European perch (*Perca fluviatilis*) as a possible predator of the invasive round goby (*Neogobius melanostomus*) in the Baltic Sea.

Abborre (Perca fluviatilis) som en möjlig predator för den invasiva Svartmunnad smörbult (Neogobius melanostomus) i Östersjön.

Mari-Helen Westlund

Degree project • 30 hp
Swedish University of Agricultural Sciences, SLU
Faculty of Natural Resources and Agricultural Sciences
Department of Aquatic Resources
Öregrund 2020

European perch (*Perca fluviatilis*) as a possible predator of the invasive round goby (*Neogobius melanostomus*) in the Baltic Sea.

Abborre (Perca fluviatilis) som en möjlig predator för den invasiva Svartmunnad smörbult (Neogobius melanostomus) i Östersjön.

Mari-Helen Westlund

Supervisor: Ann-Britt Florin, Swedish University of Agricultural Sciences, Department of Aquatic Resources

Assistant supervisor: Isa Wallin, Swedish University of Agricultural Sciences, Department of Aquatic Resources

Examiner: Örjan Östman, Swedish University of Agricultural Sciences, Department of Aquatic Resources

Credits:	30 hp
Level:	Second cycle, A2E
Course title:	Master thesis in Biology
Course code:	EX0895
Course coordinating dept:	Department of Aquatic Resources
Place of publication:	Öregrund
Year of publication:	2020

Keywords: Baltic Sea, invasive species, Round goby, Perch, prey-predator interaction

SLU, Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
Department of Aquatic Resources (SLU Aqua)

Publishing and archiving

Approved students' theses at SLU are published electronically. As a student, you have the copyright to your own work and need to approve the electronic publishing. If you check the box for **YES**, the full text (pdf file) and metadata will be visible and searchable online. If you check the box for **NO**, only the metadata and the abstract will be visible and searchable online. Nevertheless, when the document is uploaded it will still be archived as a digital file.

If you are more than one author you all need to agree on a decision. Read about SLU's publishing agreement here: https://www.slu.se/en/subweb/library/publish-and-analyse/register-and-publish/agreement-for-publishing/.

☒ YES, I/we hereby give permission to publish the present thesis in accordance with the SLU agreement regarding the transfer of the right to publish a work.

☐ NO, I/we do not give permission to publish the present work. The work will still be archived and its metadata and abstract will be visible and searchable.

Abstract

Invasive species is a global issue with a strong link to reduced biodiversity and large economic costs. The invasive fish species round goby (*Neogobius melanostomus*) is one of the species that are spreading in the Baltic Sea area most rapidly, and risk causing major issues. The round goby originally comes from the Black and Caspian Seas and is believed to have been introduced to the Baltic Sea via ballast water. Since they were first discovered in the Gulf of Gdansk in 1990, the species has spread and is now found along the majority of the Baltic Sea coastline.

Several ongoing studies aim at following the progress of the round goby in the Baltic Sea. One of the areas of most interest is how the round goby affects the local ecosystem, and the interaction between the invasive species and native predators.

In this study, Perch (*Perca fluviatilis*) is investigated as a possible predator on the round goby. Perch from three areas in the Baltic Sea were examined; Mariehamn and, Karlskrona (both with well-established round goby populations), and Långnäs (without a known round goby population). The perch were caught between spring and autumn in 2018 and 2019, and examined to see if round goby was found as part of the perch diet. The aim was to see how important the round goby was in the diet, whether the three areas differed, and, whether the consumption of round goby differed over the spring-autumn period, and if the condition of the perch was affected by eating the round goby. The total diet of the perch was also examined for the three areas. A total of 207 perch from Karlskrona and Mariehamn were examined and then combined with data from 905 perch previously examined from Mariehamn and Långnäs.

Round goby was found in the stomachs of perch from all three areas examined. It was the most common prey in Karlskrona and the second most common in Mariehamn. Consumption of round goby was highest in the spring, and lowest in the summer, might be caused by the behaviour of round goby in the mating season. Perch that ate round goby had a better condition than those who did not have round goby in the stomach, which indicates that the perch benefits from including round goby in its diet. In the general diet, a total of 48 species of prey were found, of which fish made up the largest prey-group for all areas and seasons examined. Perch with several prey or prey species in the stomach generally had a worse condition, which could be explained by how the prey was usually smaller and that more energy was required to catch them compared to more optimal sized prey. In conclusion, this study shows perch is an important predator on the invasive round goby in areas where established, but that there were variations found for the intake rate between, seasons and year.

Keywords: Baltic Sea, invasive species, Round goby, Perch, prey-predator interaction

Sammanfattning

Invasiva arter är ett globalt problem med stark koppling till minskad biodiversitet och stora ekonomiska kostnader. Den invasiva fiskarten Svartmunnad smörbult (*Neogobius melanostomus*) är en utav de arter som sprider sig i Östersjöområdet snabbast, och riskerar att leda till stora problem. Svartmunnad smörbult kommer ursprungligen från Svarta- och Kaspiska havet och tros ha introducerats till Östersjön via ballastvatten. Sedan de först upptäcktes i Gdańskbukten 1990 så har arten spridit sig och hittas nu längs större delen av Östersjöns kustområden.

Det pågår ett flertal olika studier för att följa den svartmunnade smörbultens framfart i Östersjön. Ett av de mest aktuella områdena är hur smörbulten påverkar det lokala ekosystemet, samt interaktionen mellan den invasiva arten och inhemska predatorer.

I denna studie undersöks Abborre (*Perca fluviatilis*) som en möjlig predator på den svartmunnade smörbulten. Abborrar från tre områden i Östersjön undersöktes; Mariehamn och Karlskrona (båda med väletablerade smörbults populationer), och Långnäs (utan en känd svartmunnad smörbults population). Abborrarna fångades mellan våren och hösten 2018 och 2019, och undersöktes för att se om svartmunnad smörbult fanns som en del i dieten. Syftet var att se hur viktig den svartmunnade smörbulten var i dieten, om de tre områdena skiljde sig åt, och om konsumtionen av smörbult skiljde sig över vår-höstperioden, och hur abborrarnas kondition påverkades av att äta smörbulten. Även den generella dieten hos abborrren undersöktes för de tre områdena. Totalt undersöktes 207 abborrar från Karlskrona och Mariehamn vilket sedan kombinerades med data från 905 abborrar som tidigare undersökts från Mariehamn och Långnäs.

Svartmunnad smörbult hittades i magarna på abborrar från alla tre områden som undersöktes. Det var det vanligaste bytet i Karlskrona och näst vanligast i Mariehamn. Konsumtionen av svartmunnad smörbult var störst på våren, och lägst på sommaren, vilket tros ha att göra med smörbultens beteende under parningssäsongen. Abborrar som åt svartmunnad smörbult hade bättre kondition än de som inte hade smörbultar i magen, vilket indikerar att abborren gynnas av att inkludera den svartmunnade smörbulten i sin diet. I den generella dieten hittades totalt 48 sorters byten, från vilket fisk var den största bytesgruppen för alla områden och säsonger som undersöktes. Abborrar med flera byten eller bytesarter i magen hade generellt sämre kondition vilket tros vara kopplat till att bytena då oftast var mindre och att det krävdes mer energi att fånga dem jämfört med större byten. Som slutsats så hittade denna studie att abborre ä ren viktig predator för den invasiva svartmunnade smörbulten I områden där smörbulten är etablerad, men att fanns variation i konsumtionen tanten vid jämförelse av säsonger och år.

Nyckelord: Östersjön, invasiva arter, svartmunnad smörbult, abborre, byte-predatorinteraktion

Table of contents

List of tables

List of figures

Abbreviations

FCF	Fulton’s condition factor
GFI	Gut fullness index
IRI	Index of relative importance

1. Introduction

1.1. Baltic Sea

The Baltic Sea located in the northern part of Europe is a unique waterbody containing aquatic environments ranging from temperate marine to subarctic limnic (Snoeijs-Leijonmalm *et al.* 2017). It is one of the largest brackish water bodies in the world with a surface area of about 4.2×10^5 km^2 and a volume of about 22×10^3 km^3. (Ojaveer *et al.* 2010, Snoeijs-Leijonmalm *et al.* 2017). The waterbody's geographical placement and bathymetry creates several types of environmental gradients such as temperature and salinity. This leads to a mosaic of local variation in the climate and habitats where different species are found (Ojaveer *et al.* 2010, Snoeijs-Leijonmalm *et al.* 2017). Due to the Baltic Sea only being connected to the Atlantic Ocean by a small belt, while at the same time being connected to several major and minor freshwater river systems, the Baltic Sea have a brackish waterbody of extremely low salinity, ~25 ppm in Kattegat down to only ~2 ppm in the northern Gulf of Bothnia (Feistel *et al.* 2010).

The brackish water and the relatively shallow depths of the Baltic Sea, combined with its young age, have created a rapidly changing, but also vulnerable ecosystem (Pereyra *et al.* 2009, Snoeijs-Leijonmalm *et al.* 2017). Due to the salinity and temperature gradients many species live on the limit of what they can cope with, creating a transition of species found with some species possibly only being able to live in small restricted areas (Snoeijs-Leijonmalm *et al.* 2017). Many of the marine species living in the Baltic Sea originate from a time when the Baltic Sea had a higher salinity and the shift towards more brackish water have limited them to the more southern parts (Snoeijs-Leijonmalm *et al.* 2017, HELCOM 2018a).

Even though there are many different habitats in the Baltic Sea the waterbody is considered to be species poor in comparison to other brackish waters as well as oceans (Snoeijs-Leijonmalm *et al.* 2017). Some areas in the Baltic Sea such as the Bothnian bay host less than 300 known macroscopic species (species visible to the naked eye), which differs noticeably from the thousands of species found closer to Kattegat and in the connection to the Atlantic Sea (HELCOM 2018a, HELCOM

2018b). The reason for the species poor status of the Baltic Sea is likely due to the young age of the waterbody as well as its huge variation in habitats creating species barriers due to physiological stress (Ojaveer *et al.* 2010).

The Baltic Sea is currently facing major issues when it comes to its ecological status. According to the Helsinki Commission low oxygen levels, eutrophication, overfishing, and invasive species are some of the biggest threats at the moment and there are many ongoing projects to try to combat these issues (HELCOM 2018a).

1.2. Invasive species

Invasive species is one of the biggest issues the Baltic Sea is facing today. The threat of invasive species was already discussed in the 1992 United Nations Convention on Biological Diversity, IUCN, and has been an increasingly important topic ever since (United Nation 1992, European Commission 2019). Today several legislations have been applied trying to handle this threat in the European Union (Sundset & Europäische Kommission 2014, European Commission 2019).

The increasing spread of invasive species globally has been attributed to many different factors, with one of the main causes being globalization. The increase in trade, travel and transport of humans, plants, and animals leads to both intentional and unintentional transfer and release of species into new habitats (Perrings *et al.* 2010). Although only a low proportion of the species transferred to new habitats become invasive, the species that do become invasive are considered major drivers of biodiversity loss due to the severe impacts they have on the recipient ecosystems (Keller *et al.* 2011).

Invasive species in aquatic systems are an increasingly recognized issue. However, more focus has been placed on this issue since the European Commission and other organizations recognized the increasing rate of invasive species found in major waterbodies, as well as the economic impact they cause. (HELCOM 2018, European Commission 2019, Grabowska 2008). The total economic impact of invasive species in Europe is estimated to be at least 12 billion EUR per year (Keller *et al.* 2011, Sundset & Europäische Kommission 2014), with 2.2 billion EUR per year being the estimated minimum cost of aquatic invasive species (Keller *et al.* 2011).

The round goby (*Neogobius melanostomus*) is one of the invasive species causing the biggest issues in the Baltic Sea at this time due to its ability to threaten and outcompete local species and consequently affecting local ecosystems and fisheries (Kornis *et al.* 2012, van Kessel *et al.* 2016). This has led to an increasing need for knowledge about the round goby and its ecology in invaded ecosystems, and is the reason for reason for this study on predator-prey interaction between perch and the round goby.

1.3. Aim and hypotheses

The aim of this study was to examine perch as a potential predator of the round goby by studying the perch diet from three different areas in the Baltic Sea. Two areas with known round goby populations (Karlskrona and Mariehamn) and one without a known population (Långnäs).

The questions examined regarding round goby consumption were: 1) to what extent perch make use of round goby in its diet, 2) if consumption of round goby differs between areas, seasons or years, and 3) if perch body size, body condition and feeding intensity differed for fish who made use of the round goby as a food resource.

My hypotheses are: i) perch will prey on the round goby in the two areas where round goby exist, and it will make up a significant part of the perch diet(Corkum *et al.* 2004, Almqvist *et al.* 2010, Liversage *et al.* 2017), ii) there will be a difference in round goby consumption between the areas due to availability of round goby (Oesterwind *et al.* 2017), iii) autumn will be the season with the highest amount of round goby consumed due to the increased availability after the reproductive season (Skóra *et al.* 1999, Sapota 2012), iv) there will be a small increase of round goby consumption between the two years due to an increase in round goby population(Oesterwind *et al.* 2017), v) large perch will have a higher level of round goby consumption due to the lessened effect of the size limitation preventing them from hunting large prey (Almqvist *et al.* 2010), and vi) both perch body condition and feeding intensity will increase with the amount of round goby eaten due to it being a comparatively large and easily caught prey, even though the nutritional value of round goby is lower as compared to other prey fish (such as sprat) of the same size class (Almqvist *et al.* 2010).

The questions examined regarding the overall perch diet were: 1) what species and proportion of the different species are found in the perch diet, 2) if the overall perch diet differs between the three different areas, seasons, and years, and 3) if there is any difference in body condition and feeding intensity between the areas, seasons and years.

My hypothesises for the overall perch diet are: i) the diet composition will be similar to what have been previously found for perch studied from the Baltic Sea with the majority of the diet consisting of fish, but there will also be significant amounts of crustacean and molluscs (Mustamäki *et al.* 2014, Jacobson *et al.* 2019), ii) while the proportions of the prey types will be similar, there will be local/seasonal differences in what species are found in the diet due to differences in food availability and perch being an opportunistic predator (Rask 1986), but no annual difference, iii) body condition and feeding intensity will differ between areas and seasons due to differences in the diet composition (Mustamäki *et al.* 2014, Jacobson *et al.* 2019), and iv) that body condition and feeding intensity will increase between the years as round goby consumption increases due to the round goby population growing (Almqvist *et al.* 2010, Oesterwind *et al.* 2017).

1.4. Introduction to the round goby

Round goby is a fish species native to the Sea of Azov, the Black Sea and the Caspian Sea (Sapota 2012). Since its introduction, the round goby has become an invasive species in large parts of the world, including Europe, the North-American Great lakes and the Baltic sea (Almqvist *et al.* 2010, Ruetz *et al.* 2012, Brandner *et al.* 2018).

The round goby belongs to the family Gobiidae of which there are several species native to the Baltic Sea. The round goby was fist observed in the Baltic Sea in the Gulf of Gdansk outside the port city of Gdynia 1990 (Holmes *et al.* 2019). Since then it has become one of the most common fish species in the Gulf of Gdansk and have continued to spread. The first discovery of the round goby in Sweden was 2008 in Karlskrona’s archipelago (Florin 2017). Today it has established populations in Göteborg, Visby, Kalmarsund and in the southern part of Stockholm’s archipelago (Florin 2020). It has in a similar way spread across the eastern cost of the Baltic Sea with established populations on the Finnish coast since 2005. Established populations have also been found in the islands located in the Baltic Sea, including the Åland isles (Puntila *et al.* 2018).

