WORKSHOP ON STICKLEBACK AND ROUND GOBY IN THE BALTIC SEA (WKSTARGATE)

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Contents

i Executive summary

The aim of the Workshop on Stickleback and Round Goby in the Baltic Sea (WKSTARGATE) was to update, summarize and synthesize the current knowledge of both species with respect to their ecology and potential use in fisheries. Ongoing projects were presented in the mornings of the first two days to inform participants about current research in the respective countries (Annex 5). The group discussed ecological aspects that are relevant to fisheries, such as distribution and abundances, feeding ecology and behaviour. So far, no dedicated monitoring exists for either of the species. However, the Baltic International Acoustic Survey (BIAS), coordinated by ICES, has been used to estimate abundances and biomasses of pelagic stickleback in offshore areas across the Baltic, while the availability and quality of coastal data differs between countries, but is generally scarce. Even less current abundance information is available for round goby. It is only available for areas where it is already commercially exploited like Latvia.

Most studies on the ecological impact of these species focus on trophic interactions, and its resulting competition. It became clear, that these ecological impacts depend on the abundance of the species and that the effects therefore vary on a temporal and spatial scale. Estimating the ecological impact of a stickleback or round goby fishery is therefore very speculative without reliable abundance data, why the group decided to describe the known impact of the species on the ecosystem.

Landings of round goby increased significantly in Latvia during the last years, while stickleback landings decreased over the last five decades but most recently show a slight increase. A targeted round goby fishery exists in Latvian waters, while the stickleback is solely taken as bycatch in all Baltic countries. Both fisheries are currently unmanaged and, with the exception of round goby fishery in Latvia, unregulated. In Latvia the round goby fishery is regulated by effort, to reduce the bycatch of native species. Furthermore, Latvia has initiated work towards a stock assessment of round goby. Efforts for a Baltic-wide stickleback assessment have been undertaken by Sweden, and both, Sweden and Denmark are taking first steps towards a full analytical stock assessment.

ii Expert group information

Expert group name	Workshop on Stickleback and Round Goby in the Baltic Sea (WKSTARGATE)
Expert group cycle	Annual
Year cycle started	2022
Reporting year in cycle	1/1
Chairs	Jane Behrens, Denmark
	Daniel Oesterwind, Germany
Meeting venue and dates	23–25 August 2022, Copenhagen, Denmark (23 participants)

1 ToR a: Assess the ecological consequences of the shifts in abundance and distribution of stickleback and round goby in coastal waters of the Baltic Sea

1.1 Stickleback

1.1.1 Distribution and abundance

Distribution and stock development of stickleback

The spatial distribution of the three-spined stickleback across the Baltic Sea is best described by data from the Baltic International Acoustic Survey (BIAS), which is performed yearly in September to October and covers most of the Baltic except the Bothnian Bay and the Gulf of Riga. The purpose of this survey is to estimate the abundance and biomass of herring and sprat in the open sea to be used in stock assessment. Stickleback is thus not included in the calculations, but a method for estimating the abundance of this species has been developed and applied (Olsson *et al.* 2019; Olin *et al.*, 2022). In Olin *et al.* (2022) the spatial distribution and development of stickleback for 2001–2020 is presented. These calculations show that the highest biomasses of stickleback occur in SD 27, western part of SD28, SD29 and southern part of SD30 (Figure 1.1). In these areas densities have increased since the 1980s (Bergström *et al.*, 2015), and continued to do so during the last years (Olin *et al.*, 2022; Figure 1.2). In the central Baltic Sea, an estimated 10% of the pelagic fish biomass was made up of stickleback in 2011–2014 (Olsson *et al.*, 2019). Coastal data from these areas show a mixed picture with strong increases in some areas, and less in others (Olin *et al.*, 2022), potentially reflecting that the latter coastal areas are close to carrying capacity of this species.

The Bothnian Bay is not covered by the BIAS survey, but an acoustic survey from 1991 found that the stickleback biomass in the Bothnian Bay was around six times higher than that in the Bothnian Sea (Jurvelius *et al.*, 1996). There is no recent information available covering the offshore parts of this basin, but a recent habitat mapping study covering the whole Swedish Baltic Sea coast suggests that the pattern may be reversed today, with higher densities in the Bothnian Sea than in the Bothnian Bay (Erlandsson *et al.*, 2021).

In the Southern and Eastern parts of the central Baltic Sea, off the coasts of Poland, Lithuania, Latvia, and Estonia, biomasses are low. Coastal data from Latvia and Poland point to stable or declining abundances over time (Olin *et al.*, 2022). A German study from 2021, targeting the coastal fish community of Schleswig-Holstein using different fishing methods (multimesh gillnets, eelfykes, minnow traps, bottom trawls, beach-seine), showed that stickleback was present at all of the seven study sites, however at low abundances compared to other fish species (Henseler and Oesterwind, unpublished).

Previous studies (as summarized by Eklöf *et al.*, 2020; Olin *et al.*, 2022) suggest that predatory release is the central driver of the population increases of stickleback, while eutrophication and climate change have likely contributed to creating more favourable conditions for the species.

Given the strong territoriality and similar habitat requirements of round goby and stickleback during spawning in spring and summer, there may potentially be negative interactions between these two species as well. Interestingly, there has been a notable decline in densities of sticklebacks in the Gulf of Riga and the Gulf of Gdańsk since the 1990s, which corresponds to the time of invasion and strong population increase of round goby. Whether this pattern is evidence of a negative interaction between the two species remains to be seen.

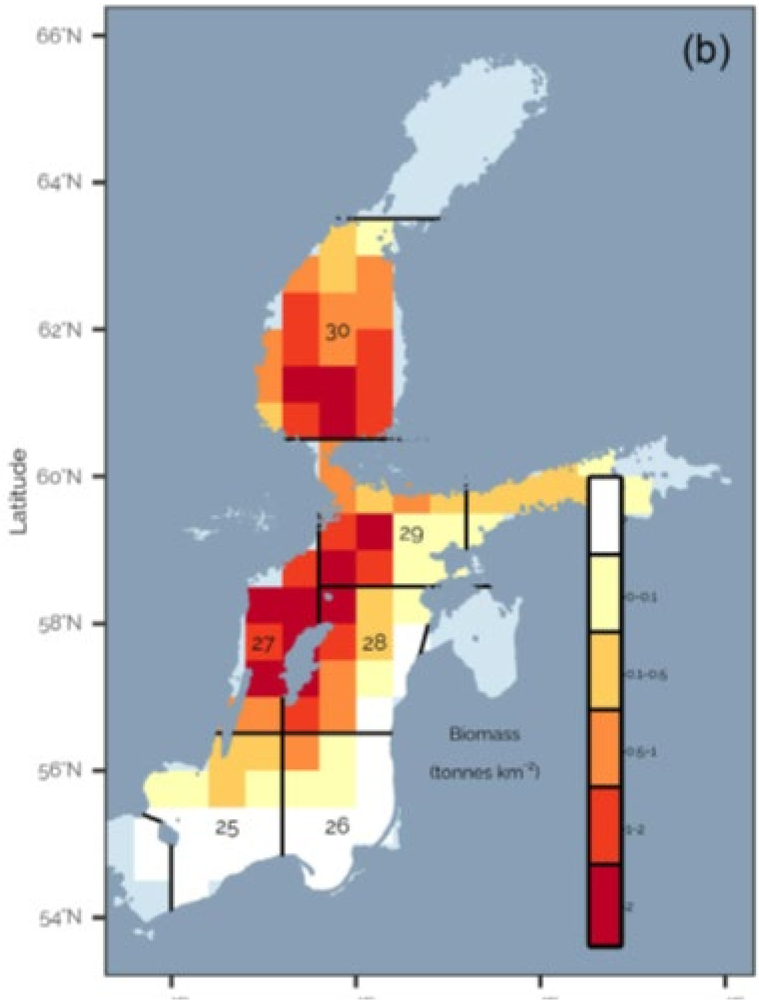

Figure 1.1. The spatial distribution of stickleback biomass in 2015–2019, as estimated by data from the BIAS. Figure from Olin *et al.* 2022.

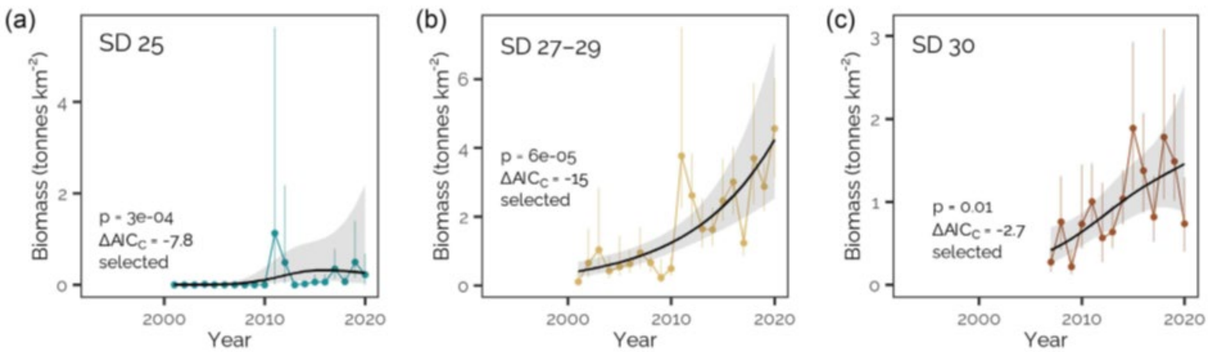

Figure 1.2. The development of stickleback biomass in the main areas of distribution in the Baltic Sea, i.e. SD25 (a), SD27-29 (b), and SD30 (c) between as estimated from data collected in BIAS in September–October in 2001–2020. Figure from Olin *et al.* 2022.

1.1.2 Feeding ecology

Three-spined stickleback is utilizing both the coastal and offshore areas in the Baltic Sea (Bergström *et al.*, 2015). At the coast it feeds on zooplankton, benthic fauna and fish eggs (e.g. herring eggs, Kotterba *et al.*, 2017) and larvae of coastal fish (Byström *et al.*, 2015; Nilsson *et al.*, 2019), and in the offshore Baltic it feeds on zooplankton (reviewed in Olin *et al.* 2022). Being a predator on juvenile coastal fish species, stickleback can (when occurring in large numbers) control the reproduction of coastal predatory fish and also promote trophic cascades leading to blooms of ephemeral algae via predation of grazing benthic fauna (reviewed in Olin *et al.*, 2022; Figure 1.3). In the offshore Baltic Sea, earlier studies have shown a significant diet overlap with other planktivorous pelagic species such as herring and sprat (reviewed in Olin *et al.*, 2022; Figure 1.3). Recent analyses of the BIAS survey in 2001–2019 (Donadi *et al.*, unpublished) suggest that there are strong negative interactions between large herring and stickleback, likely indicating the importance of herring predation as a regulating factor of stickleback. This is supported by a recent diet study with herring stomach samples collected along the Swedish coast of SD25–31 (Bergström *et al.*, unpublished), and is also indicated by a previous study from the Bothnian Sea (Parmanne *et al.*, 2004). The Donadi *et al.* study also found a negative correlation in the spatio-temporal distribution of small herring, sprat and stickleback, indicating that competition for zooplankton may also be a driver in the open sea. Whereas sticklebacks prey in coastal areas on herring eggs and can negatively affect the recruitment success of herring (Kotterba *et al.*, 2017).

Stickleback is also a key prey for predatory fish in the Baltic including perch, pike, salmon and large herring and to a minor extent also cod (reviewed in Olin *et al.*, 2022; Bergström *et al.*, unpublished; Figure 1.3). Besides being an important food source for predatory fish, stickleback is also frequently found in the diets of mammals (ringed seal) and fish-eating birds (cormorants, terns and mergansers; reviewed in Olin *et al.*, 2022).

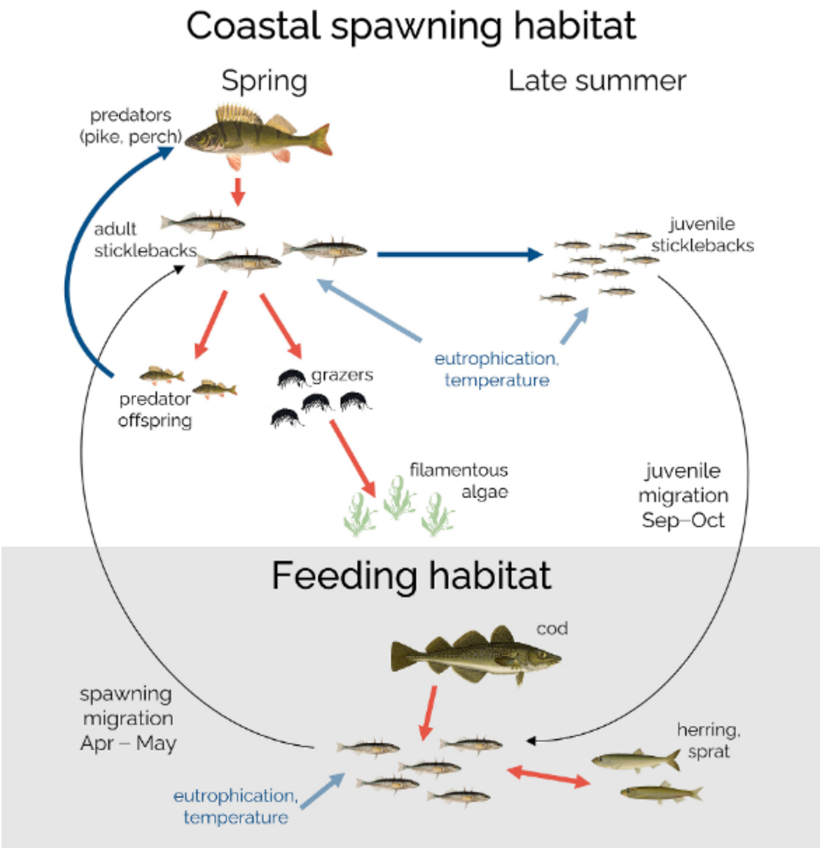

Figure 1.3 The trophic interactions of stickleback in the Baltic Sea coastal and offshore foodwebs (from Olin *et al.*, 2022).

1.1.3 Behaviour

In the Baltic Sea, the stickleback utilizes the coastal and offshore areas (Bergström *et al.*, 2015) depending on its life stage. The spawning behaviour of three-spined sticklebacks has been well documented. Most fish spawn only once during their lifetime and reach maturity at an age of 1+ or 2+. Fish generally die after spawning, but some individuals, particularly those who live in marine habitats, may survive to spawn a second time. Spawning generally takes place between March and July, although spawning activity tends to peak around June, following the identification and establishment of territories. If the conditions allow, the stickleback can reproduce more than one time during the spawning season. At the end of summer, juveniles migrate to offshore areas in the Baltic to feed and grow, and once sexually mature, they return to coastal spawning grounds during early spring.

Little is known about stickleback behaviour in the offshore areas of the Baltic Sea. According to data from BIAS surveys, sticklebacks seem to stay at the uppermost part of the water column during both day and night. Sticklebacks assemble in small schools at daytime and the schools then scatter out during the night (Figure 1.4).

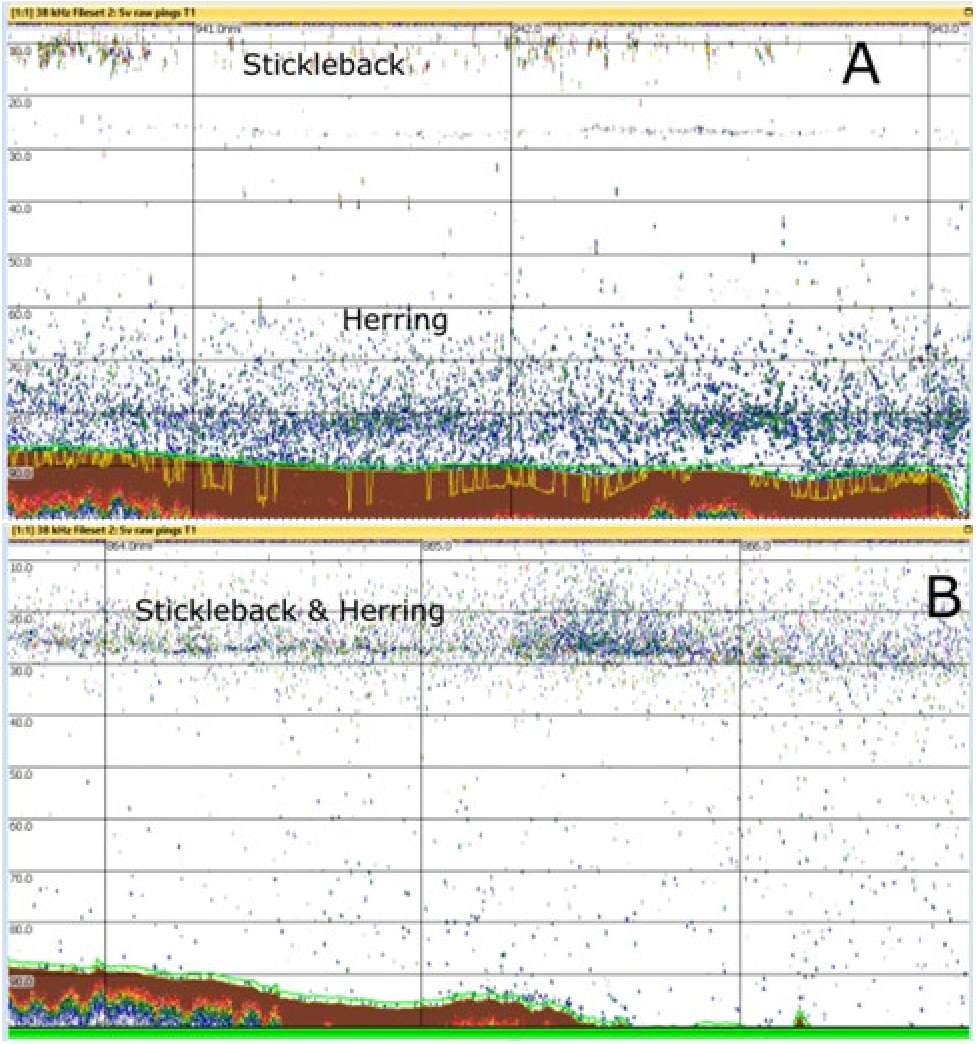

Figure 1.4 Two echograms from the Finnish BIAS survey 2020 in late September. The upper echogram (A) shows the vertical distributions of stickleback and herring during the daytime, and (B) shows the situation at night.

