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Changes in a coastal fish community following reed removal to increase reed-water interface

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Eutrophication favours both mesopredatory fish, such as cyprinids, and reed in Baltic Sea archipelagos. While reed provides important habitat for many fish species, large and dense reed beds can reduce biodiversity and limit predation on mesopredatory fish. The removal of reed to restore predatory fish and decrease mesopredatory fish is rarely investigated. Here, we created channels and lagoons in reed beds in one Baltic Sea coastal bay, predicting the resulting increased water-reed interface would favour predatory fish (pike and perch), while reducing mesopredatory fish. Using a BACI-design (before-after-control-impact), we identified an increase in pike catches and a ~50% reduction in cyprinid catches after reed cutting, relative to a reference bay, but no change in perch catches. We conclude that increasing heterogeneity through reed cutting may be one measure to locally improve conditions for pike and lower the abundance of cyprinids, but more studies are required to confirm this.

Introduction

Eutrophication in lakes and coastal waters often causes algal blooms, turbid waters and fish communities dominated by mesopredatory fish (Ådjers *et al.* 2006; Duffy *et al.* 2013; Östman *et al.* 2016; Donadi *et al.* 2017). In addition, emergent shoreline vegetation, such as common reed (*Phragmites australis*) and cattails (*Typha* sp.), often thrive in soft sediments beneath shallow waters with high allochthonous nutrient inputs (Burdick and Konisky 2003; King *et al.* 2007; Chambers *et al.* 2008, Von Numers 2011; Pitkänen *et al.* 2013; Schrank and Lishawa 2019) and low grazing pressure (Von Numers 2011; Pitkänen *et al.* 2013). In the Baltic Sea, as in other eutrophic coastal areas, reed beds have both expanded (Von Numers 2011; Altartouri *et al.* 2014) and become denser and wider (Pitkänen *et al.* 2013).

Reed has important ecological and structural functions as it protects shorelines from wave erosion, buffers internal nutrient loading, absorbs external nutrient loadings (Kaitaranta *et al.* 2013), and acts as a carbon sink (Buczko *et al.* 2022). It also functions as a nesting and feeding area for birds and insects and provides important spawning and nursery habitat for fish (Sandström *et al.* 2005; Valkama *et al.* 2008; Härmä *et al.* 2008; Snickars *et al.* 2010; Kallasvuo *et al.* 2011; Hansen *et al.* 2019; Kiviat 2019).

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The relationship between reed, or other structure forming vegetation, and predatory fish can be complex. On one hand reed and vegetation forms important nursery grounds for fish and for predatory fish in particular, which utilise different micro-habitats during different life-stages (Casselman and Lewis 1996, Eklöv 1997; Skov and Berg 1999, Hawkins *et al.* 2003; Hansen *et al.* 2019). On the other hand, both emergent and submerged vegetation provides shelter to prey fish (Donadi *et al.* 2017; Gagnon *et al.* 2017), demonstrated in experiments showing lower predation rates on prey fish in structured habitats (Nelson & Bonsdorff 1990; Persson & Eklöv 1995). Several studies have shown that too much aquatic vegetation may therefore negatively affect predatory fish populations (Casselman and Lewis 1996, Olson *et al.* 1998; Schrank and Lishawa 2019; Massa and Farrell 2020). Thus, eutrophication may favour mesopredatory fish, like cyprinids, both due to productive and turbid waters via bottom-up effects and decreasing habitat heterogeneity due to the expansion of emergent vegetation (Schrank and Lishawa 2019). Emergent vegetation expansion can in turn reduce habitat diversity and access to prey for predatory fish (Eklöv 1997; Hawkins *et al.* 2003; Massa and Farrell 2020) impeding top-down control and further exacerbating eutrophication symptoms (Duffy *et al.* 2013; Östman *et al.* 2016).