The round goby can grow up to 25 cm long, but is usually smaller (Skóra *et al.* 1999, Grabowska 2008). The round goby has an elongated body with a varied body-coloration of everything from flecked yellow-green, brown, greyish to dark brown (Skóra *et al.* 1999, Kornis *et al.* 2012). Males are often found almost black during the breeding season (Fig. 1). It often has a large black spot on the back end of the first dorsal fin (Skóra *et al.* 1999, Kornis *et al.* 2012). The round goby can be hard to tell apart from the black goby (*Gobius niger*), as well as other gobiids, but some distinguishing characteristics is the larger size of the round goby as well as the more plume-like dorsal fin with its characteristic dark spot when comparing the round and the black goby (Grabowska 2008, Kottelat & Freyhof 2007, Skóra *et al.* 1999).

Figure 1. Picture of a female (top) and male (bottom) round goby displaying its plume-like dorsal fin and its dark spot. Photos by: SLU and Rickard Gustafsson.

The common lifespan of the round goby is 3-4 years, but individuals up to 6 years old have been found (Grabowska 2008, Skóra *et al.* 1999). Females reaches sexual maturity at around 1 to 2 years while males do so at around 3 to 4 years. In the Baltic Sea the round goby spawns around two times per year (Almqvist *et al.* 2007). The males guard the eggs and juveniles aggressively until they die after the breeding season (Skóra *et al.* 1999, Sapota 2012).

The round goby can live and reproduce in a wide range of temperatures (0-30°C) but is believed to prefer warmer temperatures (Kornis *et al.* 2012). The round goby prefers brackish water but can also live and survive in freshwater systems (Skóra *et al.* 1999). It is an adaptable species with high resistance to low oxygen levels and is known from its native habitat in the Caspian Sea to reach densities of several individuals per m^2 (Skóra *et al.* 1999). The round goby is usually found in shallow waters (1-30 m) and prefers a gravelled or sandy hardbottom habitat, preferably with rocks and vegetation in the area (Almqvist *et al*. 2007). Previous studies have indicated that the one of the restricting factors for the round gobies to establish themselves is the need for suitable habitats with a gravelled or sandy hardbottom (Ray & Corkum 2001, Almqvist *et al*. 2007).

The diet of round goby consists mainly of mussels and clams, but it is also known to eat other invertebrates and some smaller fish species. In the Baltic Sea, blue-/common mussle (*Mytilus sp.*), Zebra mussel (*Dreissena polymorpha*) and *Macoma balthica* are common prey species (Skabeikis & Lesutienė 2015, Nurkse *et al.* 2016, Oesterwind *et al.* 2017). Cannibalism has also been observed for the round goby (Skabeikis & Lesutienė 2015).

The impact of the round goby on a ecosystem have been documented to be both positive and negative. It can contribute positively by functioning as a new food source for native piscivorous bird, fish and mammal species (Florin *et al.* 2018). However, the majority of the recognized effects from the round goby establishing in new habitats are negative as it may out compete native species (Kornis *et al.* 2012, van Kessel *et al.* 2016). Especially vulnerable are local prey species and species that may compete with the round goby for resources such as food or shelter. One species threatened by the round goby due to food competition is the European flounder (*Platichthys flesus*) (Karlson *et al.* 2007), but other bottom dwelling species could also be affected (Kornis *et al.* 2012, van Kessel *et al.* 2016).

Some of the known predators of round goby in the Baltic Sea include perch (*Perca fluviatilis*), cod (*Gadus morhua*), turbot (*Scophthalmus maximus*), zander (*Sander lucioperca*) and cormorants (*Phalacrocorax carbo*) (Almqvist *et al.* 2010, Kornis *et al.* 2012, Oesterwind *et al.* 2017). Burbot (*Lota lota*) could also be a predator as it has been found to consume round goby in North America (Jude, 1997).

The most likely explanation for the introduction of the round goby in the Baltic Sea is that eggs or larvae were transported in ship ballast water and were able to establish a population (Corkum *et al.* 2004). This would be similar to the way the species were established in North America (Kottelat & Freyhof 2007). This is supported by new observations of the round goby often being made in and around large harbours (Kornis *et al.* 2012), and in connection to shipping activity (Florin *et al.* 2018, Holmes *et al.* 2019). While round goby generally is not known to move around much, studies from North America have found that round goby occasionally can move up to 50m per day, facilitating its expansion on a more local level (Lynch & Mensinger 2011). Studies in North America have also established that there are several different pathways for the species to spread to new systems including interbasin transfer, travel using interconnected waterways, ship ballast water and sediment and ship hull fouling (Jude, 1997, Corkum *et al.* 2004).

1.5. Introduction to perch

Perch (*Perca fluviatilis*), also commonly known as European perch or Eurasian perch, is a fish species native throughout most of Europe. It is one of the most common fish species found in the coastal areas of the Baltic Sea with both a high ecological and economic value (Bryhn *et al.* 2020). This makes the ecological status of perch a topic of big interest as any change in its population could have considerate impact on both the ecosystem and the resources humans gain from it (Bryhn *et al.* 2020).

The perch is easily recognized from the other species found in the Baltic Sea. Though it has some interspecies variation, the distinct characteristics of the yellowish-green body with dark bars running along its body and the yellow-red coloration of the pelvic and anal fins makes it hard to misidentify (Fig. 2) (Kottelat & Freyhof. 2007).

Figure 2. Illustration of perch with the typical dark markings on a yellowish-green body and its characteristic yellow-red coloured pelvic and anal fins. Image by: W. von Wright

The female perch can reach over 50 cm in length and can weight more than 3kg, males are commonly smaller than females (ArtDatabanken, Bryhn *et al.* 2020). The known maximum age for perch is 22 years, but they often do not live longer than 10-15 years. The female reaches sexual maturity between 3-7 years of age, while the male between 2-6 years (Kottelat & Freyhof. 2007, Ceccuzzi *et al.* 2011, ArtDatabanken).

Perch can survive in a wide range of temperatures but mainly lives in clear water systems. As it is a visually oriented predator active during dusk and dawn, habitats with clear water increases its ability to survive and forage (Granqvist & Mattila 2004, Westrelin *et al.* 2018). The species lives and breeds in both freshwater and brackish water and is usually found in the water column between 1-30 meters depth

(ArtDatabanken, Kottelat & Freyhof. 2007, Bryhn *et al.* 2020). Though it can live in brackish water it is sensitive and cannot live in waters with a salinity higher than 7–10 psu (Ložys 2004). Different populations might prefer the littoral-zone or pelagic-zone, with some studies showing differences in body morphologies based on the preferred habitat (Hjelm *et al.* 2000, Vrede *et al.* 2010).

The perch spawn and eggs hatches in the spring and early summer after which the larvae primarily eat zooplankton (Granqvist & Mattila 2004). Throughout its life the perch is an opportunistic feeder, but as it grows the diet shift towards feeding on benthic invertebrates as well as other fish (Rask 1986, Yazıcıoğlu *et al.* 2016, Jacobson *et al.* 2019). Larg perches have also been found to exhibit cannibalism of smaller individuals (Byström *et al.* 2012, Yazıcıoğlu *et al.* 2016).

Perch from the Baltic Sea have an increased predation on fish and large invertebrates with increased length (Mustamäki *et al.* 2014, Yazıcıoğlu *et al.* 2016, Linzmaier *et al.* 2018). Though the classification of large perch differs, one study found that the diet of perch larger than 22.5 cm in length consisted of between 40-90% of fishes (Jacobson *et al.* 2019), Dietary studies on perch have found that Gobiidae, including round goby, make up a significant part of its diet which have made perch of interest as a possible predator for the invasive fish species round goby (Almqvist *et al.* 2010, Mustamäki *et al.* 2014, Jacobson *et al.* 2019, Oesterwind *et al.* 2017).

Due to a general decline of perch in the Baltic Sea (HELCOME 2018a, Olsson 2019, Bryhn *et al.* 2020), monitoring programs have been developed to follow the populations, and asses their status. While perch seem to have stabilized in the last few years, overexploitation and loss of suitable breeding habitats are still issues that need to be studied (HELCOME 2018a, Sundblad *et al.* 2014, Olsson 2019).

2. Materials and methods

2.1. Fish sampling and study setup

Perch were collected in 2018 and 2019 during the spring (April to Maj), summer (June to August) and autumn (September to October) from Åland (Mariehamn and Långnäs) in the northern Baltic Sea, and from Karlskrona in the southern Baltic proper (Fig. 3).

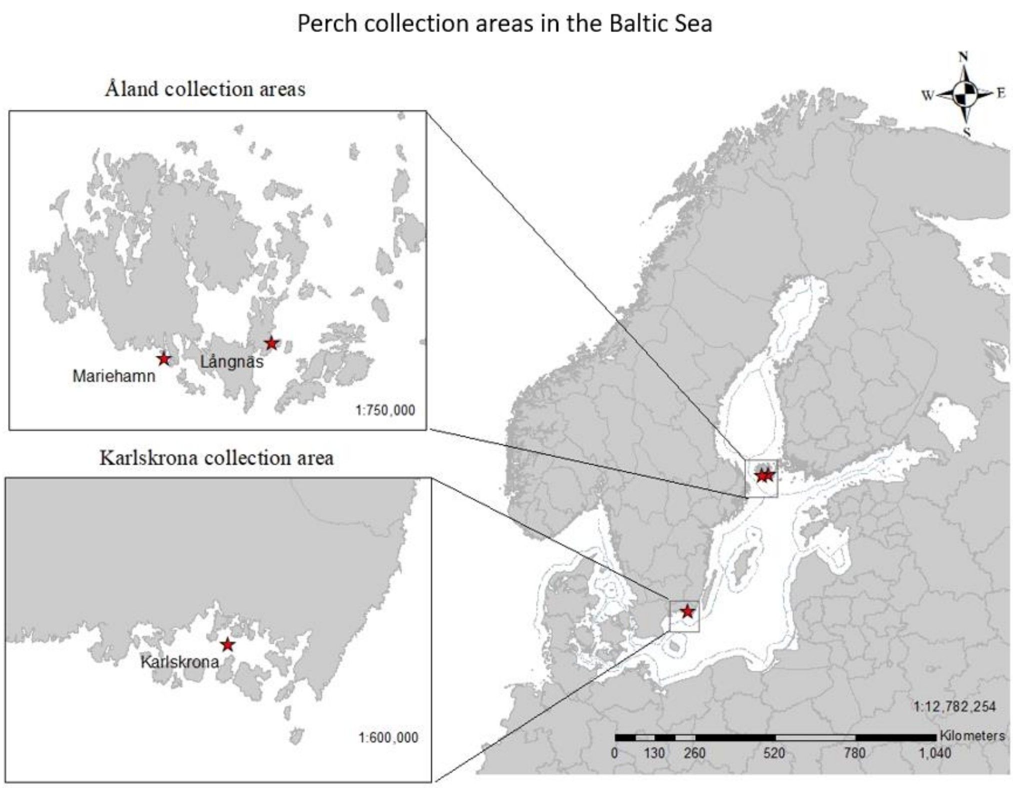

Figure 3. Map over the Baltic Sea showing the three perch collection areas; Mariehamn and Långnäs located on Åland, and Karlskrona on the Swedish east-coast. GIS data: Hannerz, F. and Destouni, G. 2006.

The perch from Åland was collected from a combination of test-fishing and commercial fishing while the perch from Karlskrona was collected solely from commercial fishing. The perch were sampled using gillnets overnight and collected in the morning. Perch from Åland, and perch stomachs from Karlskrona was frozen upon return to land and sent to SLU Kustlaboratoriet in Öregrund, where the dissections were carried out. Perch from Mariehamn and Långnäs was caught between May-September in 2018, and April-October in 2019. Perch from Karlskrona was caught between May-October in 2018, and between April-September in 2019. See overview of the samples, from each area, season, year and perch size in table 1.

No ethical permits were needed for the perch collected from commercial fishing, but the study was done under SLU Aquas permit 5.8.18-07747/2018, for round goby research. The test fishing from Åland was done under permit ÅLR 2018/3983.

2.2. Weighing, measuring and dissection of perch

Perch from Åland were weighted, measured and sexed. Weight was measured down to 0.1 g accuracy and length were rounded down to 0.1 cm. Perch shorter 23 cm were classified as small and longer fish were classified as large, based on previous studies indicating an ontogenetic shift around that size. Perch from Karlskrona were weighed down to 1 g accuracy, measured rounded down to 1 cm and sexed (when possible) by the fisher before the stomach, and liver were sent to SLU Kustlaboratoriet in Öregrund.

Using sterilized equipment by washing and flame-treatment (using 70% ethanol) the perch/perch-intestines were dissected and the stomach separated onto a sterile petri-dish. Sterile scissors and tweezers were used to open up the stomach and the scooper was used to empty out the stomach content. During the dissection the liver and stomach were removed and weighted when possible. The stomach content was emptied out on a sterile petri- dish and the stomach-lining were scraped to get as much of the stomach content as possible before the contents were weighted. An estimate of stomach volume and digestion state was taken, but not included in any of the later analyses. See appendix table 1 for full table over how stomach volume and digestion state was estimated. Stable isotope samples and DNA samples of the stomach content were also collected and prepared according to standard protocol for use in later studies.

2.3. Stomach analysis

Stomach analyses were caried out according to the same protocol followed by Robin Ramstedt and Heidi Herlevi from Åbo Akademi University.
Prey from stomach content were sorted under stereo microscope and identified to the lowest taxonomic level possible. The number of prey, prey lengths, and an estimated volume percentage (assigned by visual estimation of the whole sample, minimum estimated volume given were 5%) for each prey species were noted. Parasites and other observations were also documented for each fish. Solid/prey items from the stomach content were collected in bags marked with stomach ID and stored in the freezer for future reference.

The identification of the prey in the stomachs was done using reference pictures of black goby and round goby bones (Ljung 2020), the database Bonebase (v. Busekist 2004), the book Havets djur (Køie 2004), the book Ryggsträngsdjur: strålfeniga fiskar. Chordata: Actinopterygii (Kullander & Delling 2012) and the article Shapes of otoliths in some Baltic fish and their proportions (R. Sapota & Dąbrowska 2019).

Bones often used for species identification included parasphenoid, pharyngeal teeth, preoperculum, cleithrum as well as spines, scales or other identifying characteristics. Otoliths were also collected and used for identification. Images used to help identify which species the bones came from were taken from Ljung 2020 and the program Bonebase (v. Busekist 2004).

The collected data (from both Åland and Karlskrona) were compiled together with data from Robin Ramstedt and Heidi Herlevi. Data preparation were done by examining the data for missing values/oddities before any statistical analysis were conducted as well as cleaning up columns to make working with the data easier. Data with uncertainties due to possible duplicated samples, unknown origin etc., were excluded. Adjustments for missing data for number of individuals of a prey species per perch, or estimated volume for a species, was done according to a standardized correctional method (see section 2 in the appendix for details).

In total, 207 perch from Karlskrona, and 53 from Mariehamn (caught during spring and summer 2018) were examined, data from 905 perch (from Mariehamn and Långnäs from 2018 and 2019) previously examined by Robin Ramstedt and Heidi was used as a supplement during analysis. After removing perch with questionable data (ex. due to possible duplicates), the total number of perch included in this study was 1132. See overview of the samples, from each area, season, year and perch size in table 1.

Table 1. Total number of perch stomachs analysed (n=1132) from the different areas, seasons, years and perch sizes

Area	Karlskrona (n=199)			Mariehamn (n= 581)			Långnäs (n= 352)		
Season	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn
2018	**0**	**47**	**33**	**42**	**125**	**38**	**0**	**135**	**42**
Large	0	47	33	37	42	31	0	71	42
Small	0	0	0	5	23	7	0	36	0
Unknown	0	0	0	0	60	0	0	28	0
2019	**33**	**51**	**35**	**64**	**209**	**103**	**0**	**139**	**36**
Large	33	51	35	64	131	102	0	93	36
Small	0	0	0	0	78	1	0	46	0
Unknown	0	0	0	0	0	0	0	0	0

2.4. Calculation of body condition, feeding intensity and index of relative importance

To examine the effects of diet on perch condition Fulton's condition factor (FCF) was calculated and used as a measure of perch body condition (Froese, 2006, Khristenko and Kotovska1 2017). FCF was calculated as followed:

$$FCF = 100 * (\frac{W}{L^3})$$

W is the total weight of the individual in grams, L is the length in cm cubed and the factor 100 is used to make FCF easier to work with by bringing the value closer to unity (Froese. 2006). A FCF value of 1 indicates that a fish has a "normal" condition state while higher values indicate individuals that have been better of (Froese. 2006).