1.2 Round goby

1.2.1 Distribution and abundance

Previous period overview

Round goby pan-Baltic distribution was first mapped by Kotta *et al.* (2016), based on published occurrences and local fisher information from 1990–2014. HELCOM updated the map in 2018 and included published observations from 2015–2016 (HELCOM Baltic Sea Environment Fact Sheet, 2018).

Kotta *et al.* (2016) also modelled how external drivers and local environmental conditions contribute to the spatial distribution of round goby in the Baltic Sea. Their modelling results suggest that the distribution of round goby is primarily related to local abiotic hydrological conditions (wave exposure). Furthermore, the probability of round goby occurrence was very high in areas in close proximity to large cargo ports. This links patterns of the round goby distribution in the Baltic Sea to shipping traffic and suggests that human factors together with natural environmental conditions are responsible for the spread of this non-native species (NIS) at a regional sea scale.

The latest scientific report on the environmental niche space of round goby in the Baltic Sea (including known round goby occurrences up to 2018 based on various literature and expert data) was published by Holmes *et al.* (2019). This show that round goby is more likely to be distributed in shallow, warmer and coastal areas protected from wave action, and areas associated with shipping activity. The current distribution suggests that high salinities (25–30 PSU) in the western parts of the Baltic and low temperature in the northern parts of the Baltic may limit its distribution, by reducing physiological performance of adult fish, and/or by affecting reproductive output (Green *et al.*, 2020; Christensen *et al.*, 2021; Behrens *et al.*, 2022). Holmes *et al.* (2019) also showed that suitable habitats in protected areas are less likely to be invaded by round goby than unprotected areas. Holmes *et al.* (2019) also show round goby known occurrences up to 2018 based on various literature and expert data.

Based on observations from published and unpublished sources from 2018 to 2022 from Estonian, Latvian, Finnish, Swedish, German and Danish experts an updated observation map was created (Figure 1.5).

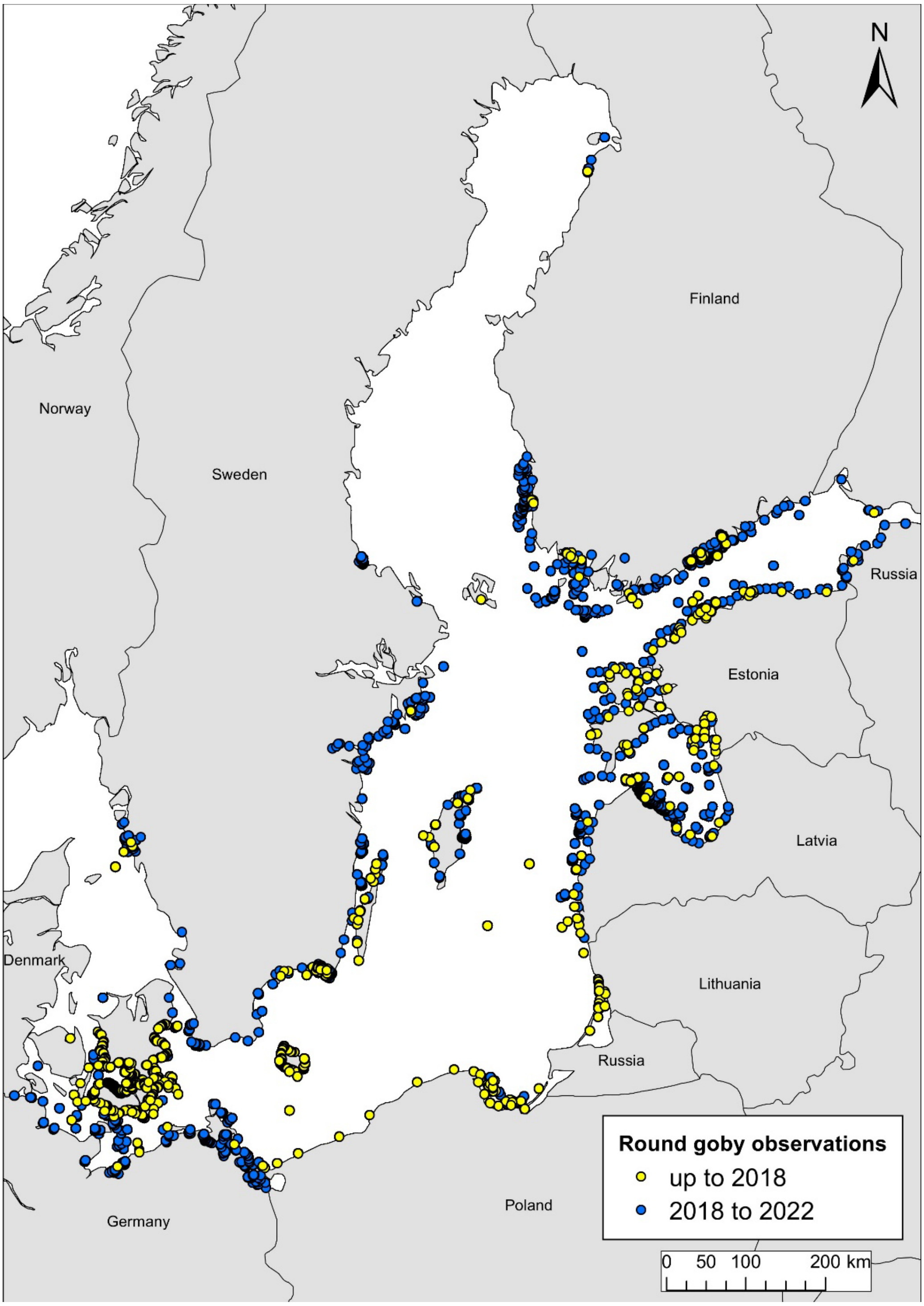

Figure 1.5. Round goby known occurrence locations in the Baltic Sea. Yellow marks indicate published occurrences until 2018 (Carl *et al.* 2016, Holmes *et al.* 2019 and references therein) and blue mark occurrences from 2018 to 2022 from national databases (Estonian Ministry of Agriculture, Artportalen, Kustfiskdatabasen (KUL), Shark SMHI, BITS surveys, LajiGIS and Latvian coastal fishery logbooks), projects (FishNet Ostsee MELUND, Eelproject LFAMV, Baltbox), publications (Uspenskiy *et al.,* 2021) and experts (Moran unpublished data).

Round goby distribution in relation to temperature

Originating in the Ponto-Caspian region, which is in general warmer than the Baltic region, temperature likely also has an influence on the distribution pattern of round goby in the Baltic Sea. Two recent studies support this; Laboratory experiments on Baltic round goby acclimated to 5, 10, 15, 20, 25 or 28°C, have shown that the fish have the highest aerobic performance at temperatures between 15 and 28°C, and on average prefer 21°C, irrespectively of acclimation temperature. Overall, when given a choice, the fish avoided temperatures below 18°C and above 24°C, but endured temperatures as high as 32–34°C, depending on acclimation temperature (Christensen *et al.,* 2021). Based on this, the authors also speculated that this avoidance of low temperatures (and poor physiological performance at low temperatures) might partly explain the lack of round goby presence in the most northerly areas of the Baltic Sea, except for a few observations in the Northeastern part of the Bothnian Bay (Figure 1.5). Along the same lines, pan-Baltic catch data have revealed a pronounced seasonal migration where the fish spend autumn and winter at significantly deeper and offshore areas compared to spring and summer. Notably here, the fish overall sought the depths within each season with the highest possible temperatures, supporting an affinity for the highest possible temperatures in the occupied areas (Behrens *et al.*, 2022).

Round goby distribution along the German coast of the Baltic Sea

Currently, round goby can be found along the entire German coastline of the Baltic Sea. Its occurrence in several inner and outer coastal waters of the eastern German coast (Mecklenburg-West Pomerania) has been documented from 2009 until 2020 in a monitoring programme targeting eels (LFA MV; Ubl and Dorow, 2015). At the western German coast (Schleswig-Holstein), a pilot monitoring study targeting coastal fish communities was conducted in 2021. Based on the data collected using five different fishing methods (multimesh gillnets, eelfykes, minnow traps, bottom trawls, beach-seine), round goby was present at all of the seven study sites ranging from Flensburg fjord in the north to the bay of Lübeck in the south, thus covering the entire coastline of Schleswig-Holstein. However, round goby abundances in the study areas were comparably low (< 4%) compared to other fish species, such as native gobiids, from February until December (Henseler and Oesterwind, unpublished data).

Round goby distribution and spread in the inner Danish waters

Round goby was first observed in Danish waters at Bornholm in 2008, and in the following year (2009) it was seen in Guldborgsund in the inner Danish waters (Western Baltic). From Guldborgsund the fish has spread on average 30 km yr^{-1} along the coastline until 2013, both eastward and westward, reaching Skælskør Fjord in 2012. In 2013, the first observation was made on Langeland, the island just South of Fynen (Azour *et al.,* 2015; Carl *et al.,* 2016). Since 2019 the fish is observed along the coastline of all islands south of Zealand and Fynen, along the Eastern and Western coastline of Zealand up to the north of Copenhagen, on several places on Fynen, and in the lower parts of several streams. It does however not seem to occur in large numbers in these freshwater bodies. Furthermore, the fish is now seen along the entire coastline of Bornholm, where it has spread on average 10 km yr^{-1} along the coastline (Azour *et al.*, 2015; Carl *et al.*, 2019).

Round goby spread in the Kattegat/Skagerrak area

The round goby was first recorded north of the Danish straits in Gothenburg harbour in 2010. Gothenburg is situated on the middle of the Swedish west-coast has Scandinavia's largest shipping harbour, with an average of 14 cargo vessel visits per day throughout the year. The environment is also brackish, with a steep, but variable, salinity gradient that likely provides good conditions for brackish invaders, and novel species continue to be reported from the area. Since its establishment, the round goby has been increasing s and expanding its range (Green, 2020; Artportalen.se, 2022). Currently, monitoring of the spread is conducted by researchers with financial and advisory input from the county board administrators (the regional administration judicially responsible for combating invasive species). This effort is also a test-bed for novel monitoring approaches, and research on eDNA, BRUV systems and acoustic monitoring is in development in the area. So far, the spread from Gothenburg has reached the town of Marstrand, approximately 26 km north of the shipping harbour. To the south, the limit is not formally established, but a similar distance of southwards spread is likely. In 2021, observations were also made north of the town of Helsingborg, where the species has likely spread from the Danish straits and Öresund. Models predict the species to be able to colonize the southern part of Norway (Forsgren and Hanssen, 2022). The similarity between the southern Norwegian and Swedish coastal habitats makes ation of the Kattegat and Skagerrak coastlines likely. Limits to the species spread have been studied in the context of their osmoregulatory capacity (Behrens *et al.*, 2017), and reproduction in relation to salinity (Green *et al.*, 2021a). Experimental data which is yet to be incorporated into the models show that round goby sampled from high salinity sites in the Gothenburg area are unable to reproduce in 30 PSU (average salinity of Skagerrak). However, refugia from these marine salinities are readily available along the Danish and Swedish estuaries lining the region. Furthermore, round goby has been shown to locally adapt to novel salinity conditions, specifically in reproductive traits, which might affect where they can establish populations (Green *et al.*, 2020).

Distribution, migration vectors, dispersal

So far, the distribution of round goby and other invasive species in large rivers and canals in Germany/Europe (and they are all colonized by the round goby) point to ships as vectors, as shown in an empirical study for invasive goby species in Europe on the large river systems (Danube, Rhine etc.). There is also genetic data that support this hypothesis. On the other hand, mainly based on some analyses from the Great Lakes in North America, active migration upstream is limited to a few kilometres a year. So far there are no signs, especially in Germany, that invasive gobies including the round goby expand their distribution in small rivers (maybe a few kilometres upstream the mouth, but nowhere into some headwaters) that lack shipping transport. Downstream dispersal is supported by drift of small individuals (potentially an obligate drift period at around 8.8 mm TL in round goby of approximately 4 days of age), that have even been shown to perform vertical migrations in lakes in North America (Gutowsky and Fox, 2011; Roche *et al.*, 2013; Thorlacius *et al.*, 2015; Adrian-Kalchhauser *et al.*, 2016; Borcherding *et al.*, 2016; Hirsch *et al.*, 2016; Blair *et al.* 2019; Nogueira Tavares *et al.*, 2020).

Notably, the future spread of round goby northwards into the Kattegat and Skagerrak regions may be primarily limited by physiological and behavioural factors. These regions differ from the inner Baltic Sea in several respects: (1) salinity is higher; (2) consequently species diversity is also higher; and (3) more marine organisms which can compete with the round goby are living closer to their osmoregulatory optima, unlike the round goby (Snoeijs-Leijonmalm *et al.*, 2017). Higher salinity can have physiological consequences for the round goby living in this region. Higher osmoregulatory costs are likely to affect somatic growth (Behrens *et al.*, 2017), reproductive output (Green *et al.*, 2021a), energy budgets related to behaviour and immune responses. The populations spreading in the Baltic region are adapted to a brackish condition of the Black Sea, with an average salinity of around 17 PSU (Green *et al.* 2021b). Conditions deviating from these have been shown to be tolerated by the species to varying degrees in experiments, but ecological factors are often not accounted for during these tests. The species diversity of the area likely provides a larger pool of potential competitors and predators (Snoeijs-Leijonmalm *et al.*, 2017). Furthermore, these predators and competitors are potentially living closer to their physiological optima than the round goby occupying the same area.

Round goby abundance estimations

Estonia

In 2015–2016 round goby densities were estimated in altogether 12 stations placed in different habitats and depths in two localities, in theGulf of Riga and the Gulf of Finland. Each station was sampled during warm months (May to October). The experiment included 3 densities estimated strategies i) diver transect counting, ii) underwater video transects counting and iii) 5 small box traps (baited) 2-night catches. Results showed great variability of methods estimating round goby densities (Figure 1.6, Nõomaa *et al*., unpublished). The overall conclusion is that diver estimation is the most stable methodology throughout different seasons in estimating round goby density, while baited trap estimations show higher numbers in spring and autumn in the Gulf of Finland. This could suggest food limitations in an earlier invasion site (start of invasion in 2007 in Gulf of Finland and 2012 in Gulf of Riga experimental area; Nõomaa *et al.*,2022) causing the round goby to more actively search for food. Counting round goby individuals from underwater video showed rare sightings in only spring season, as the detection was affected by water transparency and vegetation in benthic habitats. Round goby abundance calculated per m² varies between seasons from an average 1.4 m^{-2} (max 8) by diver count, 0.12 m^{-2} (max 5) by video count and 2.7 (max 31) per location (area ca 25 m²; max 31) by traps (Nõomaa *et al.*, unpublished).

