment of ulcers and in ulceration of the mouth and throat [22].
The fresh fruit has a slightly laxative effect upon the body, when dried it is astringent and is commonly used in the treatment of diarrhoea [22], [28], [26], [29]. The fruit is a rich source of anthocyanosides, which have been shown experimentally to dilate the blood vessels [26], making it a potentially valuable treatment for varicose veins, haemorrhoids and capillary fragility [26].

Raw material: The juice of the berries has been used as a blue dye to colour linen and paper [30].

Co-benefits: The extensive rhizome network of dwarf bilberry can aid in preventing soil erosion.

Further reading: [2], [19]

Similar species:
Vaccinium uliginosum L. - bog bilberry (Rauschbeere, Moorbeere):
It grows in circumboreal regions of the Northern Hemisphere in bogs and moist acid forests. The fruits are harvested and sold locally, or pressed for juice that was marketed around China and in the Western U.S. [31]. In Scandinavia, the fruits are sold from wild harvested plants and cultivars have been developed for commercial production [32], [33]. Currently a commercial cultivation is unknown.

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Picture: Christian Fischer

Vaccinium oxycoccos L.

(*Oxycoccus palustris* Pers.)
European cranberry
(Gemeine Moosbeere)

Family: Ericaceae
Life form: shrub
Main use category: food
Used part: fruit

General information

Morphology: Perennial. Plant procumbent with creeping woody stems, occasionally up to 80 cm long with short, erect or ascending flowering branches. Leaves 6-10 x 2.5-5 mm, ovate to oblong, dark shining green above, whitish beneath; margin revolute; evergreen. Hermaphrodite. Inflorescence a terminal raceme. Corolla pinkish-red, lobes 5-6 mm, ovate-oblong. Berry (6-)8-10(-15) mm, globose to pyriform, red. Fruiting end of October [1], [2], [3].

Geographic distribution: Europe, from Scandinavia south and east to France, Romania; N. Asia to Japan; northern N. America [4], [5].

Natural habitat: Cranberry can be found in ombrotrophic *Sphagnum* bogs and sometimes in minerotrophic fens in moist coastal and boreal forests [6]. This microsite is supplied with water, but not permanently flooded [2].

Site specific properties

Water regime: moist-wet
Trophic conditions: oligo-mesotrophic
pH: acid-subneutral
Light conditions: shade intolerant
Salinity: no tolerance

Cultivation

Cranberries are gathered from the wild, e.g., from natural bogs in the U.S. and in Belarus, where the collection can contribute substantially to the income of many local households (ca. 125.5 kg per household per year) [7]. It is also extensively gathered in Finland, Ukraine and Russia where it is the most important species among all wild growing berry plants [8], [9]. In Finland average annual collected cranberry yield is estimated to be more than 20.000 t [9].

Cultivation experiences of *Vaccinium oxycoccus* are available. Cranberry cultivation in Estonia has been aimed mainly at nature conservation but has simultaneously obtained a fairly good berry crop [10]. Thus, paludiculture with *V. oxycoccus* seems promising and such an enterprise is indeed either already implemented (in one way or another) or upcoming [e.g., 9].

Propagation and establishment: Cranberries can be propagated by seeds or by cuttings. Germination rates in nature are low (2-5 %), but cold stratification enhances germination (storage of seeds at 0 °C for 6-7 months [11] or 30 days [3]). Soaking the seeds in a 10 % Na_2CO_3 solution also increases germination rates and subsequent growth [12], [10]. Cleaned seeds are mixed with sawdust and then sown on the field (ca. 15 kg per ha [10]). After 5-6 years a considerable crop can be gathered.
For plantation establishment the best propagation method is via unrooted or rooted cuttings (about 10-15 cm). Unrooted cuttings are planted in the peat before bud break, which normally occurs at the end of April to early May. The rooted cuttings are planted in clusters of 2-3, leaving 2-3 leaves above the surface [10]. The rooted cuttings are ready for harvest after 2 to 3 years and the unrooted one year later [10].
Vegetative regeneration is also the most important mode of reproduction of cranberry in the wild, whereas seedlings are rare [13], [3].

Management: Fertilization will increase berry yields, but it will probably increase mineralisation rates of the peat soil also and thus lead to the expansion of weed species. Fertilisation in waterlogged soil is usually forbidden anyway. The growth is best with an average level of groundwater 25-30 cm below the root-stem junction [12]. It is necessary to find a sustainable balance in water table depth to sustain good yields on the one hand and prevent/minimize subsidence on the other. The water table should be kept not lower than necessary to assure adequate root aeration.
An imitation of a habitat like in 'transitional bogs' (cf. reference; subneutral pH, meso-oligotrophic conditions) [8] might lead to high yields.

Harvest: Fruits ripen from August to October. The berries are gathered by hand at the end of the summer until autumn or early winter. The fruit can persist on the plant throughout the winter without rotting. Mechanized harvesting techniques are not available up to now.