Gut fullness index (GFI) was used as an estimate of feeding intensity for the perch (Herbold, 1986). GFI was calculated as followed:

$$GFI = 100 * \left(\frac{W(s.c.)}{W(tot.)}\right)$$

W(tot.) is the total weight of the individual, and W(s.c.) is the weight of the stomach contents for each individual. The higher the GFI value found, the higher the feeding intensity is estimated to be. An assumption was made that feeding intensity did not differ between perch inside a size class (small/large).

Index of relative importance (IRI) was used to get a ranking of the different food items found in perch's diet (Hart *et al.* 2002). IRI was calculated in the same way as (Oesterwind *et al.* 2017):

$$IRI = \frac{N(i) + W(i) + F(i)}{\Sigma(N + W + F)} \times 100\%$$

Ni (%) is the number of prey observed, Wi (%) is the reconstructed weight of the prey-type, and Fi (%) is the frequency of occurrence of the prey taxon. The reconstructed weight (Wi) was calculated from the estimated volume-percentage times the stomach content weight for each fish where the species were found. The IRI% given for each species value was used as an estimate of its important in the diet.

All calculation was done using Microsoft Excel (Microsoft Excel 2016).

2.5. Statistical tests used for the stomach analysis

Statistical tests were done exclusively on perch containing stomach content. This was to exclude any possible bias caused by differences in perch gastric evacuation while caught in the nets. Table 2 displays an overview of the perch used in the analysis from each area, season, year and perch size. Statistical analyses were done using R version 4.0.2 (RStudio Team 2020).

Table 2. Number of fish analysed containing prey (n=761) from different areas, seasons, years and perch size.

Area	Karlskrona (n=155)			Mariehamn (n= 360)			Långnäs (n= 241)		
Season	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn
2018	**0**	**30**	**28**	**38**	**68**	**23**	**0**	**86**	**23**
Large	0	30	28	34	26	18	0	47	23
Small	0	0	0	4	17	5	0	20	0
Unknown	0	0	0	0	25	0	0	19	0
2019	**28**	**42**	**27**	**54**	**129**	**48**	**0**	**100**	**32**
Large	28	42	27	54	80	47	0	62	32
Small	0	0	0	0	49	1	0	38	0
Unknown	0	0	0	0	0	0	0	0	0

A Shapiro-Wilk normality test was carried out for perch length, weight, body condition (FCF), feeding intensity (GFI), prey-per fish, prey-species per fish and round goby prey to examine if the parameters were normally distributed. Parameters were classified to be normally distributed of the p-value was more than 0.05. Normal distribution was tested to determine which statistical test would be used for analysis of these parameters.

A PERMANVA was used to examine what factors to use when studying the perch diet. The analysis was done on a prey data matrix with the factors: area, seasons, catch year and perch size. Results from the PERMANOVA was used to adjust following statistical analyses to analyse the data in the best way. The PERMANOVA was done using R package Vegan (Oksanen, *et al.* 2019).

The distribution of the prey in the perch diet and the effect from the different factors was examined by a metaNMDS. The prey-matrix was square-root transformed in the metaNMDS function to remove bias of many small individuals. The ordination analysis was done using R package Vegan, using the functions; metaMDS, envfit and sppscores (Oksanen, *et al.* 2019).

The differences between areas, seasons and years were compared for round goby consumption (abundance and presence-absence of round goby), the general diet (number of prey and prey species) and perch body condition and feeding intensity. Kruskal-Wallis tests with a following Dunn post hoc test was used to compare differences in general diet and round goby consumption for the different areas and seasons, and, differences in perch body condition and feeding intensity between the different areas, seasons and years. To compare differences in general diet and round goby consumption between the years, and, the effect on perch body condition and feeding intensity for frequency of occurrence of round goby Wilcoxon-Mann-Whitney tests were used. Finally, Kendall's rank correlation tests were used to study the effect from the abundance of round goby, number of prey, and number of prey-species in the diet on perch body condition and perch feeding intensity. Boxplots presenting the number of prey-items found in the stomachs were logarithmized.

IRI was done for the comparison of the different areas, seasons and years. To make comparison easier, the prey-species were sorted into five higher-taxonomical-groups (Fish, Crustacea, Mollusca, Other Invertebrates, and Other) and compared. The differences found for the taxonomical-group fish was also examined.

3. Result

Out of these 1132 stomachs 761 (67%) contained prey while 376 (~33%) were empty. A total of 3523 food items were found in the non-empty stomachs, with prey found in 48 categories. Se table 2 for the distribution of the perch analysed from the different areas, seasons and years.

Of the 1132 perch examined 84 were males while 525 were female. 523 either lacked gender information or were impossible to determine the sex from. The female:male ratio for the perch in this study was noticeably different from the recognized standard 0.25 (table 3) (Jellyman D. J. 1980, Ceccuzzi *et al.* 2011).

Table 3. The male:female gender ratio for the different subsets of the perch data.

Sample	Males	Females	Unknown	male:female ratio (%)
All perch (n=1132)	84	525	523	0.14
Perch with stomach content (n=761)	58	369	334	0.14
Large perch with stomach content (n=581)	48	347	186	0.12

The data was not normally distributed, therefor non-parametric tests were used (Shapiro-Wilk normality test, GFI: W =0.75, p<0.001, FCF: W= 0.97, p<0.001, Number of prey: W= 0.23, p<0.001, Number of prey-species: W= 0. 70, p<0.001, and, Number of round goby: W= 0.37, p<0.001).

3.1. Variable interactions and subsetting the data

The proportion of perch smaller than 23 cm were extremely underrepresented in Karlskrona, and for spring and autumn (Table 2). To examine if this could affect the result of diet analysis, a PERMANOVA on all perch caught in Mariehamn was done. It showed significant differences in diet between different perch sizes (p=0.003), as well as a tendency for interaction between Season:Perch size (p=0.09). To avoid the lack of small perch in both Karlskrona and the two seasons I decided to only use large perch in following analyses.

Another PERMANOVA was done on the diet for a subset with only large perch. The factors; Season, Area, and Catch year were examined. There were significant results for all of the individual factors examined; (Area: $p<0.001$, Season: $p<0.001$, and, Catch year: $p<0.001$). Interactions were also found between the factors (Season:Area: $p<0.001$, Season:Catch year: $p<0.001$, Area:Catch year: $p<0.001$, and, Season:Area:Catch year: $p<0.001$).

Based on this, when examining season as a factor this was done only on perch caught 2019 and on perch from Karlskrona and Mariehamn. When examining differences between years and areas only data from summer and autumn were used.

3.2. Round goby

3.2.1. Differences in round goby consumption between areas

The abundance of round goby in the perch diet was significantly different between all areas with it being highest in Karlskrona and lowest in Långnäs (Fig. 4, Kruskal-wallis rank sum test: $\chi^2 = 50.91$, df = 2, $p<0.001$; Dunn post hoc test: All areas; $p<0.001$).

The same result was found when comparing the frequency of occurrence of round goby in the perch diet. (Kruskal-wallis rank sum test: $\chi^2 = 49.60$, df = 2, $p<0.001$; Dunn post hoc test: All areas; $p<0.001$). The frequency of occurrence of round goby found was 30 % in Karlskrona, 14% in Mariehamn and 1.2% in Långnäs (Fig. 4).

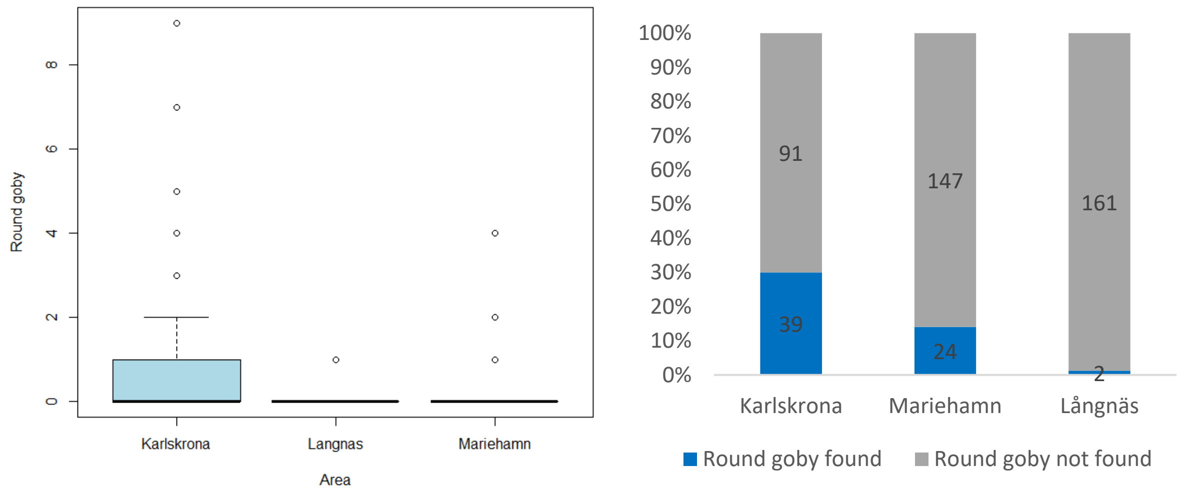

Figure 4. Abundance of round goby in the diet (left), and frequency of occurrence (right) in different areas (numbers mark the number of perch with (bottom) and without (top) round goby in the stomachs).

3.2.2. Differences in round goby consumption between seasons

The abundance of round goby in the diet was significantly higher in spring compared to summer, and there was a tendency for round goby consumption to be higher in autumn compared to summer (Fig. 5, Kruskal-wallis rank sum test: χ^2= 7.86, df = 2, p = 0.019; Dunn post hoc test: Spring and summer: p= 0.003, spring and autumn: p = 0.14, autumn and summer: p = 0.053).

The same result was found when comparing the frequency of occurrence of round goby in the perch diet. (Kruskal-wallis rank sum test: χ^2= 8.02, df = 2, p = 0.018; Dunn post hoc test: Spring and summer: p= 0.003, spring and autumn: p = 0.14, autumn and summer: p = 0.052. The frequency of occurrence of round goby was 19.5% in spring, 10.6% in summer, and 18.9% in autumn (Fig. 5).

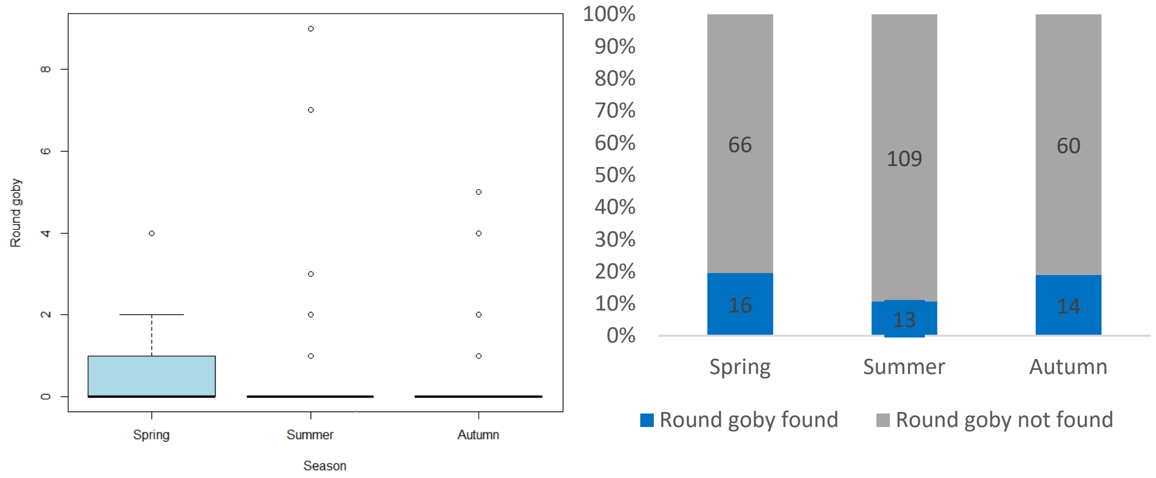

Figure 5. Abundance of round goby in the stomachs (left) and frequency of occurrence (right) in different seasons (numbers mark the number of perch with (bottom) and without (top) round goby in the stomachs).

3.2.3. Differences in round goby consumption between years

Both the abundance and the frequency of occurrence of round goby in the perch diet was significantly higher in 2018 compared to 2019 (Fig. 6, Wilcoxon-Mann-Whitney test, Abundance of round goby: W= 21713, p<0.001, Frequency of occurrence: W= 10554, p<0.001). The frequency of occurrence of round goby was 20.6% in 2018 compared to 10.0% in 2019 (Fig. 6).

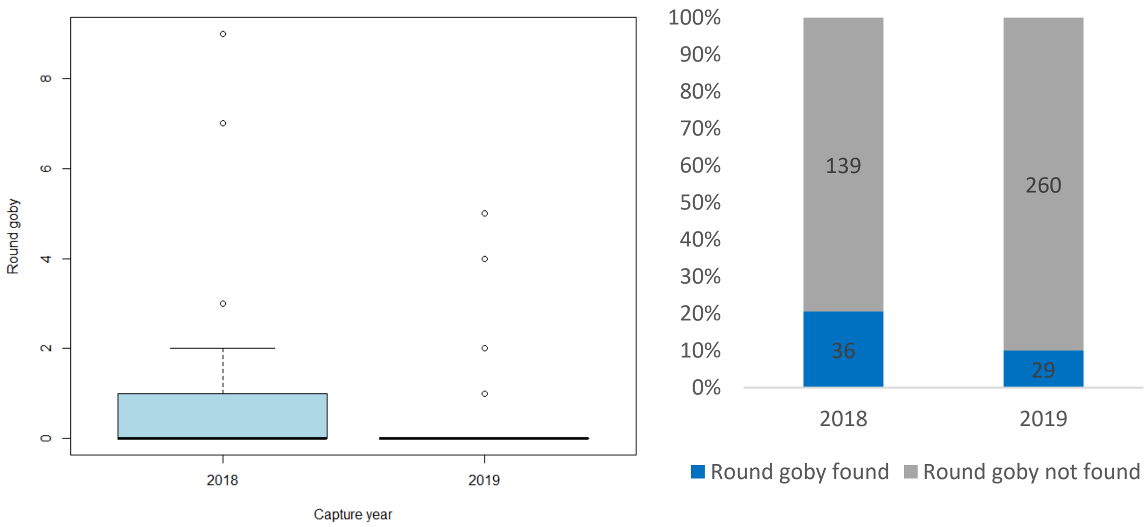

Figure 6. Abundance of round goby in the stomachs (left) and frequency of occurrence (right) in the different years (numbers mark the number of perch with (bottom) and without (top) round goby in the stomachs).

3.3. General diet

48 food-item groups were found for the perch diet, including two invasive species, the round goby *N. melanostomus*, and the Harris mud crab *Rhithropanopeus harrisii*. Full species lists can be found in the appendix table 3.

3.3.1. Prey distribution

Three dimensions were used for the ordination (stress k_3=0.097). The goodness of fit for the ordination found significant values for Area ($p<0.001$), but not for Season ($p=0.90$), or, Catch year ($p=0.79$). There were clear spatial differences for the different areas with Karlskrona being the furthest separated from Mariehamn and Långnäs (Fig. 7). Based on the ranked Pearson correlation score, the six species with the highest effect on the first ordination dimension was: *Gobiidae sp*, *N. melanostomus*, *P. fluviatilis*, *Decapoda sp*, *Crustacea* and, *Polychaeta sp*. See complete species-score table 2 in the appendix.

