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Juvenile flatfish in the northern Baltic Sea — long-term decline and potential links to habitat characteristics

Henri Jokinen [a,*], Håkan Wennhage [b], Victoria Ollus [a], Eero Aro [c], Alf Norkko [a,d]

[a] Tvärminne Zoological Station, University of Helsinki, J.A. Palménin tie 260, FI-10900 Hanko, Finland
[b] Havsfiskelaboratoriet, Swedish University of Agricultural Sciences, Turistgatan 5, SE-453 21 Lysekil, Sweden
[c] Nature Resources Institute Finland (LUKE), Viikinkaari 4, FI-00791 Helsinki, Finland
[d] Marine Research Centre, Finnish Environment Institute (SYKE), FI-00251 Helsinki, Finland

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ABSTRACT

Flatfish in the northern Baltic Sea are facing multiple environmental pressures due to on-going large-scale ecosystem changes linked to eutrophication and climate change. Shallow juvenile habitats of flatfishes are expected to be especially susceptible to these environmental pressures. Using previously unpublished historical and present-state data on juvenile flatfish in nursery areas along the Finnish coast we demonstrate a drastic (up to 40×) decline in 1-Y-O flounder densities since the 1980s and a particularly low current occurrence of both flounders and turbots in several known juvenile habitats. As a consequence of ongoing coastal eutrophication vegetation coverage and filamentous algae have generally increased in shallow areas. We examined the predicted negative effect of vegetation/algae by exploring quantitative relationships between juvenile flatfish (flounder and turbot) occurrence and vegetation/algae among other environmental factors in shallow juvenile habitats. Despite sparse occurrence of juveniles we found a significant negative relationship between flatfish abundance and vegetation cover, implicating eutrophication as a potential major driver affecting the value of juvenile habitat. Shallow littoral habitats play a particularly central role for flatfish due to the spatial concentration of fish in these areas during the critical juvenile stage. Despite their importance, these areas have been relatively poorly studied in the northern Baltic Sea, which makes it difficult to quantify overall changes in environmental conditions and to relate these changes to flatfish recruitment. The low present-state flatfish densities recorded preclude strong inferences of the role of habitat quality to be drawn. Our study does, however, provide a baseline for future assessment. Based on existing evidence, we cannot thus establish any bottlenecks but hypothesize that the current low occurrence of juvenile flatfish, and the population decline of flounder on the Finnish coast, might have resulted from a combination of altered larval supply and reduced nursery value.

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1. Introduction

Once upon a time flatfish were abundant in the coastal archipelago waters of Finland, northern Baltic Sea (Ådjers et al., 2006; Lappalainen et al., 2000). Based on convincing evidence from fishery-independent data across the south coast of Finland, the adult flounder (*Platichthys flesus*) population (defined as flounders of the demersal spawning stock along the southern coast of Finland; ICES, 2014) has declined markedly (46–97% in abundance) over the past decades (Jokinen et al., 2015). Turbot (*Scophthalmus maximus*), which is the other flatfish species present in the area, has always been less common. The reason for the decline in flounder is unknown, but flatfishes living in the northern Baltic Sea, are (a) at the margin of their distribution range as determined by salinity (Bagge, 1981), and (b) are facing multiple environmental pressures due to on-going large-scale ecosystem changes linked to eutrophication and climate change (Elmgren, 2001; Korpinen et al., 2012; Niiranen et al., 2013). Shallow juvenile habitats of the two flatfish species present in the area are expected to be especially susceptible to these environmental pressures, and a subsequent degradation might have constituted a bottleneck for recruitment and population maintenance.

