Boating and Navigation Activities Influence the Recruitment of Fish in a Baltic Sea Archipelago Area

We studied the effects of boating and navigation activities on the recruitment of coastal fish in the Stockholm archipelago in the NW Baltic proper. The impacts were quantified by sampling metamorphosed young-of-the-year (Y-O-Y) fish in inlets adjacent to i) routes for medium-sized passenger ferries; ii) berths (small marinas) with small boats; and iii) references. Species with high preference for vegetation were negatively influenced by boating and navigation activities and species with low preference positively influenced. Pike (Esox lucius) Y-O-Y were significantly more abundant in reference areas, while bleak (Alburnus alburnus) were more abundant in dredged marinas. No statistically significant patterns were identified for perch (Perca fluviatilis) although there was a trend of low abundance along ferry routes. Many species of nearshor fishes are dependent on submerged vegetation as spawning and larval substrate, structural refuge and feeding habitat. Our results suggest that the negative effects from boating and navigation activities on the coverage and height of vegetation, especially on species of Chara and Potamogeton spp., may contribute to changes in the Y-O-Y fish community.

INTRODUCTION

Importance and State of Nursery Areas for Fish in the Baltic Coastal Zone

The early-life mortality of fish is often extremely high, hence, the conditions of their nursery habitats frequently regulate the size and dynamics of the adult populations (1). The survival of juveniles in temperate areas is normally highly dependent on their ability to outgrow and escape potential predators and to avoid over-winter mortality (2, 3). In the relatively cold Baltic Sea, temperature and feeding conditions for larvae and juveniles of many species are only suitable in the most shallow and sheltered coastal areas (4–6). The high potential for production of young-of-the-year (Y-O-Y) in such areas is also further enhanced by the availability of suitable spawning substrates and structural refuges consisting of vegetation (7–9). In the last 5–10 years, marked decreases in catches of freshwater species such as pike (Esox lucius) and perch (Perca fluviatilis) have been reported from many coastal areas in the Baltic (10–12). The decline has been attributed to recruitment failure (13). The cause of the problem has not yet been revealed, but it nevertheless accentuates the importance of protecting functioning recruitment areas to sustain strong coastal fish stocks.

The influence of anthropogenic disturbances on fish reproduction and recruitment has been investigated to some extent, especially the effects from eutrophication (7, 14, 15) and effluents from pulp mills (16). Many other types of potential disturbances are, however, less well understood. One commonly occurring disturbance in sheltered nursery areas is boating and navigation—in this paper defined as the traffic of small and medium-sized boats and the activities associated with them, e.g. physical arrangements of the shoreline and dredging. Dredging has been particularly extensive in the northern Baltic due to gradual land uplift (up to 11 mm per year). Hence, dredging is often used to maintain the access of boats to berth places.

It can be hypothesized that boating and navigation activities affect fish recruitment via a number of mechanisms. Direct effects on eggs and larvae may stem from the shear stress from propellers (17), emissions of toxic substances (18) and return currents and waves from passing vessels causing eggs and larvae to wash up onto the shore (19). The composition and coverage of submerged vegetation as well as temperature and visual conditions are also influenced by boating and navigation (20).

The objective of this study was to quantify the effects of potential disturbances from boating and navigation activities on recruitment areas for nearshore fish in a Baltic archipelago area. An extensive field survey investigating the abundance and composition of Y-O-Y fish was targeted to i) areas affected by the traffic of small- and medium-sized passenger ferries; and ii) berth places (marinas) for small- and medium-sized boats (< 10 m in length).

MATERIALS AND METHODS

The study was carried out in August – early September 2001 in the Stockholm archipelago, an extensive area on the Swedish east coast in the NW Baltic proper that consists of approximately 30 000 islands and small islets. The Baltic Sea is practically without tidal fluctuations and is brackish, with a clear gradient from the south (Baltic Sea proper 6–17‰) to the north (Bothnian Sea ca 3–5‰, Bothnian Bay < 2‰). The surface salinity in the investigated areas varied from 4.5 to 5.4‰.

