The Great cormorant, *Phalacrocorax carbo*, as a predator of the invasive Round goby

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Storskarv, Phalacrocorax carbo, som predator av den invasiva svartmunnade smörbulten

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Abstract

Dispersal of invasive species poses a significant threat to biodiversity loss globally and is one of the major threats to the ecological condition in the Baltic Sea. The Baltic Sea is facing potential problems caused by the Round goby, *Neogobius melanostomus*, which was presumably introduced via ballast water. Since its first discovery in 1990, the Round goby has continued to expand and is currently established along certain parts of the Swedish coast.

An invasive species can play a substantial ecological role by serving as prey for native species. An abundancy of prey can alter diets and foraging behaviors of native predators, such as the Great cormorant, *Phalacrocorax carbo*. Since the Round goby might have negative impacts on local ecosystems, cormorants can play a beneficial role by regulating Round gobys' population growth.

The objective of this study was to examine predation on Round goby by the Great cormorant in the Karlskrona archipelago, in the South-eastern Swedish coast. The aim of the study was to investigate prey selectivity on round gobies by cormorants throughout years and seasons. Monitoring-and catch data from the same area during the years 2015-2018 was analysed to see the role Round goby play as a prey for cormorants. The diet composition of cormorants was determined by analysing stomach contents of 182 cormorants. Identification of species in the stomach content was possible due to examination of prey and otoliths.

My analyses detected an indication of active selection of round gobies in June-September 2015 and 2017, whereas inaccessibility or non-selection of Round goby was observed in 2018. Selection of round gobies during summer months might be a result of seasonal changes in diet. To better understand the dynamics between cormorants and round gobies in the archipelago in Karlskrona, further sampling and research is required.

Keywords: Round goby, invasive species, Great cormorant, predator-prey interaction, prey selectivity.

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1. Introduction

Intensified demand for global travel and trade has led to an increase of the anthropogenic dispersal of non-indigenous species and is one of the major global diversity threats (Almqvist et al. 2010). Introducing non-native species to new environments is usually beneficial or has only minor effects (Keller et al. 2011). Numerous species are unable to thrive beyond their original habitat because of unfavourable environmental and ecological conditions. Although, a few species withstand these alterations and adjust to their new surroundings (Tobin 2018). Therefore, only a small proportion of transferred non-indigenous species establish in new habitats and become an invasive species. However, in some cases, these newly introduced species can have significant adverse effects on local ecosystems (Keller et al. 2011). When a species is widespread and causes significant environmental, economic, or health impacts, it is considered invasive (Keller et al. 2011). Invasive species can outcompete native species for resources, space or introduce novel diseases or predators (Kornis et al. 2012). Consequently, native species displacement or extinction results in biodiversity loss (Almqvist et al. 2010; Bailey 2015).

The loss of biodiversity is specifically denoted as a serious environmental consequence (Bailey 2015). At present, the ecological condition of the Baltic Sea is a matter of significant concern. The Helsinki Commission reports that the proliferation of invasive species are one of the most pressing challenges (HELCOM 2018a).

1.1 The Round goby, *Neogobius melanostomus*

The Baltic Sea is currently facing a potential problematic invasive species known as the Round goby (*Neogobius melanostomus*). In 1990, the Round goby was first observed in the southern Baltic Sea in the Gulf of Gdańsk, Poland. Due to its late discovery, the species is labelled as a recent invader (Almqvist et al. 2010; Rakauskas et al. 2013). The prevailing assumption is that the Round goby was introduced through the ballast water of ships in transit, whereby juveniles were primarily released in the Bay of Gdańsk. By 1999 the Round goby had become one of the dominant species in biomass and numbers in the region (Almqvist et al. 2010). By 2008 the Round goby was discovered in Karlskrona. The Round goby have established stocks at least in Blekinge's eastern archipelago, Kalmar Strait and the southern Stockholm archipelago as well the surrounding areas of harbours around Gotland and Gothenburg (Florin & Jonsson 2021). It is deemed impossible to eradicate the Round goby from the Baltic Sea due to the establishment of several self-sustaining populations in various locations and its ongoing expansion to new sites (Christoffersen et al. 2019). The Round goby is currently part of the Swedish ichthyofauna - the fish of a specific region (Almqvist et al. 2010). Round gobies are capable of threatening and outcompeting local species, which in turn affects local ecosystems and fisheries (Florin & Jonsson 2021). Its potential effects on the fish community and entire ecosystem are of great scientific interest, as invasive species pose a significant threat to biodiversity loss (Rakauskas et al. 2013).

Figure 1: Round goby established populations. Southern Stockholm archipelago (1), Gotland (2), Kalmar Strait (3), Blekinge's eastern archipelago (4) and Gothenburg (5). ©Lantmäteriet

Figure 2: Male of Round goby. Illustration: Karl Jilg/ArtDatabanken, SLU

Figure 3: Female of Round goby. Illustration: Karl Jilg/ArtDatabanken, SLU

Evidence deems the impacts of the Round goby on an ecosystem to be both positive and negative. The Round goby can positively contribute by acting as a new food source for native piscivorous bird, fish, and mammal species. In spite of that, impacts of the Round goby on environments are mainly negative since it has potential to outcompete native species (Kessel et al. 2016).

