Nutrient removal capacity of floating installations

LiveLagoons project report

2021

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Executive Summary

AFWs (artificial floating wetland) are an innovative variant of a constructed treatment wetland that allows non-land-based water treatment in water bodies that are too deep for plants to grow and under fluctuating water levels (Grosshans et al., 2019). Nutrient-rich water is treated by bacteria (biofilms) attached to the plant roots performing nitrification/denitrification (release of N2 gas), biological breakdown, and detoxification. Roots and installation themselves enhance particle retention. As a result, increased water clarity, reduced algae, and cyanobacteria growth, as well as reduced nutrient levels, could be achieved. In addition, floating wetlands provide habitats for aquatic and terrestrial fauna. In recent decades the commercially available floating mats (e.g. BioHaven®, Biomatrix®, AquaGreen® or Beemats®) are increasingly applied as a technique to create artificial wetlands for diffuse pollution treatment, water quality improvement, and biodiversity habitat creation. Various types of floating vegetation platforms increasingly available on the market (e.g. Aquascape, Velda, SiboFluidra, EkoWyspa) suggest many types of floating substrates adapted for small ponds and gardens.

Live Lagoon project is dedicated to studying AFW environmental impact on the natural coastal eutrophic waters to assess its potential for nutrient removal. In addition, habitat creation and coastal protection function of AFW was under focus.

The nutrient removal capacity of the island is the sum of nutrients accumulated in the aerial biomass (stems and leaves) and underwater biomass (roots), nitrogen loss by microbial activity, phosphorus uptake by microorganisms, and sedimentation. The nutrient removal capacity of AFW in the natural open water systems is nearly impossible to estimate. Therefore we selected a simple methodology for estimating nutrient content in the harvested plants, although the aerial biomass could contribute only ~10% of nutrient removal while the rest is accounted for by the root-associated microbial community.

The total plant harvest from 24-28m2 island could reach ~70-90kg of fresh weight. This amount of plant biomass contained ~290-590g of N and ~18-38g of P. While multiplied by a factor of ×10 the total nutrient removal capacity of a single island could be estimated as a maximum of 5,9kg N and 0,38kg of P annually. This rough amount of P is equivalent to P content in ~63m^3 of treated household effluent. One island's annual function could cover a footprint of a single household (producing 15m^3 wastewater per month) for 4-5 months only. For a larger impact, a higher AFW area is needed.

Even though the nutrient removal capacity of the island is very low compared to the anthropogenic inputs into the coastal systems reaching thousand tons annually, it provides value for biodiversity and ecosystem services for the society.

AFW serves as a new habitat for birds. It could be a resting place in winter or migration season, nesting hunting, or a lurking location in summer. In the underwater part of the island, the shelter is provided for juvenile fish, even protected species such as eels. AFW planted with some exotic and ornamental plant species provides aesthetic value in urban environments.

Overview of installations

Experimental floating structures were placed in five locations, where net and different island designs were tested.

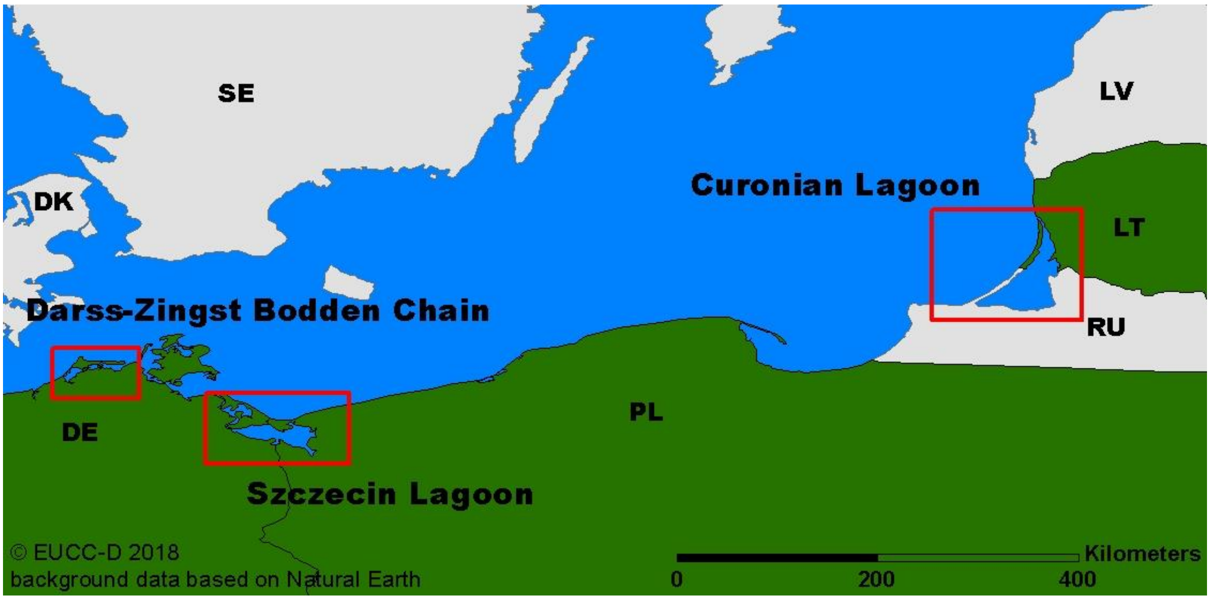


Fig. 1. Island and net instalation sites in the SE Baltic Sea.

The net barrier was installed closing the basin between two piers in the **Nida in the Curonian Spit NP** in May 2018. The net was planted with *Salix* spp. and *Phragmites australis*. Both species are native to the area. This was the only installation that has to be removed each autumn to prevent damage by the spring ice movements.

The first floating islands in Germany were installed in **Born at the Darss-Zingst Bodden Chain** (Born) in May 2018 with our cooperation partner – the Federal State Institute of Agriculture and Fishery MV. The islands are located directly behind the outlet of an aquaculture pond (sturgeon cultivation). The first islands were made out of stainless steel mesh filled with reed stems. They were planted with a pre-cultivated coir mat with a variety of native emergent macrophytes: *Lythrum salicaria*, *Bolboschoenus maritimus*, *Iris pseudacorus*, *Carex acutiformis* and *Schoenoplectus lacustris*.

A modified new island made out of thermowood was installed in Born in April 2019.

In Poland and Lithuania Biomatrix 3D – Matrix Islands of size: 3.45 m x 6.9 m and a total of 23.9 m^2 (**Wolin NP, Juodkrantė Gintaro bay**) and 28 m^2 areas (Juodkrantė 14km) were installed in May 2019. The Wolin NP island is located in the marina.

The third floating island in Germany was planted with *Carex acutiformis*, *Carex acuta*, *Lythrum salicaria*, and *Iris pseudacorus* and installed within a drainage channel close to the beach in **Vogelsang-Warsin in the Szczecin Lagoon** in December 2020. Impact monitoring will be carried out together with the local environmental agency.

The third island in Lithuania was installed in the **Klaipeda city** center (Jonas Hill water reservoir) in June 2020 using the same Biomatrix 3D design, but different plant assemblage including non-native species.

Description of methods

Climatic conditions at pilot locations

Compilation of climatic data and calculation of Growing Degree Days (GDD) for three location was performed using ChillR R package (Luedeling & Brown, 2011, Luedeling, 2021). The available daily minimum and maximum air temperature data from NOAA GSOD (Global Surface Summary of the Day) archives were used (Klaipeda MS for Juodkrante, Swinoujscie for Wolin and average for Laage and Gedser for Born). The cumulative GDD were calculated for all three locations over years 2018, 2019

and 2020. The calculated GDD dynamics in all three locations were quite similar (Fig.2),