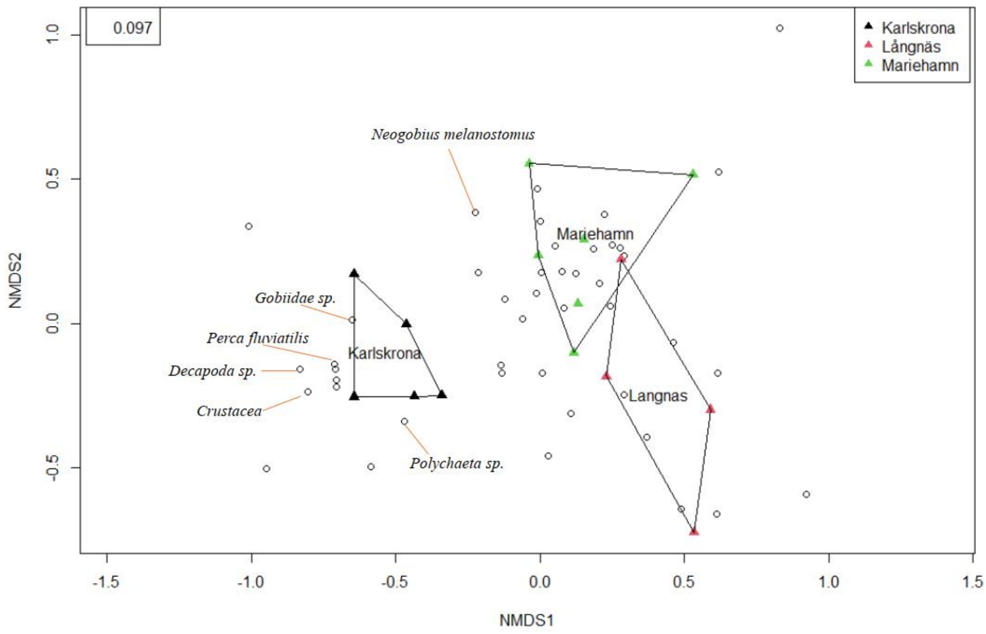

Figure 7. Distribution of perch prey community with coloured triangles marking the areas. Circles indicate the location of the 45 different prey-type. The six species with the highest effect on the first dimension of the ordination are shown.

3.3.2. Differences in general diet between area

The number of prey species in the diet was significantly higher for Karlskrona compared to Mariehamn and Långnäs (Fig. 8, Kruskal-wallis rank sum test: χ^2= 9.71, df = 2, p = 0.0078; Dunn post hoc test: Karlskrona and Långnäs: p=0.0014, Karlskrona and Mariehamn: p=0. 0082, Långnäs and Mariehamn: p=0.18).

The number of prey-items in the diet differed only between Karlskrona and Långnäs (Fig. 8, Kruskal-wallis rank sum test: χ^2= 9.71, df = 2, p= 0.0078; Dunn post hoc test: Karlskrona and Långnäs: p=0.0014, Karlskrona and Mariehamn: p=0.1787, Långnäs and Mariehamn: p=0.18).

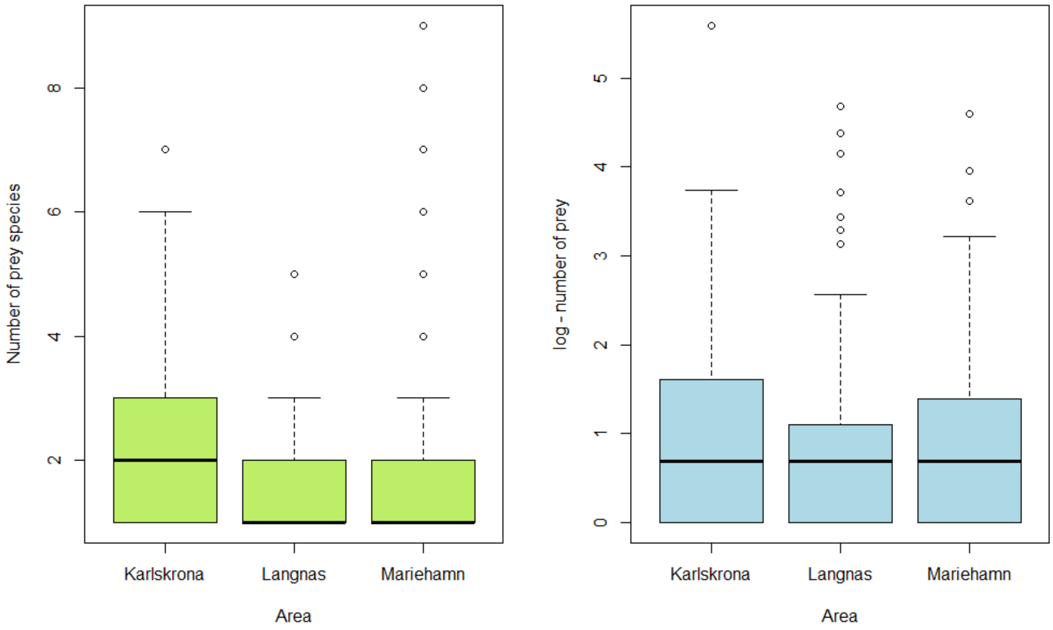

Figure 8. Abundance of prey-species (left), and total number of prey (right) in perch diet in different areas.

3.3.3. Differences in general diet between seasons

The number of prey species in the diet was significantly higher in spring compared to summer and autumn (Fig. 9, Kruskal-wallis rank sum test: χ^2= 28.59, df = 2, p<0.001; Dunn post hoc test: Spring and summer/autumn: p<0.001, summer and autumn: p = 0.13).

The number of prey-items was also significantly higher in spring compared to summer and autumn and there was a tendency for the number of prey-items to be higher in summer compared to autumn (Fig. 9, Kruskal-wallis rank sum test: χ^2= 18.56, df = 2, p<0.001; Dunn post hoc test: Spring and summer/autumn: p<0.001, summer and autumn: p = 0.055).

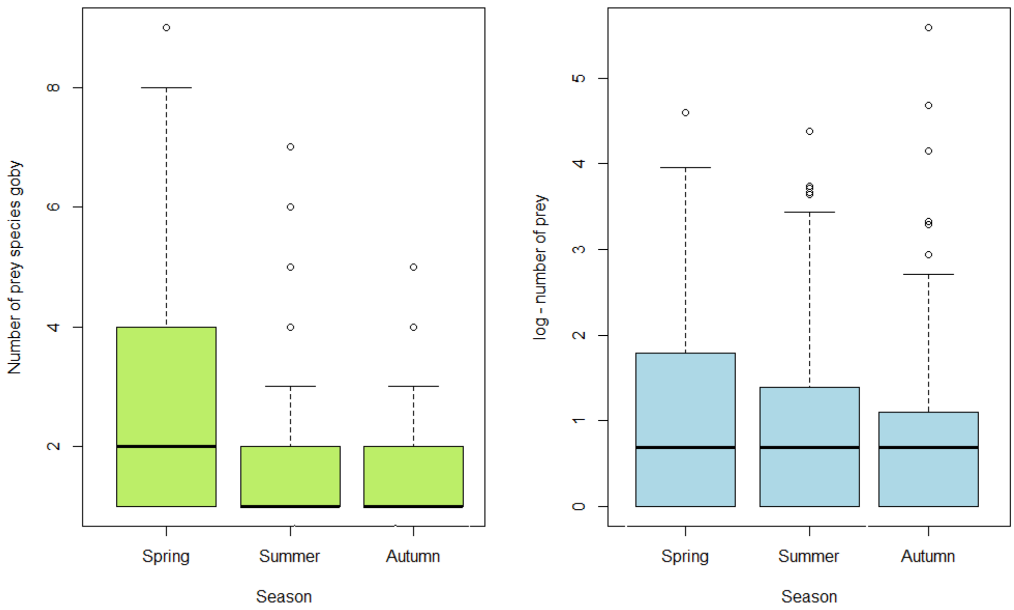

Figure 9. Abundance of prey-species (left), and number of prey (right) in the diet in the different seasons.

3.3.4. Differences in general diet between years

The number of prey species as well as the number of prey-items in the diet was significantly lower in 2018 compared to 2019 (Fig. 10, Wilcoxon-Mann-Whitney test, Prey species: W= 157424, p= 0.037, Number of prey: W= 207466, p<0. 001).

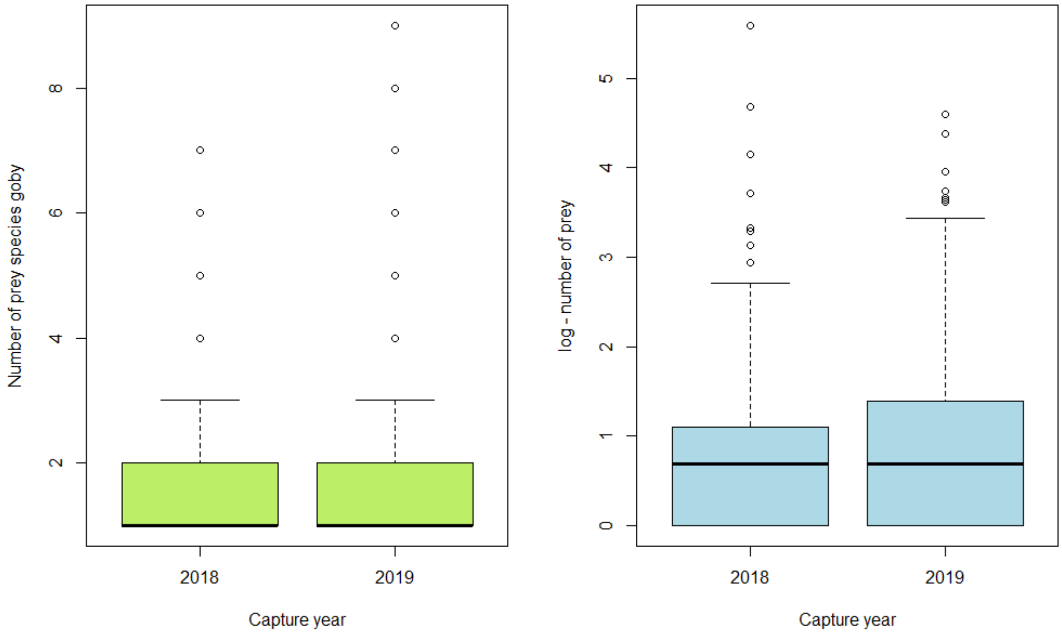

Figure 10. Abundance of prey-species (left), and number of prey (right) in the diet in the different years.

3.4. Differences in condition and feeding intensity due to diet

3.4.1. Effect of diet on perch body condition

There was a positive correlation between the abundance of round goby in the diet and body condition (Fig. 11, Kendall's rank correlation test: z= 2.40, rt= 0.08, p=0.016). Perch having consumed round goby also had a significantly higher body condition compared to perch with no round goby in the stomach (Fig. 11, Wilcoxon-Mann-Whitney test: W= 328935, p<0.001).

There was a negative correlation for the number of prey species, as well as the number of prey-items in the diet, and body condition (Fig. 12, Kendall's rank correlation tau, Prey species: z= -4.21, rt= -0.14, p<0.001, Number of prey-items: z= -2.34, rt= -0.071, p=0.019).

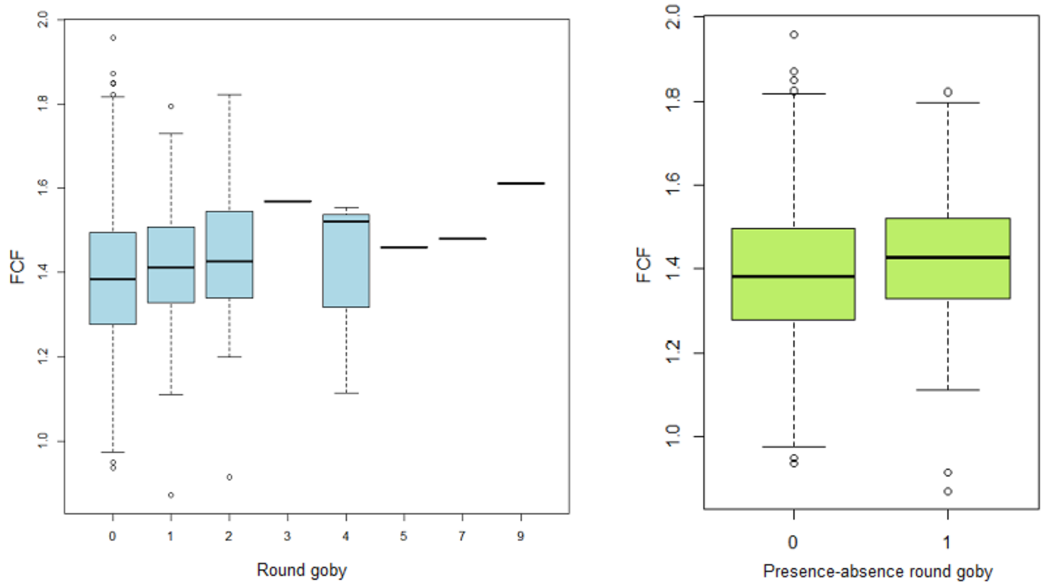

Figure 11. Differences in body condition for abundance of round goby in the stomachs (left), and frequency of occurrence of round goby (right).

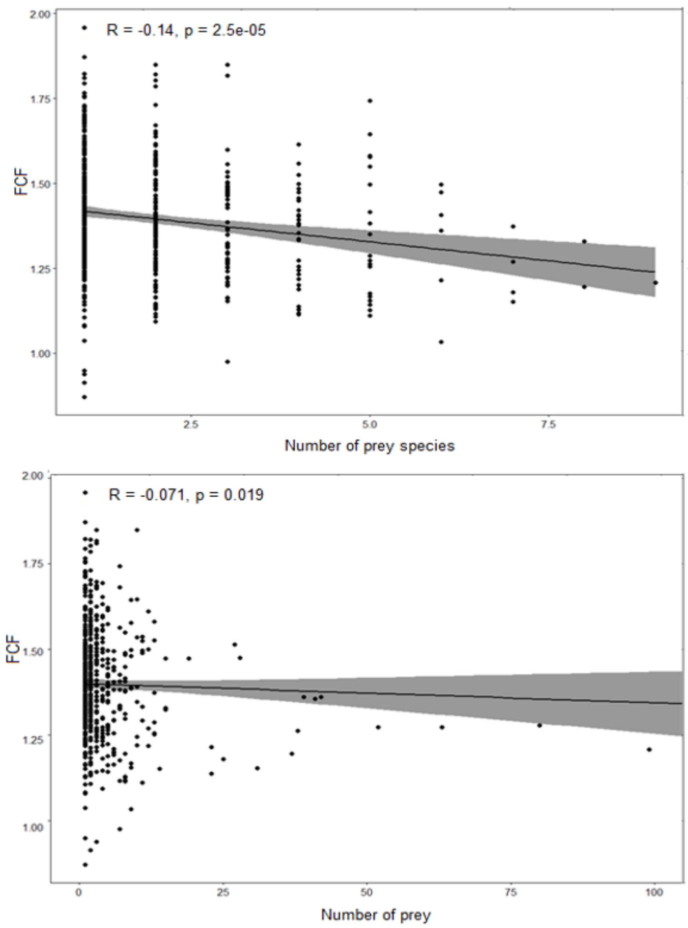

Figure 12. Correlation between body condition and the number of prey-species (top), and number of prey (bottom) in the diet. R = correlation coefficient, p= significance level, grey area marks residual.

3.4.2. Effect of diet on perch feeding intensity

There was a positive correlation between the abundance of round goby in the diet and feeding intensity (Fig. 13, Kendall's rank correlation test: z= 7.50, rt= 0.25, p<0.001). There was also a significantly increase between the presence-absence of round goby in the perch diet and feeding intensity (Fig. 13, Wilcoxon-Mann-Whitney test: W= 299394, p<0.001).