The Round goby was able to colonize and thrive in the Baltic Sea after its initial arrival due to traits of a successful colonizer. These include a generalist feeding strategy, early sexual maturation, high tolerance to variations in temperature (-1 °C till + 30 °C) and salinity concentrations (<5 ‰- 40 ‰), in addition to the rapid ability to adapt to different habitats (Kornis et al. 2012). The Round goby exhibits seasonal pattern in its depth distribution. During spring and winter, there were only a few captures of Round goby above 25 meters whereas during spring and summer, no captures of Round goby below 25 meters (Behrens et al. 2022). The specie can reproduce at high rates, spawn multiple times during the same season, and their nests are aggressively guarded by the males (Almqvist et al. 2010; Kornis et al. 2012). Round gobies ability to outcompete native species for resources and spawning sites additionally contributes to its ability to withstand competition from native species (Kornis et al. 2012; Kessel et al. 2016). In the Swedish fauna, there is a risk that Round goby outcompetes e.g. viviparous Eelpout and European flounder, as well as consuming roe and fry from various fish species. Furthermore, grazing of mussel banks might reduce food availability for other mussel-eating animals (Florin & Jonsson 2021).

Although the Round goby possesses great qualities of a colonizer it lacks good swimming ability and anti-predatory attributes. Therefore, the Round goby is seen as an easy prey for predators (Almqvist et al. 2010). The Round goby serves as prey for predatory fish such as e.g., Perch (*Perca fluviatilis*) or Cod (*Gadus Morhua*) and for fish-eating birds such as the Great cormorant (*Phalacrocorax carbo*). A greater abundance of round gobies can potentially benefit native piscivorous fish along with terrestrial predator species such as the Great cormorant (Oesterwind et al. 2017). The increased supply of prey, in this case the Round goby, is likely to enhance survival of predators. A Greater number of native predators is observed to decrease the population of round gobies (Kornis et al. 2012).

1.2 The Great cormorant, *Phalacrocorax carbo*

Interactions between predator and prey can have a structural impact on aquatic ecosystems and the biological community can be affected both directly and indirectly. Predation can regulate size and class structures in a fish community, which can diminish population densities. An abundance reduction of prey and biomass could be a direct effect of predation. Indirect effects of predator-prey interactions can involve changes in prey behaviour and distribution (Kangur et al. 2007). Current comprehension of autecology and fish populations ecological role is thanks to diet studies derived from analysation of stomach contents (Kangur et al. 2007).

The Great cormorant, is a piscivore with an opportunistic and generalistic feeding strategy (Dehnhard et al. 2021). Predators with a generalistic and opportunistic feeding strategy will feed on a wide range of species and adapt their diet depending on availability, nutritional value, and handling costs (Johnson et al. 2010; Dehnhard et al. 2021). Generalist predators, such as the Great cormorant, are often involved in human-wildlife conflicts as a competitor for the same resources (Dehnhard et al. 2021).

In the Baltic Sea the Great cormorant has recognised the Round goby as a valuable prey and is a known predator of the Round goby (Almqvist et al. 2010; Kornis et al. 2012; Rakauskas et al. 2013; Ovegård et al. 2016; Oesterwind et al. 2017). Since the Round goby is considered an invasive and unwanted species, cormorants can play a beneficial role in regulating the round gobies population growth (Ovegård et al. 2016). Diet alterations of top predators such as the Great cormorant are certain to change due to the expansion and increase of prey population. It’s been proposed that the diet and population of birds that feed and breed in the gulf of Puck in Poland are both impacted by the rapid proliferation of round gobies (Rakauskas et al. 2013). A similar fashion in the Gulf of Gdańsk and Curonian lagoon, Lithuania/Russia, where the Great cormorant is the main predator of the Round goby and consumption of Round goby increased over time (Corkum et al. 2004; Rakauskas et al. 2013). In the Gulf of Gdańsk, Great cormorants predominantly consumed Round goby, accounting for 72% of their diet. As the Round goby became more abundant, a dietary shift took place for the cormorants of Gulf of Gdańsk. Their diet shifted away from eel *(Anguilla anguilla*) and sprat (*Spratus spratus*), giving rise to an eel and sprat increase (Corkum et al. 2004). The rise in the population of overwintering Great cormorants in the Gulf of Gdańsk has been suggested to be linked to the invasion of round gobies. Supplementary, an abundance of the Round goby may give rise to the abundance of piscivorous birds. Furthermore, it is important to consider that proficiency of predatory birds could potentially regulate the population of round gobies in the Curonian Lagoon (Rakauskas et al. 2013). In the Baltic Sea, a possible approach to tackle the invasion of the Round goby is to maintain native predators (Kornis et al. 2012).