Productivity: Cultivation trials with *Vaccinium oxycoccus* on a cutaway peatland in Estonia showed the following berry yields (without fertilizer): 4.1-4.6 t/ha; with the application of "Kemira" combined fertilizer: 4.7-5.5 t/ha; and with the application of combined "Rekle" fertilizer: 0.6-2.5 t/ha [14]. In good crop years, yields of up to 10 t/ha can be obtained [15]. Breeding could increase berry yield, as the Estonian variety `Virussaare` achieved already high productivities [15]. After 5-6 years and installation, a sown cranberry field yielded 2 tonnes per ha [10]. The yield in the former USSR ranged from 0.05 to 1 t/ha [17], [18]. The yield varies between different years from 0.05 to 0.8 [16], or from 0.02 to 0.3 t/ha [19]. Berry yields from natural habitats in Poland range from 0.09 to 2.4 t/ha, with the greatest yields found in meso-oligotrophic transitional bogs, in particular in the community Sphagno recurvi-Eriophoretum angustifolii [8].

Cultivation experiences: For example, in Estonia [14], [20], [10], Latvia [21], Russia and Finland.

Utilisation

Human food: The fruit is edible, raw or cooked [22], [23], [24], [25], [26], [27]. It is used mainly to produce juice and for compote and in pies [28], [29]. The fruit is high in pectin [30], which means that it can be mixed with fruits that are low in pectin to help them set when making jam [5]. Pectin has also been shown to have a valuable role in the diet, where it is said to protect the body against radiation [31]. Having an acid taste, the fruits are usually cooked in preserves [32], [33]. Although smaller than the related Vac*cinium macrocarpon*, the fruit of this species is considered to be of superior taste [32]. A tea is made from the leaves [23], [27], [29].

Medicine: An infusion of the plant has been used to treat cases of slight nausea [27]. Cranberry is used for prevention and treatment of urinary tract infections. It is also used for neurogenic bladder, as well as to deodorize urine in people with urinary incontinence. A tea is prepared from the leaves that is used to remedy cold [28], [29].

Ornament: It is sometimes used as a groundcover plant in bog gardens, for which purpose it is planted about 1 m apart each way [34].

Raw material for industry: The juice of the fruit is used to clean silver [35]. A red dye can be obtained from the fruit [23].

Co-benefits: The plant is used for wetland restoration [10], [36], [9].

Further reading: [3], [6], [20], [8].

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Vaccinium vitis-idaea L.

lingonberry, cowberry (Preiselbeere)

Family: Ericaceae
Life form: shrub
Main use category: food
Used part: fruit, leave

Picture: Arnstein Rønning, Kristian Peters

General information

Morphology: Perennial. Height up to 30 cm. Stem erect, arching or decumbent, arising from a creeping rhizome; twigs terete. Leaves elliptical to oblong or obovate, entire, obtuse, dark green above, paler and dotted with dark glands beneath; evergreen. Hermaphrodite. Flowers 4- or 5-merous, in short, crowded, terminal racemes. Corolla 5-8 mm, campanulate, white or pink. Berry 5-10 mm, globose, red, acidic [1].

Geographic distribution: Throughout the Northern Hemisphere - Europe, from Iceland south and east to the Pyrenees, Macedonia, N. Asia to Japan, N. America.

Natural habitat: This plant is mainly found on well-drained soils, on rocky surfaces or in sandy acidic soils. In Fennoscandia, lingonberry abundantly covers the ground of Norway pine forests and can also be found in peat soils, although there it is less frequent [2]. It grows in very different habitats with an extensive natural range [3].

Site specific properties

Water regime: moist soil
Trophic conditions: oligotrophic
pH: acid (optimal 4.5-5.5)
Light conditions: intermediate shade tolerant
Salinity: no tolerance

Cultivation

Lingonberry is mainly harvested from the wild. It is cultivated in Europe and N. America. There are many named cultivars [4]. The majority of plantations are in sandy soils. However, trials conducted in peat soils revealed that vegetative growth and berry yield was better than in sandy soils [2], [5], [3], [6]. Since it grows naturally in well drained peat, it could be cultivated in areas of rewetted bogs that are not fully rewettable to the surface (moist), because the roots need to be aerated. Additional drainage should be no option in peatlands. A peat-conserving paludiculture with lingonberries seems not feasible. Here further research is necessary.

Propagation and establishment: While plants can be propagated vegetatively via stem cuttings and rhizomes, stem cuttings are much more effective [3]. Lingonberry is also easily propagated by seeds. The seeds germinate directly after harvest and much better when cold-stored for 2 to 5 months [5], [3]. The seeds should not be covered, because light is necessary [5]. The best conditions for germination is in pure acid peat with temperatures of 20-25 °C and long day conditions [3]. Seed viability decreases quickly [6].
For vegetative propagation mature stem cuttings should be taken in spring before bud break or in late summer. They should be planted directly in their permanent position. A row system with plant spacing of 25-30 x 80-100 cm is recommended [5].

Management: Little fertilizer is required for good growth and development. If too much is added, vegetative growth may be promoted at the expense of fruit production [7]. As lingonberry is not a competitive plant, weeds can be problematic in cultivations, especially when fertilized too much. Weed control is therefore necessary [3].

Harvest: Berry picking is done by hand or with a berry picking rake. There are also prototype machine harvesters available for cultivated areas [8]. Only mature fruits are picked, fully bright red, to avoid bitterness.
The leaves are harvested for medicinal use. They can be harvested sustainably every 4-5 years and for the Pinetum myrtillosum forest type every seventh year is suggested [3].