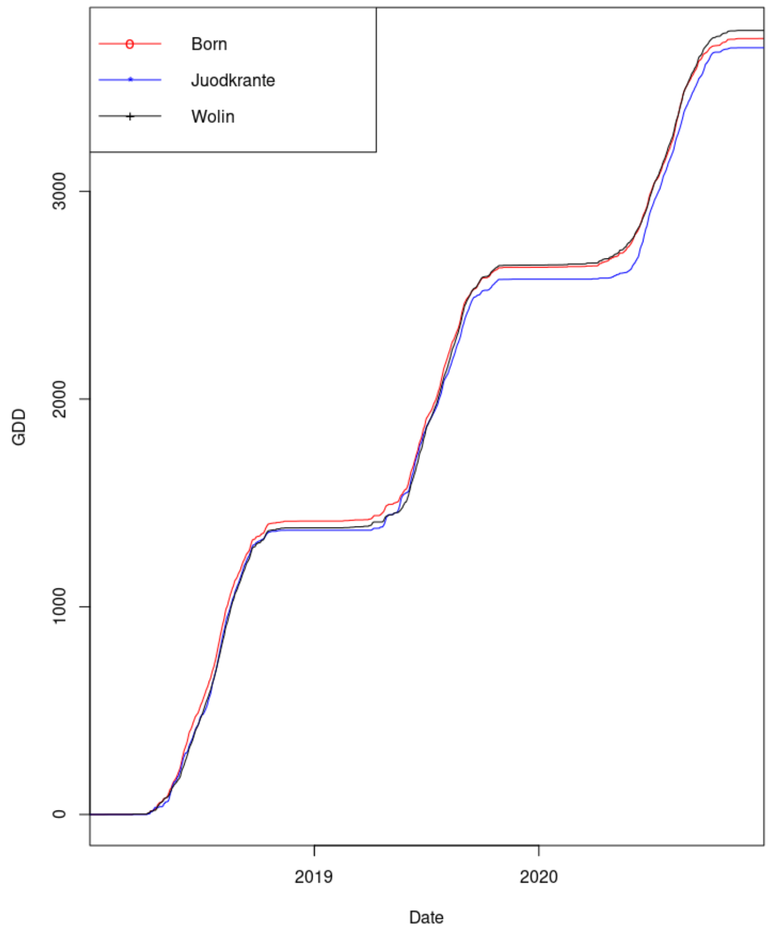


Fig. 2. The cumulative GDD graph at pilot locations

Nutrient and pigment analysis in water column

Data on daily water level fluctuations and ice cover were obtained from the national waterways and shipping office. Prior to installations (April), during the vegetation peak (June and July) and at the harvest time (September), water pH, dissolved oxygen and water temperature were measured at 10 cm depth *in situ* at two sampling sites monthly with a multiparametric probe (Hach-Lange). For dissolved nutrient analysis, water samples (n=3 per site) were filtered. Dissolved nitrites (NO2-), combined nitrites and nitrates (NOx-) and inorganic phosphorus (DIP) concentrations in filtered water samples were measured using standard colorimetric methods with a 4-channel continuous flow analyzer (San++, Skalar) (Grasshoff et al., 1983). NO3- concentrations were calculated as a difference between NOx- and NO2-, Dissolved NH4+ was determined using nitroprussiate as a catalyst by the salicylate-hypochlorite method (Bower and Holm-Hansen, 1980). Total nitrogen (TN) was determined applying high temperature (680°C) combustion catalytic oxidation/NDIR method using a Shimadzu TOC V-CPH analyzer equipped with a TN module. Total phosphorus (TP) was quantified spectrophotometrically with the molybdate method (Koroleff,1983) after digestion and oxidation of the organic P forms with alkaline peroxodisulphate acid (see also Vybernaite-Lubiene et al. 2017).

Table 1. Water quality monitoring parameters.

Parameter	Nida (Lithuania)	Juodkrante (Lithuania)	Germany	Poland
NH_4^+	+	+	+	+
NO_2^-	+	+	+	+
NO_3^-	+	+	+	+
TDN	+	+	+	+
TN	+	+	+	+
DIP	+	+	+	+
TDP	+	+	+	+
TP	+	+	+	+
TPP	+	+	+	+
$HSiO_2$	+	+	-	-

Nutrient analysis in cultivated macrophytes

For the plants fixed at the net in the end of vegetation season some specimens of salix and Phragmites have been removed for more detailed observations in the laboratory, estimation of biomass and taking samples for nutrient content analysis. Stams of salix were cleaned and molluscs removed and weighted. Leafs and roots samples were taken for N and P analysis. The sample material was dried at 100°C and grinded. Carbonate was removed from root samples using 1M HCl.

The Juodkrantė, Wolin and Born islands have been harvested annually in 2019, 2020 and 2021. The time varied at different sites from September to November. The plants were cut using breakable knif, sorted, removed to the shore and weighted. Subsamples of dominant species for dry weight and nutrient analyses were taken.

Total phosphorus was estimated using a molybdate-ascorbic acid method, after potassium persulfate digestion at 120°C for 1h. Carbon and nitrogen (%) in the samples were determined using Thermo Scientific Delta V Advantage mass spectrometer coupled to a Flash EA 1112 elemental analyser.

Biodiversity estimation

Macrobenthic species were determined at level of species or other taxa where possible in the Curonian Lagoon island and natural read habitat.

Islands were frequently visted and observed as well the video recording took place in Juodkrante island and Born. Which provided information on birds and mammals visiting the island.

Salinity and nutrient concentrations

Out of 4 pilot locations only 2 were the real estuarine conditions. Salinity fluctuated in the range 2.4 -3.7 in Born, Darss-Zingst (Karstens et al., 2021) and 0.2-6.5 in Juodkrantė, Curonian Lagoon.

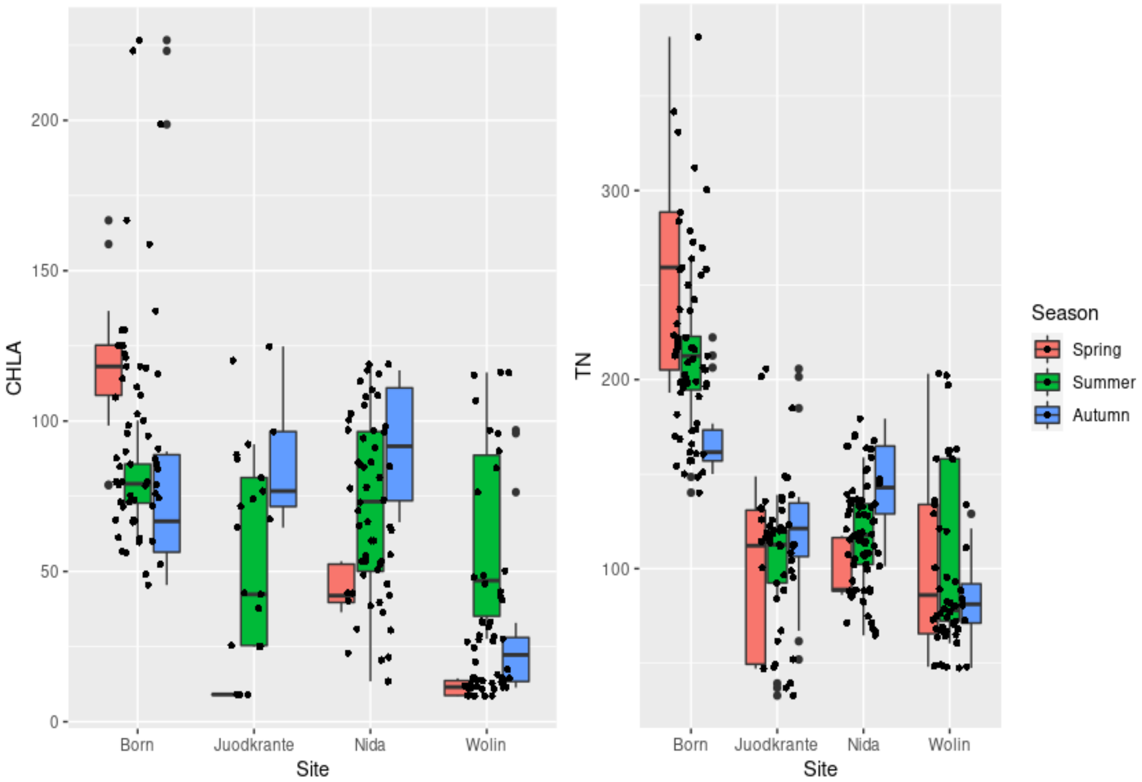


Fig. 3. Seasonal variation in ChlA and TN at 4 experimental locations

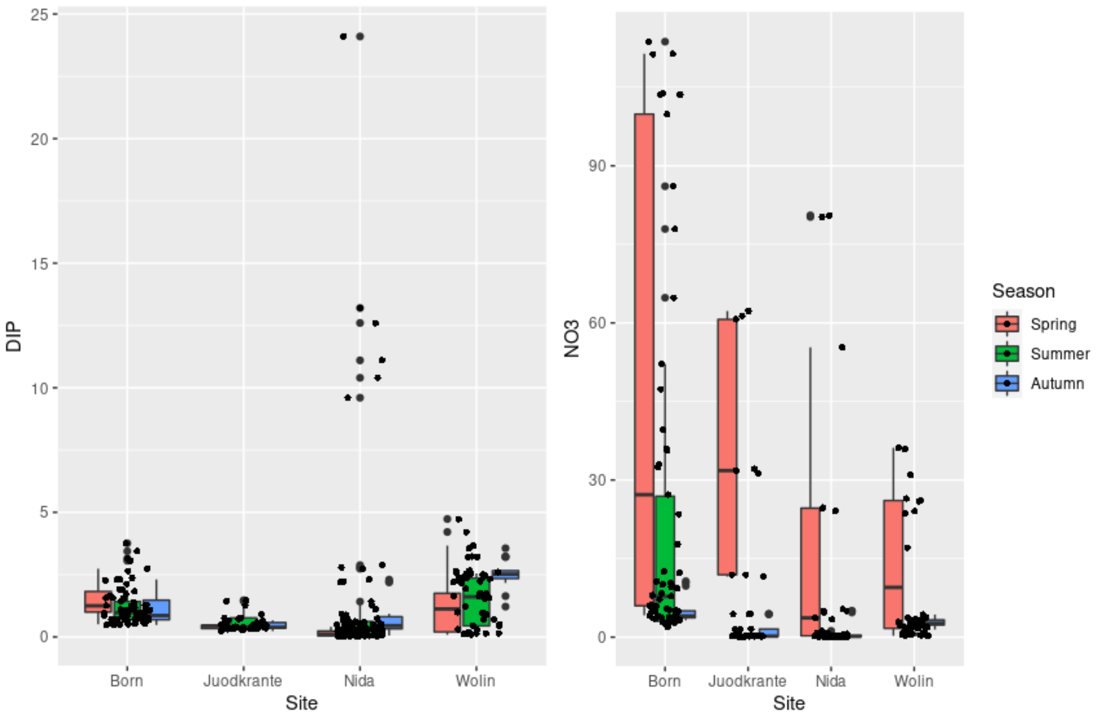


Fig. 4. Seasonal variation in DIP and NO_3 and at 4 experimental locations.

