Information paper on paludiculture and biodiversity

Background on paludiculture

Drainage and the intensive agricultural use of peatlands have led to them becoming hotspots for greenhouse gas emissions. Drained peatlands currently contribute to 7% of the total national emissions in Germany (UBA 2023). Rewetting peatlands is an important measure for achieving climate protection targets. Paludiculture makes it possible to combine rewetting and cultivation: Paludiculture refers to agricultural and forestry production on rewetted peatlands while still preserving the peat body (LM M-V 2017, Wichtmann et al. 2016). In Germany, mowing reeds for roofing and the using plant matter from wet meadows has been practiced for a long time. Nevertheless, paludiculture is something new: Peatlands that have been drained for decades and cultivated with moisture intolerant plants are now being rewetted and plants typical of peatlands are being harvested. The utilization of biomass from wet peatlands is often new and innovative: the production of food takes a back seat and grazing only plays a marginal role - in contrast, the bioeconomy is central, which includes the replacement of fossil fuels and the development of alternative material flows (e.g. Hartung et al. 2020, 2023, Nordt et al. 2022, Eickenscheidt et al. 2023).

All paludicultures are permanent crops in which the above-ground or, in the case of peat mosses, newly grown biomass is used. The prerequisite is that the average water levels are consistently at the level of the soil or only a maximum of 10 cm below - in other words, the areas are "wet". They can be differentiated according to the way they are used and established: Adapted plant communities form naturally depending on the water level and type of peatland. **Summer mowing creates wet meadows and grazing creates wet pastures. Cropping paludicultures develop through the targeted establishment of typical peatland species such as reed, cattail, cultivated grasses, or alder on fens, or peat moss, sundew, or berries on bogs** (Birr et al. 2021, Närmann et al. 2021, Nordt et al. 2022). Priority areas for cropping paludicultures should be previously deeply drained and therefore heavily degraded peatlands (see p. 7).

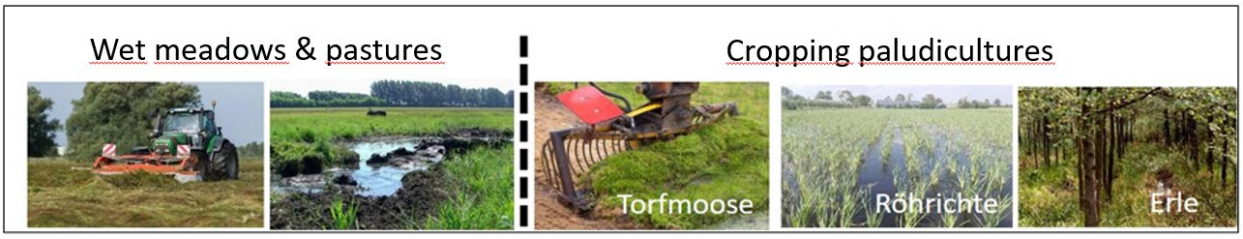

Fig. 1: Paludicultures include wet meadows, wet pastures, and deliberately established cropping paludicultures (here: peat mosses, reeds, alder trees) (Nordt et al. 2022).

Protection of mire-typical and mire-specific diversity

The special ecosystem characteristics of (near-)natural peatlands (permanent water saturation, peat formation, water storage, and special microclimate) result in a very specific living environment. These ecosystems vary due to different nutrient levels and acidity, as well as fluctuations in the water supply. Nutrient-poor raised bogs in particular are home to specialized species - in other words, they are **mire-specific**. In other peatland types, there are species that can also be found in other wet locations, e.g. in floodplains without peat soils. These species are referred to as **mire-typical** species. Some 8% of the vascular plant species occurring in Germany are only found in near-natural bogs (Dierßen 1998); in the peatland-rich state of Brandenburg it is even 13% (Luthardt & Zeitz 2014). Here, 15% of vascular plant species, 18% of moss species, 27% of ground beetle species, 36% of grasshopper species and 34% of dragonfly species are linked to peatland habitats (Luthardt & Zeitz 2014). The protection of these mire-typical and mire-specific species is particularly important in the protection of biodiversity on peat soils.