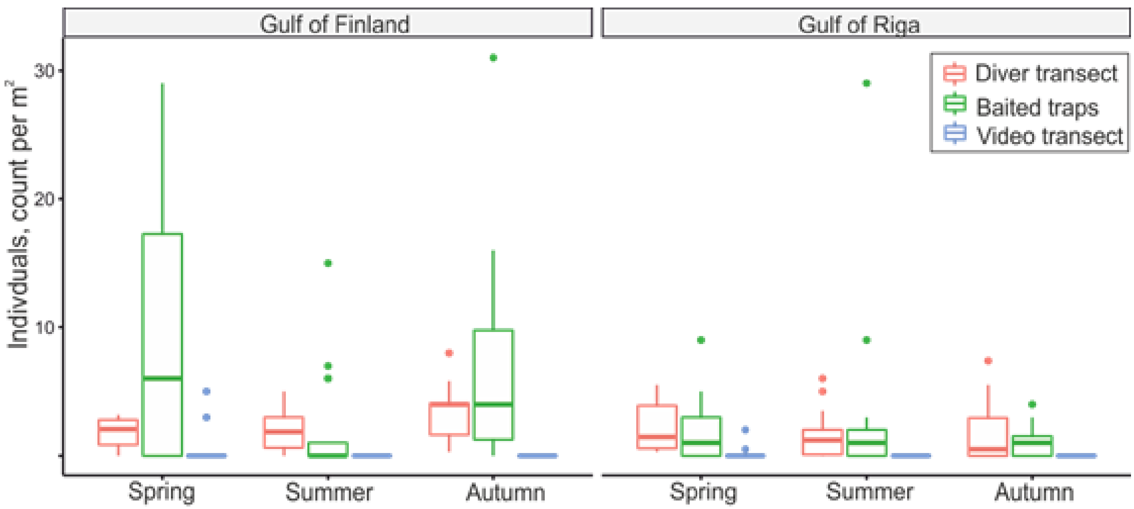

Figure 1.6 Round goby average (2015 and 2016) individual counts calculated for m2 for diver and video estimations and per location for baited traps. (Nõomaa *et al.*, unpublished).

In modelling long-term round goby impact on benthic communities, fine-scale round goby biomass trends are needed. Coastal fisher's landings in small statistical quadrats were used as a proxy for round goby biomass, as they might be able to reflected changes in biomass trends under certain assumptions (Probst and Oesterwind 2014; Nõomaa *et al.,* 2022) (Figure 2.3).

Another source of catch/abundance data from the Danish waters is from the so-called 'key fishermen program'. This is an ongoing collaboration between voluntary locally organized recreational fishers and scientists at DTU Aqua, with the overarching aim to investigate potential changes in fish distribution or abundances in inshore areas (Støttrup *et al.,* 2018). Since 2005, the fishers have used fixed gears and fixed positions, to allow comparison between areas, years, and season. These results show that in the areas with large numbers of round goby where key fisher have been fishing (Bornholm, Fehmarn Belt, Præstø Fjord, Smålandsfarvandet, Faxe Bugt/the Sound), the abundance of round goby peaked in 2014–2016, after which sharp declines in catches were observed.

1.2.2 Feeding ecology

The role of round goby as both prey and predator in the Baltic Sea region has been extensively studied (Ojaveer *et al*., 2021, Annex 4). To date, a list of over 100 unique taxa have been found to be consumed (Annex 3) by adult round goby, including several fish species such as stickleback, herring and eelpout (BIOR, 2022; Wiegleb *et al*., 2018). However, larval feeding ecology is understudied, with little knowledge of food preferences or consumption rates. Overall, round goby are opportunistic feeders that feed mainly on invertebrate prey that fits into their mouths (gape size limited). There are clear differences in feeding over the season that are combined with ontogenetic changes in food preference (Borcherding *et al*., 2013a; Skabeikis and Lesutiene, 2015). So far, no signs of individual specialization have been found, but when bivalves are present in the environment, these constitute an important part of the diet in round goby, especially for gobies larger than 100 mm (Oesterwind *et al.,* 2017). Surveys from the eastern Baltic (Latvia, 2017 and onwards) show that round goby diet composition is related to habitat type and fish body size (BIOR, 2022). In all size groups, the most popular food object are bivalves (in Gulf of Riga primarily *Macoma balthica*, and along the SE Baltic coast *Mytilus*). For smaller individuals (50–100 mm) amphipods dominate the diet, medium-sized round goby (100–150 mm) feed heavily on *Saduria*, and fish prey is found mainly in the guts of larger individuals (150–200 mm) (BIOR, 2022). These trends are supported in studies from Lithuania (Skabeikis and Lesutiene, 2015). Fish constitute a minor part of round goby diet < 10% (Skabeikis and Lesutiene, 2015). Predation from round goby on Atlantic herring eggs has been found but deemed to be of minor importance for the herring stock compared to the predation from other species, such as sticklebacks or perch (Wiegleb *et al*., 2018). This conclusion was also supported by a spatio-temporal mismatch between round goby and herring eggs in spring at herring spawning sites, egg consumption mainly in round goby < 100 mm (Wiegleb *et al*., 2018) and that alternative prey items were preferred in lab experiments (Wiegleb *et al*., 2018). Salmon eggs have also been tested as a potential prey item but very little consumption occurred in the experimental trials when eggs could be protected by substrate (as they normally are in nature) (Efstathiadis *et al.,* unpubl.).

Round goby is now a substantial part of the diet in most piscivorous predators of the Baltic Sea, see Annex 3 (Almqvist *et al*., 2011; Madenjian *et al*., 2011; Gertzen, 2016; Liversage *et al.*, 2017; Oesterwind *et al*., 2017). Fishes such as perch, pike and cod prey extensively on them. Grey seal (Scharff-Olssen *et al.*, 2019) and cormorant (Oesterwind *et al*., 2017) population growth could benefited from the increasing abundance of round goby in the Baltic. A monthly monitoring of perch diet in the Karlskrona archipelago from 2018 to 2021 revealed a seasonal pattern, with round goby dominating the diet in spring and autumn and other bony fishes dominating in summer. Ongoing predator experiments suggest a prey size preference in perch of prey representing approximately 30% of predator length, which is approximately a similar size that is found for other prey species (Anders Persson, personal communication).

Important for ecosystem function and recovery of the Baltic cod populations, round goby is likely to be an important prey item in areas where they are abundant. In an unpublished study of predator–prey interactions in November 2018, cod were collected from two Danish coastal sites: 19 individuals from Nakskov (south of Zealand) and 43 from Bornholm using passive gear by local fisher. Mean length of the cod was 31 cm (ranging from 21 to 42 cm). The share of cod with stomach content containing at least one goby (total gobies = 9) was 29% in Nakskov, compared to 42% in Bornholm (total gobies = 54). Genetic identification of 29 individual gobies from these stomachs showed that these were all round goby. Round goby is the second most common prey type in both locations after shrimps. Based on retrieved round goby otoliths in the cod stomachs, it was shown that cod had fed on round goby ranging from 3 to 14 cm in size, however mainly feeding on the smaller size classes 3–7 cm (Figure 1.7) (Jane Behrens, personal communication).

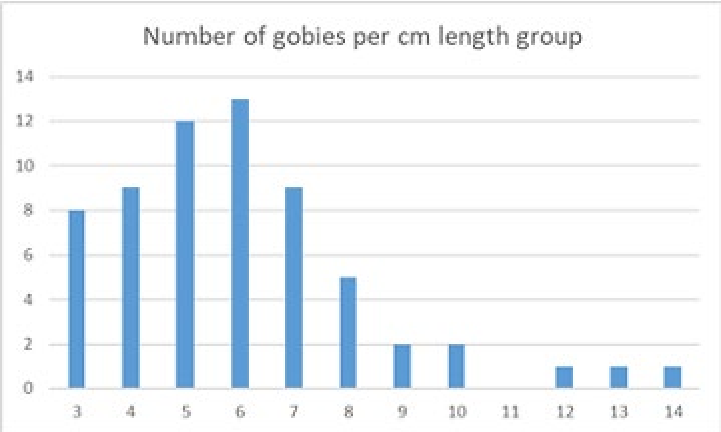

Figure 1.7 Length distribution round gobies found in cod stomachs caught at Nakskov and Bornholm.

Feeding ecology has been shown to be a strong mediator of direct and indirect ecosystem effects, often with very complex dynamics and spanning taxonomic groups outside other fishes. An experimental study illustrates that round goby (13.5 ± 0.8 cm) affected macroinvertebrate biodiversity from a taxonomic and a functional point of view. Specifically, round goby decreased overall abundance, biomass and taxon richness of epifaunal invertebrates (Henseler *et al.*, 2021). Other direct effects on the benthic community is mainly attributed to gastropod and bivalve decline (Skabeikis *et al.*, 2019; van Deurs *et al.*, 2021; Nõomaa *et al.*, 2022) but the bivalve decline also indirectly affects other organisms. For example, globally vulnerable Long tailed ducks (*Clangula hyemalis*) were found to increase their diet of fish up to a tenfold (and shift to a higher trophic level) when blue mussels disappeared from their wintering grounds due to round goby predation (Skabeikis *et al.*, 2019). Interactions with other organisms can also affect round goby prey selectivity. Blue mussels (*Mytilus spp.*) are important prey items both for green crab (*Carcinus maenas*) and round goby, but green crab have a higher energetic return of, and selectively feed on larger mussels than the round goby, suggesting niche differentiation where they overlap (Papageanopoulos *et al.*, unpubl.). However, the presence of green crab affects antipredator strategies that result in higher crushing resistance in mussels that potentially would drive prey size preference in round goby towards smaller mussels (Hu *et al.*, unpubl.). In total, higher salinities and a higher number of bivalve predators likely decreases the opportunities for round goby to invade areas that are also occupied by crabs and other bivalve predators. Several studies have shown round goby to compete with other fishes for food resources (Karlson *et al.*, 2007; Ericsson *et al.*, 2021). An experimental study showed that the round goby likely reduces predation of the Harris mud crab (*Rhithropanopeus harrisii*) on some bivalve species in the Northeastern Baltic Sea area (Nurkse *et al.*, 2018).

1.2.3 Behaviour

Behavioural studies focusing on round goby personality, migration and dispersal may assist our understanding of how round goby populations are interacting with and affecting local ecosystems, and to predict future changes in their distribution and abundance in the Baltic Sea region.

Round goby populations often display among-individual variation in behaviour (i.e. personality, often concentrating on the bold/shy continuum), which can have consequences for intra- and interspecific interactions and dispersal. For example, in a competition experiment Ericsson *et al.* (2021) found that Atlantic cod consumed fewer prey when they were together with bold round goby than when competing with shy round goby, suggesting that boldness traits can mediate interspecific competitive interactions. However, in this case intraspecific foraging competition was not personality dependent. Additional examples from the Baltic region have shown predator response behaviour linked to metabolism (Behrens *et al.*, 2020), and various personality traits linked dispersal tendency (Thorlacius *et al.*, 2015; Thorlacius and Brodin, 2018). These results mirror similar studies from riverine environment, linking behavioural variation to social and predator interactions (Loftus and Borcherding, 2017), competitive interactions (Borcherding *et al.*, 2019), and dispersal (Myles-Gonzalez *et al.*, 2015; Hirsch *et al.*, 2017). Personality differences within round goby populations in the Baltic appear to be common, and studies of their interactions with local species and their dispersal should consider this variation.

It should also be noted that parasite infection (see section 1.2.4) may influence behaviour, and potentially their susceptibility to predation (Flink *et al.*, 2017). Therefore, variation in parasite effects across the round goby's Baltic Sea range may also influence how round goby populations are affecting local ecosystems.

Seasonal migratory behaviour appears common in the Baltic region, in particular overwintering migrations into deeper waters (Behrens *et al.*, 2022), but upstream migrations into freshwater environments also appear to occur to some degree (Christoffersen *et al.*, 2019). Related to migratory and reproductive behaviour, catch rates are generally highest in spring and autumn (Brauer *et al.*, 2020), but the timing and relative significance of spring and autumn peaks may differ between regions within the Baltic. For example, catch data from Latvia shows that catches are higher in spring compared to autumn season. This is likely to be related to migration and activity patterns, or post-spawning mortality resulting in fewer large gobies active in the population in autumn.

A major mechanism for round goby spreads appears to be via shipping (Kotta *et al.*, 2016). Secondary dispersal via active movement obviously also take places from the points of introduction (often harbours), e.g. has dispersal rates of approx. 30 km per year along the coastline been reported for round goby in the inner Danish waters (Western Baltic) (Azour *et al.* 2015) and tagging of round goby has revealed migration between a fjord system and the adjacent sea (and return migration for some of the tagged fish), with a few fish also revealing riverine upstream dispersal (Christoffersen *et al.*, 2019). Round goby performs a characteristic burst-and-hold swimming mode (Tierney *et al.*, 2011; Egger *et al.*, 2020). In riverine systems, round goby can make use of its pectoral fins to create negative lift forces and hold station with minimal effort (Carlson and Lauder, 2010; Gilbert *et al.*, 2016; Wiegleb *et al.*, 2020). The literature reports varying swimming performance (Ucrit) of the round goby (0.21 m/s (Hoover *et al.*, 2003); 0.36 m/s (Tierney *et al.*, 2011); 0.54 m/s (Egger *et al.*, 2020). There was a rheotactic tendency reported for the round goby at lower water velocity (Tierney *et al.*, 2011; Wiegleb *et al.*, 2022). A recent study using pan-Baltic catch data has documented a pronounced seasonal migration between coastal areas in the warmer period of the year, and deeper offshore areas during winter (Behrens *et al.*, 2022). The extent to which dispersal occurs preferentially in any of these two periods remains uncertain, and further studies of round goby movement, including studies in the wild (e.g. tagging/tracking studies) and studies specific to the Baltic Sea, may assist in understanding round goby movement in relation to migration, habitat use and spread in this region.

Round goby movement patterns in relation to suitable benthic habitats were investigated with tagging experiments in the Estonian coastal waters in 2016 and 2017 (Nõomaa *et al.*, unpubl.). Preliminary results indicated that the round goby has a much larger home range than previously indicated. On average, the adult males moved in a 100 m radius and could even swim 1 km in 24h. In a fjord system and using acoustic telemetry, Christoffersen *et al.* (2018) found pronounced movements of round gobies, where the fish on several occasions were found to cover distances between 1.5 and 2 km in less than a day, and up to 2 km travelled in 4.2 h. Nõomaa *et al.* (unpubl.) also found that round goby moved around more in less suitable habitat (soft bottom, muddy) then in mixed bottom habitat. This suggests the species has high secondary invasion potential and its impact likely varies between different habitats.

The LIFE REEF project, commenced in 2021 in Latvia, will assess round goby distribution range, including their migration patterns, and use this information to inform spatial management of round goby fisheries in future. Within 2 years, 8000 round gobies are expected to be tagged using T-tags during their spring-spawning-migration period in two separate coastal locations (i.e. Baltic Sea and the Gulf of Riga). To support the return of tags and information, a contract will be signed with the Latvian coastal fisher organisation. Currently, 2000 round gobies have been tagged, but quantitative results are not yet available. In the coming years this information will help to determine round goby migration range, with the aim to determine if it is possible to use fisheries to exclude round goby from selected areas.

1.2.4 Management (ecological)

Management of the round goby invasion in the Baltic Sea

The group is not aware of explicit management measures targeting round goby populations in the Baltic Sea region. While eradication of round goby, and aquatic invasive species in general, from invaded ecosystems is unrealistic, population control that leads to minimizing the risk of transfer to yet uncolonized areas is feasible and likely the most effective management measure (Havel *et al.* 2015; Ojaveer *et al.* 2015). Extensive involvement of stakeholders is crucial at all phases of the management process (Ojaveer *et al.*, 2015), not least at early stages of the invasion, where modelling the potential invasion proceeding can provide a scientific basis for stakeholder engagement for early management decisions (Samson *et al.*, 2017). As ship's ballast-water is an important long-distance distribution pathway for the round goby (Brown and Stepien 2009; LaRue *et al.*, 2011), the potential origin of invasions in harbours has been accounted for in the HELCOM action plan. This action plan foresees establishing an early warning system by 2024 to detect new invasive species introductions. In addition, HELCOM requested to improve the co-operation between stakeholders in the development of sustainable biofouling management options to reduce the translocation of invasive species via ship hulls (HELCOM Baltic Sea Action Plan, 2007). Further actions to exert population control include landing the species in commercial fishery bycatch, the management of ships' ballast water and sediments, and hull fouling of inland and sea-going vessels, including recreational boats (Ojaveer *et al.*, 2015).

1.2.5 Parasites

In the Estonian coastline round goby parasite community abundance and richness were investigated in two populations in different invasion stages (Ojaveer *et al*., 2020). We found a very rich parasite community (at least 24 species) consisting solely of native species. It appeared that there were only marginal differences between the well-established population in the Gulf of Finland and the population which was at the establishment phase near the Gulf of Riga. Based on findings in the study and considering previous work on parasite-host relationships in the Baltic Sea and beyond and on the foodweb interactions of the round goby in various parts of the Baltic Sea, an extended schematic diagram on the role of the round goby in parasite life cycles and transfer in the system was created (Figure 1.8; Ojaveer *et al.*, 2020 and references therein). This diagram does not necessarily illustrate the transfer pathways of all parasites either occurring in the system or infecting the round goby, but rather focuses on the role of the fish in parasite life cycles and transmission. The figure shows that in addition to previous knowledge (Kvach and Skóra,2007), this system also involves copepods as first intermediate hosts and seals as definitive hosts. Thus, the introduction of the round goby has resulted in additional or alternative pathways of parasite transmission in the Baltic Sea, likely affecting the parasite communities of definitive hosts in the system.