Floating net installation

Plants used in the floating barrier

The 'net' i.e. custom-made floating rig of 200m length and 1m height was placed at ~1m depth between the two moles in the end of May 2018. Two types of plants and different fixation methods have been used. The common reed (*Phragmites australis)* was planted in to the cylindrical PVC containers filled in with expanded clay. While single branches of the willow (*Salix*, ~1-1.2m length) have been fixed directly to the net. The plants were taken from the close coastal area at Juodkrante site and have already developed fresh leaves.

Both species survived the waving and water level fluctuation conditions. Within two months *Salix* stems produced a significant amount of roots (Fig. 5), while above ground growth was not significant.

Fig. 5. Roots developed by *Salix* on the 19th of July i.e. within two months of growth (photo by R. Ilginė).

Harvesting and estimation of production

In the end of vegetation season on the 18th of September, 2018 some planted specimens have been removed from the net for more detailed observations in the laboratory, estimation of biomass and taking samples for nutrient content analysis (Fig. 6).

Phragmites developed a root system shaped and limited by the container form and size (Fig. 6). The average root wet weight within the single container is 174±140 g, which could be converted to root biomass production 35 ± 28 g dry weight. The lowest root biomass was recorded in the container without expanded clay filling, which indicates importance of stable substrate for root development.

Salix root production was 54 ± 29 g WW, which is 5 ± 3 g DW per single stem. In comparison to mid-season (Fig. 5) roots have less intense red color and a significant cover of carbonate precipitates (Fig. 6).

For both species the aboveground production could not be estimated, because it is not possible to differentiate the new growth parts of the plants from those that have been planted. The planted *Salix* branches were defoliated by storms, while newly produced leaves were smaller and in relatively worse condition.

In conclusion, plants growing under sub-optimal conditions produce small amount of ‘above ground’ tissues but larger amount of root biomass. Therefore entire plant must be removed to remove nutrients permanently. *Salix* is easier to harvest than *Phragmites*.

Fig. 6. Plants removed from the net for nutrient content analysis (photo by J. Lesutienė)

Phosphorus and nitrogen content in plants

Salix leafs contained 3 fold less P and N compared to planted individuals (Fig. 7). Roots contained higher amount of nitrogen than leafs at the time of harvest i.e. 23 ± 4 mg/gDM or g/kgDM. Root production 5 ± 3 gDW/stem is equivalent to ~5mgP/stem and 114mgN/stem. Presence of diazotrophic endophytes in the willows stems is a known phenomenon which explains ability of this species to grow under nitrogen limitation (Doty et al., 2009, von Wuehlisch 2011).

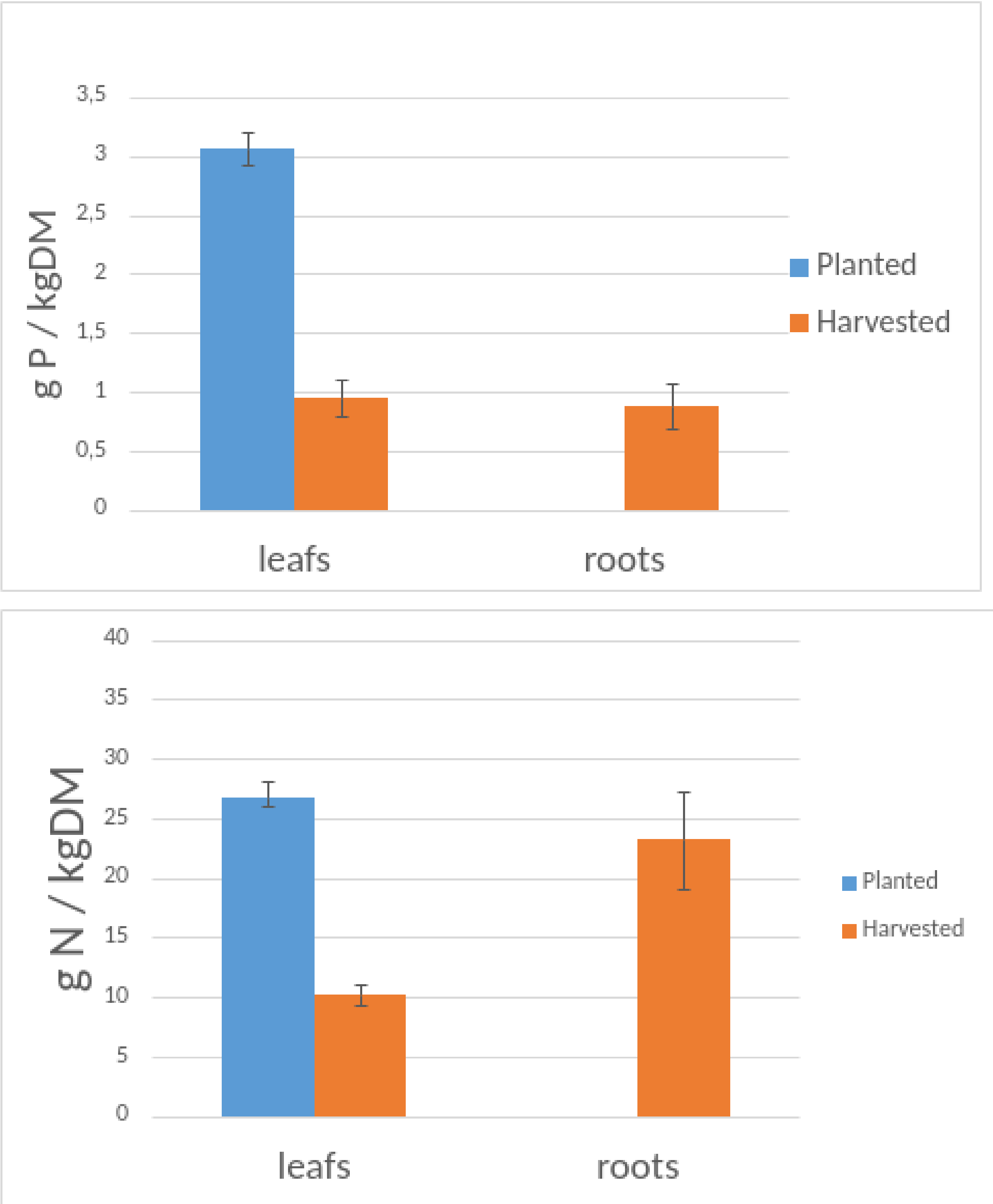
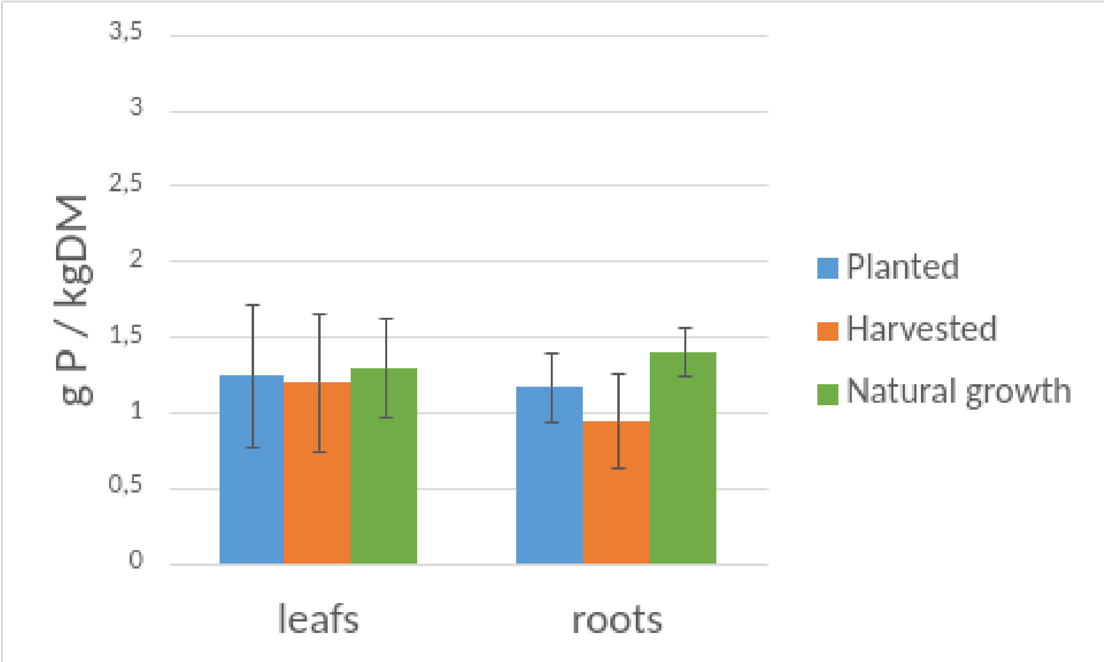


Fig. 7. P and N content in the harvested *Salix* roots and leafs.

In contrast to *Salix*, *Phragmites* accumulates more nitrogen in leafs than in roots (Fig. 8). Average root biomass 35±28 gDW estimated within the container is equivalent to ~33mgP and ~398mgN. *Phragmites* taken from its natural growth habitat from the shore of the study site contained higher concentrations of N in leafs, indicating sub-optimal conditions for above ground growth. The total nutrient removal capacity by underwater production is shown in Table 2.