Effects of rewetting

In drained peatlands, the species typical for near-natural peatlands find little or no habitat. Rewetted peatlands are important in many ways for the establishment of mire-typical and mire-specific species as habitats, for connectivity, and as food sources (Luthardt & Zeitz 2014, Närmann et al. 2021). Rewetted peatlands can be similar to near-natural peatlands in terms of vegetation, water level, and material balance, but can also differ significantly (Kreyling et al. 2021). A qualitative deviation from the near-natural initial state is likely (Beckert & Rodríguez 2023). The microbiome in rewetted peatlands is similar to that in near-natural peatlands (Emsens et al. 2020). Rewetting leads to a shift from species preferring moist to wet environments and from widespread to now rare, endangered species (Tanneberger et al. 2022). The assessment of biodiversity should include the levels of species, biocenoses, and ecosystems in equal measure (Hammerich et al. 2022).

Effects of mowing and grazing

Compared to unused, wet sites, wet management has both positive and negative effects on the frequency and diversity of various species groups (Table 1). With mowing, the lower litter cover, greater light availability, and leaching are particularly relevant for the *vegetation*, resulting in more species-rich vegetation communities. Heat- and light-loving species and open land species are the main beneficiaries. Habitat changes due to changes in the microclimate, the lack of vertical structures and the presence or absence of host plants and winter refuges are also relevant for *wildlife*, as is the direct impact of mowing through killing or injury. The effects are species- or taxon-specific (Table 1). For example, management promotes phytophagous species that feed on fresh growth. Saprophagous species, for which the litter serves as a food source, are inhibited, as are shade-loving species. Grazing also influences the *vegetation* through browsing, trampling and manure, resulting in a vegetation mosaic with different heights, species and stages of development. In addition to the trampling, the indirect influence on the vegetation and the dung as a habitat for coprophilous species has an effect on the *fauna* (Närmann et al. 2021).

Tab. 1: Effects (+: positive; +/-: positive and negative; -: negative, gray: not specified) of the management of moist/wet fen areas on abundance and species diversity within species groups compared to the unmanaged wet state (after Närmann et al. 2021, modified).

	Wet meadow	Wet pasture	Reed	Cattail	Sedges	Reed canary grass
Vegetation	+	+	+	+	+	+
Birds	+	+	+/-	+	+	+/-
Mosquitoes			-			
Water boatmen			-			
Thrips			-			
Butterflies	+	+/-	-			
Hymenoptera			-			
Isopoda			-			
Spiders	+/-	+/-	+/-			
Beetles		+	+	+	+/-	+/-
Aphids			+			
Flies			+			
Annelids			+			
Mites			+			
Water scavenger beetles				+		
Grasshoppers	+/-	+/-	+/-	+/-	+/-	+/-
Molluscs	-	-	-			
Ants	+					
Amphibians		+				
Dragonflies		+		+	+	+
Rove beetles		+				

Many studies have compared managed, wet areas with near-natural, unmanaged, wet controls. As paludiculture is to be established primarily on previously drained arable or intensive grassland sites in the future, these drained conditions should be used as a reference. **Based on current knowledge, it can be assumed that paludiculture will lead to an increase in mire-typical and, under certain conditions, mire-specific biodiversity**.