There was a positive correlation for the number of prey species, as well as the number of prey-items in the diet, and feeding intensity (Fig. 14, Kendall's rank correlation test, Prey species: z=4.38, rt= 0.14, p<0.001, Prey-items: z = 7.19, rt= 0.22, p<0.001).

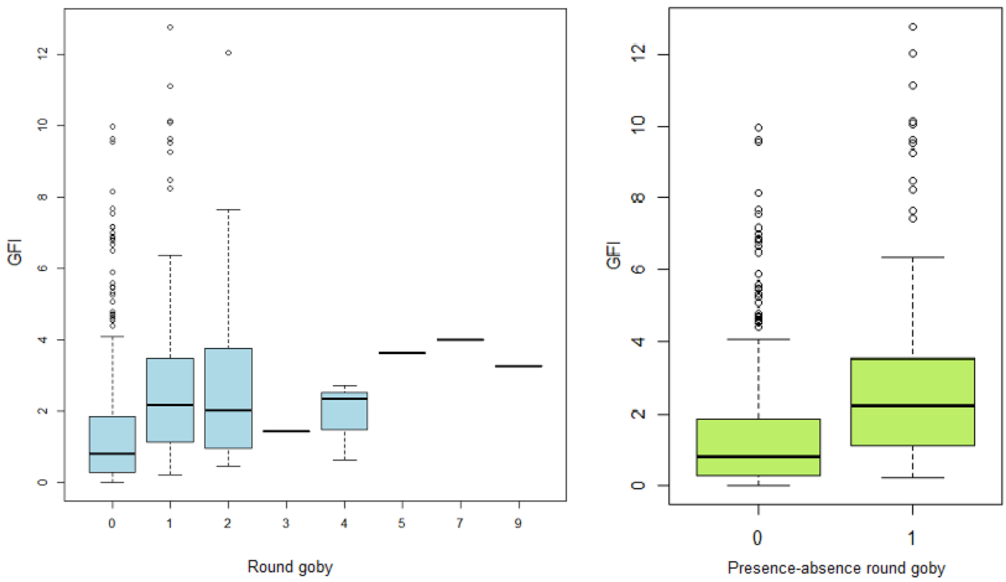

Figure 13. Differences in feeding intensity for abundance of round goby in the stomachs (left), and frequency of occurrence of round goby (right).

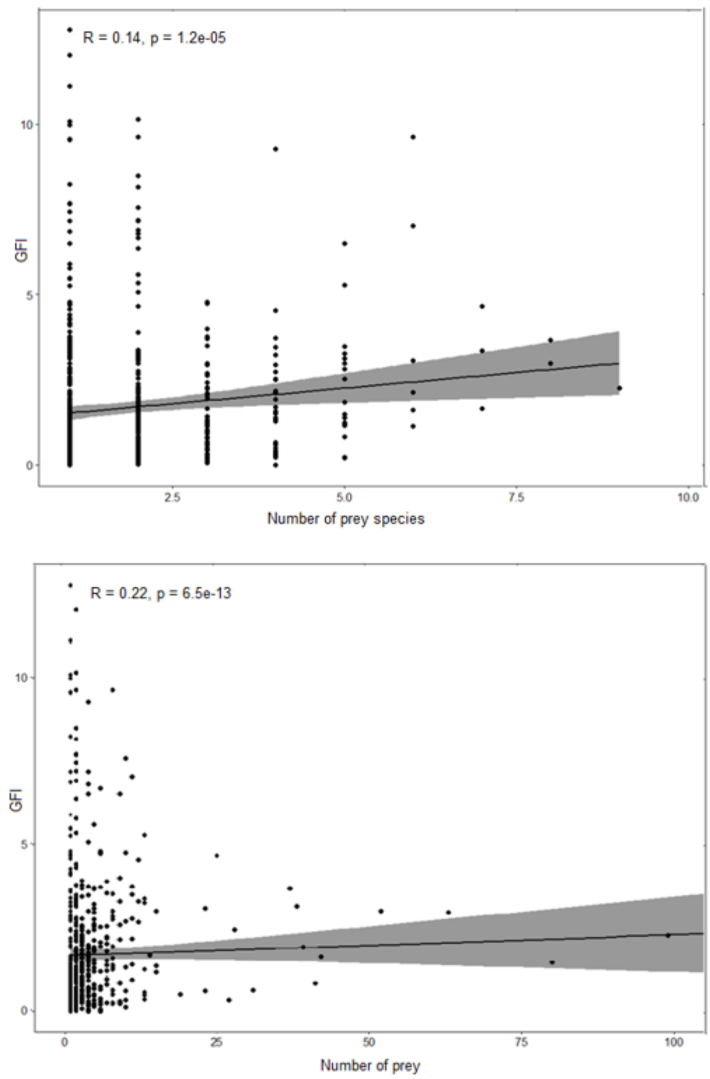

Figure 14. Correlation between feeding intensity and number of prey-species (top), and number of prey (bottom) in the diet. R = correlation coefficient, p= significance level, grey area marks residual.

3.4.3. Differences in perch body condition and feeding intensity between the areas

There were significant differences in the body condition between all areas with Karlskrona having the highest condition, and Långnäs having the lowest (Fig. 15, Kruskal-wallis rank sum test: χ^2= 16.18, df = 2, p<0.001; Dunn post hoc test: Långnäs and Karlskrona: p<0.001, Långnäs and Mariehamn: p=0.006, Karlskrona and Mariehamn: p=0.03).

No significant differences for feeding intensity were found between the different areas (Kruskal-wallis rank sum test: χ^2= 1.92, df = 2, p= 0.38).

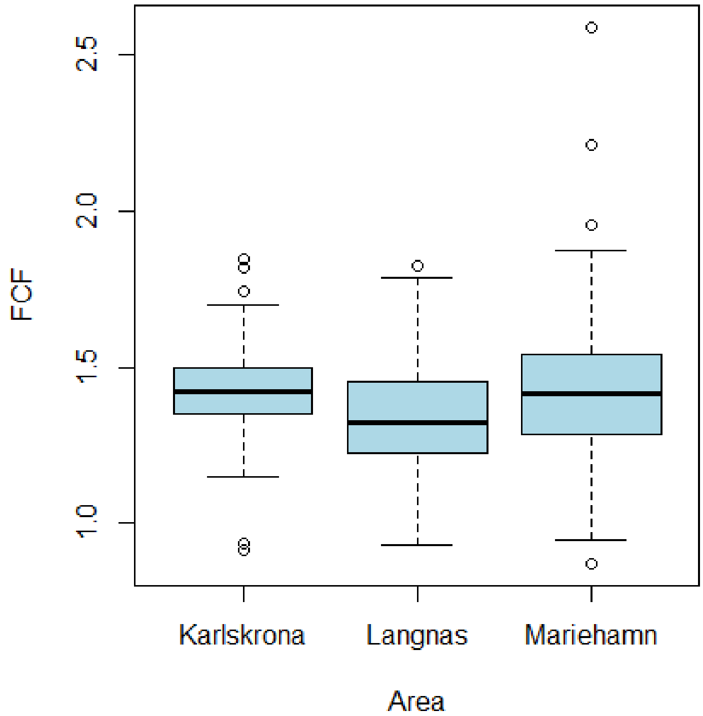

Figure 15. Differences in body condition between the areas.

3.4.4. Differences in perch body condition and feeding intensity between seasons

The body condition was significantly different between the seasons, being lowest in autumn and highest in summer (Fig. 16, Kruskal-wallis rank sum test: χ^2= 24.01, df = 2, p<0.001; Dunn post hoc test: spring and autumn: p=0.009, summer and autumn: p<0.001, spring and summer: p= 0.04).

The feeding intensity was significantly lower in autumn and highest in spring (Fig. 16, Kruskal-wallis rank sum test: χ^2= 31.24, df = 2, p<0.001; Dunn post hoc test: autumn and spring/summer: p<0.001, spring and summer: p=0.043)

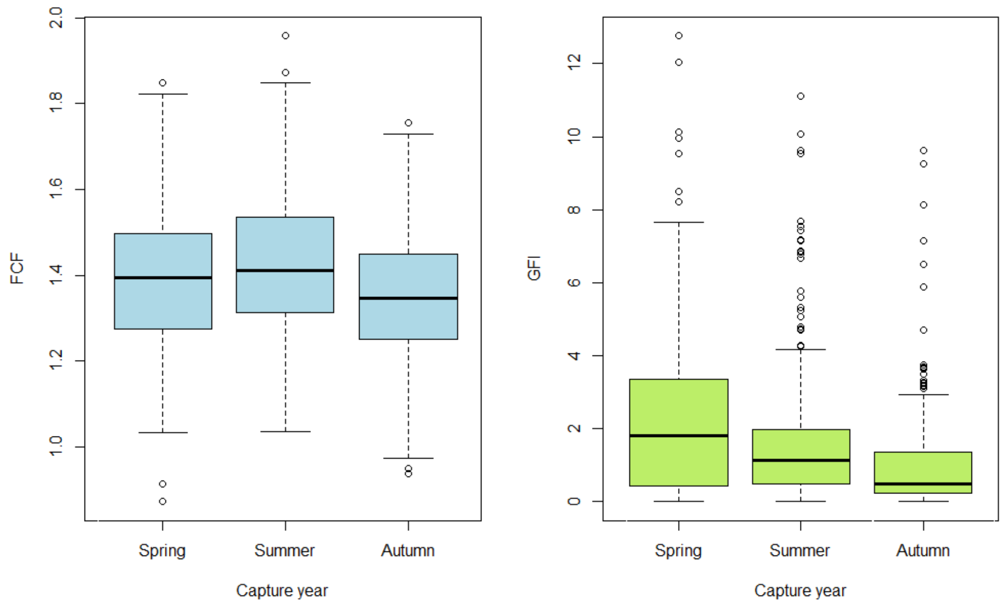

Figure 16. Differences in body condition (left), and feeding intensity (right) between the seasons.

3.4.5. Differences in feeding intensity between years

Both the body condition and the feeding intensity was significantly higher in 2018 compared to 2019 (Fig. 17, Kruskal-wallis rank sum test, Body condition: χ^2= 5.98, df = 1, p=0.015, Feeding intensity: χ^2= 5.22, df = 1, p= 0.02).

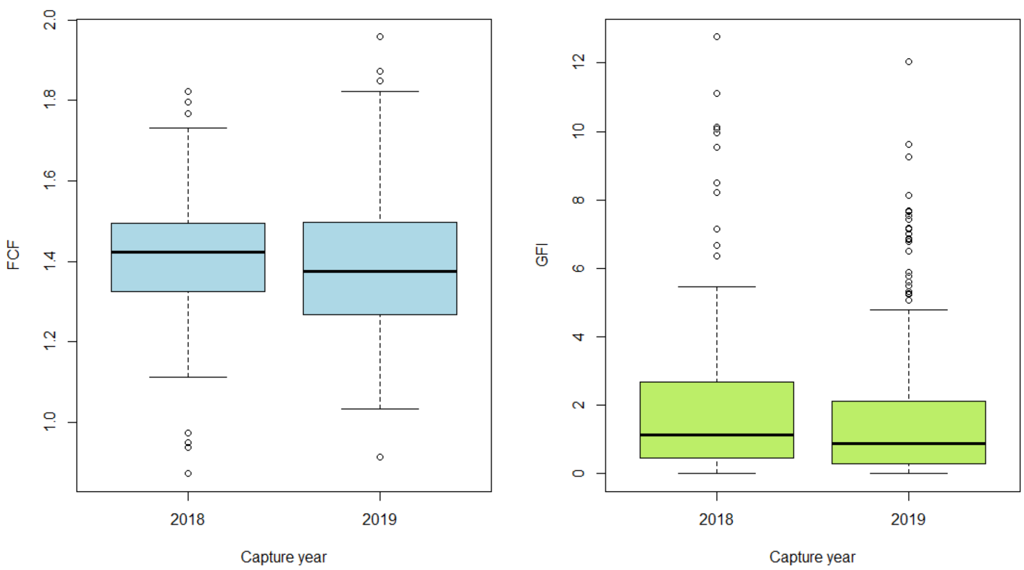

Figure 17. Differences in body condition (left) and feeding intensity (right) in the different years.

3.5. Index of relative importance

3.5.1. Differences in IRI between areas

All three areas have similar proportions of the different prey groups with fish and Crustacea being the two most commonly found prey types (Table 4). *Gasterosteus aculeatus, N. melanostomus, Zoarces viviparus* and *Idotea* were some of the most common species found in the diet. Mariehamn stands out as having the highest amount of fish in the diet out of the three areas, with Karlskrona and Långnäs appearing to have more similar proportions. The second biggest group Crustacea was more commonly found in the perch diet from Karlskrona and Långnäs, though the species primarily making up this group differed between the two areas (Table 4).

Table 4. Table showing the total IRI% for the five higher taxonomical prey groups (bold), as well as any species that were found to make up at least 5% of the perch diet in any of the three areas.

Species	IRI% Karlskrona	IRI% Mariehamn	IRI% Långnäs
Fish	**61.8**	**71.8**	**59.5**
Gasterosteus aculeatus	17.2	32.2	22.6
Neogobius melanostomus	18.4	12.3	0.8
Clupea harengus	6.0	10.5	2.5
Zoarces viviparus	4.1	4.1	18.5
Unidentified fish	7.5	3.2	3.2
Pomatoschistus sp.	0.3	6.1	6.5
Crustacea	**27.6**	**17.4**	**32.4**
Gammarus	13.7	4.3	5.9
Idotea	4.4	2.8	18.6
Palaemon adspersus	1.2	5.3	2.7
Mollusca	**2.5**	**3.6**	**2.6**
Other invertebrates	**1.6**	**1.8**	**0.7**
Other food items	**6.6**	**5.5**	**4.8**

In total 20 fish species were observed in the three areas; 13 species in Karlskrona, 13 species in Långnäs and 10 species in Mariehamn. The proportion of fish were of highest importance in Mariehamn 71.8%, second highest in Karlskrona 61.8% and lowest in Långnäs 59.5%. The most common fish in Karlskrona was round goby making up 18.4%, while three-spined stickleback was the most common species in Mariehamn and Långnäs making up 32.2% and 22.6% respectively (Table 4). See appendix table 4 for full IRI data for the different areas.

3.5.2. Differences in IRI between the seasons

All three seasons have similar proportions of the different prey groups with fish and Crustacea being the two most commonly found prey types (Table 5). *Gasterosteus aculeatus, N. melanostomus, Clupea harengus* and *Gammarus* were some of the most common species found in the diet. Summer stands out as having the highest proportion of fish in the diet, and the lowest proportion of Crustacea. Spring and autumn are more similar for those two groups, but spring differ noticeably compared to the other two seasons when looking at the groups: other invertebrates and other (Table 5)

Table 5. Table showing the total IRI% for the five higher taxonomical prey groups (bold), as well as any species that were found to make up at least 5% of the perch diet in any of the three seasons.

Species	IRI - Spring	IRI - Summer	IRI - Autumn
Fish	**52.8**	**69.9**	**56.8**
Gasterosteus aculeatus	11.8	41.3	3.8
Neogobius melanostomus	14.8	8.1	14.4
Clupea harengus	6.0	10.5	9.4
Zoarces viviparus	1.0	2.2	10.3
Unidentified fish	6.1	3.6	5.9
Pomatoschistus sp.	5.4	0.8	7.5
Crustacea	**35.8**	**16.8**	**30.6**
Gammarus	11.1	5.4	3.2
Idotea	1.8	6.2	1.1
Palaemon adspersus	7.8	0.5	11.6
Mysidae	8.8	0	0.5
Mollusca	**2.2**	**4.3**	**3.7**
Other Invertebrate	**7.2**	**1.6**	**2.1**
Insecta	6.3	0.4	0
Other food items	**2.0**	**7.4**	**6.7**

In total 16 fish species were observed for the three seasons; 12 species in spring, 12 species in summer and 10 species in autumn. Fish were consumed most during summer 69.9%, then in autumn 56.8% and least in spring 52.8%. The most common fish species consumed in spring and autumn was round goby making up a total of 14.8% and 14.4% respectively, while three-spined stickleback was the most consumed fish in summer (41.3%, Table 5). See appendix table 5 for full IRI data for the different seasons.