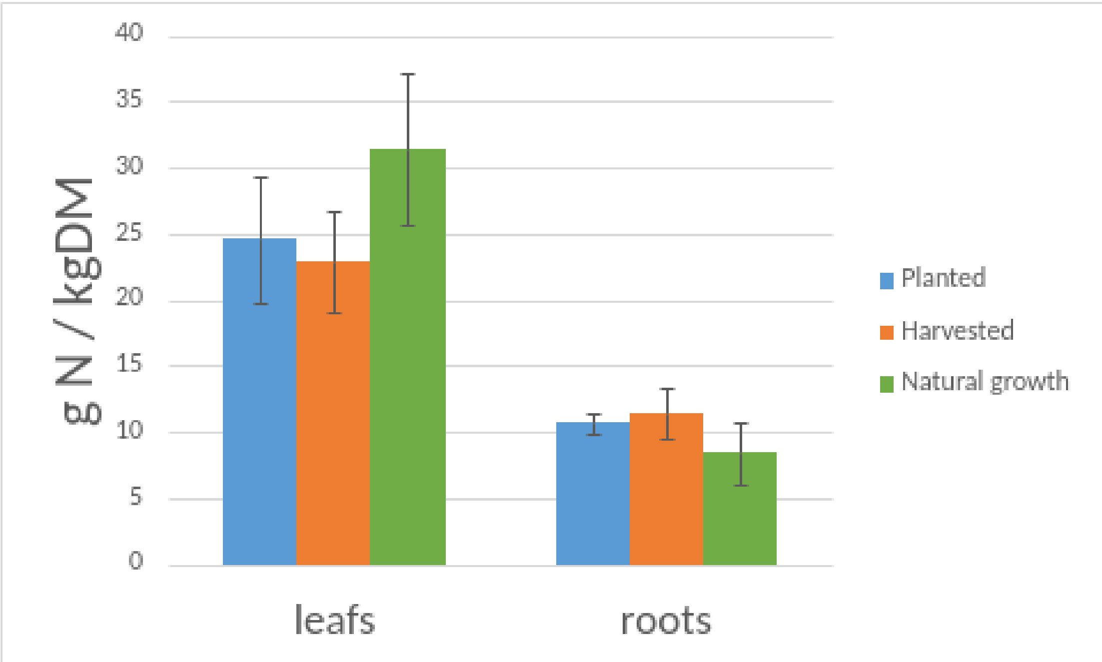


Fig. 8. P and N content in the harvested *Phragmites* roots and leafs.

Mussels add to nutrient removal capacity

The net has its structure disposed at whole cross-section of the water column. Zebra mussel *Dreissena polymorpha* attached to the rig itself and the plants fixed to the net at ~40cm below water surface, presumably avoiding waving and ultraviolet radiation. Below this depth, 60cm of the willow stem was fully covered with the newly settled zebra mussels. The nutrient content in soft tissues of zebra mussel is ~100.9 mg N/ gDM and 9.3 mgP/gdDM; shell contains ~0.38% of N and

0.45 mg P/g DM (McLaughlan and Aldridge, 2013). Zebra mussel can grow to the end of season and produce ~8 g of DW equivalent to ~8mg of P and 79mg of N.

Fig. 9. Zebra mussel (*Dreissena polymorpha*) attached to willow stem (photo by Ž. Grigaitis).

Table 2. The total nutrient removal by underwater production of willow stems and roots of *Phragmites*. N is number of stems and containers fixed to the net.

Biomass parameter	Nitrogen, mg	Phosphorus, mg	N	Nitrogen, g	Phosphorus, g
Salix					
Roots	114	5	100	11.400	0.500
Mussels	79	8	100	7.900	0.800
Above ground	NA	NA		NA	NA
Phragmites					
Roots	398	33	100	39.800	3.300
Above ground	NA	NA		NA	NA
			Sum	59.1	4.6

Plants used in the AFW

Choice of the macrophyte species was dependent on the purpose of the floating island and environmental constrains. In the protected territories only native plants were used.

- Perennial plants (the annual plants will grow spontaneously);

- Species resistant to local environmental conditions, e.g. salinity and climate.
- For nutrient removal choose *Carex acutiformis*, *Typha*, Iris, *Juncus*, *Sagittaria*, *Phragmites*.
- For biodiversity integration of endangered species (e.g. *Iris pseudacorus*)
- For aesthetic enjoyment integration of flowering plants such as *Lythrum salicaria*;
- Herbal collections (e.g. *Acorus calamus*, *Petasitis hybridus*, *P. spurius*, *Valeriana*).

Plants in these installations also divided into four different categories (Table 3), according to their height and size.

Table 3. Plants used in the floating installations in the urban islands (Klaipeda City Jonas Hill and Žardės pond islands).

Latin name	Common name	Origin
Lower-medium height		
Juncus conglomeratus	Common rush	native
Juncus effusus	Soft rush	native
Carex acuta	Slender Tufted-sedge	native
Carex riparia	Greater pond sedge	native
Carex pendula	Weeping sedge	native
Carex acutiformis	Lesser pond sedge	native
Decorative flowering		
Lysimachia vulgaris	Yellow loosestrife	native
Butomus umbellatus	Flowering Rush	native
Aster tripolium	Sea aster	native
Pontederia cordata	Pickerelweed	N. America
Thailia dealbata	Hardy water canna	N. America
Hibiscus moscheutos	Swamp mallow	N. America
Decorative foliage		
Iris pseudacorus	Yellow flag	native
Carex morrowii	Japanese sedge	E Asia
High		
Glyceria maxima	Great Manna Grass	native
Typha angustifolia	Narrowleaf cattail	native
Typha latifolia	Broadleaf cattail	native
Schoenoplectus lacustris	Lakeshore bulrush	native
Scirpus sylvaticus	Wood Club-rush	native
Trees and bushes		

Taxodium distichum	Bald cypress	N. America
Viburnum x burkwoodii	Burkwood viburnum	Garden origin hybrid

In the urban location (Klaipeda city) exotic ornamental plants were selected:

- Exotic ornamental species (e.g. *Iris* cultivars, *Thalia dealbata*, *Pontederia cordata*, *Hibiscus moscheutos*, variegated *Carex* cultivars)
- Trees and ornamental bushes (e.g. swamp cypress *Taxodium distichum*, *Viburnum* x *burkwoodii*).

Fig. 10. Ornamental plant species in Jonas Hill urban island, Klaipeda.

The total harvest and nutrient removal capacity

For comparison and harvest estimation we selected three islands of similar technology (Biomatrix).

Table 4. AFW Island factsheet.

Curonian Lagoon Gintaro	Island area 24m^2 Producer: Biomatrix Water Installed in 2019 Dominant plant species: *Carex acutiformes*, *Typha angustifolia* Harvesting in September	
Curonian Lagoon 14km	Island area 28m^2 Producer: Biomatrix Water Installed in 2019 Dominant plant species: *Carex acutiformes*, other Harvesting in September	
Wolin NP	Island area 24m^2 Producer: Biomatrix Water Installed in 2019 Dominant plant species: *Phragmites australis* Harvesting in November	

After first growth season (2019) the plant biomass was low with exception of Gintaro island. The dense initial planting resulted in high production of plant biomass. Gintaro island reached its steady state, after three years, in 2021, there was no more increase of the harvest. While, In Curonian Lagoon second island (14km) and Wolin NP biomass of plants increased during all investigation period.

The nutrient removal capacity increased in Wolin NP island significantly in 2021. Table 4 shows nitrogen and phosphorus removal with harvest. It is assumed that annual average plant harvest is 2.3kg/m^2. It varied from 0.5 to 4kg /m^2 in 2019-2021.

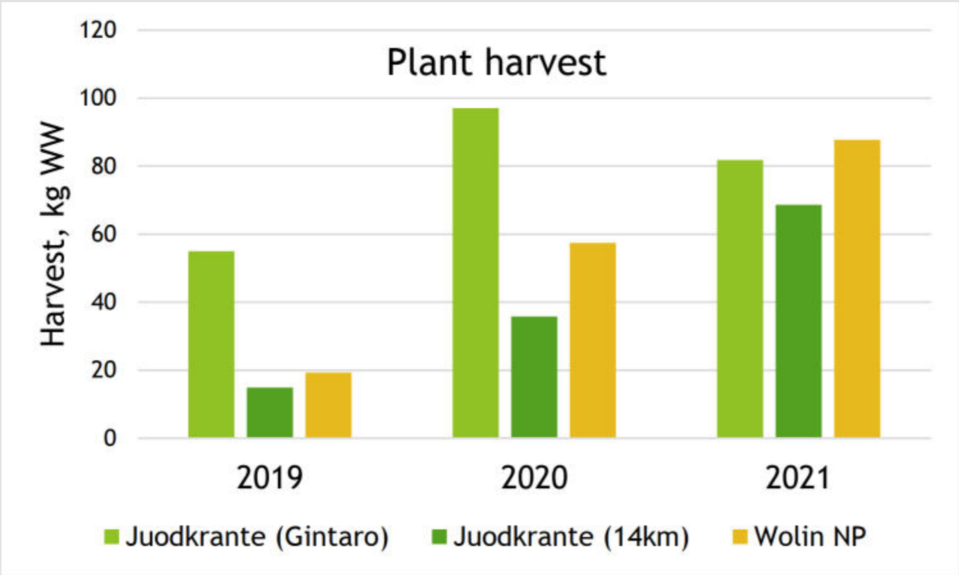


Fig. 11. Plant harvest in the Curonian Lagoon and Szczecin Laggon islands in 2019-2021.