Effects of different intensities of paludiculture

All of the paludiculture sites studied so far are home to species of high national and international conservation value, which shows that not only protected "wilderness" sites, but also paludiculture sites of varying intensity can provide habitats for endangered species. In Mecklenburg-Western Pomerania, rewetted fen areas (sedges and cattail) without cultivation and with different intensities of paludiculture were investigated. A total of 78 plant species, 18 breeding bird species, 55 ground beetle species and 73 spider species were recorded on the six sites. These included 32 Red List species (3 plants, 7 birds, 12 ground beetles and 10 spiders). The species on the German endangered species list (Red List categories 1 and 2) all occurred only in the cultivated sites, with the exception of three spider species which were present in the unharvested site. The site with the greatest management intensity (cattail cultivation) had both the lowest and the highest qualitative biodiversity values, depending on the taxon. **As the responses of the individual taxa varied, future management should aim to create a habitat mosaic with different management intensities** (Martens et al. 2023). The type and intensity of management play a major role in this.

Stand establishment: While vegetation stands within wet meadows and pastures on rewetted fens establish spontaneously, in cultivated paludicultures, species are planted intentionally. Seeds or seedlings are used to establish the stand. Other mire-typical (and, more rarely, mire-specific species) can also become established, often through input from the surroundings of a paludiculture area or by spreading from near-natural stands.

Crop maintenance: Between crop establishment and harvest, it may be necessary to maintain paludicultures. In addition to maintaining the irrigation system, production-inhibiting factors such as the growth of highly competitive species (e.g. maintenance mowing of rushes in peat moss paludiculture) must be counteracted, particularly in the case of cultivated paludicultures. Maintenance can specifically promote peatland species. Reed, reed canary grass, and sedges in particular are naturally so competitive at optimized water levels that maintenance is usually not necessary.

Harvesting: In addition to the general effects of mowing/grazing (see above), the time of harvesting has a significant impact on species diversity. Studies of a cultivated paludiculture area for cattail in a Bavarian fen showed that the **time of harvest** has a significant influence on the attractiveness as a resting area for migratory birds. For example, tall cattail stands were popular with migrating reed warblers from July to September. Migrating waders, pipits, and stilts were almost only found on harvested areas from August to October and from March to April. Therefore, greater use by migratory birds can be expected if wet, harvested areas are available during the migration period. Therefore, while summer mowing in July can provide potential habitat advantages for certain bird species, other species or species groups may end up losing habitat. In principle, it can be assumed that **late mowing dates or winter mowing is the least intensive form of paludiculture and has particularly positive effects on the development of species-rich fauna and flora** (Eickenscheidt et al. 2023). In the Hankhauser Moor, a raised bog with cultivation paludiculture for peat mosses, harvesting has already been carried out several times and at different times of the year, during which all peat moss that had grown was removed in some areas. The impact of the harvest was only temporary and the previous biodiversity was restored with the establishment of the new peat moss turf. The rapid recolonization was achieved by replanting moss fragments from the same location and from unharvested areas.

Box 1: Cultivation - Paludiculture Polder Teichweide

Brief info:

Approx. 10 ha, Mecklenburg-Western Pomerania, cattail, established 2018/19, PaludiPRIMA, PaludiPROGRESS projects

Breeding birds:

A total of 70 breeding pairs of 18 species were recorded. The maximum was 11 species in 2020 and 25 breeding pairs in 2022. The composition of the breeding birds changed; open land species disappeared and the number of reedbed breeders increased. Due to the significantly higher density of breeding birds and an increase in the number of species, a higher nature conservation value can be assumed after the establishment of the cattail cultivation area.

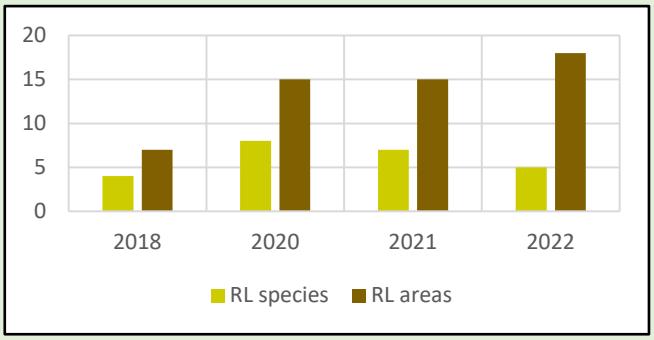

Fig. 2: Absolute number of Red List species (RL species) and territories of Red List species (RL areas). The Red Lists for Germany and Mecklenburg-Western Pomerania were taken into account. The year 2018 shows the reference status prior to the establishment of the paludiculture area.