In the western Baltic, more specifically the Bay of Pomerania, the Round goby has become a valuable and possibly the most significant prey for cormorants at this location during breeding season (March-August) (Oesterwind et al. 2017). Similar feeding habits of Great cormorants were observed 1999 in the Gulf of Gdańsk. As prey, Round goby were especially rich in number from June to August (Corkum et al. 2004). Examination of pellets from the Great cormorant and stomach contents of piscivorous fishes reveals a decrease in the biomass of native species within their diet. Reduced predation pressure on native species could potentially have positive effects on the population of those local species (Oesterwind et al. 2017).

In the Great Lakes, at the border of United States/Canada, diets of double-crested cormorants (*Phalacrocorax auritas*) were examined prior to, and immediately after Round goby population expansion at two sites. After two years, the main species consumed by cormorants at both sites was the Round goby. During these years, the double-crested cormorants were observed to regulate the population of round gobies by predation. The primarily consumption of round gobies effected the daily and seasonal trends in consumption of fish by cormorants, in contrast to the years before the invasion of round gobies. Differences in consumption may be attributed to the opportunistic foraging behaviour of cormorants. The cormorants quickly altering their feeding strategy from eating limnetic to benthic prey illustrates their adaptive foraging and opportunistic abilities (Johnson et al. 2010).

A management program for the Upper Niagara River studied the interactions between the Round goby and the double-crested cormorant at two sites. A stomach analysis of 600 cormorants indicated that up to 85% of the biomass consisted of round gobies during periods of the breeding season (Coleman et al. 2012).

The round gobies potential effects on the fish community and entire ecosystem are of great scientific interest, as invasive species pose a significant threat to biodiversity loss (Rakauskas et al. 2013). This study is based on data from Karlskrona and focuses on investigating the diet of Great cormorants and its selection of prey during different seasons, with a particular emphasis on the Round goby. Round goby's initial discovery in 2008 and their current well-established populations in the area provided an opportunity to observe the adaptation of Great cormorant to Round goby as new source of prey.

The study aims to investigate if the cormorants showed a preference for Round goby as prey. The significance of Round goby as a prey species for the Great cormorants is particularly relevant. The Great cormorant's predation and possible competition on fish and commercially attractive species places it at the forefront of conflicts (Dehnhard et al. 2021). The Great cormorant's interaction with Round goby can aid in mitigating any potential conflicts arising from the cormorants' predation. By studying the cormorants' diet and investigating whether they exhibit a preference for Round goby as a prey item, an insight can be gained into their ecological dynamics.

2. Method

2.1 Study areas

The study area was Karlskrona archipelago, in the southern Baltic Sea (Fig. 3-4).

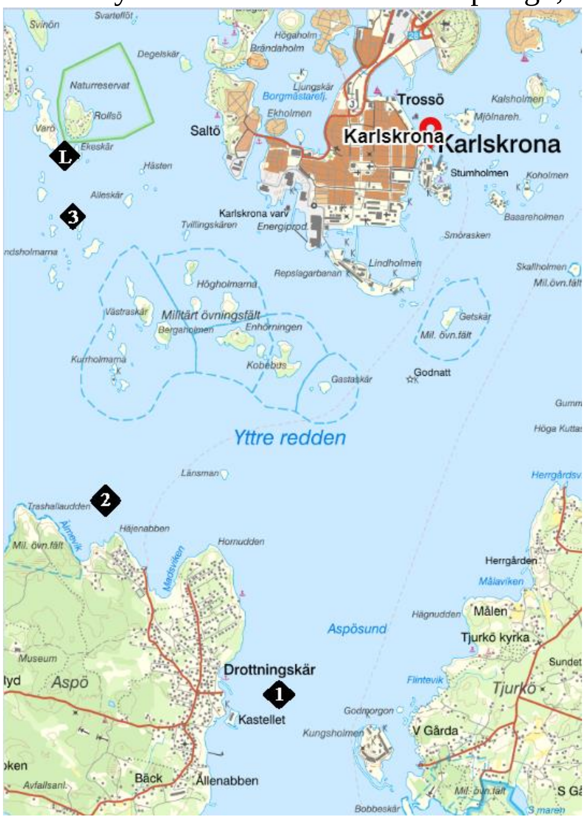

Figure 4 (left): Map of the fyke-net monitoring fishing premises 1-3 in the archipelago of Karlskrona. L (Lek) indicates a potential spawning/rearing area for Perch and pike (Lek) with more frequent monitoring fishing from April to July ©Lantmäteriet

Figure 5 (right): Karlskrona location in Sweden. ©Lantmäteriet

2.2 Monitoring fishing

Monitoring fishing was performed with standard fyke nets and fine mesh fyke nets. The fine-mesh-and standard fyke nets were fished at the same three premises (1-3).

Sampling occurred various dates in 2015, 2017 and 2018. Depths of sampling ranged from 2-12 meters.

The fisherman used 15 standard and fine-mesh fyke nets in the water for 12 hours. Catch from both standard and fine-mesh were pooled. Fishery took place according to Table 1.

Table 1: A summary table describing which fyke nets being used during which months.