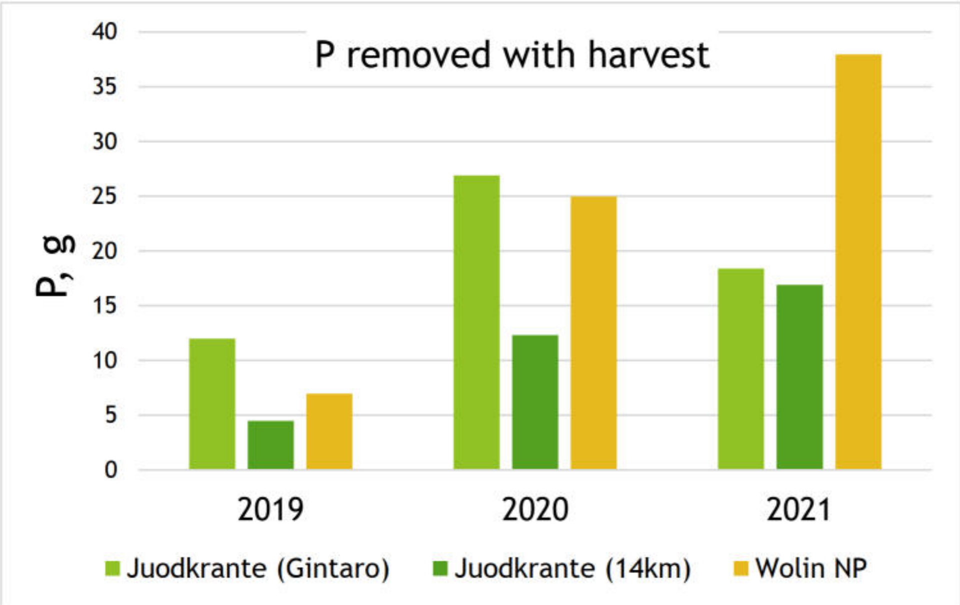


Fig. 12. Posphorus content in total plant harvest in the Curonian Lagoon and Szczecin Laggon islands in 2019-2021.

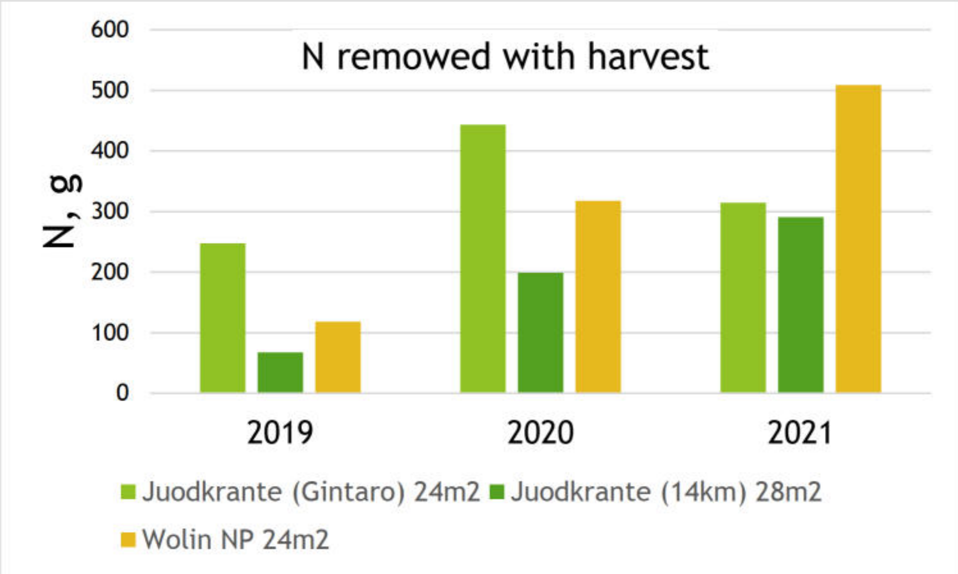


Fig. 13. Nitrogen content in total plant harvest in the Curonian Lagoon and Szczecin Laggon islands in 2019-2021.

Table 4. AFW short-term impact by area. Numbers are given for the harvest removed from the AFW. The total impact for N and P removal could be ~10x higher.

AFW	Area, m^2	Biomass, fresh weight kg			Nitrogen, gN			Phosphorus, gP		
		2019	2020	2021	2019	2020	2021	2019	2020	2021
Gintaro	24	55	97.08	81.8	247.6	443.3	314.6	12	26.9	18.4
Juodkrante14km	28	14.92	35.84	68.66	67.5	198.9	290.8	4.5	12.3	16.9
Wolin NP	24	19.3	57.48	87.77	118	317.6	508.6	6.96	24.98	37.94

Some studies report, that the aerial biomass could contribute only ~10% of nutrient removal while the rest is accounted for by the root-associated microbial community. Therefore, we could assume that the total annual removal of 24 m^2 could be ~10x higher ~2-5kg of N and ~160-380g of P.

Plant succession

In Gintaro island the initially high density of plants, resulted in a dense grass stand dominated by *Carex acutiformes*, *Typha angustifolia*. Other planted species such as *Scirpus sylvaticus*, *Shoenoplectus lacustris*, *Iris pseudacorus*, *Rumex crispus* become largelly owershadowed and representated by few individuals. There wos no free space for colonization of spontaneous species on Gintaro island. Single sprout of a tree *Alnus glutinosa* was recorded in 2020, but did not survive the next season.

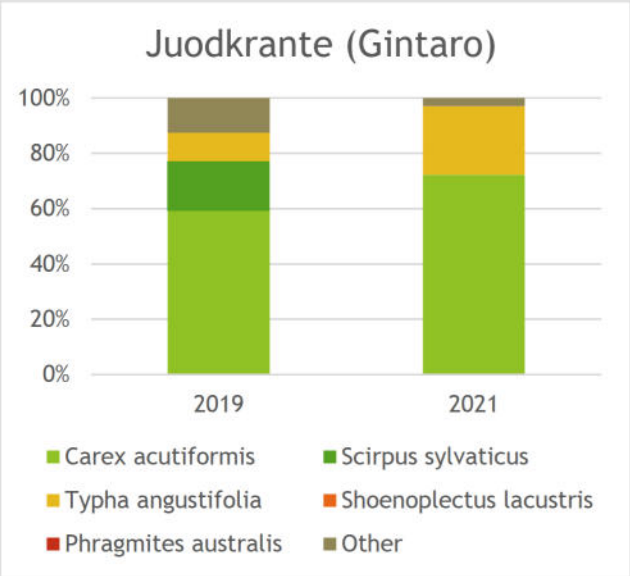


Fig. 14. Harvest composition in Gintaro island (Curonian Lagoon) in 2019 and 2021.

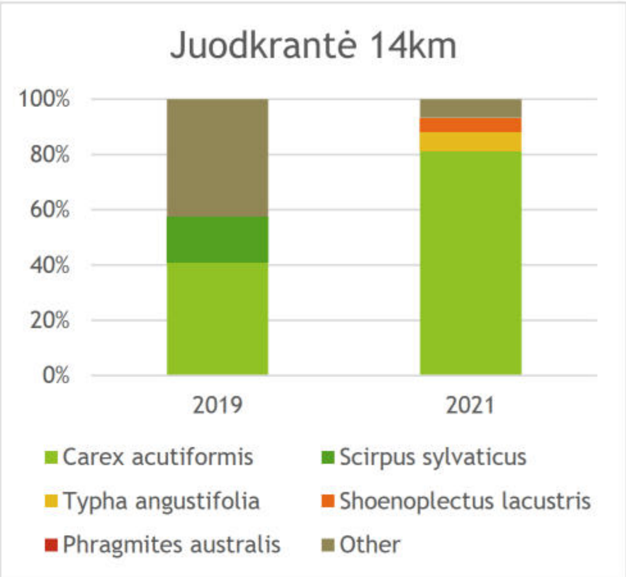


Fig. 15. Harvest composition in Juodkrantė 14km island (Curonian Lagoon) in 2019 and 2021.

In Juodkrante 14km island the initial plant density was lower and the total island area little higher. Moreover, the significant wave damage resulted in death of some plants. Therefore, as a result some open spots on the island occurred and where occupied by spontaneous colonists: *Eupatorium cannabinum*, *Rumex palustris*, *Petasites* and many smaller species. Less dense stand of *Carex acutiformes* resulted in better growth of *Shoenoplectus lacustris*, *Iris pseudacorus*. As result plant diversity on the Juodkrante 14km island was higher than on Juodkrante Gintaro island.