Dragonflies:

A total of 21 dragonfly species were observed at the site in 2023 (Table 2). Of these, five are probably established and 8 are confirmed to have established. There have been 63 dragonfly species observed in Mecklenburg-Western Pomerania and of these, at least 56 species known to be established breeding species. This means that 38% of the state's breeding dragonfly fauna has been recorded at the Teichweide site. In addition, 23% of the state's ground-dwelling species probably reproduce in the site. Overall, it can be assumed that the habitat potential has not yet been fully exploited four years after the establishment of the paludiculture area.

Table 2: Dragonfly species detected *in 2023. RL. MV = Red List Mecklenburg-Western Pomerania, RL D. = Red List Germany, 1 - threatened with extinction, 2 - critically endangered, 3 - endangered, V - early warning list*. Sorted by scientific species name.
● = confirmed to be established; ○ = probably established.

Scientific Name	English Name	RL. MV	RL D.	Establishment status
Aeshna affinis	Southern migrant hawker	N/A.	-	
Aeshna isoceles	Green-eyed hawker	3	-	●
Aeshna mixta	Migrant hawker	-	-	
Coenagrion puella	Azure damselfly	-	-	○
Coenagrion pulchellum	Variable damselfly	-	-	●
Crocothemis erythraea	Scarlet dragonfly	N/A.	-	
Erythromma najas	Red-eyed damselfly	-	-	
Erythromma viridulum	Small red-eyed damselfly	2	-	○
Ischnura elegans	Blue-tailed damselfly	-	-	●
Ischnura pumilio	Scarce blue-tailed damselfly	2	V	○
Lestes sponsa	Emerald damselfly	-	-	○
Libellula fulva	Scarce chaser	3	-	
Libellula quadrimaculata	Four-spotted chaser	-	-	●
Orthetrum cancellatum	Black-tailed skimmer	-	-	○
Platycnemis pennipes	White-legged damselfly	-	-	
Somatochlora flavomaculata	Yellow-spotted emerald	3	3	
Sympecma fusca	Common winter dragonfly	V	-	
Sympetrum danae	Black darter	-	-	●
Sympetrum sanguineum	Ruddy darter	-	-	●
Sympetrum striolatum	Common darter	1	-	●
Sympetrum vulgatum	Vagrant darter	-	-	●

Data basis: Eickmanns et al. in prep.; Martens et al. 2023; A. Drexler

Box 2: Cultivation - Paludiculture Langenmosen

Brief info:

5 ha, Bavaria, cattail, sedges, and reed canary grass, established in 2018, MoorUse project

Breeding birds:

A total of 67 bird species were observed at the site (Table 3). Of these, 37 species were directly associated with the paludicultures (Table 3). Of the bird species detected, 18 were documented as breeding birds (Table 4).

Table 3: Species numbers determined by the ornithological surveys. RLB - Red List of Bavaria, 0 - extinct or lost, 1 - threatened with extinction, 2 - critically endangered, 3 - endangered, V - early warning list.

Total number of species	Species associated with paludiculture	RLB - V	RLB - 3	RLB - 2	RLB - 1	RLB - 0
67	37	4	4	2	4	2

Table 4: Species numbers of breeding birds determined by the ornithological surveys.