A recent study shows that across coastal bays along the Swedish east coast of the Baltic Sea, pike (*Esox lucius*) abundance displays a positive association with the extension of reed beds (Niemi *et al.* 2023). In that study only natural reed beds were considered, where larger reed beds actually also show a more heterogenous interface between reed and water. The study does not address the question of whether an increased interface perimeter between reed and water can further improve conditions for predatory fish. Although vegetation management is a relatively common measure in eutrophic lakes and coastal areas, there is a lack of evaluation on how experimental vegetation removal effects fish (but see examples in Casselman & Lewis 1996). Olson *et al.* (1998) showed in a North American lake that removal and increased heterogeneity of submerged vegetation from cutting channels in vegetation resulted in increased body growth of piscivorous fish, bluegill (*Lepomis nigricans*) and largemouth bass (*Micropterus salmoides*). Also in North America, Neveldine *et al.* (2019) found that dredging channels in a homogeneous *Typha* habitat increased pike recruitment. However, evaluations of experimentally increasing habitat heterogeneity through reed removal in coastal bays seem to be absent from the literature.

Here we aim to investigate whether increasing the heterogeneity between reed and water by mechanically cutting lanes and lagoons in the otherwise homogeneous reed beds in one coastal bay (Supplementary Information Fig. S1) can improve conditions for predatory fish, primarily pike and perch (*Perca fluviatalis*) while reducing the abundance of mesopredatory prey fish, especially cyprinids which are important prey for perch and pike (Jacobson *et al.* 2019). We hypothesise that catch per unit effort of pike and perch would increase over time in the coastal bay with reed cutting relative to a reference bay with no reed cutting, while prey fish such as cyprinids and sticklebacks display the opposite pattern.

Material and methods

Study area and fish surveys

We compared community composition, catch per unit effort and body length of coastal fish during June-July 2019–2022 and 2025 in two coastal areas on the Island of Gräsö, off the Swedish Baltic Sea coast (Fig.1). In the Österbyn-Västerbyn bay area (~50 ha, Fig. 1), reed beds were cut in channels and lagoons (Supplementary Information Fig. S1) to increase the interface between reed and water. In total, around 3 ha, or app. 1/3 of all reed was cut around 30 cm below water surface in August each year 2019–2022 with a 'Truxor' amphibious machine (truxor.com) with the purpose to locally kill the reed. The Måssten bay area (28 ha, Fig. 1a) was the reference bay as it contains extensive reed beds but experienced no reed cutting or any other major human influence on the reed. Both bays have similar environmental conditions (Table 1). They

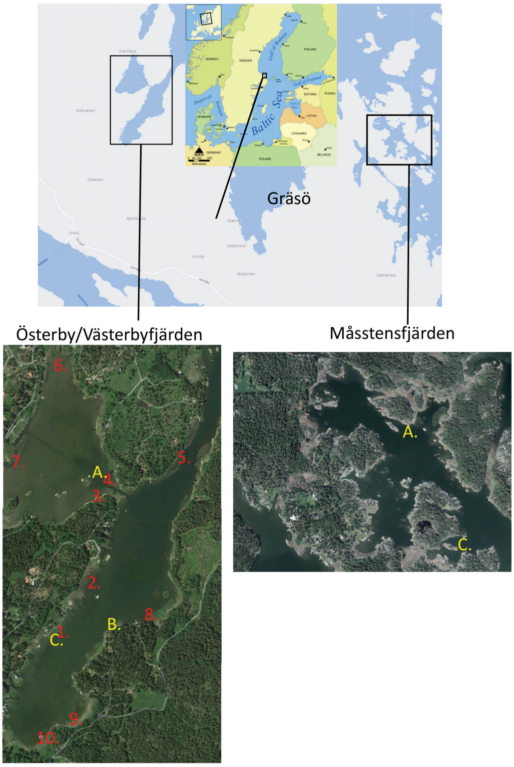

Fig 1. Map of the study area at the Island of Gräsö and the location of Gräsö in the Baltic Sea. Letters indicate the sites of the multimesh gillnet survey and numbers in Österby-Västerbyfjärden indicate underwater detonations (1-5 cut, 6-10 uncut) for larveae survey.

are shallow (< 3 m deep) with extensive submerged vegetation (*Chara* spp., *Myriophyllum* spp., *Potamogeton* spp., *Callitriche hermaphroditica* and *Ceratophyllum demersum*; Hjelm *et al.* 2007) and open towards deeper (> 10 m deep) more wave exposed archipelagos. There are no reed beds outside these two bays. In the summer following the first cut (2020), reed in the cut area regrew but was less dense. During the summers of 2021 and 2022, reed was largely absent in the cut areas (Supplementary Information Fig. S1). After the latest cut in 2022, reed has sparsely grown back into the cut areas but are still markedly more open than uncut reed in 2025.