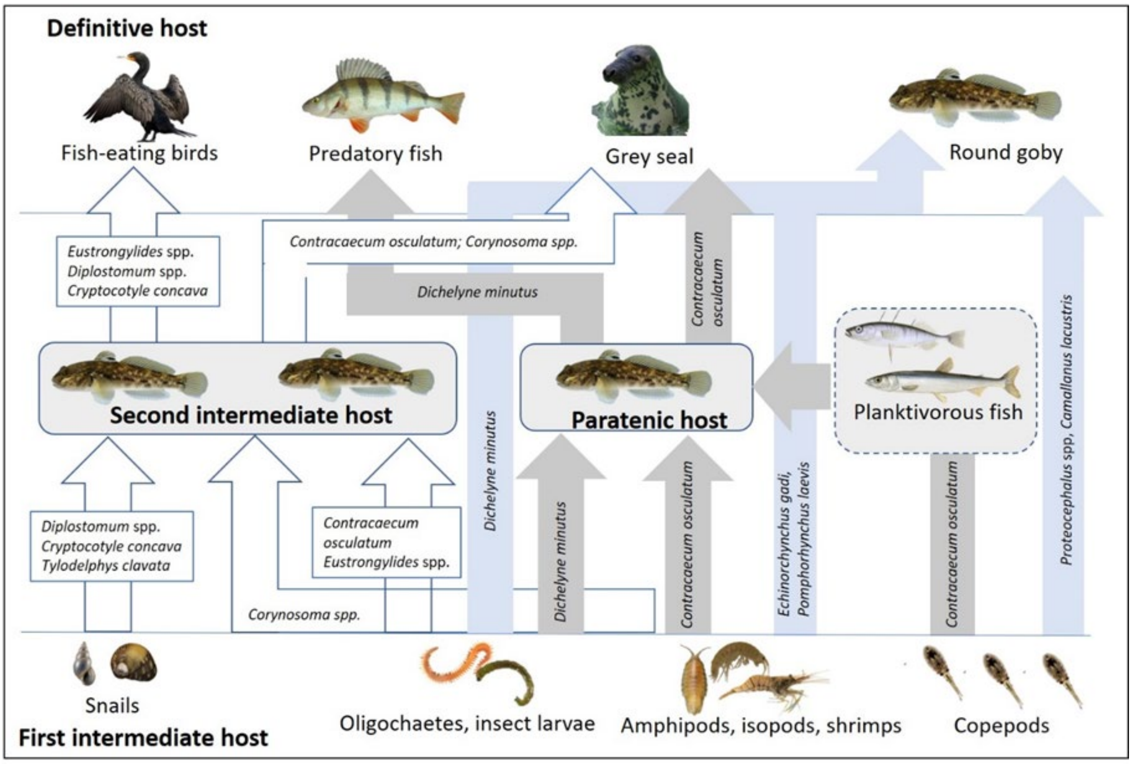

Figure 1.8. The role of the round goby in the transfer of parasites in the Baltic Sea (Kvach and Skóra, 2007 updated), together with examples of parasites found in the current study for each transfer pathway. The infection of the round goby by *Trichodina* spp., *Diplostomum* spp., *Cryptocotyle concava* and *Tylodelphys clavata* is not directly through prey consumption but results from physical contact with parasite larvae released into the sea by their intermediate hosts (marine invertebrates) (Ojaveer *et al.*, 2020).

A dedicated study investigating eye flukes (*Diplostomum spp*.) in round goby from the Kalmar Sound (Sweden) showed that the fish in this area had an eye fluke prevalence of 90–100%, and that the more intense the parasite-induced cataract, the weaker the host's response was to simulated avian attack (Flink *et al.*, 2017). This suggests that for this parasite-host system, the parasites induce changes in host behaviour that will facilitate transfer to their final host, which are birds.

Round goby parasites in freshwater in the Baltic Sea area

In the freshwater area (lagoons and river systems) related to the Baltic Sea (Ondrackova *et al.* 2005, 2009, 2010, 2015, 2021; Francova et al. 2011; Mierzejewska et al. 2011; Emde *et al.* 2012; Slapansky *et al*. 2016) and in the Great Lakes (Kvach and Stepien 2008; Gendron *et al.* 2012) round goby parasite communities have been studied more extensively than in the brackish Baltic Sea (Kvach and Skora 2007; Kvach and Winkler 2011; Kornis *et al.* 2012; Flink *et al.*, 2017). There are some studies on parasites in round goby and other invasive gobies that support the idea of the parasite release hypothesis (in leaning to the predation release hypothesis) when alien species enter new environments, also showing that these species act to a certain extent as vector of new parasites (Kvach and Stepien 2008; Emde *et al.*, 2014; Hohenandler *et al.*, 2018).

2 ToR b: Evaluate the ecological, economic and legal boundary conditions for a commercial use of stickleback and round goby

2.1 Stickleback

2.1.1 Landings statistics

Historically, the stickleback has been an important species for Baltic fisheries. In the 1800s and early 1900s stickleback was caught mainly to produce oil to be used as lamp fuel or in varnish, while the residue was used as animal feed or fertilizer (Bergström *et al.*, 2015). With the rise of the petroleum industry, this coastal fishery however declined quickly. During the 1970s and 1980s, fairly large biomasses of stickleback, with an average of 7000 tons a year, were caught for animal feed and fishmeal production mainly by the former Soviet Union states in the eastern Baltic (Ojaveer, 1999). It was obligatory to catch sticklebacks in the fishery kolkhoses (governmental fisheries companies), which received money if they caught more than according to the obligatory catch plan. This fishery along the eastern Baltic coast was eventually terminated, as bycatches (of mainly percids and cyprinids) were high and damaged coastal populations (Henn Ojaveer pers.comm.). During the last three decades (data available to 2019) catches have been low, averaging 700 tonnes a year (ICES catch statistics; Figure 2.1). Stickleback has not been actively targeted by fisheries during the last decades, as the smallest mesh size allowed in pelagic trawling is too large to efficiently catch stickleback. The landings thus mainly constitute bycatches in the industrial pelagic fishery, and as the proportion of stickleback is small the reported landings are likely uncertain.

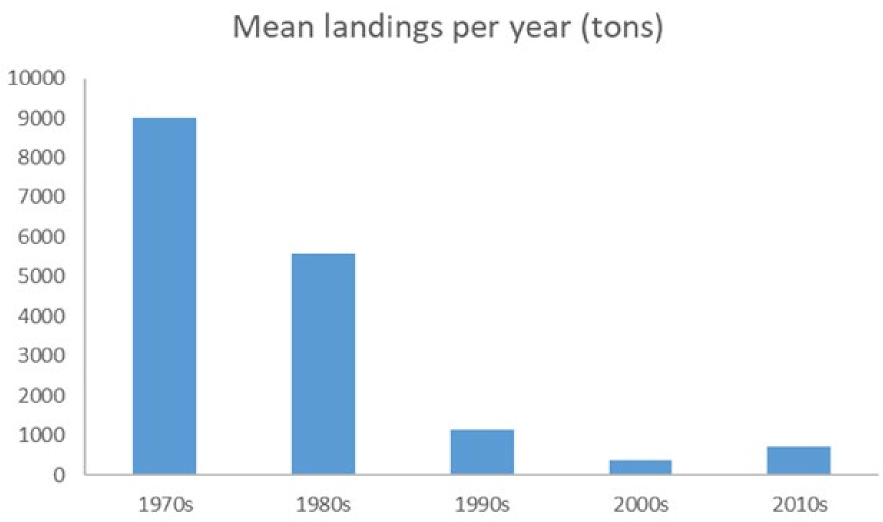

Figure 2.1. Catch of stickleback in the Baltic Sea in the 1973–2019, presented as mean catch per year of all countries together according to ICES landings statistics.

2.1.2 Fisheries management and regulations

Stickleback is currently an unmanaged species, and there are hence no catch regulations or quotas set by the EU Commission. Fisheries are not targeting stickleback, mainly as a result of not being allowed to use a fine enough mesh size in pelagic trawls to catch the species efficiently. Stickleback is, however, to a lesser extent still taken as bycatch in the pelagic fishery (see paragraph on Landings statistics below).

As a large-scale future commercial fishery targeting stickleback in the Baltic Sea would be a clear example of fishing down the foodweb. To prevent further negative impacts on the ecosystems along coasts and offshore areas, such an activity needs to be carefully evaluated by implementing a scientific trial fishery (Appelberg *et al.,* 2020; BSAC 2021). Such trials have now been initiated by several countries around the Baltic Sea, where the programs led by DTU Aqua and SLU Aqua are the so far most extensive ones. If the results of these trial fisheries indicate that a commercial fishery can be performed without risking negative consequences in the form of bycatches or ecosystem effects, such a commercial fishery still needs to be highly regulated and monitored with clear precautionary management targets and adaptive decision-making. Future stickleback quotas should not be set from a single-species/stock perspective, as it is the current approach by ICES. Catch levels should rather be set considering the impact on other interacting species and the ecosystem as a whole. In addition, bycatch rates of other species, as for example salmon, cod, sprat and herring, in such a fishery need to be carefully monitored and assessed, and measures and gear development to prevent further bycatches should be instated. A monitoring program focused on stickleback should be in place to allow for a sound scientific basis of catch levels that also allows tracking changes in the population sizes and spatial distribution. To further limit the potential negative impact of a future stickleback fishery in the Baltic Sea, trawling should not be allowed in coastal areas and other areas where large bycatches can be anticipated (Appelberg *et al.,* 2020; BSAC 2021).

2.1.3 Assessment

Currently being a non-quota species, there are no stock assessment models developed for stickleback in the Baltic Sea. The available information on biomasses and abundances of the species is instead derived from scientific surveys only (the BIAS survey), and estimated in research projects (reviewed in Olin *et al.,* 2022). Estimates from the early 2010s suggest that the biomass of stickleback in the Central Baltic Sea equals some 100–200000 tonnes and 20–60000 tonnes in the Bothnian Sea (Olsson *et al.,* 2019). Based on these figures, stickleback have been estimated to make up around 10 and 6% of the pelagic fish biomass in the Central Baltic Sea and Bothnian Sea respectively during the period 2011–2014 (Olsson *et al.,* 2019). Further increases in population numbers in the Bothnian Sea suggest significantly higher biomasses in more recent years, while only slight increases have been seen in the Central Baltic Sea (Olin *et al.,* 2022).

In future, fully analytical assessment models should be developed to address the biomass of stickleback in the Baltic Sea. As there are currently no fishery targeting stickleback in the region, assessment models based on catches in scientific surveys only are likely most suitable to use. Currently there is work planned in both Denmark and Sweden to develop stock assessment models for stickleback in the Baltic Sea. This work also involves development of hydroacoustic methods and of procedures for ageing stickleback from otolith readings. Future cooperation between countries in the region for the development of such models would be fruitful to include and consider as wide expertise as possible.

2.1.4 Gear selectivity and fishing methods

Coastal area

In 2021, a pilot monitoring study targeting coastal fish communities was conducted at the western German coast of the Baltic Sea (Schleswig-Holstein). Data were collected from February until December in different habitat types (bare sand, seagrass meadow, bladderwrack belt, rocky reef, blue mussel bed) using five different fishing methods (multimesh gillnets i.e. coastal survey nets, eelfykes, minnow traps, bottom trawls, beach-seines). The following comparison of stickleback numbers between gear types is based on the number of fishes per replicate for the respective fishing gear across all habitat types (Henseler and Oesterwind, unpublished data). In winter (February/March) and autumn (October), three-spined sticklebacks were primarily caught with beach-seines, while fewer individuals were documented in bottom trawl catches. Gillnets and beach-seines performed equally well in catching sticklebacks in spring (April/May), followed by bottom trawls. In summer (June/July), beach-seines caught the highest numbers of sticklebacks followed by gillnets and bottom trawls. Contrary, bottom trawls and beach-seines were most efficient at catching the species in late summer (August/September).

In another study, the efficiency of different fishing methods in catching sticklebacks was evaluated specifically for seagrass meadows (Henseler and Oesterwind, manuscript in preparation). Beach-seines performed significantly better than multimesh gillnets in catching the species throughout the year, while bottom trawls mostly caught fewer individuals than beach-seines in seagrass meadows. Thus, active fishing methods seem to be more efficient at catching sticklebacks in shallow coastal habitats than passive methods. However, catchability of fishing gear differs between seasons.

Offshore

In the Baltic Sea, the pelagic trawl fishery targets herring and sprat, whereas the stickleback is an unwanted species and fishers have tried to avoid them. However, most sticklebacks escape through the regular meshes of 16 mm or 32 mm which are used in the pelagic commercial trawl fishery. Thus, to fish sticklebacks a smaller mesh size is necessary. Decreasing the mesh size will, however, increase the risk of bycatch of juvenile herring and sprat. Thus far, there are no specific regulations for stickleback fishery and gear, although some regulation will most likely be needed in the future. For example, the vertical opening of the "stickleback trawl" could be quite low (e.g. 10–15 m). This will also decrease the towing resistance of the gear, which would otherwise be higher due to the small mesh size needed.

Herring, sprat and stickleback are found in the same depth layer during night, at daytime herring and sprat migrate in deeper waters, while stickleback still occupies the surface layers (usually 5–20 m). Therefore, bycatches of clupeids in a stickleback fishery can be minimized by fishing during daytime and close to the surface. However, there is still a risk of bycatch of other species, such as salmon and trout. To minimize bycatch of these larger species, trawl gear with a selection panel or escape window could be applied.

2.1.5 Potential fishing areas

Potential stickleback fishing areas

Potential commercial fishing for stickleback would most efficiently be performed in the parts of the Baltic Sea with the highest biomasses of the species, i.e. SD 27, western part of SD28, SD29 and southern part of SD30 (see section on Distribution and stock development). To minimize bycatches, coastal areas and open sea areas with high concentrations of salmon, trout and cod should be avoided, and fishing preferentially be performed in surface waters during winter (Appelberg *et al.*, 2020). In order to reduce bycatch of other pelagic fish species, a future stickleback fishery should also avoid fishing in areas or times where stickleback aggregates with herring and sprat.

A recommendation regarding a trial fishery for stickleback in the Baltic Sea issued by the Baltic Sea Advisory Council (BSAC) suggests that the central Baltic (SDs 25–29) would be the best area for a targeted stickleback fishery, but that SDs 30–31 are also possible fishing areas. BSAC also concludes that the fishery should be conducted away from the coastal areas in order to avoid habitat disturbance and bycatch and undertaken in close cooperation with scientists for a thorough evaluation of the information gathered (BSAC, 2021).

2.1.6 Potential effects of introducing a stickleback fishery

A detailed discussion on the consequences of a potential introduction of a stickleback fishery are well addressed in the studies by Olin *et al.* (2022) and Jusufovski *et al.* (under review). Here we summarize their main arguments.

From an ecological and socio-economic perspective, an introduction of a stickleback fishery in the Baltic Sea could be beneficial for several reasons. If we assume that the total fishing effort in the pelagic fishery will remain the same, the introduction of a stickleback fishery could lessen the fishing pressure on the exploited commercial stocks of herring and sprat. The removal of stickleback can at the same time decrease the predation pressure on eggs and juveniles of coastal predatory fish (e.g. pike, perch) and herring (Kotterba *et al.*, 2017). Additionally, a reduction in stickleback abundance will minimize the predation pressure on mesograzers, preserving the herbivore species community that keep the algal growth in check. This will have a positive effect on the water quality by controlling the growth of filamentous algae. Moreover, the removal of stickleback biomass could to a certain extent contribute to the abatement of high nutrient levels.

Introducing the stickleback as a new target species will expand the fishing activity and fish market with additional products (e.g. fishmeal, supplements) and allow for the development of other innovative solutions derived from stickleback (e.g. biogas production).

Yet, commencing a stickleback fishery in a sensitive and species-poor ecosystem as the Baltic Sea raises several risks. Regardless of the fishing location, the small mesh size needed to catch stickleback efficiently will increase the risk of bycatch (such as herring, sprat, salmon and cod mentioned in previous sections). This potential bycatch will increase the mortality of other fish species lowering their viability and survival, particularly if those species are also commercially targeted. A new stickleback fishery will require proper monitoring of species compositions of landings, to decrease the risk of misreporting. Currently, there are a number of studies that address the complex ecological role of stickleback in the Baltic Sea. However, the current knowledge does not provide sufficient insight into stickleback ecology in the open sea, as well as the characteristics and effects of coastal-offshore migrations. Failing to understand the cause-and-effect connections behind the relevant ecological processes could have negative direct and indirect effects on the species depending on stickleback as prey as well as other trophically near species. Based on that, the introduction of stickleback fishery carries a potential risk of harming the concomitant ecosystem and reducing the availability of relevant commercial species to fisheries.

Any unsustainable practice in harvesting stickleback will not lead to positive impacts of stickleback removal on the nutrient levels, but could rather cause further worsening of already existing threats.

Insufficient knowledge of stickleback abundance and distribution as well as the lack of efficient gear, could render the stickleback fishing operations unprofitable due to costs incurred by longer handling time and additional fishing effort.