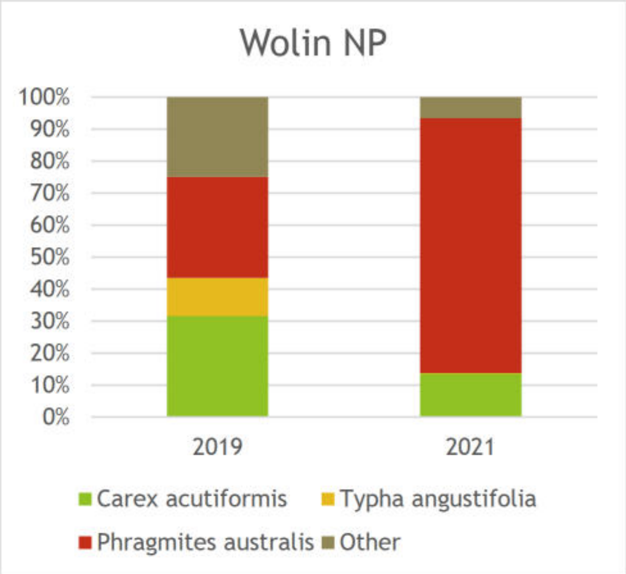


Fig. 16. Harvest composition in Juodkrantė 14km island (Curonian Lagoon) in 2019 and 2021.

In Wolin NP island the macrophyte stand is dominated by *Phragmites australis*. This species grows tall and produces high biomass. However, oversharing of other species is significant and the overall plant diversity is low.

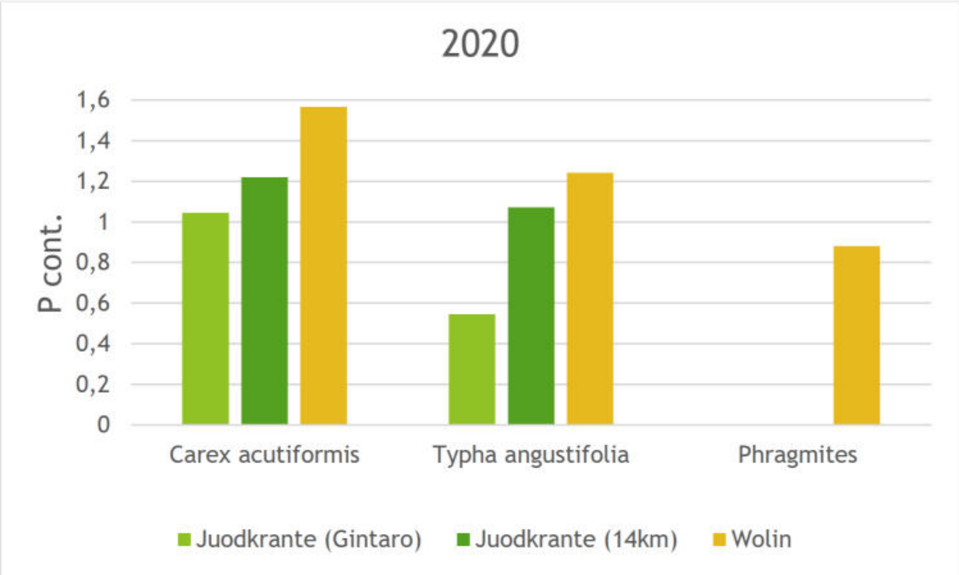
It could be concluded that initial plant species selection, planting density is very important for the final result. But the natural succession should be taken in to account and overall management goals should be defined in the beginning, whether the island serves as nutrient removal barrier or plays an aesthetic role, or biodiversity support function.

Fig. 17. Spontaneous species in Juodkrantė 14km island (Curonian Lagoon) in 2019 after first growth season.

Fig. 18. Spontaneous species in Juodkrantė 14km island (Curonian Lagoon) in 2020 after second growth season.

Nutrient content in main plant species

The highest nitrogen and phosphorus content was recorded in *Carex*. It was lower in *Typha* and *Phragmites*, but varied among the islands. In general, all species contained higher P concentration in Wolin NP island, whereas N content in many cases was higher in Juodkrante 14km island.



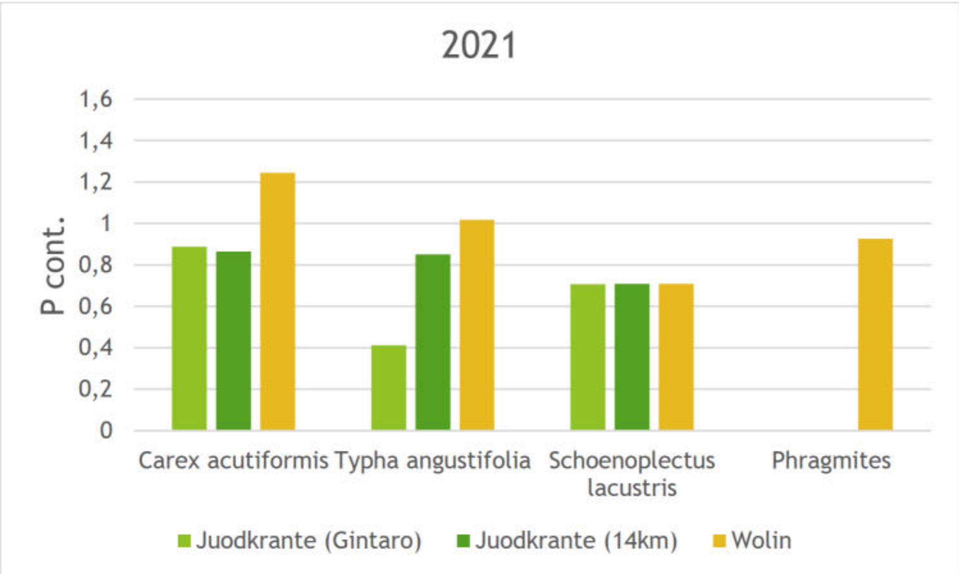


Fig. 19. Phosphorus content (%) in dry plant biomass.

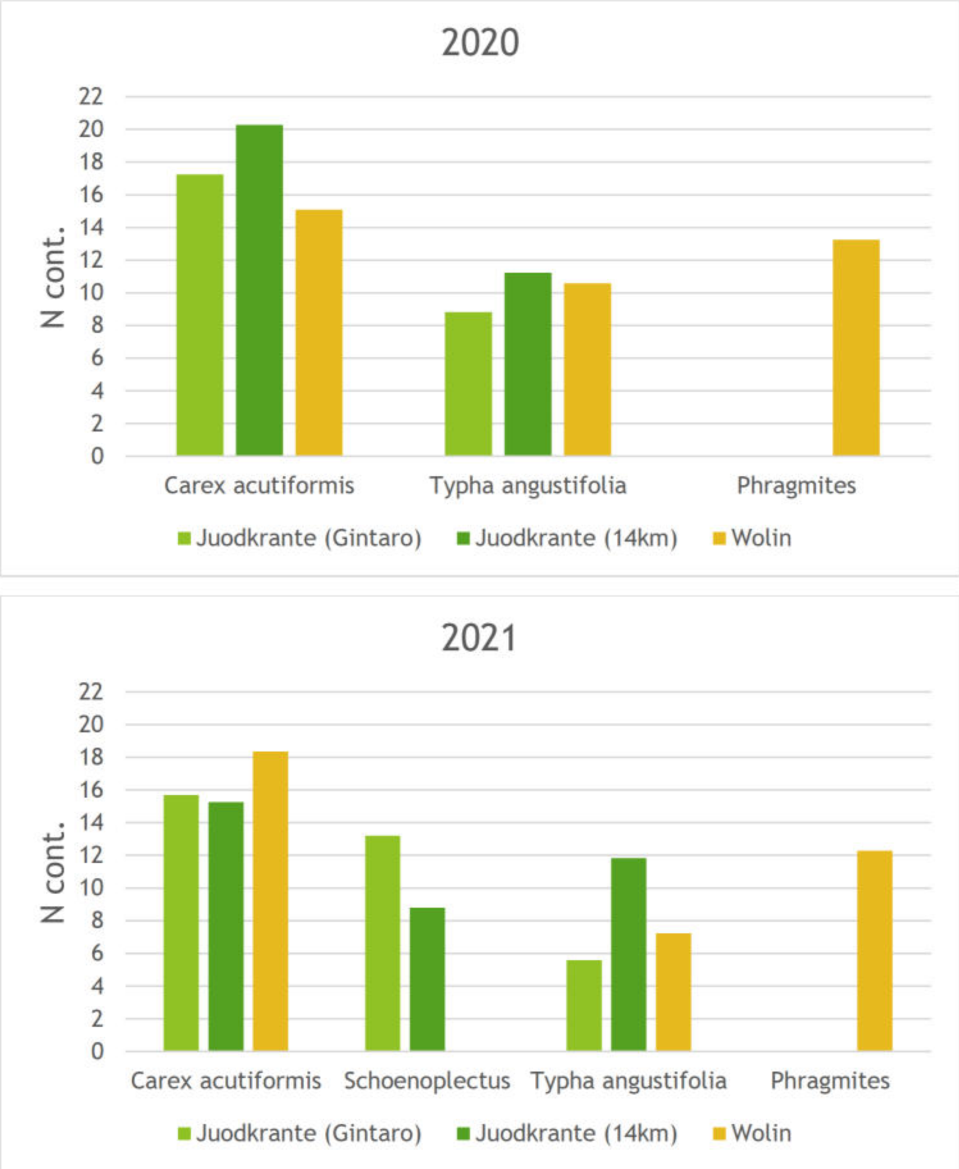


Fig. 20. Nitrogen content (%) in dry plant biomass.

Harvesting timing

Harvesting time is interesting issue as it tackles a trade-off between the aesthetic value and nutrient removal capacity. It is assumed that plants start allocating nutrients from leaves and shoots in to the roots in the early autumn, thus early harvesting in September is recommended.