We conducted fish surveys in both bays in late June or early July each year 2019–2022, and in 2025 to study longer term responses. The first fish survey was in June the same year as cutting started in August to have an estimate of species abundances prior to the reed cutting. Three multimesh survey gillnet of 'Nordic' type (SS-EN 14757) were used in each of the two bays (CEN 2015). These nets were set at the bottom, 1.50 m deep and 30 m long with twelve different mesh sizes in the range 5-55 mm. Multimesh nets are suitable for obtaining a representative catch of both smaller juvenile and lager adult fish of mobile species. In both bays, we deployed the survey gillnets outside reed beds (Fig. 1) as water depth is too low in the reed and we are interested in the effect of reed cutting on a bay scale. All nets were deployed 3–5 pm and pulled up at 7–9 am, the following morning. The whole catch was divided into species, counted and weighed. For large counts of small fish, i.e. bleak (*Alburnus alburnus*) and three-spined sticklebacks (*Gasterosteus aculeatus*), we weighed a subsample of around 100 fish and scaled up the total number of fish from the total weight of catch of that species. We individually measured length and weight of all perch ≥ 15 cm. To study the response of reed cutting on somatic growth of perch we from 2020 and later sampled the operculum bone of the ten largest perch individuals per net and year for back-calculation of size at age (Holmgren & Appelberg 2001).

Table 1. Mean and ± standard deviation of environmental variables at the two studied bays Österbyfjärden (Cut) and Måssten (Reference). 'At fishing' is the temperature and salinity measured at bottom at each survey gillnet, and 'Seasonal average' is the modelled environmental variables at surface (0.5 m) between June-August 2019–2023 from SMHI Waterweb (https://www.smhi.se/data/sjoar-och-vattendrag/vattenwebb/om-tjanster-i-vattenwebb/modelldata-per-omrade).

Area	At Fishing		Seasonal Average				
	Temp (˚C)	Salinity (‰)	Temp (˚C)	Salinity (PSU)	TOTN ($mg*m^{-3}$)	TOTOP ($mg*m^{-3}$)	CHLA ($mg\ chl*m^{-3}$)
Cut bay	15.8±1.78	4.7±0.38	16.35±1.95	5.03±0.19	262.2±3.51	11.4±0.46	1.69±0.34
Reference bay	15.9±1.56	4.9±0.45	15.82±2.02	5.02±0.19	262.2±4.1	11.2±0.54	1.53±0.40

As pike was a target species for the reed cutting but is poorly represented in gillnets due to its sedentary behaviour, we conducted rod-and-reel angling from boats targeting pike with a standardized set of rods, reels and lures. Each bay was fished each year for in total 8 h by two anglers from a boat over two days. One area was fished 4 h in morning and the other 4 h in the afternoon, and at the second fishing occasion the order of bays were swapped.

In September 2021, we did a fish larvae survey through small underwater detonations (Hav- vattenmyndigheten 2021), which kills or sedates larvae and small fish within a radius of approx. 5 m, allowing the sample to be collected with a net. We sampled fish larvae at ten stations in the Österby–Västerbyfjärden, but not in the Måssten bay. To study the effect of reed cutting, five stations (1–5 in Fig. 1) were from cut lagoons and channels, and five stations (6–10 in Fig. 1) were from areas where the reed beds were undisturbed.

Analyses

We used R ver. 4.0.4 (R core team 2021) for all statistical analyses. To study changes in fish community composition in multimesh nets we did an RDA using the vegan-package (Oksanen *et al.* 2020), with species specific catch in weight (g) per unit effort (WPUE) as dependent variables and year (categorical variable), bay area (cutting treatment) and their interactions as explanatory variables. Each net (three per year and bay) was used as a replicate. We $\log_e$(WPUE + 1) transformed dependent variables to reduce the variation of the most common species.