3.5.3. Differences in IRI between the years

The two years had similar proportions of the different prey groups with fish and Crustacea being the two most commonly found prey types (Table 6). *Gasterosteus aculeatus, N. melanostomus, Z. viviparus, Gammarus* and *Idotea* were some of the most common species found in the diet. There appeared to be a slight decline in fish prey, and an increase in “other”-prey between 2018 and 2019 (Table 6).

Table 6. Table showing the total IRI% for the five higher taxonomical prey groups (bold), as well as any species that were found to make up at least 5% of the perch diet in any of the two years.

Species	IRI - 2018	IRI - 2019
Fish	**65.6**	**62.7**
Gasterosteus aculeatus	18.5	26.3
Neogobius melanostomus	16.8	7.7
Clupea harengus	2.5	8.7
Zoarces viviparus	11.5	6.5
Unidentified fish	6.1	3.9
Pomatoschistus sp.	2.0	5.2
Crustacea	**27.6**	**25.7**
Gammarus	12.1	5.9
Idotea	10.3	8.3
Mollusca	**2.3**	**3.2**
Other invertebrates	**1.1**	**1.4**
Other food items	**3.4**	**6.9**

In total 20 fish species were observed between the two years; 16 species in 2018 and 17 species in 2019. The proportion of fish consumed were higher in 2018, (65.6%), compared to 2019 (62.7%). The most common fish species for both 2018 and 2019 was three-spined stickleback making up a total of 18.5% and 26.3% respectively. There was a noticeable drop in round goby consumed from 16.8% in 2018 and 7.7% in 2019 (Table 6). See appendix table 6 for full IRI data for the different years.

4. Discussion

4.1. Occurrence of round goby in perch diet

Round goby was found to be part of the perch diet in all areas, seasons and years compared. The result that round goby was frequently used as a prey-item was as expected, as studies on perch from other areas had found similar results (Almqvist *et al.* 2010, Oesterwind *et al.* 2017). The discovery that round goby was established in Långnäs was unexpected though as no prior observations of round goby had been reported from Långnäs at the beginning of this study.

4.1.1. Differences in perch predation of round goby between different areas

Perch from Karlskrona were found to have the highest level of round goby consumption (both in numbers and frequency) while perch from Långnäs had the lowest. This could be explained by how long the species have been in each area as well as the sizes of the population in each area. As both Karlskrona and Mariehamn have had round goby populations longer than Långnäs, these two areas were hypothesised to have a larger population and consequently a higher amount of round goby in the diet. This was supported by the result that round goby was the most common fish species observed in perch for Karlskrona, and the second most common prey-fish species for Mariehamn, while only making up a tiny fraction of the diet in Långnäs. This shows that since the round goby first establishing, it has become common enough that the perch in these areas use it as one of the primary food sources, which is similar to the result found in other areas (Oesterwind *et al.* 2017). The result that Karlskrona had a higher proportion of round goby than Mariehamn might either be explained by round goby being more common in Karlskrona, or by the existence of other equally available prey-fish alternatives in Mariehamn. This is supported by the perch being a known opportunistic predator (Rask 1986). However, if the occurrence of round goby found in the perch stomachs are used as an indication of the prey community in the different areas, the round goby seems to have become one of the most common fish species in both Karlskrona and Mariehamn.

The result that round goby was found in perch from Långnäs seem to indicate that the round goby has continued to spread throughout the Åland isles, and that at least a somewhat stable population have established itself in the Långnäs area. Although the round goby is not known to move across huge areas each day (Lynch & Mensinger 2012), they have been found to have different migration patterns which allows it to spread to new areas (Brandner *et al.* 2018, Christoffersen *et al.* 2019).

4.1.2. Differences in seasonal and yearly consumption of round goby

I had expected the highest amounts of round goby to have been consumed in the autumn, after the breeding season. While there was an increase between summer and autumn, spring was the season with the highest amount of round goby consumed, which did not support my hypothesis. If the amount of round goby in the stomachs was a direct result of feeding intensity, the intake would have been expected to be higher in summer than in autumn due to perch eating more to regain any weight lost during the breeding season (Craig 1977). This, was not the case in this study. One possible explanation for the round goby being more commonly consumed in the spring might be due to the breeding season which makes round goby migrate from the deeper waters to suitable nesting habitats in the warmer shallower waters. This would make them easier to detect and preyed upon by perch who also gathers around the same areas during breeding season (Ray & Corkum 2001, Sapota 2012, Christoffersen *et al.* 2019). The decrease found during the summer could be explained by the round goby males behaviour during the breeding season; male round goby has been shown to aggressively guard the eggs during the breeding season making them forced to remain in a small area. This could lead to round goby being harder to find and catch during large parts of the summer (Kornis *et al.* 2012). As round goby males die after the breeding season (Sapota 2012), this could make them easier prey for local predators, possibly explaining the increased intake of round goby during autumn.

The decrease of round goby in the perch stomachs 2019 as compared to 2018 was unexpected and difficult to explain. The warm summer and autumn in 2018 likely increased the perch metabolism, and food intake (Strand *et al.* 2011). While this could have explained the differences found between the years, this was not supported when comparing the seasons. However, it is possible that an increase would have been detectable if the seasons had been compared for each year. In a study done by Ljung (2020) on cod from Karlskrona, they also found a significant drop in the number of round goby being eaten between 2018 and 2019. In opposite, test fishing from Torhamn (Blekinge) and Muskö (Southern part of Stockholm archipelago) did not report any drop in number of round goby caught, between 2018 and 2019 (SLU Aquas Kustfiskedatabas (KUL)). This indicates that some other factor might be the explanation to the decreased intake. However, as this is not a perfect reflection of the study areas, no proper conclusions can really be drawn about this without more information on the round goby populations, especially as round goby intake have been shown to be affected by multiple environmental factors for perch (Liversage *et al.* 2017).

4.2. The general diet of perch

4.2.1. Species composition and proportions

Out of the 1132 perch studied, there were stomach content found in 67% of the stomachs studied, which is in the normal range to as compare to other studies on perch (Lappalainen *et al.* 2001, Almqvist *et al.* 2010, Mustamäki *et al.* 2014, Jacobson 2019).

The proportion and composition of prey found in this study was, as expected, similar to what have been observed in other studies (Lappalainen *et al.* 2001, Almqvist *et al.* 2010, Mustamäki *et al.* 2014, Yazıcıoğlu *et al.* 2016, Jacobson *et al.* 2019). The exception being the invasive species Harris mud crab *Rhithropanopeus harrisii*, and the two fish lices *Caligus curtus* and *Argulus sp*, which have not been frequently documented before (Meehan 1940, Bandilla *et al.* 2005, Hamre *et al.* 2011, Mustamäki *et al.* 2014, Møller 2015, Hemmingsen *et al.* 2020).

Harris mud crab was observed in all three areas, indicating that the Harris mud crab continue to spread in the Baltic Sea and have established populations in the study areas, creating another possible threat to the native ecosystem. The occurrence of Harris mud crab has been documented in the northern Baltic Sea since 2009, and have been suggested as a potential threat to costal macroalgae forests and the eelgrass meadows and connected ecosystem (Gagnon & Boström 2015). The findings that perch act as a predator on this crab could be a positive sign as a that it, by acting as a predator, can limit the rate of the invasion as there exists little competition for the crab in the northern part of the Baltic Sea.

Only a few observations of black goby were done during the study. When compared to the numerous round goby observed, it indicates a large difference in population size between the native species and the invasive species.

4.2.2. Differences in perch diet between the areas, season and years

For the general diet, area turned out to be the most important factor for explaining the differences found. This seem logical as the geographic location will have a strong effect on numerous environmental variables as well as on what prey species are available. Both the ordination and the IRI showed that Karlskrona was the area that differed most compared to the other two. Out of the two Åland areas, Mariehamn was the most similar to Karlskrona. The similarities between Mariehamn and Karlskrona likely come from both areas being highly disturbed due to their location close to a heavily trafficked harbour. The effect and disturbance from the harbour activity might increase the similarities between the two areas as the habitat are limited in what species can survive there (Erftemeijer *et al.* 2013. Macura *et al.* 2019). This also link up with the observations of the round goby in the two areas as it is believed that they were spread there by ship traffic (Jude, 1997, Corkum *et al.* 2004, Florin *et al.* 2018, Holmes *et al.* 2019).

As expected, seasonal differences, though not as clear as the differences between area, also existed in the diet. Some food types, such as fish roe, were clearly seasonal, but differences were also seen for number of prey and prey-species. Both the number of prey and prey species were higher during spring and to some extent summer. This coincides with the increase in feeding intensity for spring as compared to the other seasons, and could be caused by perch having a longer hunting window due to the increased time there is light, increased temperature or by prey being more available (Rask 1986, Granqvist & Mattila 2004, Liversage *et al.* 2017).

The proportions of the different prey groups were quite similar between 2018 and 2019. This differ though when looking at the composition of the fish prey in 2019 as compared to 2018. Most noticeable is the more than 50% drop of round goby observed in the perch diet. The reason why this does not have a larger impact on the total prey fish levels is likely the increase in the number of three-spined sticklebacks found in the stomachs. If the increase in three-spined stickle back is directly connected to the decrease of round goby, is unknown. Since the three-spined stickleback have been found to increase all across the Baltic Sea (Candolin & Voigt. 2020), it is possible that it was the next best option if round goby became less available.

4.3. The effect of diet on body condition and feeding intensity

Perch from the areas, seasons and year with higher levels of round goby consumption were shown to have a higher body condition as hypothesised. While there were significant differences in feeding intensity when comparing the seasons there were unexpectedly no differences found when comparing the areas. There was also an unexpected decrease in feeding intensity between years.

When comparing differences found between the areas it is clear that predation on round goby had an effect on body condition. The consumption of round goby matched the increase in body condition found for the areas, indicating that there is a nutritional gain for perch to include round goby in the diet even though the nutritional value of round goby is lower as compared to other prey fish (such as sprat) of the same size class (Almqvist *et al.* 2010). This could indicate that the round goby is a better match for the perch optimal prey-size than the other available prey-fish which is similar to what's suggested by Almqvist *et al.* 2010. This was especially noticeable as, if predicted by the number of prey and prey species, the expected condition for the areas would have been highest in Långnäs, and lowest in Karlskrona. Likely the decline in condition found in connection to an increasing number of prey and prey-species comes from the prey consumed being smaller and collectively taking more effort to catch as compared to fewer large prey. That there was no difference found in feeding intensity between the areas could mean that the overall diet had a stronger effect on the feeding intensity than from round goby consumption alone.

The differences found between seasons are harder to explain. The highest condition for perch were found during summer which is surprising as perch often are lean after the breeding season (Craig 1977). The seasonal differences found are likely connected to the reproductive season and the increased weight from the gonads, higher feeding intensity and the longer hunting hours (Rask 1986, Granqvist & Mattila 2004). This makes it uncertain how much of the increase in condition can be explained by the diet. The result that feeding intensity was highest during spring and lowest during autumn could be explained by differences in digestion rate due to an increase in temperature (Linløkken *et al.* 2010, Strand *et al.* 2011). Likely there are other variables, such as perch size, digestion rate and sampling method affecting these results, which makes it difficult to understand if there is a direct connection between body condition, feeding intensity and diet when comparing the seasons.

The difference found for condition and feeding intensity between 2018 and 2019 was not as hypothesised. I expected body condition to increase between the years as the round goby populations grew. However, as there was a decline in both condition and round goby consumption between the years the effect of round goby consumption on perch condition can still be seen, only in the opposite direction to what was expected. The decline in feeding intensity for 2019 could be explained by the prey from 2019 being smaller and the resulting effect on the calculation of GFI. The increase of smaller prey is supported by the both the increase in three-spined stickleback, and the general increase in number of prey and prey-species found in the diet.

4.4. Critical evaluation of the methods and results

Due to the need to rely on commercial fishers for much of the samples studied, it was not possible to control exactly when the perch were collected as this was dependent on when the normal fishing was caried out. Possible due to the nets used or differences in fishing depths, the amount of smaller perch caught were less than expected, making statistical tests based on perch size difficult.

The choice to only use large fish for the statistical analyses means that the loss of a certain percentage of the data collected could have caused some species to appear more or less common than truly found in the perch diet. Likely there will be species not found during this study that are a regular part of the perch diet, and some species found that may appear more common than in nature due to the method of the study. Some smaller prey-items that were found alone in the stomach might have gotten slightly overrepresented due to the fact that the whole stomach content (including the liquid and slime) was weighted, and not just the dry-mass of the prey found.

Concerning the issue of difficulties when identifying certain food-items (either due to the extreme state of digestion, or certain species being hard to reliably tell apart), it could lead to the proportion of some species being underrepresented. The biggest risk identified was to distinguish between the different gobies. While there were some that was not possible to identify, most were identifiable using literature and pictures (v, Busekist 2004, Ljung 2020). There is also a possibility that some prey was missed to a higher level due to them being digested quicker (Schneider 2004). This could mean that the actual proportion of certain prey species might be higher than suggested, especially as the digestion rate can be affected by multiple factors, such as temperature, perch size and prey type (Schneider 2004).

The lack of smaller perch might explain the lack of male perch found in the study (males:females= 0.14 as compared to the normal gender ratio for perch; = 0.25 (Jellyman 1980, Ceccuzzi *et al.* 2011). This is a potential issue as prior studies have shown that size have a significant effect on perch diet (Hjelm *et al.* 2001, Mustamäki *et al.* 2014. Yazıcıoğlu *et al.* 2016). The lack of male perch could also have had an effect on the reliability of FCF as females have noticeable enlarged gonads during the breeding season (Herbold, 1986, Froese 2006, Vrede *et al.* 2010). The condition of a perch population have been shown to be depend on not only its age and gender composition, but also on environmental elements as well as season (Pravdin, 1966, as interpreted by Khristenko and Kotovska1 2017). To know the full extent of the different seasons effect on body condition it would be necessary to separate the effect of the different variables that could have an effect. To be able to do so it would be needed to either: find some type of transformation index so that the values could be standardized, to only compare males as they show a lesser effect of the reproductive season, or, to measure the fish weight after the gonads (alternatively both guts and gonads) have been removed. Unfortunately, it was impossible to do any of these adjustments due to being unable to find a transformation index the limited numbers of male perch, and the lack of control in how the weight was measured for some of the samples.

4.5. Future studies

Due to time limitations, it was not possible to complement the data from this study with the results from the DNA and stable isotope analysis, as was originally planned. But this could be an interesting follow up study, as it could see to what level the prey identified from the stomach content analysis was reflected by the DNA samples. It would also be interesting to use the isotope samples to see if perch preying on round goby had created a change in trophic level for the perch.

Size and sex comparison would also be of interest for future studies as perch size have been found to have significant effect on the diet (Amundsen *et al.* 2003, Mustamäki *et al.* 2014, Jacobson 2019, Linzmaier *et al.* 2018). Unless it would be possible to collect the samples within the study, this might be something that is hard to control. But if size were to be studied, alternative collection methods might be worth looking into.

It would also be interesting to examine the body condition of both perch with empty and full stomachs, to see if the result found here were a proper representation of the population. I chose not to do this as due to the method used when measuring weight, the weight from the stomach content was included in the total weight which would have led to a bias for perch with empty stomachs.

More information on the prey communities for the different areas studied (from for example test-fishing), would also be good to include in future studies as this could give a better picture of the perch prey selection and the inclusion of round goby in the diet.

4.6. Conclusion

This study showed that the overall perch diet and the consumption of round goby differed between areas, seasons and years. It also showed that round goby quickly becomes a significant part in the perch diet after establishing itself in new areas, and that consumption of round goby had a positive effect on the perch body condition indicating that perch benefits from the round goby being present in the area. This means that perch can function as a natural predator for the round goby (and possibly other invasive species such as the Harris mud crab) but also that there is need for further research to fully understand the interactions between these species.