The number of species and the abundance of Y-O-Y fish were monitored in inlets adjacent to marinas for small boats (N = 12), in the vicinity of ferry routes (N = 15) for small- and medium-sized ferries (25–40 m). Reference areas with no significant boating activities were also monitored (N = 9). We selected the inlets in order to have a considerable, but not extreme, variation in exposure and a minimum of influence from other anthropogenic sources of disturbance. The size of the inlets varied from 1 to 11 ha and their depths did not exceed 5 m.

We sampled young fish using small underwater detonations (0.94 g explosives) that stun fish within an area of approximately 15 m². The number of samples in each inlet was proportional to the size of the inlet and varied from 11 in the smallest to 24 in the largest inlet (total number of samples in references = 166, marinas = 172, ferry routes = 173). The detonation technique allows point sampling of fish with swim-bladders (21) in all habitats present in the coastal zone, including dense vegetation. All fish remaining in the water column after a detonation were netted, determined as to species and counted. Since a small percentage of the fish also sink to the bottom, the method is mainly used for relative comparisons of fish abundance. The sample locations in the inlets were distributed randomly within different strata. The stratification was based...
on depth and vegetation type. Data on depth and vegetation composition were collected for each inlet by a skin diver swimming along parallel transects (30 m apart), 1–2 weeks prior to sampling the fish (20). In order to obtain a measure of Y-O-Y species diversity for each inlet that was not depending on one single sampling method and that covered species without a swim-bladder (in this study: turbot (Psetta maxima) and flounder (Platichthys flesus)), two complementary sampling techniques were used. Firstly, the diver registered Y-O-Y fishes visually along the transects during the vegetation survey and secondly a beach seine was towed towards the shoreline at one randomly allocated site in each inlet.

Morphological characteristics like area, shoreline length, shape of the shoreline and opening width were calculated using digital nautical charts. The total number of berths for boats was also counted. Dredging activities were registered using data from permission records at the Municipal Administration Board, combined with observations in the field. The majority of dredging activities either increased the depth in the mouth of the inlets or the areas in the vicinity of docks and other berths. Automatic recorders located at 1-m depth, registered temperature every second hour from early May to late October in 15 of the inlets. In addition, measures were taken by hand at least three times during this time period in all of the inlets. Based on these data, deviation from mean temperature, calculated by using daily means from the automatic recorders, was estimated for all inlets. Turbidity was measured at 3–4 localities in each inlet with a turbidimeter calibrated with formacin, measuring turbidity in Nephelometric Turbidity Units (NTU). We also estimated wave-exposure for each inlet using the software WaveImpact (WI) that uses grids from a geographic information system (M. Isaeus, unpubl. data). WI uses wave data and the distance from which waves can potentially collect wind energy before reaching a site, and produces an exposure index that considers both the position of the inlet within the archipelago and inlet morphology.

Data Analysis

Since the majority of the fish species in the current study have a strong tendency to form schools the abundance data were seldom normally distributed. Therefore, for each inlet, we used the mean number of individuals for each species registered in the detona- tions (mean catch per unit effort) as input data in all analyses and figures. In the analysis of the number of species, data from sampling efforts with the beach seine and the visual observations were also used. The total number of species in each inlet, all three methods considered, was used as the statistical unit in all analyses on species diversity. To further normalize distributions before analyses we transformed data as follows: fish abundance data were square-root-transformed, vegetation data arcsine-transformed and other environmental variables log-transformed.

Firstly, we examined the species composition of fish in the inlets by performing a detrended correspondence analysis (DCA). The DCA describes the major patterns in species data without regard to environmental data (CANOCO 4.0) (22). From this, we produced ordination figures that show the interrelationship between different fish species and their relative abundance in the inlets. Secondly, we tested differences in fish abundance between inlets subject to different levels of disturbance by boating and navigation (marinas, ferryboat routes, and reference inlets) and dredging (dredged or not dredged inlets), using analysis of co-variance (ANCOVA). In these analyses we included the most common species (perch, pike, roach (Rutilus rutilus) and bleak (Alburnus alburnus)), species number and functional groups of fish based on temperature and association to vegetation (Table 1) as dependent variables. In all ANCOVA analyses we compensated for differences between inlets that depended on inlet morphology and position in the archipelago, by incorporating wave impact, inlet area and sampling depth as co-variables. Inlet area correlated strongly with all other measured aspects of inlet morphology.