To study species-specific changes in abundance of perch and cyprinids, dominated by roach (*Rutilus rutilus*) and bleak but also including rudd (*Scardinius erythrophtalmus*), bream (*Abramis brama*), and white bream (*Blicca bjoerkna*) we used WPUE as the dependent variable in ANOVA:s with year, bay area (cut/no-cut) and their interaction as explanatory variables. We also studied changes in the predator-to-prey ratio between perch (predator) and cyprinds as the log-ratio between WPUE of perch and all cyprinid species. For pike we studied changes in number of pike caught as a dependent variable in a generalised linear model (GLMM) with Poission distribution and effort (fishing hours) as an offset.

To study changes in size distributions of perch and pike we used size class, rounded downwards to nearest centimetre, of all individuals ≥ 15 cm as dependent variable in ANOVA:s. In all analyses, we interpret a significant interaction between year and bay area as a significant cutting effect. A main effect of bay area is interpreted as effects of consistent differences in the environment between the two bays not related to reed cutting, whereas a main year effect is interpreted as an effect of annual regional environmental variation affecting fish communities. QQplots of the residuals are available in Supplementary Information Fig. S2.

We estimated back-calculated length at age of female perch (too few males were sampled as we selectively sampled the largest individuals) from the operculum bone (Holmgren & Appelberg 2001) and calculated size-specific somatic growth G_L (cm yr^{-1}) as:

$$G_{L,n} = L_{n,i+1} - b_g \times L_{n,i}, \tag{1}$$

where $L_{n,i}$ is the estimated length of perch n at age i, and $L_{n,i+1}$ is the estimated length of the same perch at age i+1 (the length at catch was omitted for all individuals as sampling occurred during growing season). b_g is the slope of the linear regression model $L_{n,i+1} = a + b_g \times L_{n,i}$ for all female perch in the dataset. Thus, b_g is the size-specific scaling coefficient of somatic growth. To analyse if body growth differed between study areas before and after reed cutting, we used linear mixed models (LMM) (Morrongiello & Thresher 2015; Berggren *et al.* 2022). We used individual, Cohort (year of birth) and Year as random intercept factors. Individual accounts for correlation in growth between years due to the repeated sampling on the same individual, Cohort accounts for correlation in growth between individuals spawned in the same year, and Year accounts for other factors that vary between years but not considered in the model (Morrongiello and Thresher 2015). All perch sampled for back-calculation of size-at-age were sampled after reed cutting had started, but as

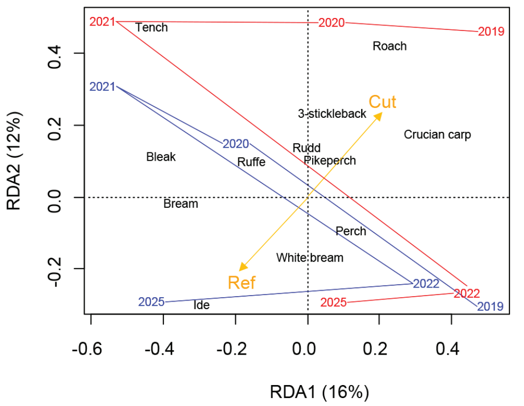

Fig 2. Biplot from the RDA of fish community composition between the cut area (red) and the reference area Måssten (blue) in 2019–2022 and 2025. Years are calculated based on average WPUE for each year and bay. Fish species with < 5 observations are omitted from the figure for clarity. Percentages are the proportion of total variation explained by the corresponding axis.

body sizes could be back-calculated we could estimate average annual growth from 2016 and later. We included Bay area (cut/reference) and Period and their interaction as fixed factors in the LMM, where Period is a categorical variable of years before the reed cutting (2016–2019) and after reed cutting (2020–2024). A significant interaction between Bay area and Period would indicate that perch have grown differently in the two bays before and after the reed cutting.

To analyse the difference in number of young-of-the-year and small fish in the underwater detonation survey we did an RDA with $\log_{10}$(BM +1) transformed (to reduce the variation of the most common species) biomasses (BM) in milligram of fish of each species as the dependent variables. Cut or uncut area was the only explanatory variable (only sampled one year).