As long as Wolin NP island is located in the marine, its aesthetic function is important. We tested nutrient content in green biomass (September/October) and brown biomass in November to investigate late harvesting time effect. Our result show, that in *Phragmites* the nutrient content could be slightly higher in September (2019). In other year (2021) it does not change significantly.

It could be concluded that given priority to aesthetic function of the island the harvesting could be postponed to October or even late November.

Fig. 21. Plant collor change in the early and late autumn Wolin NP island (Szczecin Lagoon).

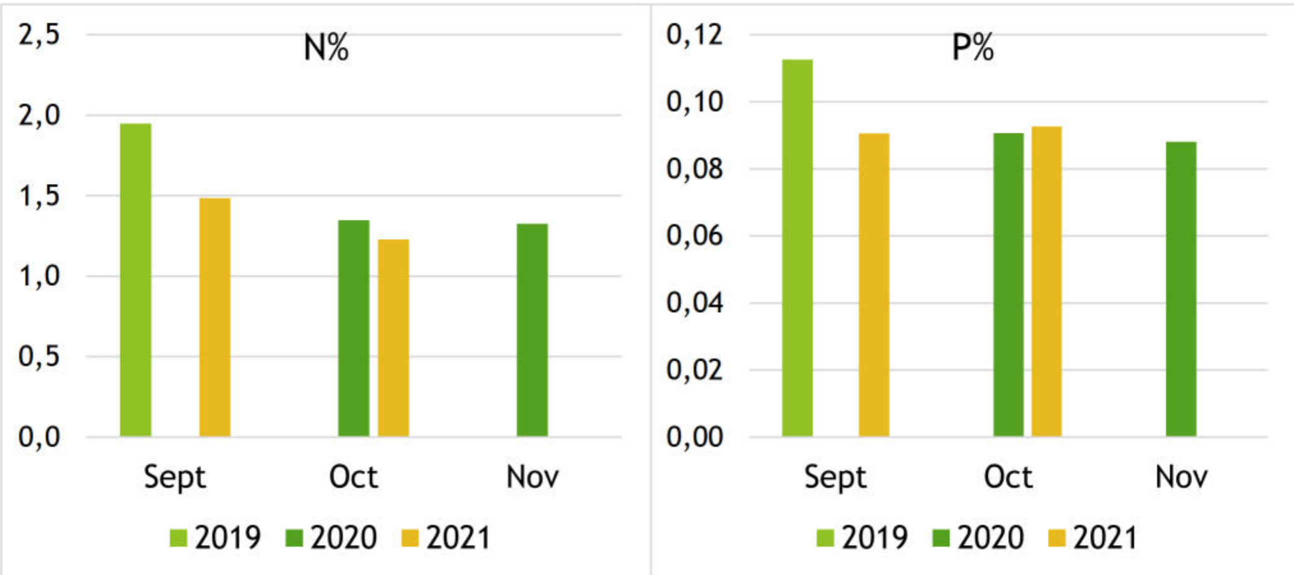


Fig. 22. Nitrogen and phosphorus content (%) in dry plant biomass in autumn.

Nutrient content in other plant species

Phosphorus content variated from 1.6 gP/kgDW in sea aster to less than 0.4 gP/kgDW in the lakeshore bulrush.

The data presented in figures five and six show variability in the relative content of nutrients both between plant species and between experimental locations. The highest content of both phosphorus and nitrogen was found in the vegetative parts of lesser pond sedge (*Carex acutiformis*). This plant species did show remarkably high biomass increase during the summer. There were significant differences in both nutrient content between different experimental locations, the lowest being recorded for the location in Born, Germany, while the highest was in Lithuania. Total calculated nutrient removal per square meter of an island could be calculated as up to 3,6 gP/m^2 and up to 103 gN/m^2, which accounts to approximately annual impact of ~100 gP and 2822 gN per annum for a 28m^2 island .

All chosen macrophytes grew well under brackish water conditions and fluctuating salinities although *C. acutiformis, I. pseudacorus* and *J. effesus* are not salt tolerant according to Ellenberg and Leuschner (2010). Nutrient concentrations differed significantly between plant species (Fig. and Fig.). Mean phosphorus concentrations ranged between 0.5 g kg^{-1} dry mass in *B. maritimus* and up to 1 g kg^{-1} dry mass in *L. salicaria*. Mean nitrogen concentrations were between 1.3 % of dry mass in *S. lacustris* and 2 % of dry mass in *I. pseudacorus*.

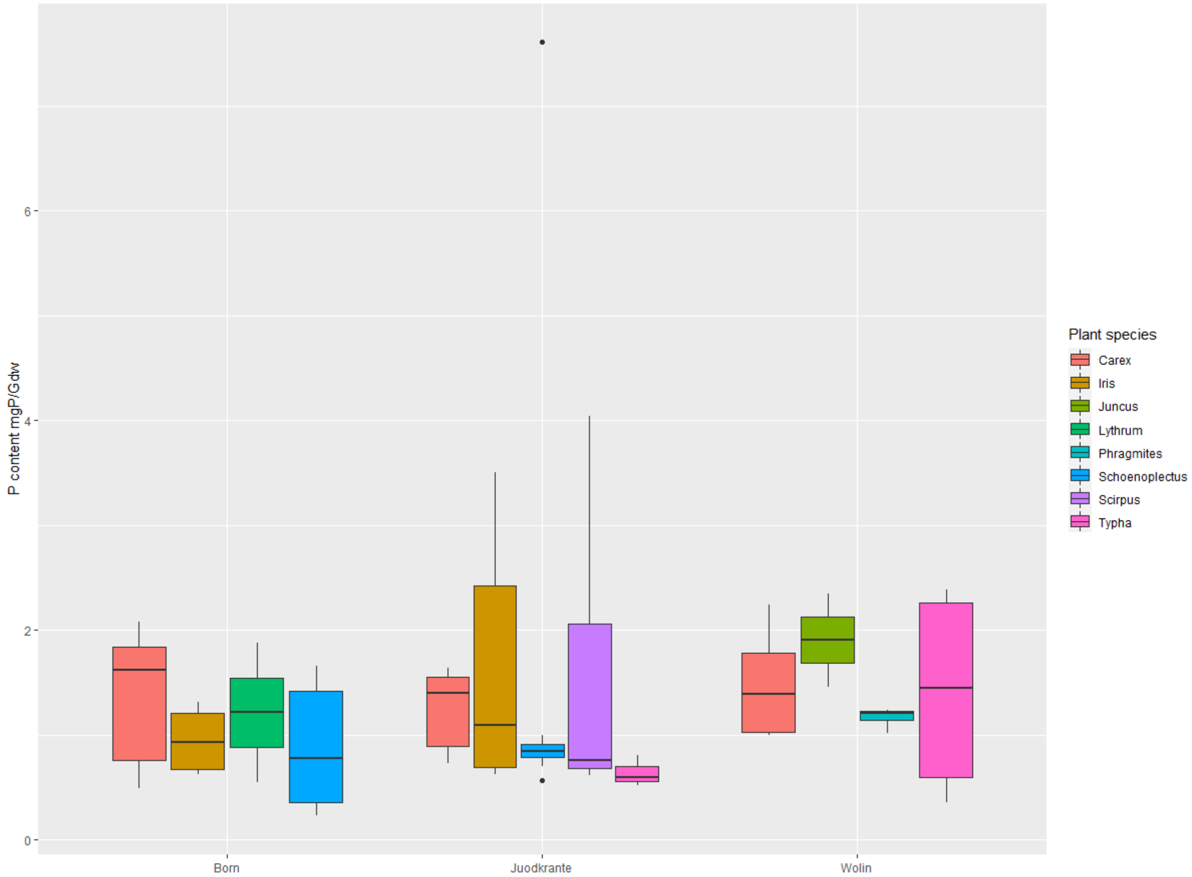


Fig. 23. Phosphorus [mgP/Gdw] in aboveground plant biomass in the eight different macrophytes species during harvest time across different sites.