2.2 Round goby

2.2.1 Landings statistics

One of the highest round goby commercial landings in the Baltic Sea is observed currently in Latvian coastal waters (SD 26, 28.2 and 28.1). According to Latvian commercial fishery logbooks, round goby was first recorded in 2006, when the total annual catch was 6.3 kg. The catch increased gradually until 2011 but increased sharply thereafter – from less than one tonne in 2011 to over 1000 tonnes in 2018. Several factors contributed to this striking development – an increase in population size, market opportunities, and national fisheries policy. At the beginning, round goby in Latvia was mostly fished as bycatch in the herring poundnet fishery. Since 2015 there is a specialised round goby fishery with nets and trapnets. Both gears in combination with the spatial and seasonal boundaries led to an increase in round goby fishing selectivity and significantly contributed to the record catch of 2018. Since then, landings have decreased (Figure 2.2). However, in respect to landings, round goby is the second most fished species after herring in the Latvian coastal fishery in recent years. It is frequently found in offshore catches as well.

In Lithuanian waters (SD 26), round goby was first discovered in 2002, and in commercial catches it was observed in 2010. The highest landings were in 2016 and 2017, exceeding 200 tonnes (Figure 2.2). The main fishing gear used for round goby is trapnets. Catches with other fishing gears (gillnets, hook-lines) are negligible and consist of 2-3% of the total catch (Tomas Zolubas and Rasa Morkūnė, information from Lithuanian coastal logbooks).

In Estonian coastal landings (SD 28.1, 28.2, 29 and 32), round goby was first recorded in 2007 when the total annual catch was 89 kg. Since 2015 catches increased more sharply and reached a maximum of 256 tonnes in 2021 (Figure 2.2). Estonian landings are mainly from the Gulf of Riga area (SD 28.1), and the main fishing gears are trapnets and gillnets (Estonian Ministry of Agriculture). In the Gulf of Riga Estonian and Latvian landing dynamics shows a very similar pattern (Figure 2.3), which probably represents the same population dynamics or could be explained by the fact that the main fishing grounds in the Gulf of Riga are located close to the Estonian/Latvian border, and Estonians are actively using Latvian market to sell round gobies. Landings from both countries could depend on the actual market situation. The landing prices show high fluctuations in the beginning and a general decrease, but substantially increased within the last years in Estonia (Figure 2.4 and Figure 2.5).

In Poland (SD 25 and 26) round goby is occasionally caught in trapnets and gillnets, however landings are negligible (up to 8 tonnes per year) (Emil Kuzebski, personal information).

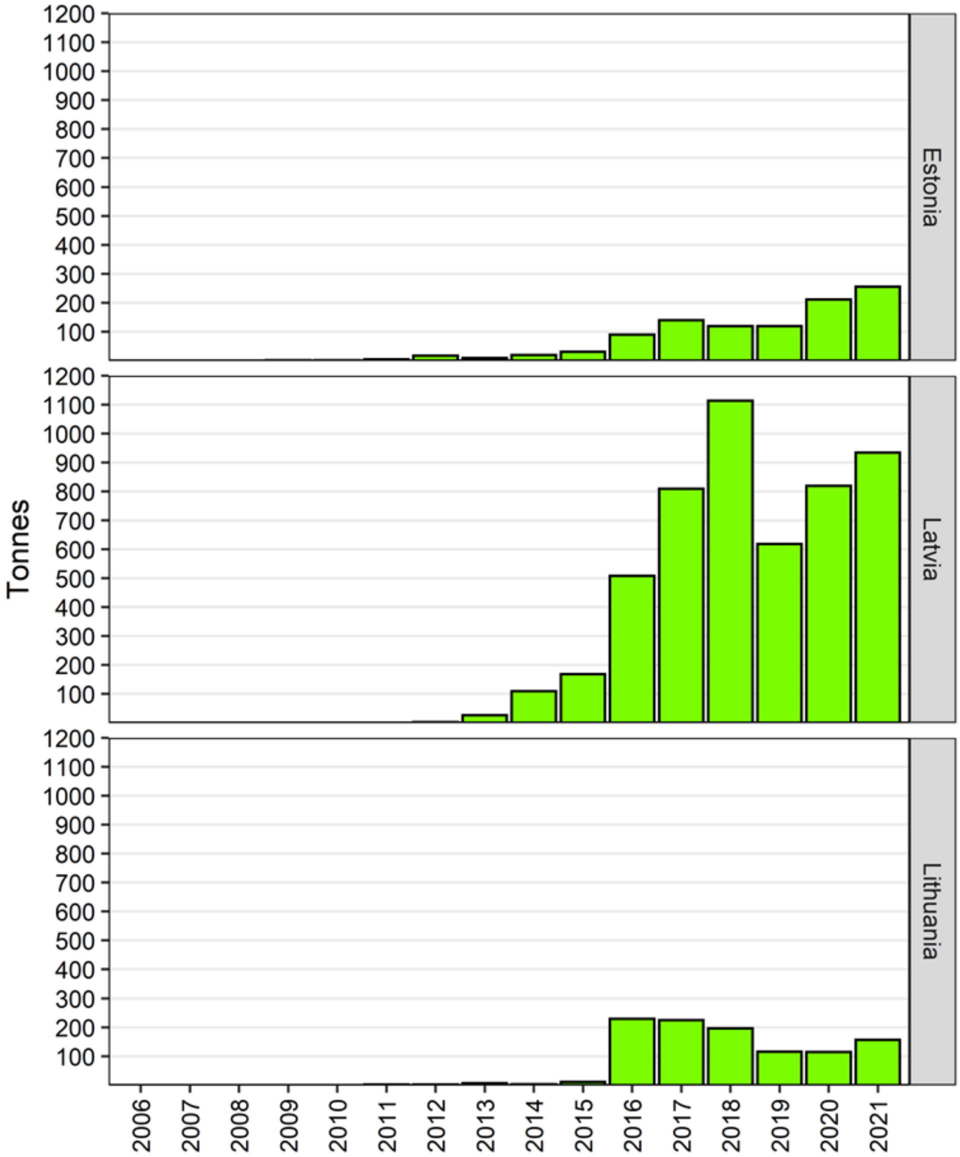

Figure 2.2. Round goby landings in the coastal fishery.

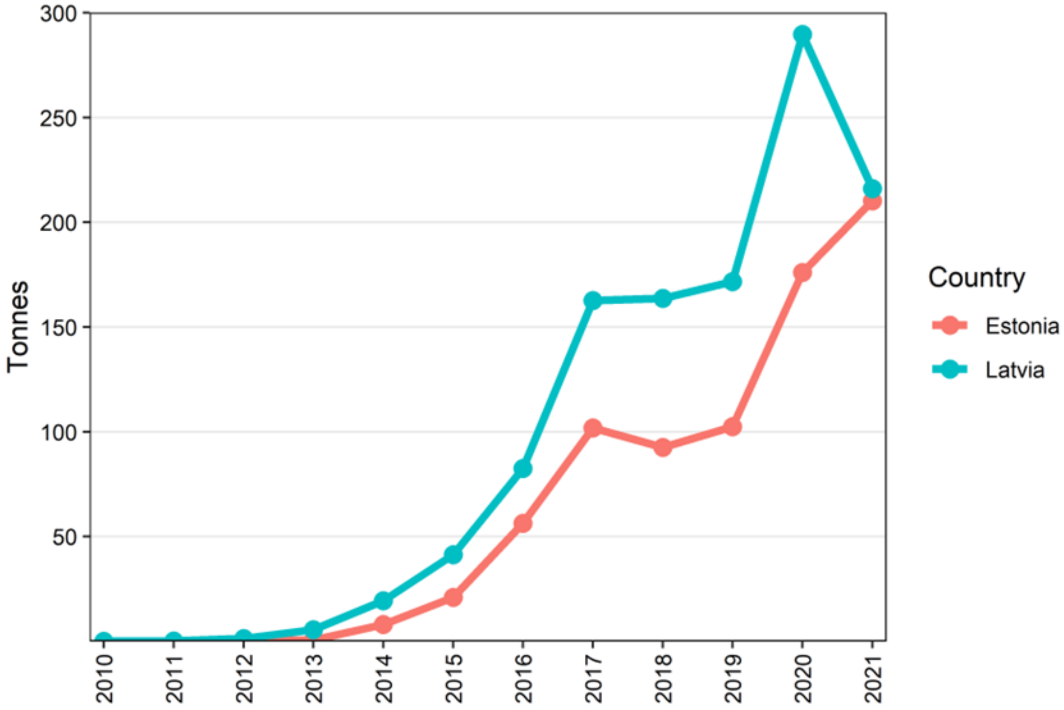

Figure 2.3. Estonian and Latvian round goby landings in the Gulf of Riga coastal fishery.

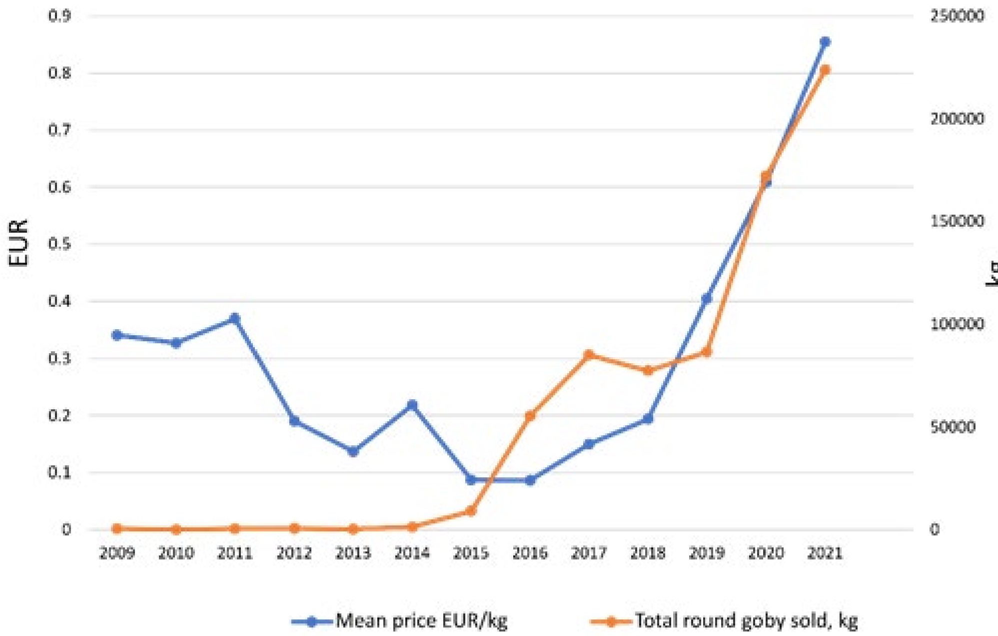

Figure 2.4. Trend between mean price of round goby and total amount of round goby sold annually in Estonia (Source: Estonian Ministry of Agriculture).

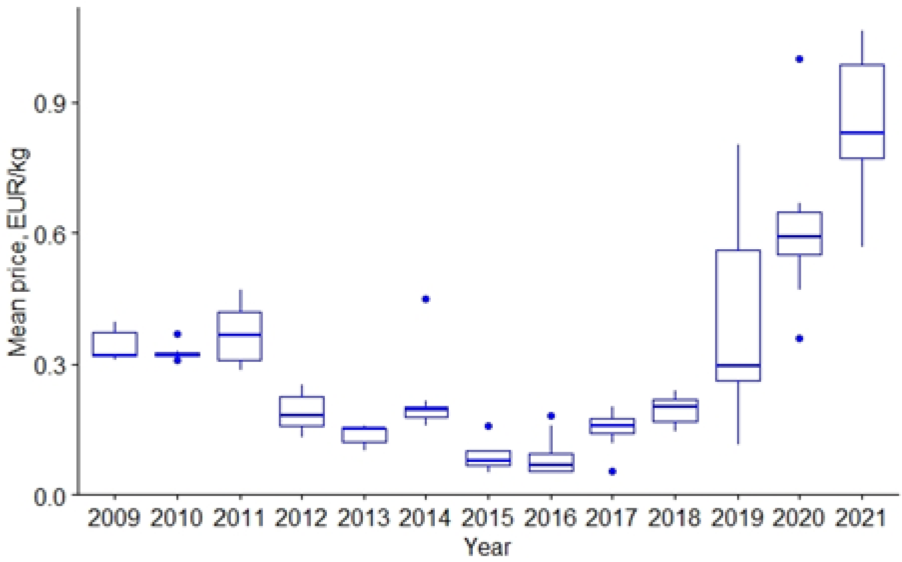

Figure 2.5. Boxplot of annual variation in the price of round goby in Estonia. (Source: Estonian Ministry of Agriculture).

Denmark

There is no Danish commercial fishery for round goby in the Baltic Sea. One project (SORTMUND, 2016–2019) has however collected information on bycatch (fykenets) from local fisher in Guldborgsund, Karrebæk and Kalvehave in the inner Danish waters (Western Baltic). These data show that CPUE are highest in May, followed by June and April (Brauer *et al.*, 2020). This suggests that these are the months when the fish are most active, entering the shallower waters after having spent winter at deeper waters (Behrens *et al.* 2022). As summer progresses and the water becomes warmer, spawning intensifies, peaking in July and August where the fish become less active, and thus are caught less in the passive gears. Mean length of the caught fish was 10, 13 and 12 cm respectively for Guldborgsund, Kalvehave and Karrebæk (average 11 cm). Investigations of the nutritional value of the fish showed that in general, the fish were rather lean (fat content up to 1%) with a high protein content (17–19%), and with some seasonal variation; mean oil content differed significantly between months, gradually increasing from spring towards autumn, and peaking at 1% in November. The protein content increased significantly from 17% in April to 19% in August, where after a small drop occurred between August and November. Condition factor was on average 1.5 and did not differ significantly between months or study areas. (Brauer *et al.*, 2020).

2.2.2 Fishing management and regulations

In the Baltic Sea, there are no catch quotas or other limitations on the round goby fishery. Thus, all management activities depend on national legislation and initiatives. To effectively utilize the abundant round goby resource, several management activities have been implemented in Latvia including the definition of specialised fishing gears and terms of use to minimize the bycatch of non-target species. The Latvian coastal fisheries management scheme involves annual data collection from the commercial and scientific fishery following by information analysis and biological parameter estimates to assess stock status. All available information is used to develop an annual scientific advice for the local policymakers suggesting necessary changes in fishing policy and defining allowable fishing gear limits in each coastal municipality. Currently, there is no information available on active round goby fishery management in other Baltic Sea countries. Round goby has become a permanent resident in the Baltic Sea. It can significantly increase catches and profits in some coastal regions. However, fishers are interested in this fishery only as long as there are well paid market opportunities, and currently, given the Latvian example, these opportunities exist mainly outside the EU.

2.2.3 Assessment

Based on catch rates, round goby population density in the Central Baltic Sea is high. In some areas round goby became an important fishing object for the coastal fishery. One of the highest round goby commercial catches has been observed in Latvian coastal waters. According to BIOR data, there has been an increasing trend in round goby abundance from less than 1 ton in 2011 up to 1112 tonnes in 2018, but in the last years round goby catch rates started to show a decreasing trend (BIOR, 2022). Despite the local importance of this species, the analytical stock assessment of round goby in the Baltic Sea region has never been performed and the total biomass is unclear.

In 2014 Latvia started collecting round goby biological samples from the commercial and scientific fishery. Based on this information, the first attempt was made to assess the round goby population biomass along the Latvian coast. ICES approved analytical XSA and SAM models were used for the first analytical stock assessment of the round goby in the Latvian west coast. The biomass estimates from stock assessment models were variable, but despite this, both models showed the same population trends.

Stock assessment of round goby along the Latvian coast showed that for the last seven years the fastest period of population development was found from 2014 to 2015. This was largely responsible for the growth of the stock and the high catch rates along the Latvian coast a couple of years later. Since 2016 fishing pressure increased and round goby population biomass decreased by more than half. Modelling results indicate that it was primarily driven by spawning-stock biomass and recruitment index, which decreased more than 3 times. At the same time, the fishing mortality index increased from 0.02 to 1.22. (Figure 2.6). This is a high indicator value, so the fishery's role in the overall process of stock reduction could be significant. Based on these results, the round goby stock along the Latvian coast most likely will decline in the coming years leading to a decrease in total catches.