Total number of breeding bird species	Species associated with paludiculture	RLB - V	RLB - 3	RLB - 2	RLB - 1
18	12		3	1	2

Dragonflies:

A total of 15 dragonfly species were sighted at the trial site in 2021 and 2022 (Table 5). Of these, six are likely or confirmed to be breeding at the site. In Bavaria, 76 dragonfly species have been recorded. This means that around 20% of the state's breeding dragonfly fauna was recorded on the site. In addition, around 8% of the state's breeding species probably reproduce on the site. Overall, it can be assumed that the habitat potential has not yet been fully exploited three or four years after the establishment of the paludiculture area.

Tab. 5: Dragonfly species detected in 2021 and 2022. RL. Bay - Red List Bavaria, RL D. - Red List Germany, 1 - threatened with extinction, 2 - critically endangered, 3 - endangered, V - early warning list. Sorted by scientific species name. X = Species established; B = Species likely established

Species scientific	Species german	RL. Bay	RL D.	Ditches	Shallow depressions, imperfections, large ruts
Anax imperator	Emperor dragonfly	-	-	-	X
Aeshna affinis	Southern migrant hawker	-	-	-	X
Coenagrio puella	Azure damselfly	-	-	B	B
Coenagrion ornatum	Ornate bluet	2	2	X	-
Ischnura elegans	Blue-tailed damselfly	-	-	B	B
Orthetrum brunneum	Southern skimmer	-	-	B	-
Orthetrum cancellatum	Black-tailed skimmer	-	-	X	B
Orthetrum coerulescens	Keeled skimmer	3	V	B	-
Libellula depressa	Broad-bodied chaser	-	-	-	X
Libellula fulva	Scarce chaser	V	-	X	-
Libellula quadrimaculata	Four-spotted chaser	-	-	-	X
Sympetrum depressiusculum	Spotted darter	1	1	-	X
Sympetrum sanguineum	Ruddy darter	-	-	B	B
Sympetrum striolatum	Common darter	-	-	-	B
Sympetrum vulgatum	Vagrant darter	-	-	B	B

Data basis: Eickenscheidt et al. 2023, C. Moning

Box 3: Cultivation - Paludiculture Hankhausen

Brief info:
17 ha, Lower Saxony, peat moss, establishment 2011-2020, projects MOOSGRÜN, MOOSWEIT, OptiMOOS

Vegetation & Fungi: After up to eleven years of growth, a total of sixteen moss species (incl. seven *Sphagnum* species) and 68 vascular plant species were observed on the cultivated area (peat moss production fields, ditches, excluding road embankments), including 45 species typical of raised bogs, eleven of which have a protected status (German Red List). The number of species increased significantly with increasing age of cultivated areas (without harvest). The fungi were typical species of natural peat moss grasslands (Borg Dahl et al. 2020).

Dragonflies: In the period 2017-2022, 27 dragonfly species (33% of the species native to Germany and 39% of the species native to Lower Saxony/Bremen) were recorded, including *Aeshna juncea* (moorland hawker), the species *Aeshna subarctica* (subarctic darner), which is closely associated with peat mosses and threatened with extinction throughout Germany, and *Leucorrhinia rubicunda* (northern white-faced darter). Notably, six of the species recorded and listed on the Red Lists are typical bog dragonfly fauna and 5 of these are known to be reproducing in the production areas. The proportion of typical bog species has risen significantly with increasing age of the peat moss production areas. The total number of typical bog species are similar to those in near-natural bogs in north-western Lower Saxony.

Spiders: A total of 26,492 spiders (80 spider species, 1 harvestman species) have been recorded in the eleven years since the area was established. With increasing age of the areas without harvesting of the peat moss turf, the proportion of valuable species increased, e.g. *Araeoncus crassiceps*, *Erigonella ignobilis*, *Cnephalocotes obscurus*, *Attulus floricola* and *Attulus caricis*, a highly endangered, stenotopic bog spider species. No lasting change in the spider communities was detectable with small-scale harvesting.