	Standard	***Fine mesh***		
Months	*April-October*	*April-July*	*April-October*	*August-October*
Premises				
1	*Once/month*		*Once/month*	
2	*Once/month*	*Twice/month*		*Once/month*
3	*Once/month*	*Twice/month*		*Once/month*
Lek		*Twice/month*		

2.3 Cormorant sampling

The Great cormorants were shot in the purpose of protective hunting in the archipelago of Karlskrona at the islands of Smörpundsholmarna, Verkö but mainly on Länsman. Shooting of cormorants occurred at various dates in 2015, 2017 and 2018. The cormorant's diet was analysed by examining the stomach contents of a total of 182 cormorants.

Figure 6: Map of the islands where cormorants where shot in the archipelago of Karlskrona. Karlskrona. Smörpundsholmarna (A), Länsman (B) and Verkö (C). ©Lantmäteriet

Table 2: A summary table of sampling dates of cormorants.
**November is not included.*

Sampling years	Months
2015	June-September
2017	January-December*
2018	September-November

Prey-species identification was mainly conducted from otoliths and prey found in the stomachs. Otoliths are structures of calcium carbonate found inside the ears of bony fish. Every fish has three different pairs of otoliths varying in shape and size (Fisheries 2021). Species-specific morphology of otoliths can be used as a taxonomic tool for species identification. The degradation of otoliths after the death of the fish takes significantly longer than that of bones and soft tissue because they are highly calcified and acellular. As a result of this, otoliths are frequently discovered in the stomach contents of piscivorous predators after the digestion of other body parts (Mitsui et al. 2020). Depending on the condition of otoliths and the prey in the stomachs, identification was narrowed down to family or species.

2.4 Frequency of occurrence

Frequency of a value, in this case a species in the number of times the species occurs in the data. For this study, there are two data sets of data: monitoring samples and stomach content samples.

2.5 Ivlev’s index

To measure selection, an index of selectivity was developed by Ivlev (1961). Ivlev's index of selectivity is commonly used to study prey selection by predatory fish (Kohler & Ney 1982). By measuring the feeding selectivity according to Ivlev’s selectivity index, the cormorant diet is described (Kangur et al. 2007). The index definition:

$$\mathrm{E} = \frac{r_i - p_i}{r_i + p_i}, \tag{7}$$

where E is the measure of selectivity, where r_i is the relative abundance of a prey in the stomach (as percentage of all stomach contents) and p_i is the relative abundance of this prey in the environment. Values of selectivity range from - 1.0 to +1.0. Negative values indicate rejection or inaccessibility of the prey, values near zero implies random feeding, and positive values active selection (Kangur et al. 2007). The relative abundance of prey fish in the environment (p_i) was calculated according to the results of monitoring fishing.

3. Results

3.1 Frequency of occurrence

In Table 3 the top four species whom are of higher frequency of occurrence are: Perch, Round goby, Three-spined stickleback and Ruffe. Majority of species are of occurrence below 5%. Species with a frequency occurrence below 1% was excluded from the table: Common bleak, Common whitefish, Lumpfish, Shorthorn sculpin, European flounder, European plaice and Fifteen-spined stickleback. In Tables 5-7 in Appendix are the tables of frequency of occurrence for prey species in diet samples of cormorants from 2015, 2017 and 2018.

Table 3: Frequency of occurrence for prey species in diet samples of cormorants from 2015-2018.

Prey, common name	**Prey, latin name**	**Frequency of Occurrence**
Perch	*Perca fluviatilis*	0,60
Round goby	*Neogobius melanostomus*	0,32
Three-spined stickleback	*Gasterosteus aculeatus*	0,28
Ruffe	*Gymnocephalus cernua*	0,19
Cyprinidae	*Cyprinidae*	0,17
Gasteroidae sp.	*Gasteroidae sp.*	0,12
Gobiidae	*Gobiidae*	0,09
Herring	*Clupea harengus*	0,09
Roach	*Rutilus rutilus*	0,07
Eelpout	*Zoarces viviparus*	0,05
Pomatoschistus sp	*Pomatoschistus sp*	0,04
Lesser sand eel	*Ammodytes tobianus*	0,04
Unknown	*Unknown*	0,03
Silver bream	*Blicca bjoerkna*	0,02
Clupeidae	*Clupeidae*	0,02
Cod	*Gadus morhua*	0,02
Ninespine stickleback	*Pungitius pungitius*	0,02

Pike	*Esox lucius*	0,02
Rudd	*Scardinius erythrophthalmus*	0,02
Sprat	*Sprattus sprattus*	0,02
Ammodytes sp.	*Ammodytes sp.*	0,01
Pleuronectidae	*Pleuronectidae*	0,01
Saduria	*Saduria entomon*	0,01
PikePerch	*Sander lucioperca*	0,01

3.2 Monitoring fishing data and diet data over different years

Data samples from monitoring sampling and cormorant sampling consisted of a Great number of species. In order to limit number of species, factors such as relatively high frequency of occurrence, ecological and economical importance was taken into consideration. Selection was made in cooperation with the supervisors of this study.

In monitoring sampling, percentage of a species is derived from the grand total for corresponding year. Meaning that 100% is all of the catch over the year. As for cormorant sampling, percentage of a species is derived from the grand total of species found in the stomachs for each corresponding year.