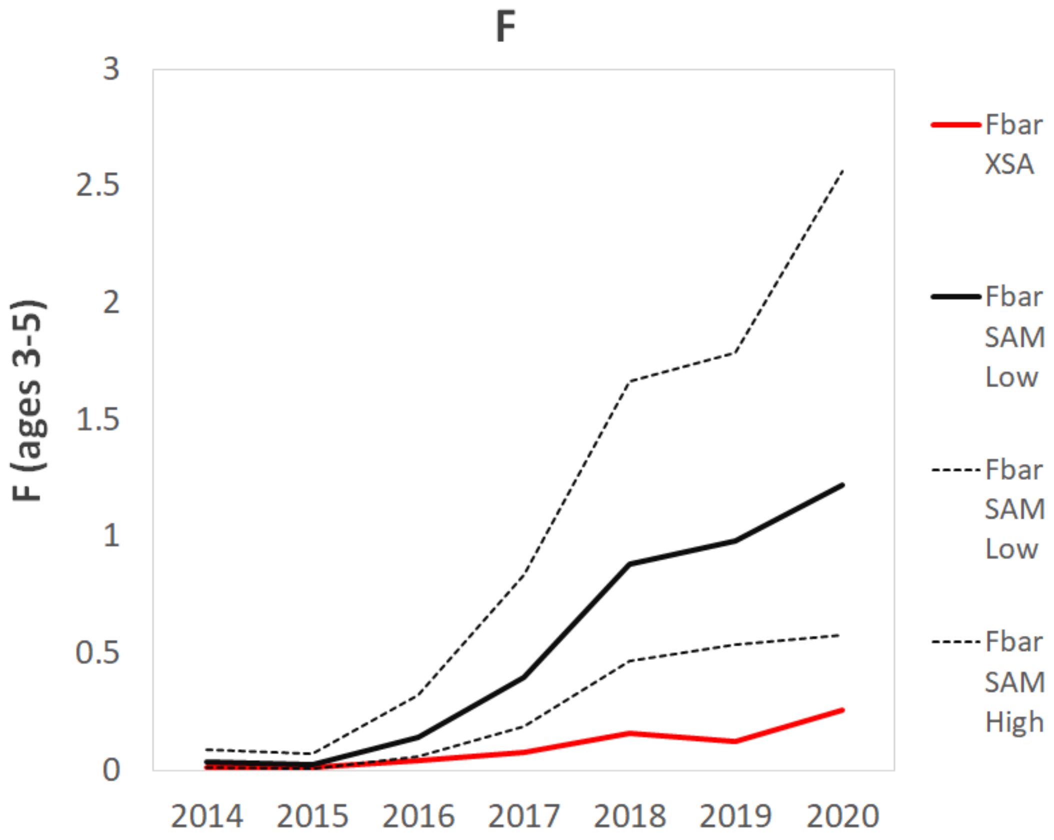

Figure 2.6. Estimation of round goby fishing mortality in XSA and SAM models (age 3–5) (2014–2020).

Despite the decline in numbers, the population most likely will not disappear from the local ichthyofauna and has the potential to become an important fishing object in the central part of the Baltic Sea. At the moment, it is difficult to assess the fishery effect on the round goby population reduction because the population also depends on environmental changes and fishing activities in neighbouring countries. In the following years, the round goby stock assessment could be further improved by extending the biological dataset and including additional information from the wider area.

2.2.4 Gear selectivity and fishing methods

Methods used for monitoring

In Germany, a pilot monitoring study targeting coastal fish communities was conducted at the western German coast of the Baltic Sea (Schleswig-Holstein) in 2021. Data were collected from February until December in different habitat types (bare sand, seagrass meadow, bladder wrack belt, rocky reef, blue mussel bed) using five different fishing methods (multimesh gillnets i.e. coastal surveynets, eelfykes, minnow traps, bottom trawls, beach-seines). The following comparison of round goby numbers between gear types is based on the number of fishes per replicate for the respective fishing gear across all habitat types. In winter (February/March), a small number of round gobies were caught in eelfykes, while gillnets, followed by eelfykes, performed best in catching the species in spring (April/May). From summer until late summer (June–September), round goby is caught equally well with gillnets and beach-seines followed by eelfykes. In autumn (October), similar numbers of gobies were documented with eelfykes and gillnets, while beach-seines caught fewer individuals. Minnow traps generally only caught single individuals of the species throughout the year (Henseler and Oesterwind, unpublished data). Thus, gillnets and eelfykes seem to be the fishing methods documenting round goby abundances most reliably, though seasonal differences in catch efficiency exist.

Methods used for commercial purposes

The analysis from scientific coastal gillnet surveys in Latvia revealed that the best mesh size and the fishing season for round goby was in spring (April–June) using gillnets with a mesh size of 60–70 mm (diagonal width). Additionally, in cooperation with local fishers, the effectiveness of trapnets specialised in round goby fishing was tested. As a result, a new fishing gear, the round goby trapnet, has been used in Latvia since 2018 for commercial purposes. In 2019, experimental fishery trials were conducted in Latvia to assess round goby fishing in autumn using gillnets with a 60–70 mm mesh size. Results showed poor round goby catchability and increased bycatch of other species below minimum reference size (Ivars Putnis, pers. communication).

Another study analysed round goby catch data from Nordic coastal multi-mesh gillnets from Gotland, Karlskrona, Muskö and Lithuania from different years. Most round goby were caught in 19–30 mm mesh sizes at shallower depths (3–10 m) and higher numbers were observed in spring/summer compared to autumn. When comparing gillnet catches to fykenet fishing in Karlskrona and Muskö, fykenets had a higher catch per unit effort and smaller proportions of bycatch. For instance, in Muskö, gillnet catches had a bycatch of herring between 40–50%, while round goby made up 38% at most. On the contrary, round goby dominated fykenet catches in the same area with 84%. In addition, fishing with fykenets is less time-consuming than using gillnets. Based on these results, experimental fishing was conducted in cooperation with commercial fishers, by modifying fykenets, to improve catchability of round goby and allow for bycatch species, mainly eel, to escape using escape patches. Preliminary results indicate that the retention of round goby differs within the same gear type, dependent on how the escape patches are placed (Florin, pers. Comm.)

2.2.5 Potential fishing areas

Potential round goby fishing areas

Local studies in Latvia suggest that round goby distribution is related to depth and bottom substrate. The highest round goby densities with 1–3 fish per m^2 were found at rocky and mixed substrate bottoms at depth ranging from 10 to 15 m in the south coastal regions. Potential fishing areas could be related to MPAs as well. Active removal of invasive NIS from MPAs, including the round goby, should be allowed, even encouraged and facilitated (Ojaveer *et al.,* 2015). Within the project LIFE REEF (Research of marine protected habitats in EEZ and determination of the necessary conservation status in Latvia) it is planned to perform habitat mapping in round goby coastal fishing grounds and bycatch assessment in order to update the national scientific advice to improve spatial and seasonal regulation of the round goby coastal fishery in Latvia.

2.2.6 Potential effects of introducing a round goby fishery

Currently the commercial landings of round goby vary strongly between basins and nations, and no stock assessment exists for round goby (see also 2.2.2). Furthermore, no fishing regulations exist for round goby with the exception of Latvia, where they have been implemented to protect native species that occur as bycatch in round goby fisheries.

An increasing fishing effort on round goby will have pros and cons depending on the point of view. Therefore, the group describes potential direct and indirect consequences rising up with an increasing fishing effort in round goby fisheries but will avoid to define the consequences as negative or positive.

Similar to a potential stickleback fishery, an introduction of a round goby fishery in the Baltic Sea could be beneficial for several reasons. If we assume that the total fishing effort in the demersal fishery will remain the same, the introduction of round goby fishery could lessen the fishing pressure on other exploited commercial stocks.

However, fishing impacts will depend on the fishing method. Round goby as a benthic fish will be fished with benthic gears or nets that might have an effect on the benthic ecosystem. However, it seems that static gear, especially traps, fykenets and gillnets, might be effective for round goby fisheries. Compared with mobile bottom gears, the impact on the benthic ecosystem is lower.

Bycatch of native species seems to be problematic in round goby fisheries at the current status. Thus, it is not surprising that first case studies exist, that analyse the bycatch in round goby fisheries and try to reduce the bycatch of native species by gear modifications or by seasonal or spatial regulations (section 2.2.3).

There are no studies illustrating that round goby has outcompeted any native species in the Baltic region. However, fishing on round goby and its subsequent change in abundance will affect both, bottom up and top down effects.

Foodweb modifications due to an exploitation of round goby are difficult to evaluate. Based on publications until 2018 (inclusive), 117 evidence of quantitatively documented impacts of the round goby is available, published in a total of 13 research papers (Ojaveer *et al.*, 2021). All of these are related to foodweb interactions, primarily as direct effects – round goby as prey or predator, or changes in the diet of predatory fish as a direct effect of the round goby invasion. The impact evidence extends from individual to population-level performance, including also indicators on body condition, reproduction, feeding ecology, trophic level and population density/biomass. Some of the most prominent evidence include: i) decline in the blue mussel *Mytilus edulis* abundance and associated reduction in the number of long-tailed duck (*Clangula hyemalis*) in wintering colonies (Skabeikis *et al.*, 2019); declines in flatfish recruitment (Ustups *et al.*, 2018), increase of weight-at-age of pikeperch *Stizostedion lucioperca* predating on the round goby (Hempel *et al.*, 2016), substantial change in the diet of cod *Gadus morhua* after the invasion of the round goby (Almqvist *et al.*, 2010). The round goby effects extend to both pelagic and benthic realms, involve several trophic guilds (filter-feeders, benthic herbivores, planktivores, sub-apex demersal predators, apex predators) and communities (benthos, fish, bird, mammals; Annex 4).

Long -term ecological impact on benthic communities' dominant bivalve biomass was shown in the Northeastern Baltic Sea (Nõomaa *et al.*, 2022). Modelling based on long-term bivalve abundance trends showed that the round goby invasion causes a substantial decline of *Mytilus trossulus* and *Macoma balthica* biomass. This will likely show indirect impacts of the round goby on water transparency and benthic community functioning. Laboratory data suggest preferential feeding of round goby on blue mussels that are considerably smaller than what the fish (according to their gape size) are actually capable of eating (Schwartzbach *et al.*, 2019), implying that round goby may cause altered size composition of the Baltic's native blue mussel populations.

In the inner Danish waters (Western Baltic Sea), a recent before-after study using long-term monitoring data of invertebrate macrofauna has revealed that in this marine-brackish habitat, round goby has exerted negative impacts on specific molluscan taxa (e.g. Cardiidae bivalves and Neritidae gastropods, showing a fall in detected densities of approximately 98% within one of the areas) (van Deurs *et al*., 2021).

In contrast to stickleback, another aspect to be considered is that round goby is a non-native and potentially even invasive species in the Baltic. This raises the question whether the management of round goby fisheries should be conducted in the same way as it is performed for native species. It is still unclear if a sustainable round goby fishery should only aim to reduce the impact of round goby fisheries on native species and other native ecosystem components, or if round goby itself should be fished in a sustainable manner. This decision will have a substantial impact on fisheries implementation.

3 Conclusions

In the 1970s and 1980s, a stickleback fishery for fishmeal production was active in the eastern part of the Baltic Sea. This fishery terminated due to bycatch issues, and the species was in the following decades only landed in minor amounts as bycatch, mainly in the pelagic fishery. The biomass of stickleback has however been in steady increase since 2000, especially in SD 27 and parts of SD 28-30, and there is commercial interest in a targeted stickleback fishery. Although there is evidence of negative impacts of high densities of stickleback on other species, e.g. via predation on eggs and larvae of species like pike, perch and herring, it is clear that a potential targeted fishery may not only release this pressure, but, as previously, also raise serious bycatch issues, not least considering that a small mesh size would be a necessity due to the small size of the fish. Acoustic data suggest a vertical separation of herring and stickleback schools during daytime, which is why daytime fishery for stickleback may minimize bycatch of herring, however with risk of bycatch of other species like trout and salmon. Trial fisheries are currently addressing the bycatch – and other potential ecosystem effects – issues, and to permit the species to become a quota species, Denmark and Sweden have started developing methods for stock assessment models. Assuming a similar total fishing effort in the Baltic, the introduction of a stickleback fishery could lessen the fishing pressure on other pelagic species. Additional positive effects of a targeted fishery are decreased predation pressure on eggs and juveniles of coastal fish, and improved water quality due to reduced predation pressure of sticklebacks on mesograzers. Yet, the risks of introducing a new fishery in a sensitive and species-poor Baltic Sea warrant clear precautionary management targets and adaptive decision-making.

Being a non-indigenous (invasive) species in the Baltic with several reports of negative impacts especially on the benthic prey community, eradication of round goby is desired, but mitigation is more realistic. Ships are the most likely vector for introductions, with secondary dispersal (i.e. active movement) occurring from the sites of introduction. Observational presence data are strong, revealing a pan-Baltic distribution, except for the most northerly areas, where the fish may be limited by low temperatures. On the contrary, abundance data are very limited, being available mainly from landing data, especially in Latvia. Here round goby is now the second most fished species after herring in the coastal fishery, and Latvia is also the only Baltic country to implement some management activities in relation to fishery for the species, including also first attempts of stock assessment of the species. This indicates that the recent fishing mortality of round goby along the Latvian coast may exert some negative impact on the size of the population. Yet, as for stickleback, bycatch issues need serious considerations, potentially being dealt with by gear modifications.

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Annex 2: Resolutions

A **Workshop on Stickleback and Round Goby in the Baltic Sea** (WKSTARGATE), chaired by Jane Behrens, Denmark; and Daniel Oesterwind, Germany; will be established and will meet at ICES Headquarters, Copenhagen, Denmark, 23–25 August 2022 to:

a) Assess the ecological consequences of the shifts in abundance and distribution of sticklebacks and round goby in coastal waters of the Baltic Sea (Science Plan codes: 1.9; 6.1);

b) Evaluate the ecological, economic and legal boundary conditions for a commercial use of stickleback and round goby (Science Plan codes: 5.4; 7.1).

WKSTARGATE will report by 30 August 2022 (via EPDSG) for the attention of ACOM and SCICOM.

Supporting information

Priority	Stickelbacks, a native species, and round goby, an alien species, affect coastal fisheries and interact with coastal species like pike and pike perch and migrating species like sprat and herring and thus affecting the ecosystem as well as the coastal fishery.
Scientific justification	Term of Reference a) The change in abundance and distribution has major impacts on coastal ecosystem: and subsequently, coastal fisheries. Knowledge has been produced in several projects and intiatives and need to be synthesized to derive a general understandin of the consequences on conservation and management of coastal ecosystem and fisheries. Term of Reference b) Fisheries in different countries are interested in the potential of a commercial fisher on stickelback and round goby. When looking at a potential commercial fishery on round goby, an alien species, the question arises if usual harvest strategies apply fc a species that is invasive and one objective could be to reduce or even eliminate it ii the Baltic.
Resource requirements	The work of the workshop builds on existing projects and initiatives. No extra resources are required.
Participants	We expect 20-30 participants, including scientific experts as well as industry and NGO representatives.
Secretariat facilities	Meeting room, video-conferencing platform.
Financial	No financial implications.
Linkages to advisory committees	The findings of the workshop will feed into the evidence base to inform about effects of changes in coastal species assemblages on the ecosystem and the coastal commercial and recreational fisheries.
Linkages to other committees or groups	There are links to WGBFAS, WGVHES, WGIAB.
Linkages to other organizations	The work of this workshop is linked to HELCOM.

Annex 3: Predator and prey tables

Table Annex 3a. Round goby prey items

Species (alphabetically)	Reference	Species (alphabetically)	Reference	Species (alphabetically)	Reference
Amphibalanus improvisus	1	*Gammaridae*	4	*Mytilus edulis*	1,7
Amphipoda	6	*Gammarus locusta*	7	*Mytilus sp.*	2,4
Amphipoda	2	*Gammarus sp.*	1	*Mytilus trossolus*	3
Arachnida	2	*Gammarus spp.*	3	*Neogobious melanostomus*	1,5,8
Balanida	8	*Gasterosteus aculeatus*	1,7	*Neomysis integer*	5
Balanidae	2,4	*Gastropoda*	2	*Nereididae*	4
Balanidae with Electra pilosa	2	*Halicryptus*	4	*Nereididae sp.*	7
Bathyporeia	6	*Halicryptus sp.*	1	*Nereis sp.*	2
Bathyporeia pilosa	1	*Hydrobia sp.*	1,2,8	*Oligochaeta*	1
Bivalvia	2	*Hydrobia ulvae*	5	*Osmerus eperlanus*	5
Bosmina sp.	4	*Hydrobia ventrosa*	7	*Ostracoda*	2,4
Bylgides sarsi	1	*Hydrobiid gastropods*	4	*Palaemon adspersus*	7
Carcinus maenas	2	*Idotea balthica*	7	*Palaemon elegans*	7

Species (alphabetically)	Reference	Species (alphabetically)	Reference	Species (alphabetically)	Reference
Cerastoderma lamarcki	5	*Idotea chelipes*	4,7	*Palaemon sp.*	2,4,7
Cerastoderma sp.	2,4	*Idotea granulosa*	7	*Parvicardium sp.*	7
Cerastodermum glaucum	3	*Idotea sp.*	2,8	*Polychaeta*	2,6,8
Chironomidae	4	*Insecta*	2,8	*Pontoporeia femorata*	1
Chironomidaen larvae	2	*Insecta larvae*	2	*Pontoporeia sp.*	1
Chlorophyta	8	*Jaera albifrons*	8	*Potamopyrgus antipodarum*	7
Chrironomida	8	*Leucothoe spinulosa*	1	*Rhodophyta*	8
Cladocera	5	*Limecola balthica*	1,4	*Rissoa membranacea*	7
Clupea harengus eggs	8	*Litorina litorea*	7	*Saduria entomon*	1
Copepoda	4	*Littorina saxatilis*	2	*Sphaeroma hookeri*	2
Corophium sp.	2,4	*Littorina sp.*	4	Synthetic particles	8
Corophium volutator	5,8	*Macoma baltica*	2,3	*Teleostei*	6
Crangon crangon	4,8	*Malacostraca*	2	*Thedoxus fluviatilis*	7
Crustacea	2,8	*Mollusca*	6,8	Unidentified *annelida*	2
Cyathura carinata	4	*Mya arenaria*	2,4,7	Unidentified *crustacea*	2
Decapoda	2,6,8	*Mya truncata*	2	Unidentified *mollusca*	2
Diptera (adult)	2	*Mysidae*	1,2	*Zoarces viviparus*	1
Gammarida	8	*Mysidae spp.*	6		

[1]Institute of Food Safety, Animal Health and Environment BIOR, Loreta Rozenfelde personal communication 2022.