References

Alboukadel Kassambara. 2020. ggpubr: “ggplot2” Based Publication Ready Plots.

Almqvist G, Skora K, Appelberg M. 2007. Shortage of spawning habitats hampers spreading rate of the invasive round goby in southern Baltic Sea? ICES CM 2007E:94

Almqvist G, Strandmark AK, Appelberg M. 2010. Has the invasive round goby caused new links in Baltic food webs? Environmental Biology of Fishes 89: 79–93.

Amundsen P-A, Bøhn T, Popova OA, Staldvik FJ, Reshetnikov YS, Kashulin NA, Lukin AA. 2003. Ontogenetic niche shifts and resource partitioning in a subarctic piscivore fish guild. 11.

ArtDatabanken S. Abborre - ArtDatabanken SLU. online: https://artfakta.se/artbestamning/taxon/perca-fluviatilis-206198. Accessed April 7, 2020.

Bandilla M, Hakalahti T, Hudson PJ, Valtonen ET. 2005. Aggregation of Argulus coregoni (Crustacea: Branchiura) on rainbow trout (*Oncorhynchus mykiss*): a consequence of host susceptibility or exposure? Parasitology 130: 169–176.

Brandner J, Cerwenka AF, Schliewen UK, Geist J. 2018. Invasion strategies in round goby (*Neogobius melanostomus*): Is bigger really better? PLOS ONE 13: e0190777.

Bryhn A., Sundblad G., Strömberg H., Wennhage H., Wickström H., Ahlbeck Bergendahl I., Olsson J., Lövgren J., Persson J., Sundin J., Lundström K., Edsman L., Ogonowski M., Ulmestrand M., Lindmark M., Bergenius M., Sjöberg N., Holmgren N., Renman O., Naddafi R., Fredriksson R., Larsson S., Axenrot T., Dekker W., Pekcan Hekim Z., Sundelöf A., Lingman A., Florin A.-B., Petersson E., Vitale F. 2020. Abborre. Fisk- och skaldjursbestånd i hav och sötvatten 2019 - Resursöversikt, pp. 23–30. Havs- och Vattenmyndigheten,

Byström P, Huss M, Persson L. 2012. Ontogenetic constraints and diet shifts in Perch (*Perca fluviatilis*): mechanisms and consequences for intra-cohort cannibalism: Ontogenetic constraints and intra-cohort cannibalism. Freshwater Biology 57: 847–857.

Candolin U, Voigt H-R. 2020. Population growth correlates with increased fecundity in three-spined stickleback populations in a human-disturbed environment. Aquatic Sciences 82: 21.

Ceccuzzi P, Terova G, Brambilla F, Antonini M, Saroglia M. 2011. Growth, diet, and reproduction of Eurasian perch *Perca fluviatilis* L. in Lake Varese, northwestern Italy. Fisheries Science 77: 533–545.

Christoffersen M, Svendsen JC, Behrens JW, Jepsen N, van Deurs M. 2019. Using acoustic telemetry and snorkel surveys to study diel activity and seasonal migration of round goby (*Neogobius melanostomus*) in an estuary of the Western Baltic Sea. Fisheries Management and Ecology 26: 172–182.

Corkum LD, Sapota MR, Skora KE. 2004. The Round Goby, Neogobius melanostomus, a Fish Invader on both sides of the Atlantic Ocean. Biological Invasions 6: 173–181.

Craig JF. 1977. The Body Composition of Adult Perch, *Perca fluviatilis* in Windermere, with Reference to Seasonal Changes and Reproduction. The Journal of Animal Ecology 46: 617.

Erftemeijer PLA, Jury MJ, Gabe B, Dijkstra JT, Leggett D, Foster TM, Shafer DJ. 2013. Dredging, port- and waterway construction near coastal plant habitats. doi 10.13140/RG.2.1.2723.5288.

European Commission. 2019. Non-indigenous species - Marine Environment. online July 8, 2019: https://ec.europa.eu/environment/marine/good-environmental-status/descriptor-2/index_en.htm. Accessed May 7, 2020.

Feistel R, Weinreben S, Wolf H, Seitz S, Spitzer P, Adel B, Nausch G, Schneider B, Wright DG. 2010. Density and Absolute Salinity of the Baltic Sea 2006–2009. Ocean Sci 22.

Florin A-B. 2017. Svartmunnad smörbult ökar kraftigt. online 2017: https://www.slu.se/ew-nyheter/2017/6/svartmunnad-smorbult-okar-kraftigt/. Accessed August 13, 2020.

Florin, A.-B. 2020. Svartmunnad smörbult. online October 2020: https://www.slu.se/institutioner/akvatiska-resurser/radgivning/frammande-arter/svartmunnad-smorbult/. Accessed May 13, 2020.

Florin A-B, Reid D, Sundblad G, Näslund J. 2018. Local conditions affecting current and potential distribution of the invasive round goby – Species distribution modelling with spatial constraints. Estuarine, Coastal and Shelf Science 207: 359–367.

Froese R. 2006. Cube law, condition factor and weight-length relationships: history, meta-analysis and recommendations. Journal of Applied Ichthyology 22: 241–253.

Gagnon K, Boström C. 2016. Habitat expansion of the Harris mud crab *Rhithropanopeus harrisii* (Gould, 1841) in the northern Baltic Sea: potential consequences for the eelgrass food web. BioInvasions Records 5: 101–106.

Grabowska J. 2008. *Neogobius melanostomus* (round goby). online April 28, 2008: https://www.cabi.org/isc/datasheet/73163. Accessed July 5, 2020.

Granqvist M, Mattila J. 2004. The effects of turbidity and light intensity on the consumption of mysids by juvenile perch (*Perca fluviatilis* L.). Hydrobiologia 514: 93-101.
Hamre LA, Lunestad BT, Hannisdal R, Samuelsen OB. 2011. An evaluation of the duration of efficacy of emamectin benzoate in the control of Caligus curtus Müller infestations in Atlantic cod, Gadus morhua L.: Efficacy of emamectin benzoate against C. curtus. Journal of Fish Diseases 34: 453–457.
Hannerz F, Destouni G. 2006. Spatial characterization of the Baltic Sea drainage basin and its unmonitored catchments. Ambio 35: 214–219.
HELCOM. 2018a. State of the Baltic Sea – Second HELCOM holistic assessment 2011-2016. Baltic Sea Environment Proceedings 155.
HELCOM. 2018b. HELCOM Thematic assessment of biodiversity 2011-2016. Baltic Sea Environment Proceedings No. 158. Baltic Marine Environment Protection Commission
Hemmingsen W, MacKenzie K, Sagerup K, Remen M, Bloch-Hansen K, Dagbjartarson Imsland AK. 2020. *Caligus elongatus* and other sea lice of the genus *Caligus* as parasites of farmed salmonids: A review. Aquaculture 522: 735160.
Herbold B. 1986. An alternative to the fullness index. In: Simenstad CA, Cailliet GM (ed.). Contemporary studies on fish feeding: the proceedings of GUTSHOP '84, pp. 315–320. Springer Netherlands, Dordrecht.
Hjelm J, Persson L, Christensen B. 2000. Growth, morphological variation and ontogenetic niche shifts in perch (*Perca fluviatilis*) in relation to resource availability. Oecologia 122: 190–199.
Holmes M, Kotta J, Persson A, Sahlin U. 2019. Marine protected areas modulate habitat suitability of the invasive round goby (*Neogobius melanostomus*) in the Baltic Sea. Estuarine, Coastal and Shelf Science 229: 106380.
Jacobson P, Bergström U, Eklöf J. 2019. Size-dependent diet composition and feeding of Eurasian perch (*Perca fluviatilis*) and northern pike (*Esox lucius*) in the Baltic Sea. Boreal Environment Research 24: 18.
Jellyman DJ. 1980. Age, growth, and reproduction of perch, *Perca fluviatilis* L., in Lake Pounui. New Zealand Journal of Marine and Freshwater Research 14: 391–400.
Jude D. J. 1997. Round goby: cyberfish of the third millennium. Great Lakes Research Review 3: 27–34.
Karlson AML, Almqvist G, Skóra KE, Appelberg M. 2007. Indications of competition between non-indigenous round goby and native flounder in the Baltic Sea. ICES Journal of Marine Science 64: 479–486.
Keller RP, Geist J, Jeschke JM, Kühn I. 2011. Invasive species in Europe: ecology, status, and policy. Environmental Sciences Europe 23: 23.
Khristenko DS, Kotovska GO. 2017. Length-Weight Relationship and Condition Factors of Freshwater Bream *Abramis brama* (Linnaeus, 1758) from the

Kremenchug Reservoir, Middle Dnieper. Turkish Journal of Fisheries and Aquatic Sciences 17: 10.

Køie M. 2004. Havets djur, 2nd ed. Prisma, Stockholm.

Kornis MS, Mercado-Silva N, Vander Zanden MJ. 2012. Twenty years of invasion: a review of round goby *Neogobius melanostomus* biology, spread and ecological implications. Journal of Fish Biology 80: 235–285.

Kottelat M, Freyhof J. 2007. Handbook of European freshwater fishes. Kottelat, Cornol and Freyhof, Berlin.

Kullander SO, Delling B. 2012. Ryggsträngsdjur : strålfeniga fiskar. Chordata : actinopterygii. ArtDatabanken SLU

Lappalainen A., Rask M., Koponen H., Vesala S. 2001. Relative abundance, diet and growth of perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*) at Tvärminne, northern Baltic Sea, in 1975 and 1997: responses to eutrophication. Boreal Environment Research 6: 107-118 6: 13.

Linløkken AN, Bergman E, Greenberg L. 2010. Effect of temperature and roach *Rutilus rutilus* group size on swimming speed and prey capture rate of perch *Perca fluviatilis* and *R. rutilus*. Journal of Fish Biology 76: 900–912.

Linzmaier SM, Twardochleb LA, Olden JD, Mehner T, Arlinghaus R. 2018. Size-dependent foraging niches of European Perch *Perca fluviatilis* (Linnaeus, 1758) and North American Yellow Perch *Perca flavescens* (Mitchill, 1814). Environmental Biology of Fishes 101: 23–37.

Liversage K, Nurkse K, Kotta J, Järv L. 2017. Environmental heterogeneity associated with European perch (Perca fluviatilis) predation on invasive round goby (Neogobius melanostomus). Marine Environmental Research 132: 132–139.

Ljung A. 2020. Invasive round goby, Neogobius melanostomus - suitable prey for native cod, Gadus morhua? MSc, Swedish University of Agricultural Sciences

Ložys L. 2004. The growth of pikeperch (*Sander lucioperca* L.) and perch (*Perca fluviatilis* L.) under different water temperature and salinity conditions in the Curonian Lagoon and Lithuanian coastal waters of the Baltic Sea. 9.

Lynch MP, Mensinger AF. 2012. Seasonal abundance and movement of the invasive round goby (*Neogobius melanostomus*) on rocky substrate in the Duluth-Superior Harbor of Lake Superior: Round goby movement on rocky substrate. Ecology of Freshwater Fish 21: 64–74.

Macura B, Byström P, Airoldi L, Eriksson BK, Rudstam L, Støttrup JG. 2019. Impact of structural habitat modifications in coastal temperate systems on fish recruitment: a systematic review. Environmental Evidence, doi 10.1186/s13750-019-0157-3.

Meehan OL. 1940. A review of the parasitic Crustacea of the genus *Argulus* in the collections of the United States National Museum. Proceedings of the United States National Museum 88: 459–522.

Møller OS. 2015. revista_103B.pdf. online 2015Accessed October 13, 2020.

Mustamäki N, Cederberg T, Mattila J. 2014. Diet, stable isotopes and morphology of Eurasian perch (*Perca fluviatilis*) in littoral and pelagic habitats in the northern Baltic Proper. Environmental Biology of Fishes 97: 675–689.

Nurkse K, Kotta J, Orav-Kotta H, Ojaveer H. 2016. A successful non-native predator, round goby, in the Baltic Sea: generalist feeding strategy, diverse diet and high prey consumption. Hydrobiologia 777: 271–281.

Oesterwind D, Bock C, Förster A, Gabel M, Henseler C, Kotterba P, Menge M, Myts D, Winkler HM. 2017. Predator and prey: the role of the round goby *Neogobius melanostomus* in the western Baltic. Marine Biology Research 13: 188–197.

Ojaveer H, Jaanus A, MacKenzie BR, Martin G, Olenin S, Radziejewska T, Telesh I, Zettler ML, Zaiko A. 2010. Status of Biodiversity in the Baltic Sea. PLoS ONE 5: e12467.

Oksanen J, Blanchet FG, Friendly M, Kindt R, Legendre P, McGlinn D, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Stevens MHH, Szoecs E, Wagner H. 2019. vegan: Community Ecology Package.

Olsson J. 2019. Past and Current Trends of Coastal Predatory Fish in the Baltic Sea with a Focus on Perch, Pike, and Pikeperch. Fishes 4: 7.

Pereyra RT, Bergström L, Kautsky L, Johannesson K. 2009. Rapid speciation in a newly opened postglacial marine environment, the Baltic Sea. BMC Evolutionary Biology 9: 70.

Perrings C, Burgiel S, Lonsdale M, Mooney H, Williamson M. 2010. International cooperation in the solution to trade-related invasive species risksa: International cooperation in the solution to trade-related invasive species risks. Annals of the New York Academy of Sciences 1195: 198–212.

Puntila R, Florin A-B, Naddafi R, Behrens JW, Kotta J, Smolinski S, Wozniczka A. 2018. Abundance and distribution of round goby (*Neogobius melanostomus*). Online

Rask M. 1986. The diet and diel feeding activity of perch, *Perca fluviatilis* L., in a small lake in southern Finland. Annales Zoologici Fennici 23: 49–56.

Ray WJ, Corkum LD. 2001. Habitat and Site Affinity of the Round Goby. J Great Lakes Res 27: 329–334.

RStudio Team. 2020. RStudio: Integrated Development for R. RStudio PBC, Boston, MA.

Ruetz CR, Reneski MR, Uzarski DG. 2012. Round goby predation on *Dreissena* in coastal areas of eastern Lake Michigan. Journal of Freshwater Ecology 27: 171–184.

Sapota MR. 2012. NOBANIS – Invasive Alien Species Fact Sheet – *Neogobius melanostomus*.

Sapota MR., Dąbrowska V. 2019. Shapes of otoliths in some Baltic fish and their proportions. Oceanological and Hydrobiological Studies 48: 296–304.

Schneider JC. 2004. Rate of food digestion by yellow perch (*Perca flavescens*) in relation to size of perch, size and type of food, and temperature. (Fisheries research report: 1803).

Skabeikis A, Lesutienė J. 2015. Feeding activity and diet composition of round goby (*Neogobius melanostomus*, Pallas 1814) in the coastal waters of SE Baltic Sea. Oceanological and Hydrobiological Studies, doi 10.1515/ohs-2015-0048.

Skóra K, Olenin S, Gollasch S. 1999. Exotics Across the Ocean - EU Concerted Action - *Neogobius melanostomus*. 69–74.

Snoeijs-Leijonmalm P, Schubert H, Radziejewska T (eds). 2017. Biological Oceanography of the Baltic Sea. doi 10.1007/978-94-007-0668-2.

Strand Å, Magnhagen C, Alanärä A. 2011. Growth and Energy Expenditures of Eurasian Perch *Perca fluviatilis* (Linnaeus) in Different Temperatures and of Different Body Sizes. Journal of Aquaculture Research & Development, doi 10.4172/2155-9546.1000114.

Sundblad G, Bergström U, Sandström A, Eklöv P. 2014. Nursery habitat availability limits adult stock sizes of predatory coastal fish. ICES Journal of Marine Science 71: 672–680.