For flatfishes the population dynamics can be affected during different parts of the life-cycle; from egg and larvae (Legget and DeBlois, 1994) to the adult phase (Rijnsdorp, 1994). Regulatory processes during the demersal post-settlement stage, when juveniles of many species aggregate into shallow nursery grounds, are often critical and can determine the recruitment success of a year class (Bailey, 1994; Gibson, 1994; Van der Veer et al., 1994). It is therefore considered that the variability in recruitment, generated by differences in egg production and survival of egg and larvae, is later regulated by density-dependent post-settlement processes in juvenile habitats (Rijnsdorp et al., 1995; Van der Veer et al., 2000). When the population size is large and egg production is high, stock size can be restricted by the spatial limitation

* Corresponding author.
E-mail address: henri.jokinen@helsinki.fi (H. Jokinen).

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of nurseries (Beverton, 1995). Towards distribution margins and for small populations, pre-settlement processes generating variability tend to be more important than the regulating ones after settling (Beverton, 1995; Miller et al., 1991; Rijnsdorp et al., 1995; but see Legget and Frank, 1997), potentially resulting in greater variation in recruitment and stock size among years. Nevertheless, when subject to large-scale (negative) environmental changes, juvenile habitats might deteriorate, affecting both the surface area available and potentially growth, condition and survival in the remaining nursery habitats (Le Pape et al., 2007; Pihl et al., 2005). Such changes in habitat quality could reduce the reproductive output (sensu Sheaves et al., 2006) and result in a population decline, which further increases the risk for the reproductive potential to become limiting.

The nursery function of shallow nearshore habitats is a well-established concept in general (Beck et al., 2001) and for flatfishes in particular (e.g., Gibson et al., 2015, and references). Shallow habitats provide good conditions for growth, survival and recruitment to the adult population if the nursery function of these areas is undisturbed (Beck et al., 2001; Gibson et al., 2015, and references; Seitz et al., 2014). Loss and degradation of coastal flatfish habitats may result in considerable decreases in nursery capacity and in adult abundances as a consequence (e.g., Rochette et al., 2010).

As a symptom of eutrophication, increased amounts of submerged vegetation and filamentous macroalgae have become common in littoral areas in and adjacent to the Baltic Sea, consequently degrading the nursery value of juvenile flatfish habitats (Berglund et al., 2003; Pihl et al., 1999). Algal mats have been estimated to reduce coast-wide recruitment of plaice by 30–40%, even if only a fraction of the nursery areas are affected (Pihl et al., 2005). Juvenile turbot prefer bare sand as a substrate (Florin et al., 2009; Sparrevohn and Støttrup, 2003) and juvenile flounders avoid vegetation if possible (Carl et al., 2008; Wennhage and Pihl, 2007). Growth of juvenile flounder is generally lower in vegetated habitats (Tarpgaard et al., 2005), probably as a result of reduced foraging efficiency (Aarnio and Mattila, 2000; Nordström and Booth, 2007). In the northern Baltic Sea, flounder and turbot juveniles settle in shallow (<1 m), littoral areas, in August (Aarnio et al., 1996; Florin et al., 2009; Martinsson and Nissling, 2011) during the seasonal peak of primary production (Berglund et al., 2003), and stay in the vicinity of these habitats for 2–3 years before they disperse to the surrounding archipelago where they reside as adults (Koli, 1990). Since juveniles are confined to the shallow areas for several years, they are susceptible to changes in the quality of their surroundings, making these habitats critical for the recruitment success.

It is clear that the adult flounder population on the Finnish coast has declined (Jokinen et al., 2015). In order to evaluate potential reasons for this decline it is important to establish whether the decline is also apparent in juveniles. We know that eutrophication in the region has progressed over time, increasing the amount of aquatic vegetation and filamentous algae in littoral areas (Berglund et al., 2003; Bonsdorff et al., 1997; Norkko and Bonsdorff, 1996). We also know, based on previous knowledge, that the occurrence of filamentous algae has a strong negative association to juvenile flatfish (Florin et al., 2009; Wennhage and Pihl, 2007) and that increased amounts of vegetation and algae have potential negative consequences for recruitment (Pihl et al., 2005). Based on these observations, we would predict that the occurrence of juvenile flatfishes should decrease with increasing vegetation/algae, which could explain a potential decline in juveniles. While long-term data on changes in environmental factors, including vegetation, is lacking, inferences on the role of vegetation could be inferred by examining spatial gradients in the present occurrence of juveniles in relation to different levels of vegetation/algae.