Productivity: Weather creates quite variable yields. Frost, severe drought or heavy rains lead to bud loss. Cross pollination by insects and good light conditions are also essential for fruit set [5]. The wild harvest in Sweden may be over 20,000 tons in some years, but as little as 2,000 tons in other years [8]. After establishment, the first harvest is after 3 years. The yields increase until year 9 from 0.6 to 75 and 0.5 to 22.6 t/ha for a high and low yielding cultivar, respectively, when optimal production practices are employed (results from Oregon, U.S.) [8].

Cultivation experiences: N. America and Europe [3].

Utilisation

Human food: The fruit is eaten raw or cooked [9], [10], [11], [12], [13], [14]. It has an acid flavour and is used to make a wide variety of products, including jams, jellies, sauces, syrups, juices, ice cream, yogurt, cookies and liquors [8]. It may be used as a substitute for cranberries. The taste is better after a frost [15], [16], [20]. Preserves and recreational tea are also prepared with it [18], [19].

Medicine: The leaves are antiseptic, astringent, diuretic and refrigerant [21], [13]. They are used in the treatment of gonorrhoea [22], arthritis, rheumatism, diabetes, diarrhoea [12] and kidney and bladder diseases [3]. A tea of the leaves is prepared to treat cold or urinary tract problems [19]. The leaves are gathered in early summer and dried for later use [21]. They are commercially sold in drugstores, but synthetic medications are replacing the drug gradually [3].
The mature fruits are eaten fresh or dried as a remedy for diarrhoea [12] and as a treatment for sore throats, coughs and colds [14]. The juice has been gargled as a treatment for sore throats [14].

Ornament: It can be grown as a ground cover plant [23].

Further reading: [5], [8], [3].

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Picture (*Z. aquatica* L.): Michael Wolf

Zizania aquatica L.

Southern wild rice, estuarine wild rice (Wildreis)

Zizania palustris L.

northern wild rice, Indian rice, wild oats, water oat (Wildreis)

Family: Poaceae
Life form: graminoid
Main use category: food
Used part: seed

General information

Zizania aquatica:

Morphology: Annual. Height 2-4 m. Culms erect, robust. Leaf blades linear to broadly lanceolate. Monoecious. Inflorescence a large panicle, spikelets unisexual, all male spikelets on lower branches and all female spikelets on upper branches. Spikelets with 1 floret, falling entire. Male lemma membranous. Female lemma papery, with scattered prickle-hairs. Caryopsis cylindrical. Rhizomes and stolons sometimes present [1].

Geographic distribution: Native to eastern N. America - New Brunswick to Manitoba, south to Florida and Texas.

Habitat: Shallow waters of rivers and lakes, preferring a slow moving current over sediments of an organic (but not peaty) layer atop sand [2], [3].

Zizania palustris:

Morphology: Annual. Height up to 1.8 m, somewhat shorter than *Z. aquatica*. Culm simple or basally branching. Leaf blades flat, 4-15 mm wide. Monoecious. Inflorescence a branched panicle, all male spikelets on lower branches and all female spikelets on upper branches. Caryopsis cylindrical, 15-20 mm long. [4].

Geographic distribution: Native to N. America, excluding the Arctic regions and the very south. It grows predominantly in the Great Lakes region [5].

Habitat: In water and mud of springs, marshes, lakes and ponds; preferring 1.5 m of water over sediments of an organic (but not peaty) layer atop sand [4].

Site specific properties

Water regime: flooded
Trophic conditions: meso-eutrophic
pH: subneutral (-slightly alkaline)
Light conditions: shade intolerant
Salinity: no(-low) tolerance [6]

Cultivation

Zizania aquatica and *Z. palustris* are both called wild rice. They are aquatic species and likely suited for paludiculture. The species most commonly harvested as grain is *Z. palustris*. Both species have a long tradition as a food crop used by Native Americans [7]. There are many named varieties. They are nowadays cultivated in paddy fields but are also harvested in the Lake Superior region from natural stands in the traditional way from a canoe with one person poling the canoe and the other knocking the ripe fruits into the canoe with two sticks. The majority of cultivated wild rice fields have been developed on organic soils with a peat depth ranging from several cm to more than 1.5 m [5].

Propagation and establishment: Wild rice is an annual grass which reseeds itself year after year under natural conditions. Upon maturation in the fall the seeds drop into the water and overwinter in the muddy substrate. For cultivation, the seeds can be stored for germination in perforated cans that are put in a stream or field covered by at least 60 cm of water. It will require no more attention until planting time the next season. In warmer areas (e.g., in California) the seeds must be cold stored in water at 2 °C, then the water needs to be changed every month [8], [16]. In general, the seeds can rapidly lose viability under dry conditions and thus will not germinate [16]. Seeds can be sown in spring or fall. Spring seeding is done when the water is some cm deep [6]. The seed is sown directly into the water from an airplane or other broadcasting equipment. Good ripe seeds range from tan to dark brown (almost black) and will sink when sown. A long awn at one end of the seeds keep them vertical as they descend through the water column; it enables the seed to bury itself into the upper 2-5 cm of sediment. These awns should not be removed, otherwise the seed descends in a horizontal manner and can become entangled in submerged vegetation and debris. They should be scattered evenly at a rate of 1 handful to 2 m^2; sowing should be more heavily if the locality is new. Seeding in fall eliminates the need to store seed over winter; in fact, this follows the natural seeding pattern [16]. In fall the seed is normally planted in the dry soil at a depth of 2-7 cm. The seed should be covered promptly with soil or water to maintain viability and minimize feeding from birds [5], [16]. This method requires a 15-20% lower seeding rate. A costly and laborious method is to transplant seedlings from nursery beds submerged in 15 to 20 cm deep water when 30-37 cm tall [6]. Generally, a plant density of 40 plants per m^2 is recommended [5].