RESULTS AND DISCUSSION

Species Composition: Correlated to Dredging

The displayed pattern in fish species composition based on the two first axes produced by the detrended correspondence analysis explained 39% of the species variation in the data-set (eigenvalues for the four first axes were: 0.66, 0.53, 0.19, 0.01) (Fig. 1a and b). The pattern of species distribution shows that breams (Abramis brama and Abramis bjoerkna), perch, roach, rudd (Scardinius erythrophthalmus) and tench (Tinca tinca), commonly occur together in many types of inlets, while the occurrence of pike, bleak, ruffe (Gymnocephalus cernuus) and gobies (Potamocharistus spp.) were not as distinctly associated with that of other species (Fig. 1a). The distribution of inlets along the same two axes show that reference inlets and marinas are separated in space, indicating that...
Many of the common species that the DCA-analysis comprises, e.g. perch and roach, are positioned on the border (Fig. 1a) between dredged and non-dredged inlets, and probably occur commonly in both habitats. This border is also identical to the division line between reference inlets and marinas, which makes conclusions as to what disturbance contributes most to the displayed pattern in species composition difficult. This is illustrated by the occurrence of bleak and pike, which was related to the presence of dredging activities. Both species also showed a clear affinity for marinas and reference inlets, respectively. The distribution pattern of the remaining species, e.g. gobies, is less associated to that of other species and seems to be related to the presence of routes for passenger ferries. Therefore, while dredging seems to be a very important variable for the species composition in the inlets, it is difficult to separate the influence of dredging from the influence of direct disturbances related to boating and navigation.

We found no effects on species richness in inlets disturbed by boating and navigation (ANCOVA, F = 0.76, p > 0.05) or dredging (ANCOVA, F = 0.40, p > 0.05). This suggests that effects of boating activities alter species composition by affecting species with dissimilar life-history traits differently, thus favoring some species and suppressing others.

### Species Dependent on Vegetation are Negatively Influenced by Boating and Navigation

An important characteristic that may explain a significant part of the species pattern generated in disturbed inlets was the dependence of some fish species on vegetation for successful recruitment (Table 1). Fish species that are highly dependent on vegetation as spawning substrate and refuge/feeding habitat during their early life stages clearly tend to be more abundant in reference inlets than in inlets disturbed by boating and navigation (ANCOVA, F = 2.84, p = 0.07) (Fig. 2a). We detected no such differences between dredged inlets or non-dredged inlets. Accordingly, the abundance of species highly dependent on vegetation was significantly correlated to the cover of *Chara tomentosa* (Pearson’s correlation, n = 35; r = 0.58; p < 0.017) and *Potamogeton pectinatus* (Pearson’s correlation, n = 35; r = 0.40; p < 0.017). These are plants that have been shown to be negatively affected by boating activities (20).

We found no differences between dredged inlets and those affected by boating and navigation for species that are moderately dependent on vegetation. However, species classified as independent of vegetation had a significantly higher abundance in marinas than in other types of inlets (ANCOVA, F = 3.62; p < 0.038) and were also significantly more abundant in dredged inlets compared to non-dredged inlets (ANCOVA, F = 10.8; p < 0.01). These species correlated negatively to vegetation height in the inlets (Pearson’s correlation, n = 35; r = -0.47; p < 0.017). Vegetation height has recently been shown to be negatively affected by navigation and boating, mainly as a consequence of increased wave exposure (20) (G. Sundblad, M. Isaevs and A. Sandström, unpubl. data). Thus, effects of such activities on the composition and height of the vegetation are clearly indicated also by our results.

### Table 1. Observed species listed in order of appearance (common species at the top and rare species at the bottom) and classified according to their dependence of vegetation and preference and sensitivity to temperature during early life-stages.