3.2.1 2015

In Figure 8, Perch and Round goby were of higher values from May-November compared to other species. Levels of Perch decreased from May-July, and showed a peak in August and increased again in November. Herring was captured during July and September-November. Throughout all of the months (May-November), Eelpout was caught and their levels never exceeded 4%.

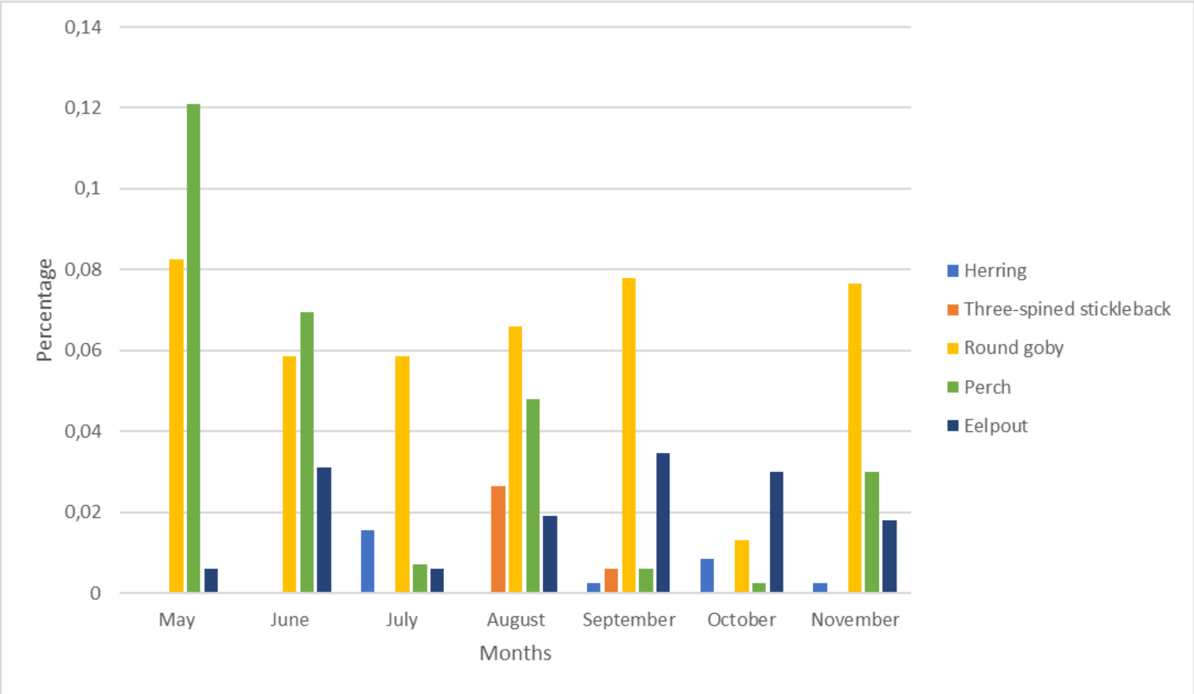

Figure 8: Relative amount of different species caught from monitoring fishing from 2015.

In Figure 9, cormorants shot in June, July and September all recorded round gobies, sticklebacks and Perch. In July, the highest percentage (almost 30%) was of Round goby. Herring occurred in stomach contents of cormorants in July and September. There is a significantly low percentage of Eelpout in July and September. Three-spined sticklebacks was of highest percentage in June, held a close value in July and decreased significantly in September.