In the second year and in older fields, plants can reseed themselves, because of seed shattering before harvest. Reducing the plant population can be necessary to increase the yield. Thinning is done in the floating leafstage of the plant by an airboat with a series of v-shaped knives ridging on the soil surface [5].

Over the past 40 years, wild rice has been bred, resulting in several varieties which are more resistant to shattering, have an increased seed size and tiller synchrony [9], [10]. Most of the paddy grown wild rice shattering is between 21 and 59% of the total possible yield [5]. This development increased the need for an artificial reseeding every year.

Management: On large scale cultivation, wild rice is grown in paddies to provide access for heavy machinery when the site is drained for harvest. The field is surrounded by dikes for proper flooding and drainage. The land is levelled with a gentle slope to allow water flow. Wild rice is easily grown in water up to 60 cm deep, tolerates depths up to 1 m, but prefers to grow in water 10-20 cm deep [11]. According to [16], the most productive plants will develop with water levels from 60 to 120 cm. It dislikes stagnant water [2], [16].
It is recommended to minimize drainage time and depth when the crop is grown on peat and to stimulate the further development of light machinery that is adapted for wet soils.
A new field with a large amount of vegetation should be tilled with a rotovator before seeding. Moldboard or land-breaking ploughs are not recommended, since the turned over peat soil might float up after flooding or unwanted underlying mineral soil is brought to the surface [5]. The final seedbed should be free of ridges and depressions. Acid peats, like sphagnum bogs, or infertile sites should be avoided. Optimum pH range is 6.0-8.0. Sites with fertile soils and sources of rich, flowing waters are ideal.
Wild rice has a relatively high requirement for plant nutrients, especially at boot stage. Fertilization needs depend on water and soil quality. Growers often apply urea nitrogen by air at boot stage or injection of fertilizers into the soil [5]. Fertilization recommendations for wild rice are available [12]. Fertilization in wet or flooded soil is usually forbidden, because leaching losses can be substantial. If fertilization is necessary, it should be done early in the growing season so that at drainage time most nutrients in the water have been consumed by the plants. See the checklist in [16, p. 32] to choose a suitable habitat for wild rice cultivation. More investigation and management adaptation can be necessary to ensure peat conservation (e.g., through reduced drainage time).

Harvesting: In early September the grain is ready for harvest. The conventional paddy fields are drained and the wild rice is harvested with combine harvesters. To avoid erosion of drainage ditches, the water should be released slowly during a one- to two-week period before harvest. Due to the shattering resistance, wild rice can be harvested at once like other small grains. In paludiculture the harvest should be done with adapted machinery (e.g., very light or tracked) to reduce soil disturbance and the necessity for full drainage.
Natural lake and river stands are harvested from boats, traditionally from canoes where stalks are pulled over into the boat with one stick and gently beaten with another stick to release only the mature kernels. Harvesting machines are used too. A reel-type beater is attached to the front end of a flat boat and moved through the rice field. Machines can only be used in lakes and rivers in Canada. Laws in Minnesota only allow harvest by boat [8]. Wild stands are repeatedly harvested because the seed does not mature evenly and readily shatters. Sufficient seed is always lost to reseed adequately. Harvest is only 30 to 50% efficient due to shattering (but shatter-resistant varieties are available for *Z. palustris*). Sometimes only part of the crop is harvested, leaving ample seed. The harvested seed is taken ashore, and immediately transported to processing plants for preliminary curing in windrows. Then the grain is parched and later the hulls are removed [8].
See [16] for harvesting procedure.

Productivity: Grain (35% moisture) yields vary from 0.09 to 0.3 t/ha from lake or river stands. From 120 to 400 t of wild rice are harvested for food in the north-central United States and in Canada annually from lakes and rivers, depending upon climatic conditions [8].

Another 1,220 t of wild rice is produced in cultivated fields; Minnesota produces about 3/4 of this amount [6]. The grain yield of paddy fields ranges from 0.8 to 1.8 t/ha, depending on variety and weather conditions [5], [10]. The total aboveground biomass after grain harvest is 11.8 t/ha [6].

Cultivation experiences: N. America - extensively in paddy fields in Minnesota [5], [6], and Saskatchewan [16].

Utilisation

Human food: Wild rice is a nutritional grain with a high protein and carbohydrate content, and a very low fat content [5]. It can be cooked like rice. It is considered a gourmet's delicacy and is sold in many parts of the world, usually in health food shops and usually at a very high price [11].