<table>
<thead>
<tr>
<th>Species</th>
<th>Latin</th>
<th>Temperature preference</th>
<th>Vegetation preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perch</td>
<td><em>P. fluviatilis</em></td>
<td>high</td>
<td>moderate</td>
</tr>
<tr>
<td>Roach</td>
<td><em>R. rutilus</em></td>
<td>high</td>
<td>strong</td>
</tr>
<tr>
<td>Bleak</td>
<td><em>A. alburnus</em></td>
<td>high</td>
<td>weak</td>
</tr>
<tr>
<td>Gobies</td>
<td><em>P. pungitius</em></td>
<td>low</td>
<td>moderate</td>
</tr>
<tr>
<td>Pike</td>
<td><em>E. lucius</em></td>
<td>strong</td>
<td>high</td>
</tr>
<tr>
<td>Herring</td>
<td><em>C. harengus</em></td>
<td>low</td>
<td>weak</td>
</tr>
<tr>
<td>Silver bream</td>
<td><em>A. björkna</em></td>
<td>strong</td>
<td>high</td>
</tr>
<tr>
<td>Bream</td>
<td><em>A. brama</em></td>
<td>strong</td>
<td>high</td>
</tr>
<tr>
<td>Three-spined stickleback</td>
<td><em>Gasterosteus aculeatus</em></td>
<td>low</td>
<td>moderate</td>
</tr>
<tr>
<td>Rudd</td>
<td><em>S. erythropthalmus</em></td>
<td>high</td>
<td>strong</td>
</tr>
<tr>
<td>Small sandeel</td>
<td><em>A. tobians</em></td>
<td>low</td>
<td>weak</td>
</tr>
<tr>
<td>Minnow</td>
<td><em>P. p. phoxinus</em></td>
<td>low</td>
<td>moderate</td>
</tr>
<tr>
<td>Nine-spined stickleback</td>
<td><em>P. pungitius</em></td>
<td>low</td>
<td>moderate</td>
</tr>
<tr>
<td>Pipefishes</td>
<td><em>N. syngnathys</em></td>
<td>low</td>
<td>strong</td>
</tr>
<tr>
<td>Ruffe</td>
<td><em>G. cembus</em></td>
<td>high</td>
<td>moderate</td>
</tr>
<tr>
<td>Turbot</td>
<td><em>P. maxima</em></td>
<td>low</td>
<td>weak</td>
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<tr>
<td>Tench</td>
<td><em>T. tinca</em></td>
<td>high</td>
<td>strong</td>
</tr>
<tr>
<td>Flounder</td>
<td><em>P. flesus</em></td>
<td>low</td>
<td>weak</td>
</tr>
<tr>
<td>Pikeperch</td>
<td><em>S. lucioperca</em></td>
<td>high</td>
<td>weak</td>
</tr>
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</table>

* low = optimum temperature for consumption < 20 °C and optimum temperature for survival of embryos < 10 °C. high = optimum temperature for consumption > 20 °C and optimum temperature for survival of embryos > 10 °C.

** Species depending on vegetation as spawning substrate and with both larval and juvenile life stages strongly associated to vegetation, moderate = species depending on vegetation as spawning substrate and/or associated to vegetation during some early life-stage, weak = other spawning substrate and not associated to vegetation during any of the early life stages.
etation seem to be an important change in habitat conditions that has significant effects on fish communities in shallow inlets in the Stockholm archipelago.

Pike and Bleak: Strongly Affected by Boating and Navigation

Of the most common species, pike and bleak showed statistically significant differences in abundance between inlets subjected to disturbances from both boating, navigation and dredging. Pike occurred in higher abundance in reference inlets than in inlets disturbed by boating and navigation activities (F = 7.76; p < 0.01) and in non-dredged inlets, compared with dredged inlets (ANCOVA, F = 8.59; p < 0.01) (Fig. 2b). Pike belongs to the group of species strongly dependent on vegetation for reproduction. Accordingly it also correlated significantly with the cover of Chara tomentosa (Pearson’s correlation, n = 35; r = 0.51; p < 0.01) and Potamogeton pectinatus (Pearson’s correlation, n = 35; r = 0.44; p < 0.01), as well as with vegetation height (Pearson’s correlation, n = 35; r = 0.48; p < 0.01). Bleak showed almost the opposite distribution and was significantly more abundant in marinas and dredged inlets, in both cases (ANCOVA, F = 4.17; p < 0.05; F = 9.45; p < 0.01). Bleak belongs to the group of species classified as independent of vegetation and showed a tendency to be negatively correlated with vegetation height (Pearson’s correlation, n = 35; r = -0.39; p < 0.02), but also positively with turbidity (Pearson’s correlation, n = 35; r = 0.38; p < 0.02) (Fig. 3).

