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# Structural changes in three coastal fish assemblages in the northern Baltic Sea archipelago

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ABSTRACT

Globally, evidence for structural changes in coastal marine ecosystems is increasing. Coastal areas are ecologically and socio-economically important, and under multiple anthropogenic stressors. In this study, changes in the structure of fish assemblages were observed during a ten-year study period (1999–2009) in three coastal areas in the northern Baltic Sea. The assemblages differed from each other in terms of species abundances, but a similar shift towards higher proportions of cyprinid fish and lower proportions of pikeperch (*Sander lucioperca*) was observed in all study areas. The resulting proportional increase of the small-bodied lower trophic level cyprinids was also reflected as declining mean length of fish and mean trophic level in all three assemblages. Variation in fish abundances was related to environmental factors and catches of commercial fisheries. The results suggest that the observed changes were caused by regional patterns of eutrophication in combination with fishing pressure. The results indicate that in the studied systems similar structural changes occurred simultaneously within a relatively short period of time.



## 1. Introduction

Shallow coastal ecosystems are affected by several anthropogenic stressors. Input of nutrients from human settlement and agriculture cause eutrophication, an increase in primary production in the aquatic ecosystems (Nixon, 1995; Andersen et al., 2011). The same systems are often exploited by fishing, which typically targets predatory species higher up in the food chain (Pauly and Palomares, 2005; Aps and Lassen, 2010). Identifying the underlying causes of ecosystem changes is far from simple, but previous studies demonstrate that the combination of eutrophication and the removal of higher order consumers by fishing has profound effects on the structure and functioning of aquatic ecosystems (Daskalov, 2002, Breitburg et al., 2009; Casini et al., 2008, Eriksson et al., 2009; Möllmann et al., 2009).

Eutrophication typically increases production of filamentous algae and phytoplankton, and thus increases also frequency of algal blooms (Nixon, 1995; Rabalais, 2010). The increase in phytoplankton provides more food for zooplankton, thereby also favouring zooplanktivorous fish (Bonsdorff et al., 1997; Thurow, 1997; Caddy, 2000). In the northern coastal Baltic Sea areas, eutrophication has led to changes in the structure and function of the aquatic communities on all trophic levels from plankton (Scheinin et al., 2013) and macrophytes (Rosqvist et al., 2010) to fish (Eriksson et al., 2009; Snickars et al., 2015). Increased turbidity and fouling by filamentous algae hamper growth of large macrophytes, changing the physical structure of and ecological interactions in littoral habitats (Eriksson et al., 2009; Rabalais, 2010). Eutrophication also causes oxygen depletion, hypoxia, near bottom and in the sediment (Carstensen et al., 2014), which is detrimental to benthic fauna (Karlson et al., 2002; Rabalais, 2010) and benthic fish (Eby et al., 2005; Snickars et al., 2015).

The Baltic Sea is considered critically eutrophic with high nutrient levels, low water transparency and frequent cyanobacterial blooms, and has become more so during the last decades (Lundberg et al., 2005; Carstensen et al., 2014, Andersen et al., 2011). Roach (*Rutilus rutilus*) in the Baltic Sea coastal waters has been considered to benefit from eutrophication (Bonsdorff et al.,

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1997; Ådjers et al., 2006), possibly because it benefits from turbidity in concurrence with Eurasian perch (hereafter perch, *Perca fluviatilis*) (Lappalainen et al., 2001). Also European pikeperch (hereafter pikeperch, *Sander lucioperca*) is considered to benefit from eutrophication as it prefers turbid water (Lehtonen et al., 1996), but at the same time the stocks are under considerable fishing pressure and high mortalities have been observed in the Finnish Archipelago Sea (Mustamäki et al., 2014; Heikinheimo et al., 2014). Stocks of perch, the most common predator in the coastal waters, have been rather stable since the late 1990's (Official Statistics of Finland, 2011; SwAM, 2012). The high temperature dependency of the recruitment of perch (Kjellman et al., 2003) and pikeperch (Heikinheimo et al., 2014; Mustamäki et al., 2014) leads to large fluctuations in the year class strengths and thereby commercial catches of these species.

Many Baltic Sea fish stocks are extensively exploited by commercial fisheries (Aps and Lassen, 2010; Heikinheimo et al., 2014; Mustamäki et al., 2014; Möllmann et al., 2014). Fishing directly affects the target species (Dulvy et al., 2004; Aps and Lassen, 2010; Mustamäki et al., 2014) but the cascading effect of removal of certain species or functional groups can shape the structure and function of the whole system (Thurow, 1997; Caddy, 2000; Eriksson et al., 2011; Möllmann et al., 2009). Globally, excessive fishing of high order consumer fish has been blamed for decline in the mean trophic level of fish communities (Pauly and Palomares, 2005). There is also growing evidence on high fishing pressure inducing trophic cascades, resulting in higher domination of phytoplankton and secondary consumer fish in the system (Daskalov, 2002, Österblom et al., 2007; Casini et al., 2008).