Medicine: Reported to be diuretic and refrigerant, *Zizania aquatica* is a folk remedy for burns, heart ailments, hepatosis, nephrosis, pulmonosis, and stomach ailments [6].

Fodder: The leaves can be used as forage for cattle and fish because of its high protein content [13].

Co-benefits: Wild rice is an aquatic plant with significant ecological value, since it attracts birds and herbivores, and provides a nursery area for fish and amphibians.

Further reading: [15], [16], [6], [5], [14].

19th Century tribal women harvesting wild rice in the traditional manner [17]

WILD RICE [6]

Whiteman say to the Redman, "Is this the Promised Land?
Wild rice in paradise and turkey in the hand!"
Whiteman say to the Redman, "Just look at what you have got,
Wild rice and wild thyme and turkey in the pot!"

Whiteman say to the Redman, "I think I envy you.
Wild rice and artichokes and groundnuts in the stew.
From seeds you haven't planted, you harvest twenty more.
While we have sowed our wild oats, and don't harvest anymore.

Redman say to the Whiteman, "Do you really have to push
Redman and greener land and turkey in the bush.
You came and showed your might man, just look what you have done.
The wild rice grows leaner, and the turkey's on the run.

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Zizania latifolia (Griseb.) Turcz. ex Stapf

mandchurian wild rice, water bamboo (Asiatischer Wildreis oder Wasserreis)

Family: Poaceae
Life form: graminoid
Main use category: food
Used part: shoot base, seed

Picture Shizhao; Micromesistius (stems peeled and unpeeled)

General information

Morphology: Perennial. Height up to 3.5 m. Culms tall, erect, robust. Leaf blades linear to broadly lanceolate; ligule membranous. Monoecious. Inflorescence a large panicle, spikelets unisexual. Fruit a cylindrical caryopsis, embryo half as long. Rhizomes and stolons sometimes present [1], [2].

Geographic distribution: Native to E. Asia (N. and S. China, Japan, Korea, Vietnam, Taiwan), southern Russia and India [2], [3]. Introduced to New Zealand [4].

Natural habitat: Shallow water of lake margins and swamps (fresh or brackish), or in slow flowing water, often forming large patches [1].

Site specific properties

Water regime: flooded
Trophic conditions: eutrophic
pH: acid-subneutral
Light conditions: intermediate shade tolerant
Salinity: medium tolerance

Cultivation

Zizania latifolia has historically been used in China mainly as an aquatic vegetable. It grows symbiotically with the fungus *Ustilago esculenta* which causes the stem to enlarge [5].

Cultivation practice is probably transferable to paludiculture. If peat conservation can be achieved with *Z. latifolia* cultivation needs to be investigated (e.g., peat disturbance during harvest, rotation times). It requires hot summers with temperatures between 20 and 30 °C if it is to do well. At 20 °C or lower, the plant grows poorly and the harvested stems are not tender [6]. The plant can be a serious weed risk in areas where it is not naturally present [7].

Propagation and establishment: The plant can be propagated via seeds or divisions. Seeds can germinate under water. The seeds must not be allowed to dry out or it will quickly lose its viability, usually within 4 weeks [8]. In cultivation, *Zizania latifolia* is usually propagated by tillers [9]. The most vigorous plants with short stout stems, large abundant leaves and no signs of floral initiation are selected for propagation. Tillers are planted in a nursery and allowed to grow for a year before transplanting to the field. Also, clumps of 4-5 tillers can be transplanted directly into the field. Tops are trimmed to about 40 cm height before planting. Transplants are put into the soil about 6 cm deep at 30-40 cm spacing and in rows 90-100 cm apart [9]. Field plantings in the sub-tropics are made in January through March, and in temperate regions in March through April [9]. Established plants spread by their long stout rhizomes forming dense impenetrable swards.
The field is probably renewed after 2-3 years because then production starts to decline [9].
The wild forms of this species have developed a resistance to the smut fungus, so special disease-susceptible cultivars are grown [10]. There are several cultivars planted in China: one is a single season crop that can be harvested once in fall. Another one is a two season crop. When planted in spring, it can be harvested in fall and once the next summer [11]. There is the green stem variety: a small plant with fine leaves that is early maturing. The white, pink or red stem one are large plants that are ripe in mid to late season.

Management: *Zizania latifolia* tolerates prolonged inundations up to a water depth of 1 m [12]. Field cultivation is similar to that of paddy rice. Initial water depth of 6 cm is soon raised to 10-20 cm [5]. Clay type soil, high in organic matter and pH range of 5.5-6.0 is preferred [9]. No information about cultivation in peat soil is available, but fertile peat is probably suitable. Under conventional practice the crop is fertilized with nitrogen four times during the season, twice with phosphorus and once early with potassium-containing fertilizer [9]. Fertilization in wet or flooded soil is usually forbidden. A lack of nutrients or low water level in the field causes the fungus to go into the reproductive phase much earlier, reducing quality and yield [9].