Perch: Abundant in Dredged Marinas and Less Abundant along Ferry Routes

We found no significant differences in abundance of perch between the disturbed inlets and reference inlets, but there was a tendency towards perch being more abundant in dredged inlets (ANCOVA, F = 3.28; p = 0.08) and less abundant in inlets adjacent to routes for passenger ferries (Fig. 4). The abundance of perch showed a positive relationship with the temperature in the inlets (Pearson’s correlation, n = 35; r = 0.53; p < 0.001), however, the temperature was not significantly different in dredged inlets compared with non-dredged inlets (Fig. 4). Temperature was significantly lower in inlets adjacent to routes for passenger ferries compared with reference inlets (ANCOVA, F = 3.62; p < 0.05).

Since dredging had a significant effect on the results, we conducted a complementary analysis where all dredged localities were excluded. All of the marinas were dredged and thus excluded. The abundance of fish as well as abiotic parameters in reference inlets were therefore only compared with non-dredged inlets located close to routes for passenger ferries. This analysis showed that in inlets not disturbed by dredging, both the abundance of perch as well as temperature were significantly higher in reference inlets compared with inlets adjacent to routes for passenger ferries (ANCOVA, F = 7.74; p < 0.05; F = 5.77; p < 0.05). Lower temperature could thus explain the lower abundance of perch along ferry routes. The lower temperature could be a result of differences in inlet morphology or possibly enhanced water exchange due to strong currents from passing boats altering the temperature conditions.

Although temperature differed between the inlet categories, there were no differences in abundance of species belonging to
the different temperature groups (low and high temperature preference) (Table 1). One reason could be the lack of detailed data on temperature requirements of early life-stages, which would have allowed a more precise classification of species in this respect. In the present categorization, the majority of abundant species fell into the group of species with high temperature preference.

Potential Causes of Recruitment Effects

Boating/navigation activities potentially influence reproduction and survival of young fish via a number of possible mechanisms. Our results suggest the indirect consequences on vegetation height and composition as key factors. As showed in a parallel study, boating activities may have species-specific effects on communities of plants and macroalgae in shallow and sheltered soft-bottoms (20). The vegetation communities are influenced through direct physical disturbance from, e.g. propellers, hulls, and increased wave-action and indirectly via elevated turbidity, sedimentation, and substrate changes. The importance of vegetated areas as nursery habitats for fish has been demonstrated in numerous other studies (9, 23–25). Similar to our results, Bryan and Scarnecchia (26) also found significant disturbances in nearshore nursery areas as a consequence of vegetation removal in a North American glacial lake. Aquatic plants and macro-algae offer spawning substrate and help the vulnerable young life-stages to avoid predation by offering refuge. They also host numerous zooplankton and macroinvertebrates that young fish can feed on. Pike is even attached to vegetation during early larval stages.

The inlets affected by boating/navigation activities had higher levels of turbidity, which can alter the behavior of young fish (27) and, depending on species and size, affect their foraging ability (28). Turbidity was significantly higher in marinas compared with reference inlets (ANCOVA, \( F = 5.29; p < 0.05 \)) and in dredged inlets compared with non-dredged inlets (ANCOVA, \( F = 11.17; p < 0.01 \)) (Fig. 3). Species equipped with sensory physiological adaptations that enhance light and lateral line sensitivity, e.g. ruffe and pikeperch, have been hypothesized to be favored by turbid conditions (7, 29, 30). Other species, like perch and pike, are better adapted for feeding in clear and brightly lit environments and would be negatively affected (7, 31, 32). The only species that was significantly correlated to turbidity, however, was bleak, which was more abundant in the most turbid inlets (Fig. 3). It is unclear whether this species does well in turbid environments in general, but due to their small size as juveniles they are especially vulnerable to predation. Inference for turbid inlets could be interpreted as a consequence of predation avoidance (33, 34). The use of diving as a survey method for vegetation prevented us from investigating disturbed inlets with turbidity levels higher than about 10 NTU. Thus, turbidity could potentially influence the Y-O-Y fish communities to a greater extent than what the present study implies.