Sundset K, Europäische Kommission (eds). 2014. Invasive alien species: a European Union response. Publ. Off. of tht Europ. Union, Luxembourg.

v. Busekist J. 2004. “Bone Base Baltic Sea”, a computer supported identification system for fish bones. University of Rostock, Germany.

van Kessel N, Dorenbosch M, Kranenbarg J, van der Velde G, Leuven R. 2016. Invasive Ponto-Caspian gobies rapidly reduce the abundance of protected native bullhead. Aquatic Invasions 11: 179–188.

Vrede T, Drakare S, Eklöv P. 2010. Ecological stoichiometry of Eurasian perch – intraspecific variation due to size, habitat and diet. Oikos 120: 886–896.

Westrelin S. 2018. Habitat use and preference of adult perch (*Perca fluviatilis* L.) in a deep reservoir: variations with seasons, water levels and individuals. Hydrobiologia 809: 121–139.

Wickham H. 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

Yazıcıoğlu O, Yılmaz S, Yazıcı R, Erbaşaran M, Polat N. 2016. Feeding ecology and prey selection of European perch, *Perca fluviatilis* inhabiting a eutrophic lake in northern Turkey. Journal of Freshwater Ecology 31: 641–651.

SLU Aquas Kustfiskedatabas (KUL). online: www.slu.se/kul. Accessed September 27, 2020.

Acknowledgements

I would like to thank the Swedish University of Agricultural Sciences for agreeing to take me on for this project. I would also like to thank Ann-Britt Florin, Isa Wallin and Örjan Östman for their guidance and support, was well as Robin Ramstedt and Heidi Herlevi for allowing me to use the data they have collected. Lastly, I would like to thank my family and friends for their love and support.

Appendix

Table 1

Table 7: Table used when estimating gut-fullness, and digestion state. Method based on instructions from: https://www.afsc.noaa.gov/REFM/REEM/Manuals/LabManual.pdf

Stomach Fullness Codes:	Description	Digestion State Codes:	Descriptive explanation (Explanations from AFSC, 2015):
1	empty	1 stomach empty	No items found in stomach
2	trace of prey	2 traces of prey items	Only a few parts left of the prey item because most of the item has been completely digested away, fish bones with no flesh remaining
3	trace- 25 % full	3 < 50% intact	Extensive digestion is evident but there may be several parts and perhaps some well digested chunks remaining. Fish would have some flesh remaining, large crustaceans may be missing parts due to digestion, and it may be impossible to distinguish individual small crustaceans in a slurry of parts
4	25 – 50 % full	4 50-75% intact	Prey items that are still partially intact, but remaining portions may be softened due to digestion. For example, fishes would have no exposed skin remaining and parts of the head or tail may be disarticulated, but a majority of the flesh would still be present; large and small crustaceans may have most of the carapace and appendages intact, but have the carapace and internal flesh softened due to digestion
5	50 – 75 % full	5 75-100% intact	Prey items that are in good to almost perfect condition, but often with some damage due to digestion. For example, fish are mostly intact, but may be missing some skin or fin rays (usually the first parts of the fish to be digested away).
6	75 – 100 % full	6 no digestion	Prey items which are in immaculate condition

Section 2

When data was missing for a perch concerning the number of individuals of a prey species, one individual were entered unless otherwise stated in comment section. For adding/adjusting volume%, a standard of 5% (minimum amount given when estimating volume%) were entered unless otherwise stated in the comments or clear from other data from the perch examined. This was to ensure that the total volume% came up to exactly 100% due to the need for this information when calculating Index of relative importance (IRI). Minor adjustments were needed when total % exceeded or were less than 100%, with any change in volume spread out in proportion to the volume% of the prey species found (small volumes were changed less than large volumes).

Table 2

Table 2: Species scores from the NMDS ordination

Species	NMDS1	NMDS2	NMDS3
Hydrobia sp	0.52251	-0.69783	-0.12658
Zoarces viviparus	0.467562	-0.4903	-0.34038
Myoxocephalus quadricornis	0.43065	-0.34527	0.096391
Idotea	0.42545	-0.49325	-0.03567
Saduria sp	0.411799	-0.2206	0.120094
Hediste diversicolor	0.389961	-0.23989	-0.15009
Gymnocephalus cernua	0.389961	-0.23989	-0.15009
Nerophis ophidion	0.350849	0.416871	-0.10376
Pomatoschistus minutus	0.331737	0.269827	0.554678
Pomatoschistus sp	0.309514	0.368704	0.536224
Gobius niger	0.283653	-0.03567	-0.49568
Rutilus rutilus	0.255622	0.217879	0.76088
Caridea	0.252731	0.235058	0.786155
Theodoxus	0.185665	0.053262	0.666698
Palaemon adspersus	0.132188	0.194465	0.720701
Chironomidae	0.125091	0.211962	0.364678
Sander lucioperca	0.087735	0.055324	0.501823
Insecta	0.086978	0.088862	0.404169
Mysidae	0.080043	0.064047	0.491483
Crangon crangon	0.07525	0.11437	0.696776
Osmerus eperlanus	0.067129	0.108193	-0.43883
Clupea harengus	0.002277	0.282933	0.254114
Cupeidae sp	-0.00341	0.191282	-0.52541
Gasterosteus aculeatus	-0.00992	-0.55874	0.24769
Fish roe	-0.03488	-0.09344	-0.29049
Unidentified	-0.03967	0.296853	0.319231
Pungitius pungitius	-0.15865	-0.46721	0.335538
Cerastoderma	-0.2338	-0.22749	0.397584
Rhithropanopeus harrisii	-0.2877	0.103976	0.383877
Mytilus edulis	-0.29055	-0.27424	0.336537
Esox lucius	-0.37599	-0.2962	0.047113
Gammarus	-0.38251	-0.23524	0.159511
Unidentified fish	-0.3904	-0.10361	0.38274
Hyperoplus lanceolatus	-0.41402	-0.09462	0.00701
Caligus curtus	-0.42288	-0.17569	0.091405
Saduria entomon	-0.42597	0.137495	0.025989
Syngnathus typhle	-0.42597	0.137495	0.025989
Argulus sp	-0.43524	-0.15	0.061224
Spigg sp	-0.46703	-0.23351	-0.02787
Non-prey items	-0.50701	-0.05957	0.359753
Polychaeta sp	-0.54749	-0.35188	0.02873
Gobiidae sp	-0.64456	-0.0446	-0.22411
Neogobius melanostomus	-0.65058	0.290036	-0.43429
Perca fluviatilis	-0.6793	-0.13398	0.133791
Decapoda sp	-0.74497	-0.1433	0.092329
Crustacea	-0.80052	-0.23653	-0.00834
Bithynia	NA	NA	NA
Physa fontinalis	NA	NA	NA
Cyprinidae	NA	NA	NA

Due to the need to exclude some data in the ordination, three prey-types were shown to be not present in the data for the ordination.

Table 3

Table 3: Species-list and recorded number of observations of the different prey in all perch examined (n=761).

Species list	Observations
Fish	
Gasterosteus aculeatus	644.00
Neogobius melanostomus	177.00
Clupea harengus	87.00
Zoarces viviparus	79.00
Unidentified fish	127.00
Pomatoschistus sp.	111.00
Pungitius pungitius	65.00
Perca fluviatilis	12.00
Pomatoschistus minutus	27.00
Gobius niger	3.00
Rutilus rutilus	4.00
Osmerus eperlanus	3.00
Cupeidae sp.	3.00
Hyperoplus lanceolatus	3.00
Sander lucioperca	1.00
Gobiidae sp.	4.00
Gasterosteidae sp.	8.00
Myoxocephalus quadricornis	3.00
Esox lucius	2.00
Gymnocephalus cernua	1.00
Syngnathus typhle	1.00
Nerophis ophidion	1.00
Crustaceae	
Gammarus	712.00
Idotea	635.00
Palaemon adspersus	113.00
Mysidae	122.00
Crangon crangon	48.00
Unknown Crustacea	22.00
Caridea	21.00
Saduria	18.00
Rhithropanopeus harrisii	17.00
Unknown Decapoda	19.00
Saduria entomon	1.00
Mollusca	
Mytilus edulis	64.00
Hydrobia sp	23.00
Cerastoderma	11.00
Theodoxus	7.00
Physa fontinalis	3.00
Bithynia	1.00
Other Invertebrate	
Insecta	120.00
Polychaeta	13.00
Chironomidae	13.00
Hediste diversicolor	4.00
Other	
Non-prey items	103.00
Unidentified food items	35.00
Fish roe	27.00
Caligus curtus	3.00
Argulus sp.	2.00

Table 4

Table 4: Index of relative importance results for the areas were perch were caught. Only large perch caught during the summer and autumn were used for comparison. Karlskrona (n=127), Mariehamn (n=171) and Långnäs (n=164).

IRI – Area	IRI - Karlskrona	IRI - Mariehamn	IRI - Långnäs
Fish			
Gasterosteus aculeatus	17.230	32.189	22.646
Neogobius melanostomus	18.357	12.265	0.849
Clupea harengus	6.043	10.534	2.528
Zoarces viviparus	4.144	4.084	18.535
Unidentified fish	7.542	3.195	3.192
Pomatoschistus sp.	0.254	6.062	6.524
Pungitius pungitius	1.640	1.126	1.604
Perca fluviatilis	3.679	0	0.000
Pomatoschistus minutus	0	0.848	0.791
Gobius niger	0	0.000	0.861
Rutilus rutilus	0	1.249	0.306
Osmerus eperlanus	0	0	0.440
Cupeidae sp.	0	0	0
Hyperoplus lanceolatus	0.969	0	0
Sander lucioperca	0	0	0
Gobiidae sp.	0.663	0	0
Gasterosteidae sp.	0.819	0	0
Myoxocephalus quadricornis	0	0	0.944
Esox lucius	0.200	0	0
Gymnocephalus cernua	0	0	0.280
Syngnathus typhle	0.225	0	0
Nerophis ophidion	0	0.226	0
Crustaceae			
Gammarus	13.727	4.304	5.899
Idotea	4.448	2.793	18.617
Palaemon adspersus	1.243	5.266	2.702
Mysidae	0.993	0.916	0.355
Crangon crangon	0.690	1.076	0.583
Unknown Crustacea	2.779	0	0
Caridea	0.000	1.122	0.624
Saduria	0.000	0.801	2.759
Rhithropanopeus harrisii	1.320	1.073	0.889
Unknown Decapoda	2.164	0	0
Saduria entomon	0.259	0	0
Mollusca			
Mytilus edulis	2.084	2.287	0.566
Hydrobia sp	0	0.660	1.656
Cerastoderma	0.415	0.225	0.175
Theodoxus	0	0.435	0.177
Physa fontinalis	0	0	0
Bithynia	0	0	0
Other Invertebrate			
Insecta	0	0.425	0.184
Polychaeta	1.561	0.217	0.177
Chironomidae	0	1.145	0.175
Hediste diversicolor	0	0	0.181
Other			
Non-prey items	3.747	2.922	2.293
Unidentified food items	1.238	1.917	1.311
Fish roe	0.605	0.637	1.176
Caligus curtus	0.572	0	0
Argulus sp.	0.391	0	0

Two round goby were found in Långnäs, but due to the need to exclude some data, the IRI for Långnäs indicated 0%.

Table 5

Table 58: Index of relative importance results comparing the seasons. Only large perch caught in 2019 and from Karlskrona and Mariehamn were used. Spring (n=82), summer (n=122) and autumn (n=74).

IRI – Seasons	IRI - Spring (n=82)	IRI - Summer (n=122)	IRI - Autumn (n=74)
Fish			
Gasterosteus aculeatus	11.847	41.290	3.767
Neogobius melanostomus	14.814	8.124	14.407
Clupea harengus	5.962	10.538	9.361
Zoarces viviparus	0.954	2.209	10.310
Unidentified fish	6.142	3.647	5.931
Pomatoschistus sp.	5.368	0.800	7.472
Pungitius pungitius	2.328	1.691	0
Perca fluviatilis	1.347	0	2.257
Pomatoschistus minutus	1.800	0	0
Gobius niger	0	0	0
Rutilus rutilus	0.457	0.335	2.087
Osmerus eperlanus	0	0	0
Cupeidae sp.	0	0	0
Hyperoplus lanceolatus	0	0.463	0
Sander lucioperca	1.536	0	0
Gobiidae sp.	0	0.299	0.588
Gasterosteidae sp.	0	0.229	0
Myoxocephalus quadricornis	0	0	0
Esox lucius	0.206	0.250	0
Gymnocephalus cernua	0	0	0
Syngnathus typhle	0	0	0.598
Nerophis ophidion	0	0	0
Crustaceae			
Gammarus	11.105	5.425	3.188
Idotea	1.836	6.202	1.140
Palaemon adspersus	7.781	0.508	11.612
Mysidae	8.822	0	0.459
Crangon crangon	4.304	0.768	2.567
Unknown Crustacea	1.026	1.007	2.671
Caridea	0.612	0.229	1.956
Saduria	0	0.528	0
Rhithropanopeus harrisii	0	0.602	4.125
Unknown Decapoda	0.271	1.549	2.221
Saduria entomon	0	0	0.689
Mollusca			
Mytilus edulis	0.541	2.904	2.810
Hydrobia sp	0.647	0.461	0.466
Cerastoderma	0.508	0.750	0.000
Theodoxus	0.525	0.228	0.464
Physa fontinalis	0	0	0
Bithynia	0	0	0
Other Invertebrate			
Insecta	6.281	0.441	0
Polychaeta	0.964	0.933	0
Chironomidae	0	0.221	2.138
Hediste diversicolor	0	0	0
Other			
Non-prey items	1.500	4.349	4.014
Unidentified food items	0.273	1.055	2.701
Fish roe	0.243	0.756	0
Caligus curtus	0	0.718	0
Argulus sp.	0	0.490	0

Table 6

Table 6: Index of relative importance results comparing 2018 and 2019. Only large perch caught during the summer and autumn were used for comparison. 2018 (n=172), and 2019 (n=290).

IRI – Year	IRI - 2018 (n=172)	IRI - 2019 (n=290)
Fish		
Gasterosteus aculeatus	18.536	26.350
Neogobius melanostomus	16.774	7.661
Clupea harengus	2.519	8.775
Zoarces viviparus	11.456	6.473
Unidentified fish	6.099	3.922
Pomatoschistus sp.	2.024	5.149
Pungitius pungitius	1.786	1.305
Perca fluviatilis	2.899	0.506
Pomatoschistus minutus	0.806	0.352
Gobius niger	0.696	0
Rutilus rutilus	0	0.790
Osmerus eperlanus	0	0.212
Cupeidae sp.	0	0
Hyperoplus lanceolatus	0.572	0.232
Sander lucioperca	0	0
Gobiidae sp.	0.187	0.272
Gasterosteidae sp.	0.597	0.105
Myoxocephalus quadricornis	0.268	0.315
Esox lucius	0	0.116
Gymnocephalus cernua	0.237	0
Syngnathus typhle	0	0.132
Nerophis ophidion	0.172	0
Crustaceae		
Gammarus	12.145	5.898
Idotea	10.310	8.319
Palaemon adspersus	0.800	4.168
Mysidae	1.710	0.100
Crangon crangon	0	1.234
Unknown Crustacea	0.925	1.040
Caridea	0	0.883
Saduria	0.900	1.311
Rhithropanopeus harrisii	0.564	1.439
Unknown Decapoda	0.246	1.188
Saduria entomon	0	0.152
Mollusca		
Mytilus edulis	1.105	1.983
Hydrobia sp	1.154	0.512
Cerastoderma	0	0.447
Theodoxus	0	0.305
Physa fontinalis	0	0
Bithynia	0	0
Other Invertebrate		
Insecta	0	0.303
Polychaeta	0.965	0.527
Chironomidae	0.000	0.581
Hediste diversicolor	0.163	0
Other		
Non-prey items	1.239	4.125
Unidentified food items	1.212	1.610
Fish roe	0.935	0.650
Caligus curtus	0	0.330
Argulus sp.	0	0.226