[2]Matern, *et al.* (2021). Differences in diet compositions and feeding strategies of invasive round goby *Neogobius melanostomus* and native black goby *Gobius niger* in the Western Baltic Sea. Aquatic Invasions, 16 (2), 314–328.

[3]Nurkse, K. *et al.* (2016). A successful non-native predator, round goby, in the Baltic Sea: generalist feeding strategy, diverse diet and high prey consumption. Hydrobiologia, 1–11.

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[8]Wiegleb, J. *et al.* (2018). Predation of the round goby (*Neogobius melanostomus* Pallas, 1814) on Atlantic herring eggs in the Western Baltic Sea. Marine Biology Research, 14(9-10), 989-1003.

Table Annex 3a. Round goby predators.

Species	Group	Source
Anguilla anguilla	Fish	3
Ardea cinerea	Bird	4
Aspius aspius	Fish	3
Esox lucius	Fish	10
Gadus morhua	Fish	1
Halichoerus grypus	Mammal	9
Lota lota	Fish	6
Natrix natrix	Reptile	2
Perca fluviatilis	Fish	7
Phalacrocorax carbo	Bird	7
Sander lucioperca	Fish	7
Scophthalmus maximus	Fish	8
Sterna hirundo	Bird	5

[1]Almqvist, G. *et al.* (2010). Has the invasive round goby caused new links in Baltic foodwebs? Environmental Biology of Fishes, 89(1), 79–93.

[2]Frederick Berg, personal communication (video evidence).

[3]Gertzen, S. 2016. The ecological niche of invasive gobies at the Lower Rhine in intra- and interspecific competitive and predatory interactions. PhD Thesis, University of Cologne. -205 pp.

[4]Jakubas, D. (2004). The response of the Grey Heron to a rapid Increase of the round goby. Waterbirds, 27(3), 304–307.

[5]Laima Bagdagonaite, personal communication (photo evidence).

[6]Madenjian, C. P. *et al.* (2011). Evidence for predatory control of the invasive round goby. Biological Invasions, 13(4), 987–1002.

[7]Oesterwind D., *et al.* (2017). Predator and prey; the role of the round goby *Neogobius melanostomus* in the western Baltic. Marine Biology Research, 13 (2): 188 – 197.

[8]Sapota, M. R., & Skóra, K. E. (2005). Spread of alien (non-indigenous) fish species *Neogobius melanostomus* in the Gulf of Gdańsk (south Baltic). Biological Invasions, 7(2), 157–164.

[9]Scharff-Olsen, C. H., *et al.* (2019). Diet of seals in the Baltic Sea region: A synthesis of published and new data from 1968 to 2013. ICES Journal of Marine Science, 76(1), 284–297. https://doi.org/10.1093/icesjms/fsy159

[10]Techincal Report: Round goby research in Estonia 2017. University of Tartu Marine Institute (in Estonian).

Annex 4: Overview ecological impact studies round goby

Table Annex 4. Information on the ecological impact studies on the round goby (based on publications until 2018 inclusive; from Ojaveer *et al.*, 2021)

No.	Subarea/ sea/gulf/bay	Study type or method	Habitat substrate type	Property investigated	Response variable measured	Measurements unit	Species/taxon/taxa impacted	Community impacted	Impacted species habitat	Trophic guild	Process responsible	Reference
1	Gulf of Gdańsk, Puck Bay	Correlative study	benthic mixed	Population size	Catch per unit effort	Average number of fish	flounder	fish	benthic	Sub-apex demersal predators	competition	Karlson *et al.* 2007
2	Southern Baltic, Gulf of Gdańsk	Presence-absence comparison	benthic mixed	Diet	Prey in the diet of piscivorous fish (different prey taxa)	Percentage	cod	fish	benthic	Sub-apex demersal predators	competition	Almqvist *et al.* 2010
3	Southern Baltic, Gulf of Gdańsk	Presence-absence comparison	benthic mixed	Diet	Trophic level	Trophic level index	cod	fish	benthic	Sub-apex demersal predators	competition	Almqvist *et al.* 2010
4	NE Baltic Proper	Presence-absence comparison	benthic mixed	Population size	Juveniles' abundance	Abundance per 10 hauls	turbot	fish	benthic	Sub-apex demersal predators	competition	Ustups *et al.* 2016

5	NE Baltic Proper	Presence-absence comparison	benthic mixed	Diet	Empty stomachs	Proportion	flounder, turbot	fish	benthic	Sub-apex demersal predators	competition	Ustups *et al.* 2016
6	NE Baltic Proper	Presence-absence comparison	benthic mixed	Diet	Feeding overlap	Shorygin index	flounder, turbot	fish	benthic	Sub-apex demersal predators	competition	Ustups *et al.* 2016
7	Gulf of Gdańsk	Presence-absence comparison	benthic mixed	Population size	Maximum number of birds staying in the area	Abundance (in thousands)	cormorant	bird	NA	Sub-apex pelagic predator	NIS as a prey	Bzoma, Meissner 2005
8	Gulf of Gdańsk	Presence-absence comparison	benthic mixed	Population size	Number of nests	Number	grey heron	bird	NA	Sub-apex pelagic predator	NIS as a prey	Jakubas 2004
9	Kiel canal	Presence-absence comparison	pelagic	Diet	Importance of herring and Pomatoschistus in piscivorous fish diet	Relative importance index	pikeperch	fish	pelagic	Sub-apex pelagic predator	NIS as a prey	Hempel *et al.* 2016
10	Kiel canal	Modelling study	pelagic	Individual	Mean total length-at-age by different age groups (von Bertalanffi)	Millimetre	pikeperch	fish	pelagic	Sub-apex pelagic predator	NIS as a prey	Hempel *et al.* 2016
11	Kiel canal	Modelling study	pelagic	Individual	Body condition	Fulton condition index	pikeperch	fish	pelagic	Sub-apex pelagic predator	NIS as a prey	Hempel *et al.* 2016

12	Gulf of Riga	Controlled lab. experiments	artificial	Consumption	Different prey taxa	Abundance per 50 l aquaria, 0.11 m2	different taxa	benthos	benthic	Filter-feeders	consumption	Nurkse *et al.* 2016
13	SE Baltic Sea	Mechanistic or autecological study	benthic hard	Individual	Size	Centimetre	Blue mussel	benthos	benthic	Filter-feeders	consumption	Skabeikis *et al.* 2018
14	SE Baltic Sea	Mechanistic or autecological study	benthic hard	Diet	Trophic level	Trophic level index	Long-tailed duck	bird	NA	Sub-apex demersal predators	NIS as a prey	Skabeikis *et al.* 2018
15	SE Baltic Sea	Mechanistic or autecological study	benthic hard	Individual	Fat score	Fat score (median)	Long-tailed duck	bird	NA	Sub-apex demersal predators	NIS as a prey	Skabeikis *et al.* 2018
16	Western Baltic	Controlled lab. experiments	artificial	Consumption	Loss of abundance/weight	Number/gramme per 1 h	Herring eggs	fish	pelagic	Planktivores	consumption	Wiegleb *et al.* 2018
17	Western Baltic	Controlled lab. experiments	artificial	Consumption	Loss of abundance/weight	Number/gramme per 1 h	Blue mussel, *Crangon crangon*	benthos	benthic	Sub-apex demersal predators	consumption	Wiegleb *et al.* 2018

18	Gulf of Finland, Gulf of Riga, NE Baltic Sea	Mechanistic or autecological study	benthic mixed	Diet	Proportion in stomachs	% of weight (in total stomach contents)	perch	fish	pelagic	Sub-apex pelagic predator	NIS as a prey	Liversage *et al.* 2017
19	Gulf of Riga	Controlled lab. experiments	benthic mixed	Consumption	Abundance of prey (different taxa)	Number of preys per 50 l (0.11 m2) per 48h	Gammarus spp.	benthos	benthic	Benthic herbivores	consumption	Nurkse *et al.* 2018
20	Western Baltic (Pomeranian Bay and adjacent areas)	Mechanistic or autecological study	benthic mixed	Diet	Share of round goby in bird pellets	%	cormorant	bird	NA	Sub-apex pelagic predator	NIS as a prey	Oesterwind *et al.* 2017
21	Western Baltic (Pomeranian Bay and adjacent areas)	Mechanistic or autecological study	benthic mixed	Diet	Share of round goby in piscivorous fish diet	Index of relative importance (%)	pikeperch	fish	pelagic	Sub-apex pelagic predator	NIS as a prey	Oesterwind *et al.* 2017
22	SW Baltic Sea (west of southern tip of Sweden)	Mechanistic or autecological study	pelagic	Diet	Share of round goby in marine mammal diet	%	grey seal, harbour seal	mammal	pelagic	Apex predators	NIS as a prey	Scharff-Olsen *et al.* 2018

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Annex 5: Abstracts

Ecological consequences of the stickleback increase in the Baltic Sea - Ulf Bergström (SLU Aqua)

The increase of three-spined stickleback in the Baltic Sea has brought about large-scale changes in the coastal ecosystem. When stickleback migrates from the open sea to the shallow coastal-zone for spawning, it can aggregate in very high densities, and affect other species through predation and competition. Stickleback is an efficient predator on eggs and larvae of other fish species, especially pike and perch. By predating on the early life stages of these large piscivores, stickleback may cause a predator–prey reversal, where local pike and perch populations are severely suppressed. The continuous increase in stickleback densities in the Baltic Sea since the 1980s has led to a loss of around 50% if perch and pike recruitment areas in the most heavily affected coastal area of the Swedish coast of SD27 and 29. The loss of perch and pike and increases in stickleback gives rise to a trophic cascade, with a decline in herbivore densities and an increase in filamentous algae, which, in turn, leads to a loss of large habitat-forming vegetation. This large-scale regime shift, which started in outer archipelago areas and open coasts and is now slowly spreading towards the mainland, is referred to as the 'stickleback wave' (Eklöf *et al.* 2020, Olin *et al.* 2022).

In the open sea, stickleback competes with herring and sprat and is eaten by cod and large herring (Olin *et al*. 2022). Ongoing studies at SLU Aqua indicate that stickleback currently constitutes a considerable proportion of the diet of herring ≥ 18 cm in the coastal zone both in the Central Baltic Sea and the Gulf of Bothnia, while spatio-temporal analyses of BIAS data (from 2001–2019) shows a strong negative relationship between the two (Donadi *et al.* unpublished). These analyses thus suggest that the decline in herring populations in the Baltic Sea during the 2000s may have contributed to the increase in stickleback. The analyses of the BIAS data also show a negative relationship between small herring, sprat and stickleback, indicating that these species compete for zooplankton resources in the pelagic zone of the Baltic Sea.

The rise of stickleback in the Baltic Sea - population development and its potential drivers - Jens Olsson (SLU Aqua)

This presentation aims to summarize the current knowledge-based on population development, spatial distribution and potential driving factors behind the recent stickleback population expansion in the Baltic Sea. The information presented is to a large extent found in the recently published paper by Olin *et al.* in ICES Journal of Marine Science in June 2022. The presentation is rounded of by some reflections on the potential implications and consequences of a future commercial stickleback fishery in the Baltic Sea.

Stickleback have increased dramatically in many offshore and coastal areas of the Baltic Sea since the early 2000s, and the center of the distribution and increase appears to be in the western (Swedish) parts of the Central Baltic Sea and Bothnian Sea. Weak and declining predatory fish populations seems to have governed the drastic increase in stickleback in the region, but favourable feeding conditions (zooplankton community composition), eutrophication and climate change might also have benefited stickleback in the Baltic Sea. A future large-scale commercial fishery as a measure to combat the stickleback increase while simultaneously utilizing a previously non-used resource comes with significant risks to the Baltic Sea ecosystem including for example high risks of bycatch and misreporting. Restoring populations of stickleback predators as perch, pike, herring and cod comes at much lower risks and ecosystem benefits in is clearly to prefer and advocate. Independent of the route taken, there is a need to explore and understand the drivers of stickleback population development and to set up a robust monitoring program for sustainable management of the species and the ecosystem as whole in the Baltic Sea.

Tackling eutrophication through the future stickleback fishery in the Baltic Sea - Dunja Jusufovski (University of Helsinki)

The eutrophication has been a longstanding and persistent threat in the Baltic Sea. Following a decrease in certain predatory fish, the high nutrient levels coupled with increasing sea temperature have contributed to the rise of a small mesopredatory fish species, the three-spined stickleback (*Gastrosteus aculeatus*), that have the capability to overtop some of the most commercially important fish species (i.e. prey-predator reversal) in the Baltic.

Sticklebacks occupy a significant trophic niche exhibiting complex interactions with other fish species (mainly other predatory fish) through intraguild predation and the competition for prey. Sticklebacks' high presence can upset the balance of lower trophic organisms and promote the growth of primary producers (e.g. filamentous algae), potentially diminishing the water quality and oxygen.

With an increasing interest to harvest sticklebacks for fishmeal and the necessity to reduce the potential negative effects of the rising stickleback abundance on the ecosystem and relevant species, this has presented itself as a new opportunity to mitigate the ongoing eutrophication. The current project focuses on the bioeconomic aspect of introducing a new fishery to abate the excess nutrient through the removal of stickleback biomass. Taking the ecological role of sticklebacks into account, a population model is developed that will incorporate the stickleback population dynamics and the environmental benefit of removing phosphorus through stickleback fishery. As we assume that the stickleback fishery will take place in the offshore areas, we also address the impacts of the new fishery on Baltic herring and sprat. The sustainability and profitability of the future stickleback fishery is tested through two scenarios of stickleback fishery introduction that (1) exclude the reduction of fishing pressure on herring and sprat and (2) include the reduction of fishing pressure on herring and sprat.

Stickleback experimental trawl - Juha Lilja (Natural Resources Institute Finland)

This presentation showed the results of the stickleback test trawl, which was done during the Baltic International Acoustic Survey (BIAS) 2020 (September 29). Due to diel vertical migration of herring and sprat, those species inhabiting a same depth layer with stickleback during the night, but at the daytime stickleback still occupied in the surface layers (usually 5-20 m), therefore, the test trawl of the stickleback was carried out during the daytime. Trawl haul was done in ICES rectangle 53G8 and the aim was catch only stickleback. Five fish species was caught, stickleback, herring, sprat, salmon, and straightnose pipefish. The result showed that numerous species in the catch were three-spined stickleback and herring with proportions of 98.2% and 1.8%, respectively. Biomass share in the catch between stickleback and herring was 88% and 11%, respectively.

Round goby status in Sweden and potential for fishery - Ann-Britt Florin (SLU Aqua)

Round goby (RG) was first discovered in 2008 in Karlskrona and is now widely distributed in Swedish coastal areas in southern and central Baltic Sea. However, it has not spread north in the Bothnian Sea nor in the saline areas at the West coast. Monitory fishing in Muskö in Stockholm archipelago, where it was discovered 2013, show a peak in 2017 and drastic decline after the hot 2018 but are now increasing again. Monitory fishing in southern Baltic Sea show a less fluctuating population. Knowledge of distribution is mainly from reports from citizens, accessible in the dataportal.

Herlevi and Wallin *et al.* in prep. show that Round goby is an important prey for native predators, such as cod, pike and perch but there are differences between predator species and areas. The importance of RG in diets is density-dependent, as RG constituted a larger dietary proportion when the environmental densities of RG were higher.

In the Research project Round goby - turning risk to Resource (financed by Swedish EPA environmental science grant in cooperation with the Swedish Research Council Formas), we aim to see if fishery can be used to limit abundance of RG. Analysing data from standardized Nordic coastal multi-mesh gillnet from Gotland, Karlskrona, Muskö and Lithuania from different years showed that most RG was caught in 19-30 mm mesh size at shallower depths (3–10m) and in spring/summer compared to autumn. It was also evident that RG where small, less than 10 cm total length, in newly established areas but after a few years the catch had shifted to 10–15 cm sized RG. Comparison with fykenet fishing in Karlskrona and Muskö the fykenets had a higher catch per unit effort and less bycatch. For example, in Muskö the gillnets had a bycatch of herring between 40-50%, and RG made up at most 38% of the catch while using fykenets in the same area RG stood for 84% of the catch. In addition, fishing with fykenets is less time-consuming than using gillnets. Based on this we decided to do experimental fishing in cooperation with commercial fishers, modifying a commonly used gear, the Fykenet, to improve catchability of round goby and allow for bycatch species, mainly eel, to escape. Preliminary results show that dependent on how the escape patches are placed the retention of round goby will differ within same gear type. Results will be further analysed, behaviour of RG around the gear will be studied and new experimental fishing done in 2023.