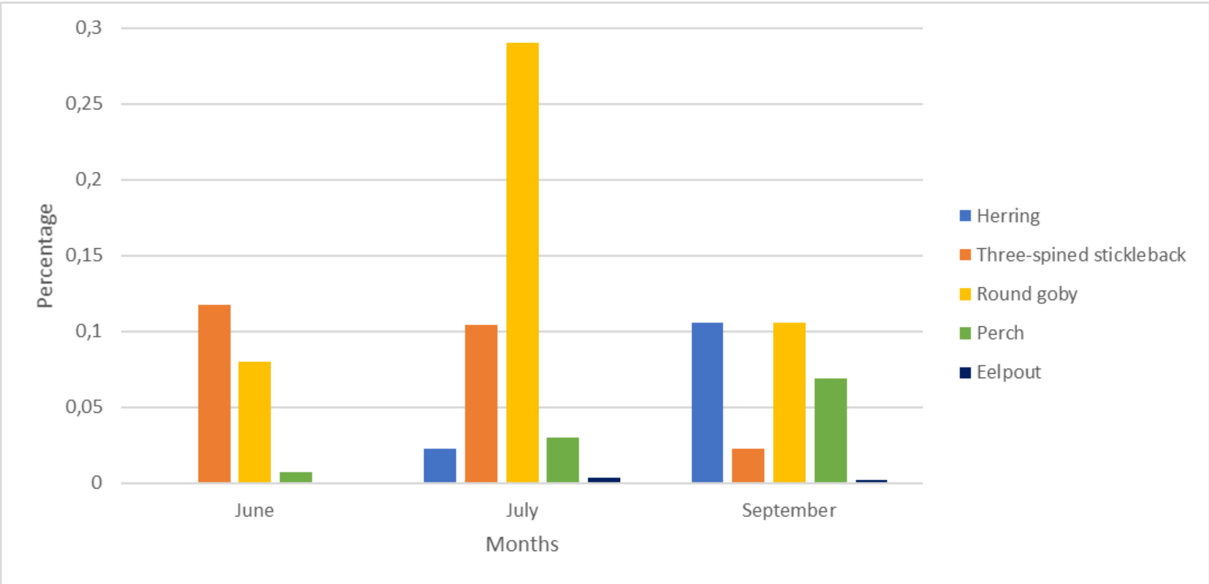

Figure 9: Diet composition data of cormorants from 2015. Number of samples (n) for each month: June (n=120), July (n=276) and September (n=212).

3.2.2 2017

In Figure 10 during May, only Perch was recorded in a low percentage. From July-September round gobies, Eelpouts and Perch were captured. Captures of round gobies started in June, decreased till August and then increased again in September. Low percentages of Herring were recorded from July-September. Percentages of Three-spined stickleback were of lower values (<5%) in July-September.

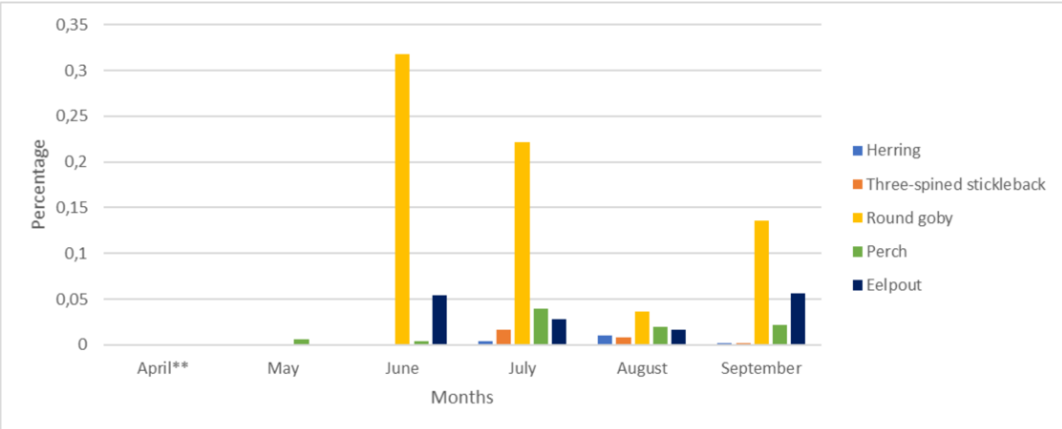

Figure 10: Relative amount of different species caught from monitoring fishing from 2017.

In Figure 11, stomachs of cormorants showed that Perch was recorded in the stomachs throughout all the months recorded. In March, round gobies values start and persists in the diet until October. Round gobies peaked in July and thereafter decreased in number. Fluctuations around 5% of round gobies occur July-October. Three-spined stickleback is recorded from every noted month except for April and September, with increasing values from January-March and June-August. Three-spined stickleback peaked in August.

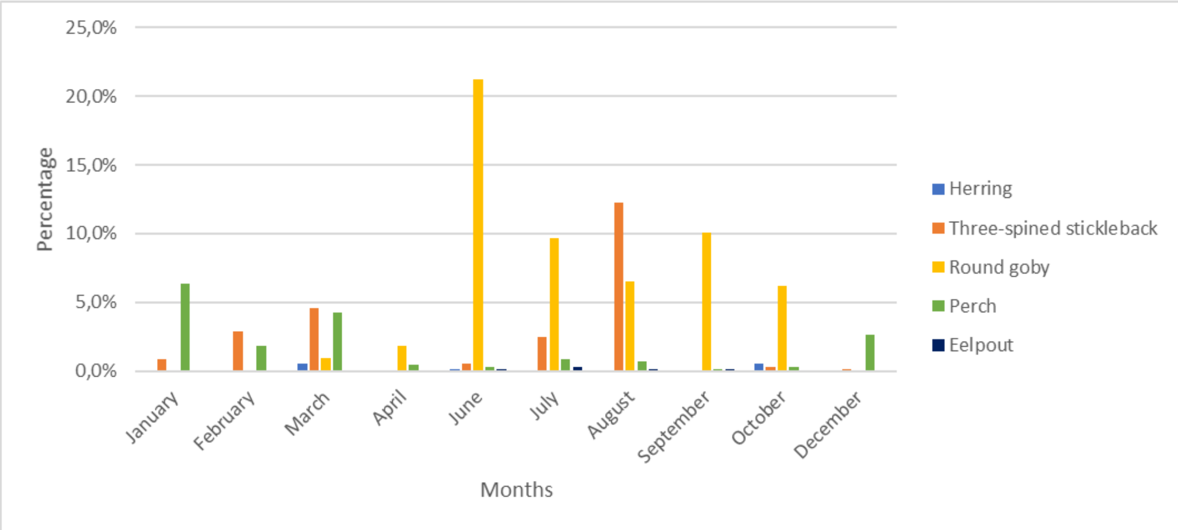

Figure 11: Diet composition data of cormorants from 2017. Number of samples (n) for each month: January (n=65), February (n=19), March (n=75), April (n=25), June (n=172), July (n=87), August (n=108), September (n=99), October (n=69) and December (n=77).