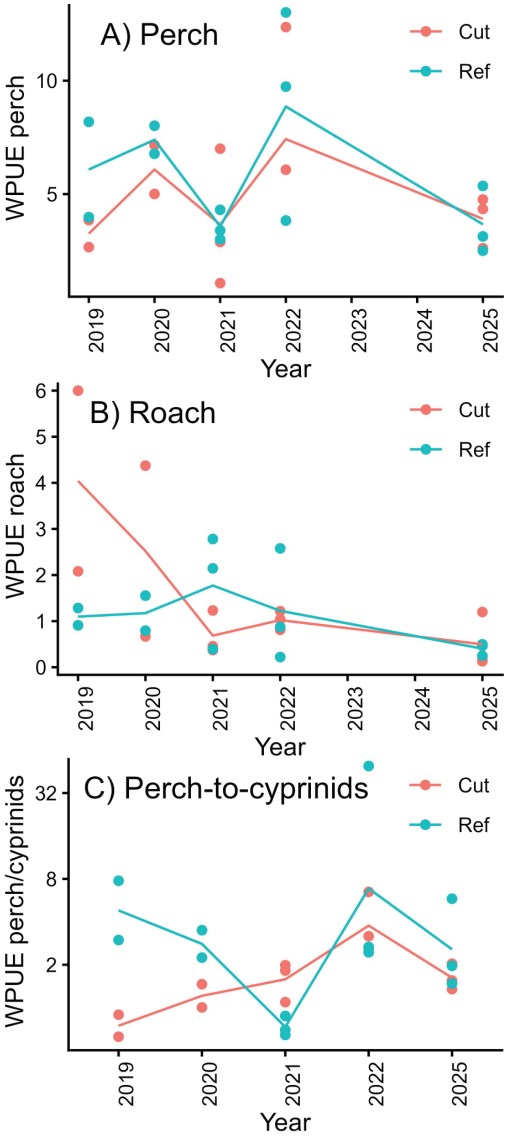

Fig 3. Comparisons between reed cutting (Cut) and reference bay (Ref) in 2019–2022 and 2025, showing: **A**) total weight of perch per net (WPUE), **B**) total weight of cyprinids per net (sum of bleak, bream, crucian carp, ide, roach, rudd, tench, white bream), and **C**) the ratio of total weight (WPUE) of perch to cyprinds.

Results

Gillnet survey

Although the fish communities of the two bays seemed to become more similar over time, there was no significant 'Year×Treatment' effect on species composition (RDA: $F_{4,16}$ = 0.9, p = 0.6; Fig. 2), only a significant difference among years (RDA: $F_{4,16}$ = 2.5, p = 0.001; Fig. 2). Perch catches (WPUE) differed between years (ANOVA: $F_{4,16}$ = 3.0, p = 0.05) but did not between bays over time (ANOVA: Year×Treatment $F_{4,16}$ = 0.3, p = 0.9; Fig. 3A).

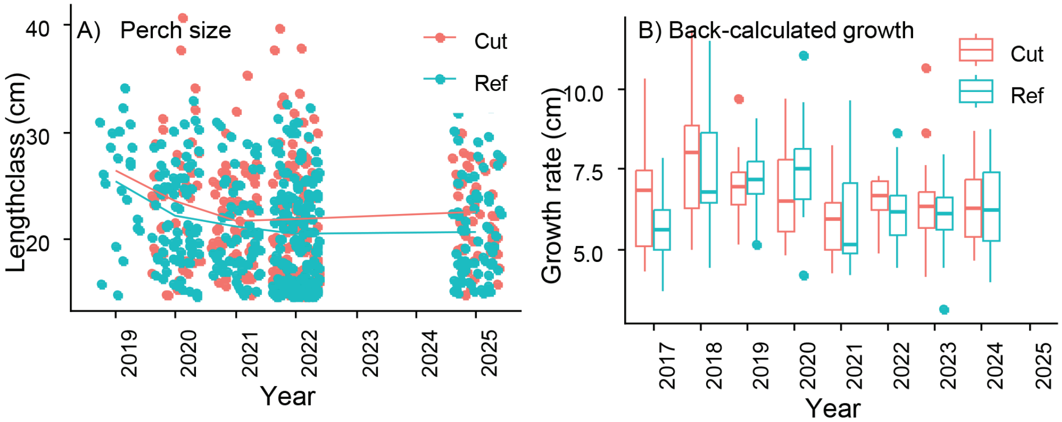

Fig 4. **A**) Length of individual perch from catches in multimesh nets in the reed cut (Cut) and the reference bay (Ref) in 2019–2022 and 2025. **B**) Estimated standardized back-calculated annual growth of individual perch from catches in multimesh nets.