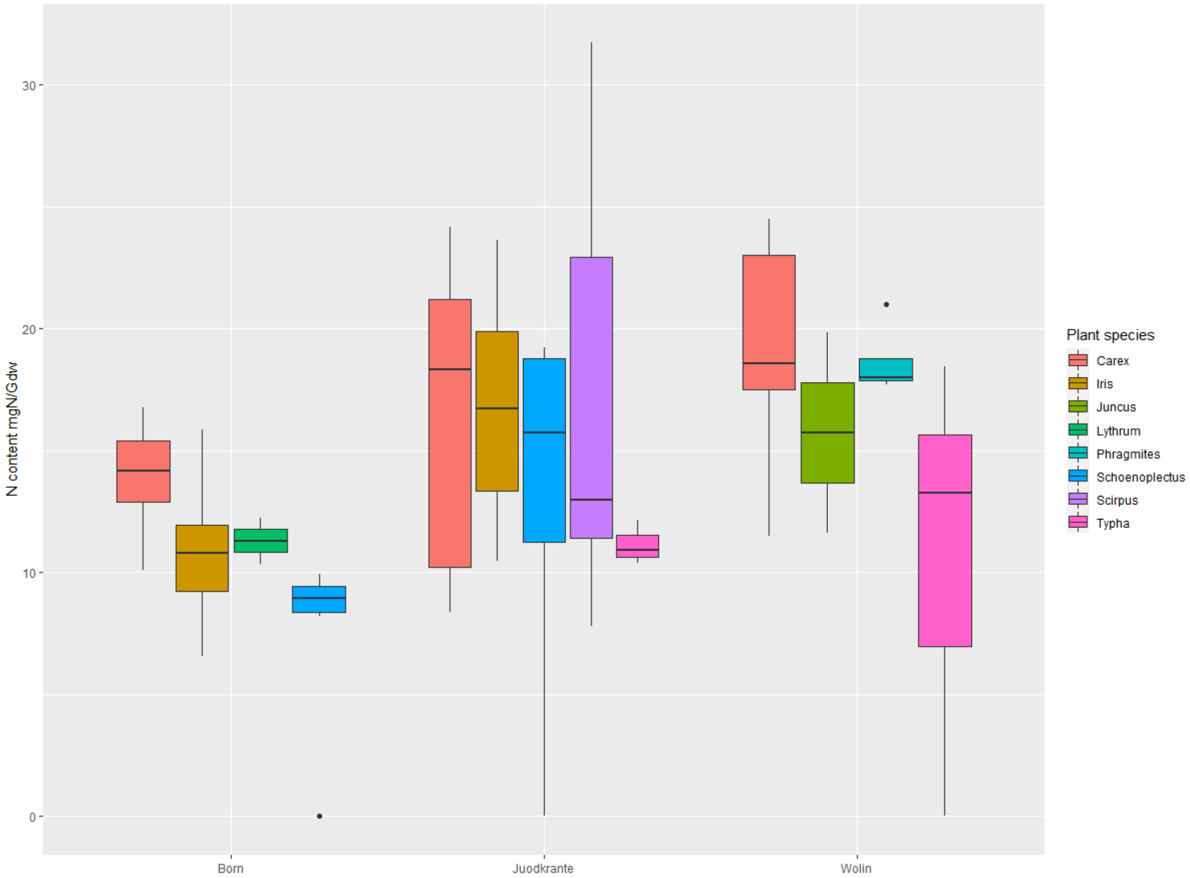


Fig. 24. Nitrogen [mgN/Gdw] in aboveground plant biomass in the eight different macrophytes species during harvest time across different sites.

Biodiversity impact

In Lithuania, we have assessed the benthic biodiversity beneath te island and a read bed located next to the island.

While the overall taxa number was slightly higher in the reed bed (11 vs. 9), the diversity index H' in the constructed island was triple of that in the reeds (0.5 vs. 1.5) (Fig. 25.).

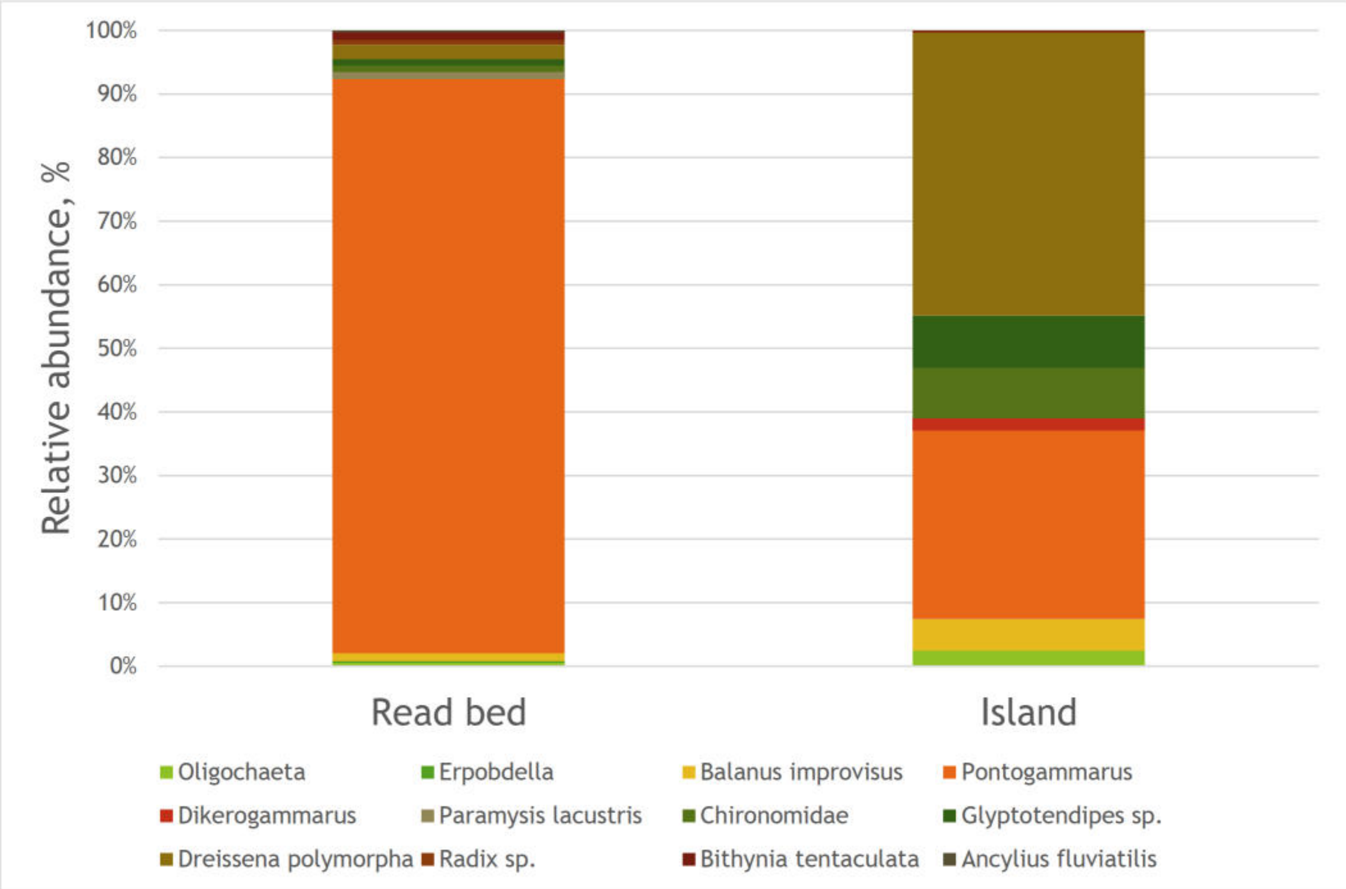


Fig. 25. Relative abundance of benthic and epibenthic species in the floating island and neighboring reed bed.

During the observation period few bird species were pictured on the islands: most common blue-headed mallard (*Anas platyrinchos*), grey heron (Ardea cinerea), great cormorant (Phalacrocorax carbo), mute swan (*Cygnus olor*), gulls.

In the night camera record we also recognised fox hunting otter on the Born island. It suggests, the biodiversity effect of new constructed habitat is significant.

Fig. 26. Birds resting on the island in winter Juodkrante 14km island (Curonian Lagoon). Photo. M. Bružas.

Fig. 27. Grey heron on the island. Record from the camera installed on the island.

Fig. 28. Nest of blue-heded mallard on Juodkrante island.

Managing urban bird effect

A newly installed and planted island could suffer severe urban bird grazing effect. The installation of the fence could be an option to manage bird grazing until the plants are rooted, gain height and volume.

Fig. 29. On May 17 the Klaipeda island was replanted and partially fenced to protect plants form ducks. This picture (June 3) shows that ducks are on the non-protected part of the island, while fenced part of island is more green.

Fig. 30. On June 3 we fenced entire island and replanted the grazed part repeatedly. This picture (June 18) shows that ducks are still on the island, breaking loosely fitted fence, but generally plants grow better.

Fig. 31. Island on July 21 has improved aesthetic view. Plants grow high they are no more vulnerable for duck grazing and there is no free unvegetated spots. There is no more need to control duck grazing and fence could be removed for the rest of the season and winter period.

Conclusions

The monitoring activities demonstrated no or very weak effects on the water quality parameters at all three locations.

The direct measurements of nutrients accumulated in the plants during the summer gave more concrete results of the nutrient removal, while the actual biomass and subsequently nutrient removal was very different both between different plant species and between locations. The planted islands had a positive effect on the benthic biodiversity comparing to the neighboring reed beds.

Even without biomass removal, remediation occurs on several levels: Plant roots attenuate wave energy and water flow and are consequently able to enhance particle settling and nutrient burial (Pavlineri et a. 2017). Furthermore, the associated microbial diversity impacts denitrification. Some studies even identified macrophyte root-associated denitrification as the main nitrogen removal pathway (e.g. Choudhurya et al. 2019).After harvesting (or not, in decorative cases) the construction could be kept in water year round, as freezing and thawing cycles do not seem to harm the islands. The floating island could be moved to sheltered area before the water body is covered by ice.

The most important aspect to be taken in to account:

- Installation: permission to install islands in public and private spaces, selection of a suitable location, initial investment
- Support: replanting (due to birds, adverse conditions such as the effects of waves), cutting and removal of biomass in September
- Maintenance: monitoring of the structure, pulling the island into the estuary during the winter, installation / removal of the fence, removal of invasive species, removal of other unwanted species of trees.

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Photo Gallery

First floating wetland in Born in 2018. The island consisted of an enveloping stainless steel net filled with native dry reed stems (*P. australis*). The margins of the floating wetlands started drowning at the end of August 2018 and biomass development was influenced thereby.

In 2019 the first island was removed and replaced by a thermowood island. Buoyancy is still sufficient after two years. The right photo shows the floating wetland in August 2020.

Island in Wolin

Island in Juodkrante, Curonian Spit NP