Harvest: Stem enlargement occurs after about 4 month's growth [9]. The edible stems must be harvested before the fungus starts to produce spores since the flesh deteriorates at this time [10]. Harvest time is fall (September to October) and summer (May to July) [13]. Enlarged stems are harvested, the upper leaves cut off and only the stem with husk-like wrapper leaves sent to market. The edible portion is the succulent stem after the husks are removed [9]. The fungus prevents floral initiation, so seed harvest is not possible when infected.

Productivity: *Z. latifolia* is a high productive species. In New Zealand (warm/temperate climate), it showed aboveground biomass yields of 38 t/ha [4]. The fresh shoot yield of *Z. latifolia* that is harvested only once in fall ranges from 12 to 30 t/ha in China [11]. The two season crop varieties produce 11-22 t/ha in the first fall harvest and 15-37 t/ha in the following summer harvest. The second harvest is generally higher [11].

Cultivation experiences: Widely cultivated in China, it is estimated that more than 20,000 ha are under cultivation with this plant in Zhejiang province alone [14]. It is also cultivated in Manipur (India) [15]. It is unknown to the authors if it is cultivated in peatlands.

Utilisation

Human food: The swollen stem bases, infected with the smut fungus *Ustilago esculenta*, are eaten as a vegetable in China [16], [17], [18]. Nutritional analysis is available [11], [15].
The seed is edible when cooked [16], [17], [8]. It is much smaller than the cultivated wild rice species *Z. palustris* or *Z. aquatica* from N. America [5]. It can be used like rice in sweet or savoury dishes [19]. The seed can also be ground into a flour and used in making cakes, biscuits etc. [2]. The seed contains about 13.7% protein, 0.9% fat, 72.7% carbohydrate, and 0.7% ash [20]. The young inflorescences can be cooked and used as a vegetable [19]. The young shoots are edible raw or cooked [21], [8], [22]. They have a pleasant sweet taste [17]. The shoots contain about 1% protein, 0.3% fat, 4.7% carbohydrate, and 0.7% ash [20].

Medicine: The shoots, roots and seeds are diuretic and febrifuge [22], [23]. The leaves are tonic [23]. There are patents for using the leaves as tea for treating various diseases; extracts are used as a component of food, pills and cosmetics [11].

Fodder: The leaves can be used as forage for cattle and fish [11], [24], [15].

Fuel: It has a high potential for the production of biomass for bioenergy [25], [26]. *Z. latifolia* is somtimes used as a fuel in China and Manipur [27], [15].

Raw material for industry: The leaves are woven into mats [16], [21], [28]. It is used for the making of handmade paper in New Zealand. In China, *Z. latifolia* is used as raw material for building purposes [27]. The finely cut pieces of leaves after making paste with soil are used as plastering material for house wall [15]. The liquid obtained by filtering the ash of the plant with water is used as a detergent substitute. The dried leaves after smashing are used as filling material for mattresses and pillows [15]. The leaves can be used as a culture substrate for edible fungi [29].

Co-benefits: High potential for utilisation in constructed wetlands to remove wastewater constituents and the harvested biomass can be used for bioenergy production [25], [4], [11].

Further reading: [11], [15], [9].

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Picture: Robert H. Mohlenbrock

Zizaniopsis miliacea (Michx.) Döll & Asch.

giant cutgrass

Family: Poaceae
Life form: graminoid
Main use category: fodder
Used part: aboveground biomass

General information

Morphology: Perennial. Height up to 3 m. Leaf blade is long and flat, rough on edges, almost saw-like; sheath rounded. Monoecious. Inflorescence a large narrow and nodding panicle. Extensive, creeping rhizome and root system [1], [2].

Geographic distribution: N. America - native to USA, mainly south-eastern states [1].

Natural habitat: Plants usually grow in fresh (to brackish) shallow water of marshes, sloughs, ditches, shores of ponds, lakes streams, and swamp forest [3].

Site specific properties

Water regime: flooded
Trophic conditions: meso-eutrophic
pH: acid-alkaline
Light conditions: shade intolerant
Salinity: low tolerance

Cultivation

Giant cutgrass naturally builds up dense monospecific stands that could be harvested for fodder or fuel [4]. Most previous interest in this grass has been in its control rather than in its use, but the high productivity makes it a good candidate for paludiculture. Paludiculture with this species is not known to the authors.

Propagation and establishment: Natural reproduction occurs vegetatively from rhizomes and generatively via fruits. Colonies also spread by flowering culms (stems) that fall over and root from the nodes [5]. Functional stolons which were able to become rooted in the substrate resulted in stand expansion of 1-3 m per year [6]. Low summer water tables (low inundation) stimulate expansion [6].

Management: When grazed in dormant season, a mineral supplement should be provided for cattle [7]. Cattle walkways are essential to distribute grazing and provide access to forage on fresh marshes [7].
A limiting nutrient study in a tidal freshwater marsh in Georgia (USA) showed that nitrogen

additions increased aboveground biomass two- to threefold but significantly decreased below-ground biomass. Significant N enrichment in leaves of *Zizaniopsis miliacea* after fertilization was observed. Tidal freshwater marsh vegetation is more limited by nitrogen than by phosphorous [8].