Perch was significantly larger in the cut area (ANOVA: $F_{1,698} = 12$, $p < 0.001$) and differed between years (ANOVA: $F_{4,698} = 10$, $p < 0.001$), but with no significant 'Year×Treatment' interaction (ANOVA: $F_{4,698} = 0.3$, $p = 0.9$; Fig. 4A). There was also no significant 'Treatment×Period' (before-after reed cut) interaction on back-calculated growth of perch (LMM: $F_{1,204.8} = 0.5$, $p = 0.5$; Fig. 4B).

The catch of cyprinds (WPUE) decreased in the cut area in Österby–Västerbyfjärden from 6 kg/net to around 3 kg/net during 2021–2022 and 2025 (Fig. 3B). At the same time in the reference bay Måsstenfjärden the catch of cyprinids varied between 2–5 kg/net per year with a peak in 2021, resulting in a significant 'Year×Treatment' interaction (ANOVA: $F_{4,16} = 5.9$, $p = 0.004$; Fig. 3B). Hence, the trophic structure changed significantly (ANOVA: 'Year×Treatment' interaction: $F_{4,12} = 3.6$, $p = 0.03$) with an increasing ratio of perch to cyprinids in the cut area from 0.5 before cutting 2019 to around 1–2 after cutting (Fig. 3C). In the reference bay the ratio of perch to cyprinids declined until 2021 but was similar to the cut area in 2022 and 2025 (Fig. 3C).

Pike angling

There was a significant Year×Treatment interaction on pike catches (GLMM: $\chi^2_{(4)} = 64$, $p < 0.001$), due to a slower decline in catches 2019–2022 and a faster recovery between 2022–2025 in the cut area relative to the reference bay (Fig. 5A). The size distributions of pike differed between bays (ANOVA: $F_{1,71} = 29$, $p = 0.003$) and years (ANOVA: $F_{4,71} = 3.9$, $p = 0.01$), but there was no statistically significant interaction between them (ANOVA: $F_{3,71} = 2.3$, $p = 0.083$; Fig. 5B).

Larvae survey

Of the ten underwater detonations in the reed cut area Österby–Västerby bay, five were in cut areas and four (one station was so shallow that there was no fish larvae) in areas with no lagoons and channels. The cyprinids bleak, roach, white bream and rudd dominated the small fish and larvae community, with some perch in a few stations (Fig. 6) and one pike at one station. There was an overall difference in composition between cut and uncut areas (RDA: $F_{1,7} = 2.9$, $p = 0.04$; Fig. 6A), with most notably more rudd and bleak in cut areas (Fig. 6B).

Discussion

The main statistically supported changes in fish communities at a bay scale following the cut-

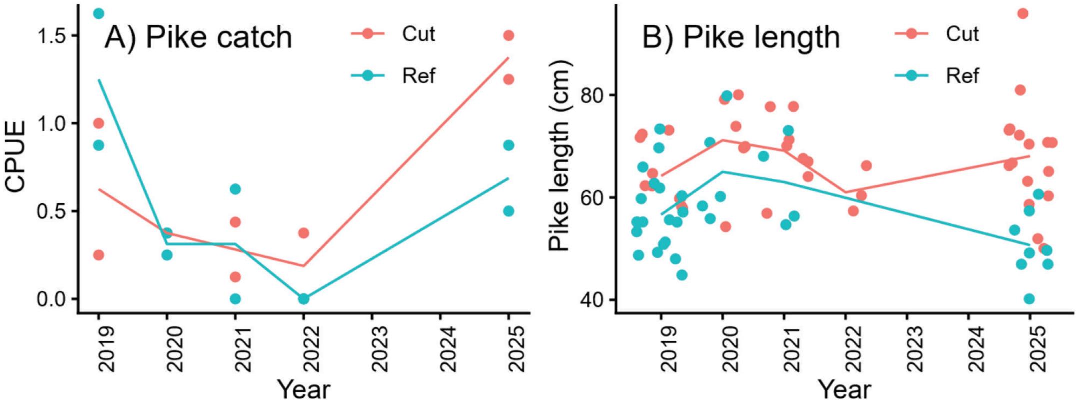

Fig 5. A) Pike catches (per fishing hour and person) in a rod-and-reel angling survey from a boat in 2019–2022 and 2025 in the reed cut area (Cut) and the reference bay (Ref). **B**) Individual lengths of pike caught. In 2022 no pike were caught in the reference bay so no length distribution could be estimated.