3.2.3 2018

In Figure 12 shows data from 2018 which as scarce, the main captures were of Perch and Round goby. The greatest value was in May, by Perch. Eelpout was detected in April, May and September. During all the observed months, except for May, there is no record of a species over 10%.

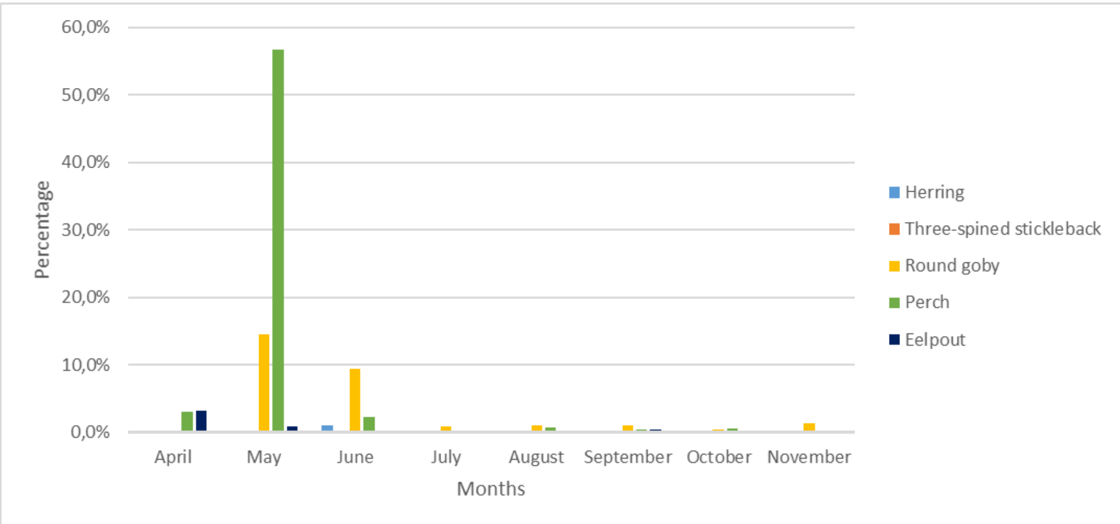

Figure 12: Relative amount of different species caught from monitoring fishing from 2018.

In Figure 13, Perch is the most common, appearing in all of the collected data. Perch peaked in March and had similar values in September and October. In February, March and November additional species of lower percentages was found. Herring was observed in February and March and Three-spined stickleback in February and November. Round gobies were only found in low percentages in March. Diet samples from April-August are non-existent.

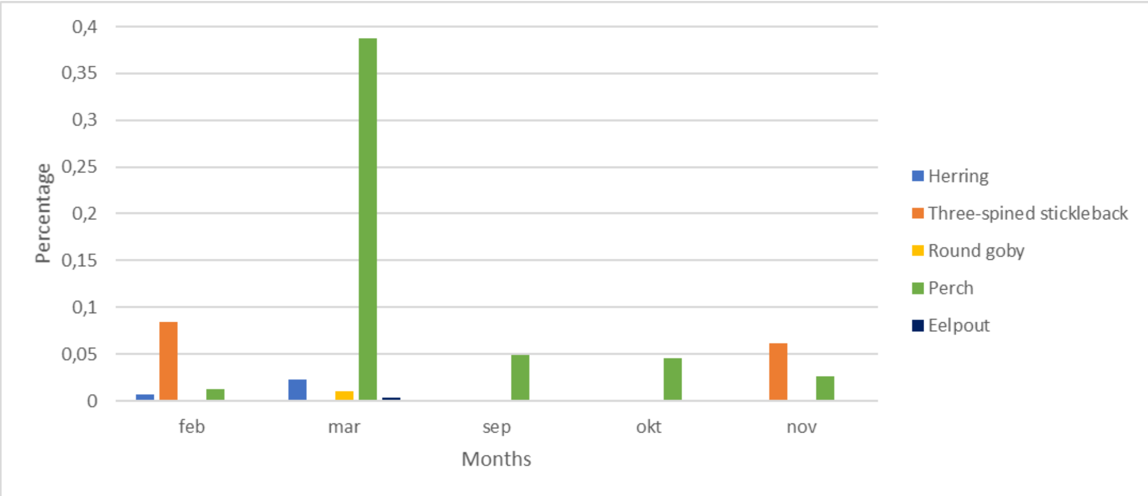

Figure 13: Diet composition data of cormorants from 2018. Number of samples (n) for each month: February (n=198), March (n=75), September (n=45), October (n=24) and November (n=55).