Large boats produce return currents that have been shown to influence fish recruitment. The waves and currents may influence fish indirectly by altering the habitat conditions, e.g. vegetation and shoreline erosion. Direct effects are less well understood but some experimental, field and theoretical studies indicate that especially the smallest early life stages (eggs and larvae) can be vulnerable to the current itself (35). Moreover, they may also suffer from de-watering (36, 37) in nearshore areas and possibly from shear stress from propellers (17, 38). The marinas in the present study were rather small and shallow and did not allow traffic from larger passenger vessels that produce more powerful waves and back currents. Thus, direct effects from waves and currents should only be present in the inlets adjacent to routes for passenger ferries. The multivariate analysis showed that parts of the species variation in the studied inlets could only be explained by ferry routes, suggesting that increased current from passing boats may affect species composition of juvenile fish. However, for the most common species only perch showed a specific response to

the presence of ferry routes. Analyzing all detonation-samples separately showed that the abundance of perch had a strong negative correlation with wave impact (ANCOVA, \( F = 8.25; p < 0.01 \)) suggesting that the recruitment of this species is sensitive to exposure. This relationship could originate from a negative effect of strong currents on their rather sensitive long egg straws, which, if torn apart, may scatter on the sediment where conditions are less optimal. Thus, effects of strong return currents and waves generated by boat traffic may contribute to the trend of low abundance of perch along ferry routes.

Besides creating waves and currents, boat engines also produce rather high noise (up to 175 dB) that can cause alarm responses (39) and affect auditory sensitivity in fish (40). Noise from boats could hypothetically disturb adult fish during the spawning season, which could make them less likely to use localities with high frequency of boats as spawning areas.

A number of toxic substances are emitted in association with boating/navigation activities. It is, however, hard to test if the presence of toxins could contribute to the observed results in this study. Outboard engines produce large quantities of combustion emissions per liter of fuel consumed. The concentrations of polycyclic aromatic hydrocarbons (PAH) have received special attention as potential pollutants in aquatic environments. In laboratory experiments, emissions from outboard motors have been shown to influence embryonic and larval development and survival negatively (18, 41, 42). The use of toxic, anti-fouling paint to protect boats and hulls from colonization of epiphytic algae, mussels and barnacles has also been viewed as a potential nuisance to marine life in the vicinity of boat berths (43). Paints containing toxic substances, such as copper and tributyl tin, have recently been banned for smaller vessels (< 25 m) (44). In conclusion, it cannot be excluded that emissions from toxins have the potential to explain why certain species are negatively influenced by boating and navigation activities, thus accentuating the effects from disturbances on vegetation.

Implications for Management of Boating and Navigation Activities

The combination of fast, frequent, public transport and boat-associated tourism has been attributed major importance in maintaining permanent households in archipelago areas, particularly since traditional sources of income from fisheries and agriculture decrease in importance. Shallow areas are exploited to give access to berths for the increasing number of private boats, which are increasing in both size and engine power (45). Parallel to this trend
medium-sized passenger ferries are growing both in size, numbers and route frequency (46). Thus, the impact from boating and navigation can be hypothesized to increase in the future and should be given specific attention in environmental conservation and management policies concerning coastal areas (47).

Our results indicate that boating/navigation activities could have negative effects on fish recruitment and that the environmental impact of these activities needs to be linked to the recruitment in the physical planning of coastal activities on both local and regional levels. Based on our data it is difficult to pinpoint one specific factor as the main cause of the negative effect on recruitment of certain species. The available results, nevertheless, indicate that damage to vegetation could be the most important factor in explaining fish recruitment responses to boating and navigation. Hence, if possible, ferry routes and berths should be allocated to areas where they will have minimal effects on the underwater vegetation. In earlier studies on vegetation (20, 48), boating and navigation activities had less dramatic effects on exposed hard-bottoms than on sheltered soft bottoms where the species are less tolerant to physical disturbances and where the vegetation is continuously renewed. Thus, navigation activities should as far as possible be allocated to deeper and more exposed coastal areas in order to minimize disturbances in fish recruitment.

References and Notes


24. Boudou, A. 1981. The reactions of rafish (Rutilus rutilus) and rudd (Scardinius erythrophthalmus) to noises produced by high-speed boating. Proc. 2nd British Fisheries Fisheries Conference, Southampton.


31. Statistics from Wuchshalembachtalnutzungsverordnung.


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