ting of lagoons and channels in the reed were a reduction in the abundance of cyprinids and a relative increase in pike catches in the cut bay compared to the reference bay, as indicated by significant Year×Treatment interactions. We could not find any response in the body size of perch or pike, nor any change in the somatic growth of perch following the reed cutting. The fish larvae and small fish community also differed between cut and uncut reed areas *within* the bay subject to reed cutting, showing in particular more rudd and bleak larvae in cut areas, but generally few young-of-the-year predatory fish in the reed at all.

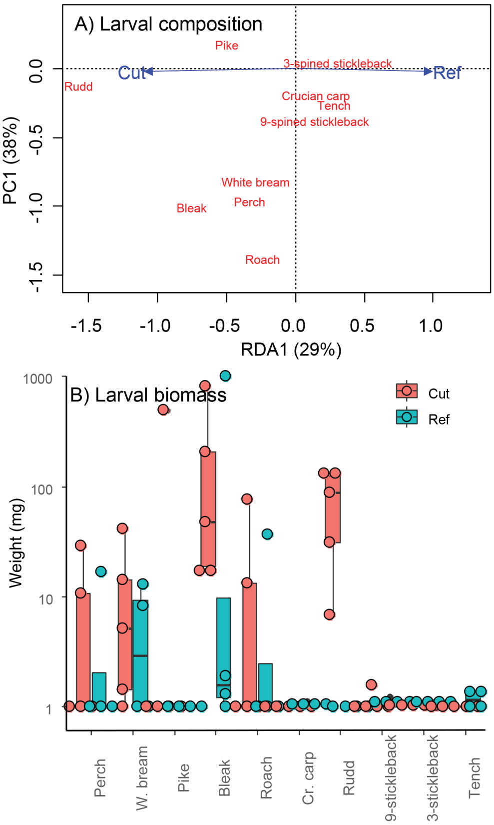

Fig 6. A) Biplot from the RDA of fish larvae composition and B) Catch per species from reed areas where reed was cut (Cut) and areas where reed was left uncut (Ref) in Österbyfjärden (see Fig. 1) in September 2021.

The primary aim of the reed cutting was to improve the conditions for predatory fish, mainly pike and perch in this study system. It should first be noted that the between year dynamics were similar for the respective species indicating clear between-year variation in both bays. Pike showed similar trends in both bays with declining catches 2019–2022, observed also in other pike populations in the Baltic Sea region (Olsson *et al.* 2023). Between 2022–2025 pike catches recovered in both bays, possibly due to several factors such as improved protection (Eklöf *et al.* 2023) and recruitment (Nilsson 2006), or recovery of submerged vegetation (Hansen *et al.* 2019). In any case, the recovery was faster in the bay where reed was cut. For perch, there was no clear trend in catches, which instead likely reflected between year variation in environmental factors (e.g. temperature; Östman *et al.* 2017; Naddafi *et al.* 2022).

The relative increase in pike catches in the bay subject to reed cutting compared to the reference bay suggests increased local pike abundance in the cut bay relative the reference bay. This pattern may reflect a positive response of pike to the increased habitat heterogeneity and reed–water interface created by lagoons and channels, although other factors cannot be ruled out. In a previous study from nearby coastal bays, we found pike abundance positively correlated with reed abundance (Niemi *et al.* 2023), but we could not separate this from more heterogeneous reed beds, as larger reed beds were also on average more heterogeneous. Taken together these two studies suggest extensive, but also heterogeneous reed areas, are favourable for local pike abundance.