Effects of eutrophication and/or removal of higher order consumers are not linear, but the system may undergo an abrupt shift from one stable state to another (Scheffer and Carpenter, 2003). The regime shift in the pelagic Baltic Sea ecosystem from the previous cod-dominated state to the present state dominated by sprat and characterised by cyanobacterial blooms has been described by Österblom et al. (2007) and Möllmann et al. (2009), among others. Similar shift scenarios in the coastal systems have been identified by Eriksson et al. (2009), Rosqvist et al. (2010) and Olsson et al. (2012). Because natural systems are always affected by several environmental factors, identifying whether an observed ecosystem-level change is driven by a top-down induced trophic cascade or a bottom-up induced regime shift is challenging (Breitburg et al., 2009). Lately, a consensus has emerged in the literature that ecosystem changes are caused by multiple drivers rather than a single main driver (Eriksson et al., 2009, 2011; HELCOM, 2012; Olsson et al., 2012; Möllmann et al., 2014).

This study reports structural changes in fish assemblages in three coastal areas in the northern Baltic Sea archipelago in 1999–2010. Previously, Mustamäki et al. (2014) reported high mortalities and declining adult fish abundances in the same study areas. High fishing pressure in all areas was reported as a plausible cause for the observed adverse changes, which in one of the areas may have been amplified by great cormorant (*Phalacrocorax carbo*) predation. We were interested to see whether changes had occurred in the abundances of other species in the same areas during the same period of time, and if the possible changes had changed the structure of the whole fish assemblage. We hypothesised that 1) also other large-bodied species may have declined in abundance due to fishing pressure, and 2) small-bodied species may have increased, and 3) this may have changed the trophic structure of the assemblages. Abundances of small-bodied species may have increased either due to relaxed top-down regulation or eutrophication that is known to benefit planktivorous fish and especially roach and other cyprinids.

## 2. Material and methods

### 2.1. Study areas

The study areas Galtfjärden, Lumparn and Ivarskärsfjärden are brackish water embayments located in the inner archipelago zone of the northern Baltic Proper (Fig. 1). Galtfjärden (60°10′N 18°34′E) is located in the eastern coast of Sweden. It is a part of an inner archipelago system with several adjacent basins, straits and islands. The total area of Galtfjärden and the adjacent bays and straits is approx. 7400 ha and the average depth 6 m. Lumparn (60°07′N 20°07′E) is located in the south-eastern Åland Islands. It is a rather round basin with narrow straits connecting it to the Archipelago Sea. The total area of Lumparn and the adjacent bays and straits is approx. 16,000 ha and the average depth is 12 m. Ivarskärsfjärden (60°16′N 19°48′E) is located in the north-western Åland Islands connected to the Archipelago Sea by a narrow strait. The total area of Ivarskärsfjärden with the adjacent bays and straits is approx. 6200 ha and the average depth is 4 m.

In the archipelago of the northern Baltic Proper, the topographic variation of the coastline shapes the coastal underwater environment creating a mosaic of habitats for fish (Vahteri et al., 2009). Because of the temperate climate, the Baltic Sea region is subjected to seasonal changes in light and temperature ranging from near-zero and ice cover in the winter to +25 °C in late summer. Primary production typically peaks in spring after the ice break (spring bloom) and in late summer (autumn bloom) when the water is warmest. Chlorophyll *a* concentration, nutrients and zooplankton abundance and biomass are typically at their highest in late summer (Scheinin and Mattila, 2010).

All study areas are under anthropogenic effects by surrounding rural human settlement and agriculture, but not directly affected by large cities or other point sources of pollution. All study areas are central for both commercial and recreational fisheries of pikeperch, perch and whitefish. Majority of the commercial fishermen in the areas are private persons who operate part-time and on small scale. In the northern Baltic Sea region, the commercial pikeperch catches increased during the 1990's, but this has been regarded to have occurred more due to increased interest in pikeperch fishing after the collapse of Baltic cod in the late 1980's and restrictions on salmon fisheries than due to any actual increase in pikeperch stocks (pers. comm. Kaj Ådjers, Åland Government, Finland). Fishing mortality of pikeperch has been high ($Z > 1.1$) in all study areas during the 2000's (Mustamäki et al., 2014). High fishing mortality — combined with predatory pressure from a great cormorant breeding colony in Galtfjärden — has previously been suggested as a likely cause for declines of adult pikeperch in the study areas (Mustamäki et al., 2014). Implementation of stricter restrictions on pikeperch fishing in the Åland Islands was enforced in 2011 and will continue till 2015 (pers. comm. Kaj Ådjers, Åland Government, Finland). Fishing pressure from recreational fishing in the Baltic Sea coastline is also considered significant, but no continuous records exist (Official Statistics of Finland, 2009; Swedish Board of Fisheries, 2009).

Because of the geographical location and topography, salinity and temperature in Galtfjärden are generally slightly lower than in Lumparn and Ivarskärsfjärden (Mustamäki et al., 2014). Previously in Mustamäki et al. (2014) the water quality in all study areas during 2000's was classified eutrophic (sensu Lundberg et al. (2005)) based on high or very high levels of chlorophyll *a* (>3.2 μg/l), total nitrogen (>360 μg/l) and total phosphorus (>24 μg/l), and low or very low Secchi depth (<3.4 m). Galtfjärden was classified highly eutrophic. Lumparn was classified moderately eutrophic, and decreasing concentrations of chlorophyll *a* during the study period ($r_S = -0.71$, $p < 0.05$) indicated slight