Impacts of round goby invasion on benthic fauna in the Baltic Sea: Effects of prey preferences and individual variation - Nicholas Moran (DTU-Auqua)

This work analyses the impacts of round goby feeding behaviour on the benthic fauna communities in coastal and inlet waters of the southwest Baltic Sea, and explores the role of intraspecific behavioural variation. Using benthic invertebrate data, changes in the abundance of specific taxonomic groups before and after round goby invasion can be identified. This shows that the taxa preferred by round gobies were more negatively impacted by the invasion than non-preferred taxa, highlighting that goby feeding preferences may drive changes community composition, structure and ecosystem function. To further explore round goby feeding behaviour, isotope analysis of foodwebs is used to measure among-individual differences in diet, and behavioural analysis is used to measure within and between population variation in behavioural traits. In multiple round goby populations along the Danish coastline, our results show high variation between individuals in behavioural traits as well as their isotopic signatures, showing evidence of within-species diet specialization in invaded areas. This work highlights that the feeding preferences of invasive species can determine their impacts on invaded communities, and that among-individual differences in feeding behaviour may also be an important factor.

Round goby long-term impact on benthic communities - Kristiina Nõomaa (University of Tartu)

The aim of the presentation was to briefly introduce topics related to the round goby – published and unpublished studies on round goby diet, round goby as prey, round goby behaviour and catch tests. The main focus was to introduce recently shown round goby impact on benthic communities (Nõomaa *et al.*, 2022). We combined data from long-term benthic monitoring, environmental conditions, and a census of round goby population to identify changes in the dominant benthic bivalve population (*Mytilus trossulus* and *Macoma balthica*) following round goby invasion. The study demonstrates a substantial change in the foodweb, with earlier primarily bottom–up regulated communities facing strong top–down control effects. The introduction of a novel predator to a species-poor ecosystem substantially reduced dominant invertebrate populations in a large part of the study area, sometimes with a time-lag of 1−3 years. In several areas, the invasion effects are likely not showing due to insufficient invasion duration, but it is also possible that high-productivity areas are more resistant to round goby impacts. In some cases, community recovery was observed but rarely to pre-invasion levels, raising the question of the ability of bivalve communities to act as a natural filter. This study demonstrates that the round goby is affecting long-term trends in benthic communities and round goby effect is likely stronger than the effects of changing environmental conditions.

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Round goby fisheries management in Latvia – Ivars Putnis (BIOR)

Round goby was first recorded in Latvian coastal fishery logbooks in 2006 when the total annual catch was 6.3 kg. At the beginning, round goby was caught as a bycatch in the herring poundnet fishery. When landings continuously increased, Latvian fisher expressed their interest in specialised round goby fishery. To effectively utilize the abundant round goby source several management activities have been implemented in Latvia, including a definition of specialised fishing gears and terms of use to reduce the bycatch of non-target species. The analysis from scientific coastal gillnet surveys in Latvia revealed that the best fishing season for round goby was in spring (April-June) using gillnets with a 60–70 mm (diagonal width) mesh size. This information led to the start of a specialised round goby gillnet fishery back in 2015. Additionally, in cooperation with local fishers effectiveness of specialised round goby trapnets was tested. As a result, a new fishing gear – the round goby trapnet – has been used in Latvia since 2018. Both gears in combination with the spatial and seasonal restrictions led to an increase in round goby fishing selectivity and significantly contributed to the record catch of 2018, which exceeded 1000 tonnes. Since then, landings have decreased. In 2019 experimental fishery trials were conducted in Latvia to assess round goby fishing in autumn using gillnets with a 60–70 mm mesh size. Results showed poor round goby catchability and increased bycatch of other species below minimum reference size. The Latvian coastal fisheries management scheme involves annual data collection from the commercial and scientific fishery following by information analysis and biological parameter estimates to assess stock status. All available information is used to develop an annual scientific advice for the local policymakers suggesting necessary changes in fishing policy and defining allowable fishing gear limits in each coastal municipality.

Reproductive limits and adaption of round goby in the Baltic and European rivers - Leon Green (University of Gothenburg)

On the Swedish west-coast, the euryhaline round goby (*Neogobius melanostomus*) has established itself wide-ranging salinities. To understand if they were at all limited by where they could reproduce, we sampled sperm from round goby in northern Europe and the ancestral Black Sea region. The sperm performance, tested in a range of salinities from freshwater to saltwater was shown to correlate strongly with their genomic ancestry. Notably, since sperm function is crucial to reproductive success, it shows that a population is likely to establish in salinity areas matching its ancestry. At a local scale, we also show that genomic diversity can differ for sites sampled across sharp salinity gradients (such as in river mouths or estuaries), pointing to genotypic sorting or selection processes already at work less than 8 years after first detection in the area. The continued spread of the species on the Swedish west-coast continues to be monitored, and we finally present a project to evaluate the validity and efficiency of three common monitoring methods - (1) baited remote underwater video; (2) standardized fishing using cages and fykenets; and (3) target-captured environmental DNA quantified using digital droplet PCR. We found the quantitative measurements from all methods to correlate positively with each other. This shows that cost efficiency and available technology can be allowed to influence monitoring without strong biases to the results. Finally, data from the video recordings of the monitoring was used to test correlations with fish community diversity indices. We found that Shannon's and Simpson's Diversity was negatively correlated with the maximum number of round goby recorded at any one time, but species richness was not.

Round goby population dynamics in Latvia - Loreta Rozenfelde (BIOR)

Based on catches, round goby population density is high, becoming the dominant species in coastal fisheries in several countries. Since 2014 from the Latvian coast have been collected biological samples from commercial and scientific catches. It was found that in the Gulf of Riga round goby body size and average age parameters in commercial catch is lower than on the Latvian coast. However, in recent years, these body size differences are decreasing and the average age in all Latvian costal parts was 3.7 years. These parameters stabilization are also indicating the stabilization of the population in both regions. Based on biological information was made the first attempt to assess the round goby population on the Latvian coast. Stock assessment of round goby has never been made in the Baltic Sea. The obtained stock assessment is approximate, because when assessing the dynamics of population parameters with different models, different trends and levels of change were found. The XSA model is considered to be the most promising model for further stock assessment, because this model allows a greater choice of model configuration options. The results showed a decrease in spawning-stock biomass, recruitment and total-stock biomass, but on the other hand there is an increase in fishing mortality. The stock of round goby on the coast of Latvia is expected to decline in the coming years, leading to a decline in total catches. The introduction of stock assessments for this species throughout the Baltic Sea is an important step in the assessment of industrial fishing forecasts. This will provide an understanding of the impact of fishing on the future growth of the round goby population.

Round goby and stickleback distribution at the coast of Schleswig-Holstein (Germany) - Christina Henseler (Thünen Institute of Baltic Sea Fisheries)

With the aim of developing a long-term monitoring programme for coastal fish communities in German waters of the Baltic Sea, a pilot monitoring study was conducted at the western German coast (Schleswig-Holstein) in 2021. Fish were sampled using different active and passive fishing methods (multimesh gillnets i.e. coastal surveynets, eelfykes, minnow traps, bottom trawls, beach-seines) in five different habitat types (bare sand, seagrass meadow, bladderwrack belt, rocky reef, blue mussel bed). Sampling was conducted from February until December within seven study areas ranging from Flensburg fjord in the north to the bay of Lübeck in the south. Round goby and three-spined sticklebacks were present in all study areas, however, their abundances were comparatively low compared to other fish species, such as native gobiids. Similarly, when assessing fish community composition during the different sampling seasons, round goby and stickleback numbers only contributed to a small extent to overall fish abundance. The monthly occurrence in coastal waters differed between the two species. Round goby abundances peaked in April and gradually decreased until December, which reflects their seasonal migration into shallow coastal waters during spring while occupying deeper waters in winter. Stickleback abundances increased continuously from February until July followed by a gradual decrease until December. Throughout the entire sampling year, highest round goby abundances were documented in bladderwrack belts and seagrass meadows, while sticklebacks mainly occupied blue mussel beds and seagrass meadows, both of them seemingly showing a preference for structurally more complex habitats.

Historical and ongoing round goby studies in Latvia – Ivars Putnis (BIOR)

Round goby studies in Latvia are being conducted in the Latvian National Data collection programme (DCP), a special Ministry of Agriculture agreement on the research of fish resources in Latvia, and various national and international projects. The most important recent projects, where part of activities are related to round goby studies, are EVIDEnT, BONUS BLUEWEBS, LIFE REEF and CODHEALTH.

EVIDEnT project (The value and dynamic of Latvia's ecosystems under changing climate (2014–2018)) included an assessment of non-native species distribution and impact on the local ecosystems. A coastal study site Jūrmalciems characterised by long round goby invasion history and high population density was selected to assess round goby population density, habitat preferences and diet. Data were collected at five different depth zones starting from the coastal line up to 25 meters. Results suggest that round goby distribution is related to depth and bottom structure. The highest round goby densities with 1–3 fish per m^2 were found at rocky and mixed substrate bottoms at depths ranging from 10 to 15 meters. Diet composition depended on the fish size and depth zone (habitat type). At all depths, the bivalves *Mytilus* spp. And *Limecola balthica* were the preferred prey. Significantly lower blue mussel biomass was found at depth zones dominated by round goby.

BONUS BLUEWEBS project (Blue growth boundaries in novel Baltic foodwebs (2017–2020)) developed mass-balanced foodweb model projections exploring the importance of invasive species for nutrient and contaminant transformation in the coastal seas. All round goby invasion scenarios had a positive impact on higher trophic level predators in the Gulf of Riga foodweb model. The round goby prey response mostly depends on prey/predator vulnerability settings. Higher vulnerability parameters caused higher round goby biomass and increased the round goby impact on its prey. Model projections showed round goby capability to significantly decrease or fully deplete Baltic macoma biomass.

LIFE REEF project (Research of marine protected habitats in EEZ and determination of the necessary conservation status in Latvia (2020–2025)) aims to develop an action plan to limit the impact of invasive marine species and to develop mitigation measures to reduce seabird and marine mammal bycatch in coastal fisheries. Main activities regarding round goby include round goby tagging, habitat mapping in various coastal fishing grounds and bycatch assessment in the coastal fishery. In the following years, the results of these activities will be included in the national scientific advice to improve spatial and seasonal regulation of the Latvian coastal fishery.

CODHEALTH project (Baltic cod (*Gadus morhua*) condition and health status in the changing ecosystem of Eastern Baltic (2022–2024)) aims to assess cod condition in association with environmental changes, in the Eastern Baltic, increased seal abundance and the occurrence of endoparasites, with specific attention to *Anisakidae* nematodes. One of the project tasks regarding round goby is to pay special attention to round goby as a new component in the foodweb of Eastern Baltic cod and its condition with special attention to *Anisakidae* life cycle.

Can we combat invasive species with native enemies? - Anders Persson (Lund University)

Successful invasion requires suitable habitat and some advantage of the invader against native species, e.g. competitive ability or predation resistance. Here I present some results relating to these issues. Modelling the environmental niche space of round goby in the Baltic sea (Holmes *et al.* 2019) showed a preference for shallow, warmer waters sheltered from wave action. Furthermore, round goby occurrence was positively correlated to shipping activities, which is suggested to be an important vector in dispersal. Finally, suitable habitats within protected areas were more resistant to round goby invasion compared to unprotected areas.

Current distribution of round goby seems to be limited by high salinity, but it is not fully understood whether this pattern is driven by salinity tolerance per se or the fact that biodiversity increases with increasing salinity. Round goby is an efficient predator on mussels and a potential competitor is the native green crab that only occurs in the western more saline parts of the Baltic sea. Using experiments, the size preference of round goby and green crab on blue mussels was tested to evaluate the potential for green crab constituting an ecological barrier against further round goby invasions. The predicted energetic return of differently sized mussels between 5 and 25 mm length showed different patterns for the two species: small mussels were most profitable for round goby, whereas the largest mussels where most profitable for green crab. Furthermore, in a recent experiment, mussels displayed a strong antipredator response in terms of shell strength to crab cues, which potentially would reduce the mussels available to round goby even further.

Round goby is a substantial part of the diet in most piscivorous predators of the Baltic sea, such as perch, pike, cod, grey seal and cormorants. A monthly monitoring of perch diet in the Karlskrona archipelago 2018–2021 revealed that round goby constituted on average 43% of the consumed biomass, and a seasonal pattern with round goby dominating the diet in spring and autumn and other bony fishes dominating in summer. Ongoing predator experiments suggests a prey size preference in perch of round goby representing approximately 30% of predator length, but that larger round goby are selected against. Future experiment with multiple prey species will test if predators displays a prey species preference or not, but so far, the results suggest that measures promoting predator populations may be one management action to reduce or control the round goby population.

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Ten Years After: Goby invasion in the Lower Rhine system - Jost Borcherding (University Cologne)

The first species from the non-native family of Gobiidae (tubenose goby, *Proterorhinus semilunaris*) was found in 1999 at the Lower Rhine, while today five species are reported that originate mainly from the Ponto-Caspian region. Roughly 10 years after the peak of the boom phase of the round goby *Neogobius melanostomus*, which is to be considered as the invader with the most pronounced impact on the ecosystem at the Lower Rhine, a more precise picture on population ecology, potential measures and future development of such invasive events can be given. Intensive ecological research revealed some fundamental aspects concerning feeding, reproduction, behavior, competition and predation. Our data seem to record the loss or at least population decline of some species (European bullhead and gudgeon, respectively), yet these declines may not solely be based on the impact of non-native gobies. However, especially during the boom phase of the round goby, the invaders turned out to be superior competitors compared to abundant native species. After the boom phase the so-called bust phase could be detected, in which abundance of non-native gobies declined. We attribute these to adaptive processes of the ecosystem, e.g. increasing predation pressure from native fish species on the invaders. Thus, strengthening of native fish species at the Lower Rhine is the major management action. As several native fish species reproduce in floodplain areas, more of these habitats are needed and existing floodplains have to be preserved, to help these species in their competitive abilities against the invaders. Our future research will now focus on the invading routes and potential vectors of these invaders, as the European distribution of at least two non-native gobies outlines some dubious picture that makes transport by ships unlikely. We will try to analyse such questions with genomic data on the round goby as well as the latest invader into the Lower Rhine, the Caucasian dwarf goby *Knipowitschia caucasica*.

Holistic management of the invasive round goby in Switzerland - Joschka Wiegleb (University Basel)

Invasive species can have important ecological, social, and economic impacts on invaded ecosystems. Shortly after arrival of the round goby in Switzerland in 2012, stakeholders from different disciplines and researchers formulated eleven action recommendations covering the fields of fisheries, water management, aquarists, and shipping for effective management of the round goby invasion. The expert group recommended to raise awareness of the invasion among fishers (1), train fisheries and water management representatives (2), implement widespread stakeholder information campaigns (3), mention the invasion in training documents of fishing patents (4), monitor exposed water bodies (5), monitor fish passes (6), remove juvenile and adult animals from invaded water bodies (7), remove spawn (8), create legal bases for management measures (9), control import and online trade of live fishing baits (10), and finally inspection and cleaning of boat hulls prior translocation (11). Ten years after the beginning of the invasion, we recommend deeper collaboration between researchers and stakeholders, structured implementation of management measures, application of new technologies like automated data acquisition and Artificial Intelligence, and refinement and optimization of existing measures. Under consideration of interests of relevant stakeholder groups, information about the invasion extent, and experience from past invasions, a holistic management plan with clear management aims and evaluation components, should be created. Management of important ecosystems is a community task and depends on successful collaboration between stakeholder groups.

Round goby population dynamics in Latvia - Loreta Rozenfelde (BIOR)

Based on catches, round goby population density is high, becoming the dominant species in coastal fisheries in several countries. Since 2014 from the Latvian coast have been collected biological samples from commercial and scientific catches. It was found that in the Gulf of Riga round gobies body size and average age parameters in commercial catch is lower than on the Latvian coast. However, in recent years, these body size differences are decreasing and the average age in all Latvian costal parts was 3.7 years. These parameters stabilisation are also indicating the stabilisation of the population in both regions. Based on biological information was made the first attempt to assess the round goby population on the Latvian coast. Stock assessment of round goby has never been made in the Baltic Sea. The obtained stock assessment is approximate, because when assessing the dynamics of population parameters with different models, different trends and levels of change were found. The XSA model is considered to be the most promising model for further stock assessment, because this model allows a greater choice of model configuration options. The results showed a decrease in spawning-stock biomass, recruitment and total-stock biomass, but on the other hand there is an increase in fishing mortality. The stock of round goby on the coast of Latvia is expected to decline in the coming years, leading to a decline in total catches. The introduction of stock assessments for this species throughout the Baltic Sea is an important step in the assessment of industrial fishing forecasts. This will provide an understanding of the impact of fishing on the future growth of the round goby population.