For neither pike nor perch did we detect any significant influence of reed cutting on size distributions or growth, using these variables as proxies for food intake. For pike, there was a tendency toward a treatment effect on body size distribution ($p = 0.083$), driven by smaller pike in the reference bay in 2025, but this pattern could also reflect a cohort effect if adult population sizes had been low several years earlier. The average body size of both species was larger in the bay with reed cutting, but this difference was evident already before the cutting started in 2019. This is in line with the spatial comparison among nearby bays where no clear association between amount of vegetation and pike body size was observed (Niemi *et al.* 2023) but differs from the results of Olson *et al.* (1998) who found that macrophyte removal increased the body growth of piscivorous fish in a North American lake. Although vegetation structure is important for the habitat use of piscivorous fish in relation to body size (Eklöv 1997; Olson *et al.* 1998; Lehtonen *et al.* 2009), with smaller piscivorous fish in densely vegetated areas, in this Baltic Sea region, body size of piscivores at a bay level seems to be driven mainly by factors other than reed vegetation.

One potential factor counteracting any positive influence of reed cutting on size and growth of predatory fish was the significantly reduced catches of cyprinids in the cut bay. This decline led to an increased predator to prey ratio after reed cutting, a trend that was not observed in the reference area. Although reed cutting in theory should facilitate foraging by predatory fish, this may be counteracted by a lower prey abundance. Donadi *et al.* (2017) observed a similar pattern in a comparative study across coastal bays in the Baltic Sea, but for another prey fish, the three-spined stickleback. Catches of three-spined stickleback increased with vegetation cover, while predatory fish abundance did not. Taken together, these studies may suggest that vegetation effects are stronger on mesopredatory prey fish than on piscivorous fish, but further studies are needed to corroborate this pattern.

The reduced abundance of cyprinids may be desirable as these species feed on zooplankton and grazers that are important for promoting habitat forming macrophytes by controlling filamentous algae (Duffy *et al.* 2013; Östman *et al.* 2016; Donadi *et al.* 2017). We cannot identify to what degree the observed change in cyprinid abundance was a direct effect of predation by perch or pike, or an indirect effect of prey fish behaviour. The (~50%) decline in cyprinid abundance the year after the first reed cutting may indicate a behavioural response to reed cutting. Indirect effects of predators on prey behaviour may have a larger impact than direct predation (Brown *et al.* 1999; Werner & Peacor 2003; Monk *et al.* 2021). Reed cutting may facilitate predatory fish to attack prey fish and increase predation, but here we cannot determine if this drives prey fish away from reed areas with cut lanes and lagoons towards other areas or alternatively induces more cautious behaviours.

We hypothesized that reed cutting would improve recruitment of young of the year (YOY) perch and pike; however, we found very few YOY perch or pike in our larvae and small fish samples. This can indicate that the bay in general is not very suitable for reproduction of predatory fish, which seems unlikely given the shallow, vegetated areas. Instead, a more likely explanation is that YOY predatory fish do not use the cut reed areas extensively (see Eklöv 1997), at least not during daytime at the time of sampling, although this remains to be tested with targeted studies. It may be that the risk of cannibalism is too high or the YOY are more dependent on other vegetation structures such as submerged macrophytes (Sandström *et al.* 2005; Hansen *et al.* 2019).

Our study uses a 'Before-After-Control-Impact' (BACI) design that is more robust than simpler study designs lacking control or pre-impact data (Christie *et al.* 2019). Still, we only had one impact and one control (reference) bay. We can therefore not exclude that there are some other confounding variables driving the observed differences between bays over time. Consequently, inferences about reed cutting effects should be viewed as site specific and indicative rather than generalizable for other coastal areas. Future studies would be valuable to confirm these observed patterns. Although reed management is a relatively common phenomena in lakes and coastal areas with abundant emergent vegetation (mainly for recreational purposes), we find there is a need to evaluate reed management as a measure to also improve the ecological status of fish communities.

Conclusions

Cutting lagoons and channels into the reed showed some desirable changes in the local fish community relative to a reference area, in particular increasing pike abundance and decreasing abundance of mesopredatory prey, as well as increasing predator-prey ratios. For the targeted species of pike and perch there was considerable year-to-year variation in abundance and size distribution, suggesting other more regional factors may still be more important. Based on this single comparison between bays, we conclude that reed management by cutting channels and lagoons into otherwise homogeneous reed beds may be one action that could improve the status of coastal fish communities, but more studies are required to assess the generality of ours results. From the context of the EU's Marine Strategy Framework Directive, reed cutting could be one measure to help reach desirable environmental status in areas with too many cyprinids and lots of reed or other emergent vegetation.

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