Birds: In 2018, northern lapwing (endangered) and mallards were recorded as breeding birds and are representatives of the open or wet habitats on the peat moss areas. The number of visiting bird species was higher, including herons and ducks in particular, but also meadow pipits and grey wagtails, rarer shorebirds such as northern lapwing, common snipe, oystercatcher, and green sandpiper. Reasons for the relatively low utilization by birds could be the small area size in a diverse landscape, the intensive cultivation, and the deepened location of the cultivated areas with higher surrounding embankments.

Data basis: Gaudig et al. 2023, V. Bohnet

Recognizing and resolving conflicting goals

Although rewetting leads to an increase in typical peatland biodiversity, there may be conflicts of interest in terms of nature conservation. This concerns species protection, e.g. strictly protected species under Annex IV of the Habitats Directive and meadow birds under Annex I of the EU Birds Directive, whose breeding and resting areas must be specially protected by law. As well, protected biotope assets may be affected. According to EU law, FFH habitat types must be maintained in good condition and, if necessary, improved (e.g. through rewetting). Conflicts arise when dry habitat types are registered on drained peatland. These are protected by the prohibition of deterioration, which means that the water levels there may not generally be restored to a level close to natural. However, continued drainage will also inevitably lead to a medium-term deterioration of these "dry" habitats. A staged approach with the creation of replacement habitats should be planned in these conflict cases so that dry habitat types do not prevent rewetting. Peatland species are a priority on peatland soils (Närmann et al. 2021). If naturally occurring watercourses flow through peatlands, water management must be developed on a site-specific basis in accordance with the requirements and objectives of the EU Water Framework Directive (WFD) for the mutual benefit of the river and the peatland. Damming a natural watercourse for peatland drainage can temporarily lead to an ecological deterioration of the watercourse. However, positive effects are also increasingly coming into focus, such as the stabilization of the water level, water retention, reduced risk of drying up, and less nutrient discharges through reduced peat mineralization. It must therefore be decided on a site-specific basis which winter and summer water levels should be targeted. The WFD requirement of continuity does not apply in the same way to ditches and other anthropogenically created watercourses.

Nature conservation area maps for wet meadows/wet pastures and cropping paludicultures were first drawn up with the nature conservation and environmental protection authorities in Mecklenburg-Western Pomerania in 2016/17 (LM M-V 2017, Tanneberger et al. 2020), and further developed in Brandenburg, Schleswig-Holstein and Baden-Württemberg (Närmann et al. 2021) and for Lower Saxony (MU Nds 2024).

Biodiversity-promoting measures for paludicultures

Basic biodiversity-promoting framework conditions for paludicultures result from the legal requirements, which stipulate no nitrogen and phosphate fertilization, no use of pesticides, and no tillage on permanently waterlogged grassland (LM M-V 2017, Wenzl et al. 2024). In addition to the legal requirements, it is recommended as a nature conservation standard for funding programs that farmers receive advice on the area-specific nature conservation conditions and possibilities before changing use. Additionally, ditch maintenance should promote biodiversity, and in wet meadows, there should be one-year rotational fallows and when harvesting, at least 10 cm grass stubble should be left. Grazing should only be carried out at a low level of intensity with adapted animal breeds. Useful additional measures that could be promoted via agricultural, environmental, and climate measures include the use of cutting (oscillating) instead of rotating mowing technology, time restrictions on field management, and staggered mowing or longer fallow periods. In the case of cultivated paludicultures, the harvest should not be carried out annually over the entire area, but as a mosaic harvest in which individual strips are left standing (reeds, sedges, reed canary grass and bulrushes). In peat moss paludiculture, harvesting only makes sense every three to five years (see Närmann et al. 2021, Muster et al. 2015). Providing gaps for light through dense vegetation and the integration of small bodies of water can promote the occurrence of dragonflies (Zitzmann et al. 2023). The extensive catalogue of measures for management methods on raised bogs and fens that are useful from a nature conservation perspective should be backed up with corresponding funding scenarios (Wenzl et al. 2024, Luthardt et al. 2024).

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