Harvest: A study indicated that late summer or fall harvests, followed by flooding or cutting again the following year, could substantially reduce biomass and thus should be avoided [6]. The stand should be harvested during the winter or early spring for sustained yields. Populations cut at the end of May resprouted vigorously within the year [9]. For maximum production, no more than 50% of current growth by weight should be removed at any season [7].

Giant cutgrass is readily grazed by cattle from late winter through summer [7]. It has a long vegetation period and grows well into the winter months when many other plants have already become dormant.

Productivity: In a freshwater tidal marsh in Georgia (USA) giant cutgrass aboveground net primary production was approximately 15 t DM/ha*yr [4]. The peak standing crop is reached in late October with 15.8 t DM/ha and consisted of 10.4 t of live and 4.8 t of standing dead material [4]. The peak aboveground standing crop in October was all produced within the year.

Cultivation experiences: It is sometimes planted for erosion control in wetlands [1].

Utilisation

Animal fodder: It is readily grazed by cattle [1].

Fuel: Good potential to be used as a bioenergy crop.

Co-benefits: This grass is used for erosion control around lakes and on stream banks [1]. It appears to be a well-suitable species for use in constructed wetlands for treatment of agricultural, nonpoint source pollutions and municipal wastewaters [2].

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Appendix: *Mauritia flexuosa* L.f. as a potential paludiculture plant of the Tropics

GREIFSWALD MIRE CENTRE

Picture: Lourdes Falen Horna

Mauritia flexuosa L.f.

Aguaje

Family: Arecaceae
Life form: tree
Main use category: food, raw material
Used part: fruits, leaves (palm fronds)

General information

Morphology: Height 25-40 m. Stem monocaulous, straight and smooth, about 50 cm in diameter. Leaves costapalmate, 8 to 25 per plant. Each leaf at most 6 m long; petiole between 1.6 and 4 m long. In average 8 inflorescences per adult plant, each raceme producing up to 900 fruits and measuring up to 3 m in length. Fruit a drupe, somewhat ellipsoid to obovoid (in Peru) or round (at the mouth of the Amazon), covered with (dark) red scales, 5-7 cm in length and 4-5 cm in diameter. Flowering and fructification from seventh or eighth year onwards. Dioecious [1], [2], [3], [4].

Geographic distribution: American tropics, especially northern S. America – from western Andes in the west to the Atlantic coast to the east; Amazon Basin up to the southern Caribbean in the north.

Natural habitat: Permanently or seasonally inundated tropical peat swamp forests and old floodplains, often forming extensive monospecific stands [1], [3].

Site specific properties

Water regime: seasonal flooded, swampy
Trophic conditions: dystrophic to eutrophic
pH: acidic
Light conditions: intermediate shade tolerant
Salinity: tolerates brackish water

Cultivation

Mauritia flexuosa is widely known and used in tropical South America [3], [4]. So far, its fruit is collected mostly from wild stocks which frequently implicates destructive harvesting techniques (felling) [2], [4]. The sites of collection are often within tropical peat swamp forests [5], where peat is accumulating and acidic soil conditions prevail [6], [7], [45], [47]. While the extent of the palm's contribution to the peat accumulation remains unclear [8], its role in the process is highly assumed [O. Lähteenoja, pers. comm.]. On a smaller scale, individuals are sometimes planted near the house or settlement [9]. The ecological amplitude suggests that a cultivation in diverse conditions might be possible. Long term flooding poses no particular problem, as pneumatophores provide for oxygen [1]. It therefore shows to be a promising paludiculture plant for the American tropics.

Propagation and establishment: The environmental conditions in which *M. flexuosa* grows best covers a maximum annual average temperature of 25.1°C and a minimum annual average temperature of 17.2°C [1]. It occurs mostly at an altitude from 50 to 850 m a.s.l., where precipitation values between 900 and 3400 mm per year are reached [1]. Propagation is primarily sexual. The seeds are buried 5 cm deep, as they germinate hypogeously; otherwise, seedlings may become malformed [10]. Ideally, certain patches are prepared (*cama almaciguera*), usually about 1.20 m in breadth and 5 m in length [10]. In such a nursery, maximum germination rates of 88 % in 60 days (minimum 9 % in 61 days) are possible [1]; however, some seeds may not germinate before one year after sowing [10]. The seeds of *Mauritia flexuosa* can germinate in water [11]. Moderate shading may pose no problems to germination, but seeds in shade condition take more days to germinate (~420 days) than seeds in irradiation condition (~200 days) [43]. So irradiation seems to not be among the limiting abiotic factors for germination in natural stands [44]. Seedlings are ready for transplanting to the final field four to five months after sowing, when they have reached 25 to 30 cm in height and bear two to three leaves [10]. Flowering and fructification can take place during the whole year, the latter preferably between August and October, but the onset varies from year to year and is related to the rainy season [1], [4], [46]. But peak fruiting season is usually from June to September [49].

Management: Up to now fruits and other products from *M. flexuosa* are predominantly gathered from the wild (see Harvest). But some individuals are cultivated close to settlements. There, appropriately spaced, they may reach maturity after about twelve years and usually remain undersized, so that the drooping fruit-laden racemes can readily be harvested without having to cut down the whole palm [5], [9]. In fact, so-called dwarf aguajes can sometimes produce fruits already with five years of age [1]. Considering that larger aguaje usually bear more fruits per infrutescence due to their experiencing more crown illumination, such cultivated individuals should be maintained as long as possible, while at the same time preventing felling of wild individuals [49]. It has been pointed out that sustainable management of the wild stands and promoting the cultivation in private areas might be able to preserve the individual palms and the peatlands as a whole [12], [13], [14].