To date, no comprehensive information on inter-annual variation in recruitment of flounder in the northern Baltic Sea has been published. Neither are there any published quantitative data on environmental predictors for the habitat use of juvenile flatfish from the Finnish coast. Our limited knowledge of recruitment processes hampers our ability to understand the overall decline in the adult flounder population observed in the area (Jokinen et al., 2015). The purpose of this study was to fill these knowledge gaps by investigating the change in the occurrence of juvenile flounders over time (the past 3 decades), and by assessing the present occurrence over different levels of vegetation/algae. The specific aims were to *i*) test whether the abundance of juvenile flounders on the Finnish coast has decreased since the 1980s, *ii*) investigate the present occurrence of juvenile flatfish at multiple sites within a known nursery area, and *iii*) to test the relationship between the occurrence of juveniles and vegetation/algae together with other environmental factors.

2. Material and methods

2.1. Study area

The Baltic Sea is a large semi-enclosed brackish water body connected to the North Sea only by the Danish Straits, through which oceanic water occasionally enter the Baltic affecting salinity, stratification and oxygen conditions (Leppäranta and Myrberg, 2009). Depending on this estuarine feature and the northern location, the Baltic Sea is characterized by strong environmental gradients, namely salinity and temperature, determining the mix of boreal marine and freshwater species present (Bonsdorff, 2006; Nohrén et al., 2009; Olsson et al., 2012). Surrounded by densely populated countries, the semi-enclosed Baltic Sea is one of the most impacted coastal seas, being exposed to high nutrient loads, pollution and exploitation as well as global climate change (Elmgren, 2001; Korpinen et al., 2012; Niiranen et al., 2013).

This study was conducted on the south coast of Finland, in the archipelago of the northern Baltic Proper. Two areas were included; the ‘Mainland’ area at the coast around Hanko Peninsula (59°N 23° E), and the ‘Archipelago’ area of the Åland Islands (60°N 20°E; Fig. 1). The study areas are historically known to encompass important juvenile habitats for flounder (e.g., Järvi, 1932). The study sites consisted of shallow (0–1 m) soft-sediment bays and beaches, typical for flatfish nursery grounds in the region (Aarnio et al., 1996; Florin et al., 2009; Martinsson and Nissling, 2011). The sites are characterized by a relatively high exposure to wind and waves, and are dominated by sandy substrates with a varying cover of vegetation. Surface water salinity is generally about 5–6. Many ecological aspects, such as temperature and production, display strong seasonality (Berglund et al., 2003). In line with the general state of the Baltic Sea, these littoral areas suffer from eutrophication effects, such as increased amounts of vegetation and filamentous macroalgae (Bonsdorff et al., 1997).

2.2. Study design and sampling

The study consisted of two parts; a ‘long-term’ and a ‘present state’ part. The long-term part was designed to reveal temporal changes in the abundance of post-settled juvenile flounder and the present state part explored current patterns of spatial occurrence of juvenile flatfish in relation to vegetation/algae together with other environmental factors. Our focus was on 0-group and 1-Y-O juvenile flounders and turbots. All sampling was conducted with a beach seine, especially designed for catching juvenile flatfish. Two different sized seine models were used; one for the long-term and one for the present state part. The long-term study was originally using a large seine and an identical was used for the revisits to facilitate comparisons. For the present state study a smaller seine, which was easy to handle at multiple locations, was used. Seining has proven to be a reliable method for sampling juvenile flatfish occurring in low densities (Borg et al., 2012).

2.2.1. The long-term study

For studying the long-term temporal development in juvenile flounder, we revisited an old monitoring series from 1979 to 1992, which

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