Harvest: The fruits are harvested in tropical swamp forests either in the dry season by foot or in the wet season by boat. However, destructive harvesting techniques and overexploitation are the rule and considered fundamental problems in the exploitation of *M. flexuosa* [15], [16], [2], [17], [4], [5]. Female trees are often felled to harvest the coveted fruit resulting in the predomination of barren male trees and a skewed sex ratio of the stands; hence, suppliers have to go deeper into the forest to obtain the fruits [5], [18], [19], [15]. Naturally, such harvesting techniques lead to losses, since cut down trees do not solely yield edible fruits [20]. At the time of felling, for instance, the palms bear simultaneously unripe, overripe, insect-ridden, and mature fruits [21]; still other fruits might be crushed through the trees falling down [19]. Destructive harvesting might also lead to cascading effects within the ecosystem, thereby compromising all species with which aguaje is associated [8]. Lest such trends exacerbate, sustainable harvesting techniques are currently implemented in some areas [1], [22], [5], [13], [14]. In eastern Brazil, for instance, selective harvesting, deliberate seed dispersal and planting of seedlings are conducted by some indigenous people to increase yield and productivity of *M. flexuosa* stands [22].

Productivity: After about eight years, aguaje palms can bear fruits annually which may be harvested bunch by bunch; it is most productive from age 12 to 20 [1], [9]. However, not all female individuals produce fruits each year and they tend to become less productive every year [L. Falen Horna, pers. comm.; see also 4]. Each raceme can generally develop up to 900 fruits [1], with fruits per palm ranging from 237 to 6452 [49]. Due to different degrees of ripeness on one and the same tree, fruits can be harvested almost throughout the year [23], [9].

Cultivation experiences: Manuals [10] and project papers with indigenous people in South American countries such as Peru [24], [18], [25], [5] are available. Experimental plantation with so-called dwarf aguajes (domesticated varieties) has been conducted as well [1]. At the "Instituto de Investigaciones de la Amazonia Peruana" (Research Institute of the Peruvian Amazon - IIAP) a research project investigates the conservation and management properties of the aguaje and aguajales ecosystem [48]. Among other results, their recent study shows that fruit production and fruit weight per bunch of aguaje increases with the age of the plantation, and that the average fruit and seed weight (size in length and width) vary annually [48; see also 49].

Utilisation

Human food: Several indigenous people of Amazonia use the fruits of *Mauritia flexuosa* in their diet [26], [3], [27], [28], [29], [17], [30]. The ripe fruits contain a vitamin C rich pulp, and the mesocarp and kernels yield a yellow oil rich in β-carotenes [31], [32], [33]. The Jivi (Guajibo) of the Venezuelan Amazon extract larvae of the palm beetle (*Rhynchophorus palmarum* L.) from rotten trunks of *M. flexuosa* to obtain protein and other essential nutrients [34], [24]. Occasionally, a wine from the sugar rich sap is prepared [27].

In the 1980s, Padoch reported that aguaje is the most abundant fruit visible on markets in Iquitos, Peru, where it figures prominently in trading networks and is among the most popular local ice cream and sorbet flavors [23]. On average, an estimated 8,206 t yr^{-1} [21] – or 20 t day^{-1} [9] – of aguaje is delivered to the market of Iquitos alone. It has been estimated that in Iquitos about 2000 persons plus their 70 families solely benefit from the revenue received by selling of aguaje [29]. In Upper Amazonia especially, *M. flexuosa* "is undoubtedly the most intensely exploited and commercially important forest fruit" [16] with Iquitos being called the "epicentre" of aguaje consumption [3].

Medicine: The fruits contain a considerable number of phenolic compounds with antioxidant and antimicrobial properties [35]. Among some indigenous peoples, roots and mesocarps are used as remedies against hepatitis, rheumatism and respiratory ailments

[36], [27]. In the Colombian Amazon, fruits are regularly added to fermented beverages (*chicha*) to yield a tonic [37].

Raw material for industry: The palm fronds are often used for thatching [17], [30], [28]. A fibre can be obtained that is fashioned into clothes and accessories [26] or used in weaving [38], [39], [40].

Cosmetics: The oil is extracted from the fruits to produce a variety of cosmetic and skincare products [4]. In Brazil, some companies even reach the global market with it [L. Falen Horna, pers. comm.].

Co-benefits: Tropical peatlands such as the monospecific stands of *Mauritia flexuosa* (*aguajales*) are quintessential for the maintenance of various ecosystem services, including the provision of water, the safeguarding of biodiversity and carbon sequestration [41], [45]. Aguajales usually harbor manifold plant species [42] and various vertebrates are dependent on *M. flexuosa* for the provision of food, shelter or habitat [8]. *M. flexuosa* has therefore been classified as a hyperkeystone [8] and cultural keystone [13] species.

Further reading: [4], [5], [8], [21], [27]

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