3.3 Monitoring fishing-and diet data for species

3.3.1 Round goby

In Figure 14, Round goby in stomach content samples were found in June, July and September of 2015. From June to July there is a significant increase in the percentage of Round goby found in the diet of cormorants. For monitoring fishing samples in 2015, percentages of caught Round goby was relatively the same around 5% except for lower values in October. In 2017 there are more samples of stomach contents than monitoring samples. Round goby was not observed in the monitoring data in May and April, and in January, February and December in diet data. In March-April of 2017 percentages of Round goby as prey is lower compared to the rest of the months. The higher percentages of goby found in the diet was from June-October. However, from June and forward values decreased. Diet samples from

February, September, October and November did not contain Round goby in 2018. The only record of Round goby as prey in 2018 was in March 2018.

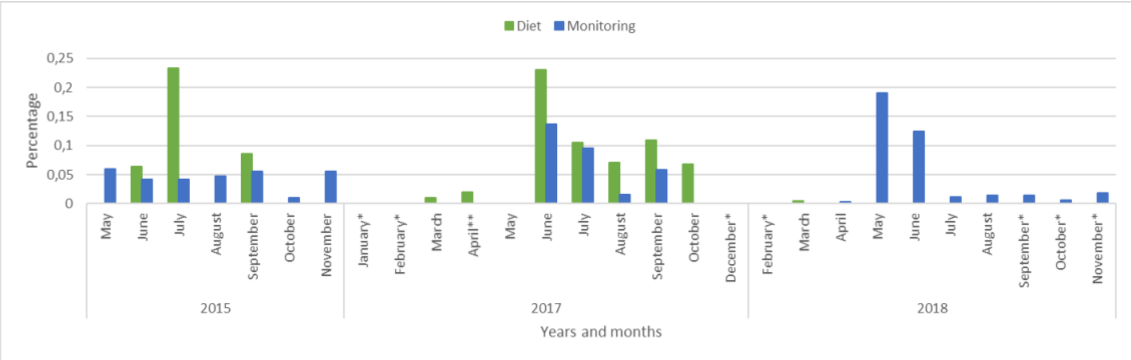

Figure 14: Percentage of Round goby in the diet composition of cormorants and monitoring fishing data over the sampled months from 2015-2018. *No record of species in stomach samples, ** No record of species in monitoring samples

3.3.2 Three-spined stickleback

In Figure 15, samples of stomach contents did not contain Three-spined stickleback in April and September 2017 and March, September and October in 2018. In monitoring samples, there were no records of Three-spined stickleback in May, June, July, October and November 2015, April, May, June in 2017 and April, May, June, July, September and October 2018. Three-spined stickleback was usually caught in July-September. Percentages of Three-spined stickleback in the diet is of cormorants exist in spring, higher values during summer and lower values during winter months.

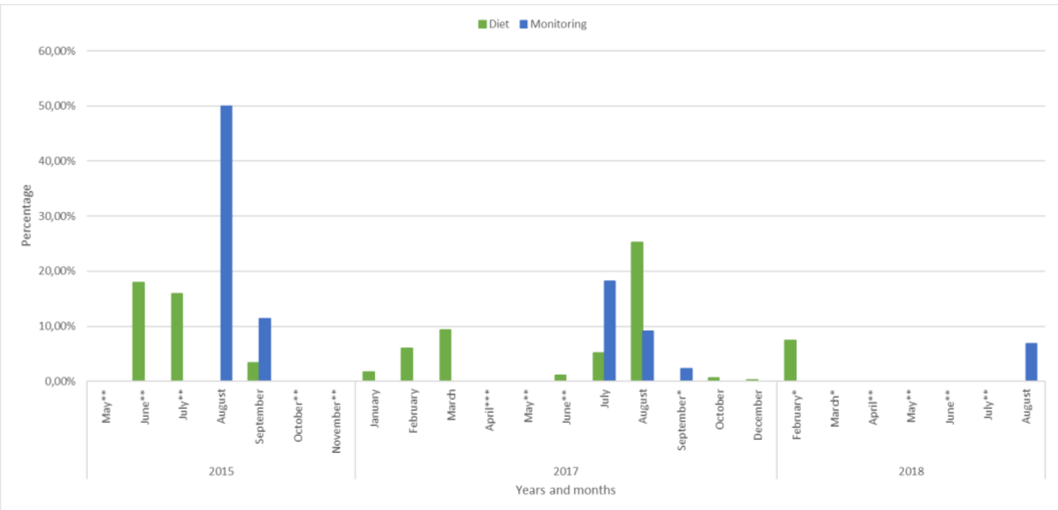

Figure 15: Percentage of Three-spined stickleback in the diet composition of cormorants and monitoring fishing over the sampled months from 2015-2018. *No record of species in stomach samples, ** No record of species in monitoring samples, *** No record of species in neither stomach contents or monitoring samples

3.3.3 Perch

In Figure 16, all samples of stomach contents contained Perch in some percentage. Monitoring samples recorded Perch in every sample except for April 2017 and July 2018. Percentages of Perch in monitoring samples are higher during the summer months. Diets of cormorants consist of higher percentages of Perch during winter, spring, autumn and lower during summer.

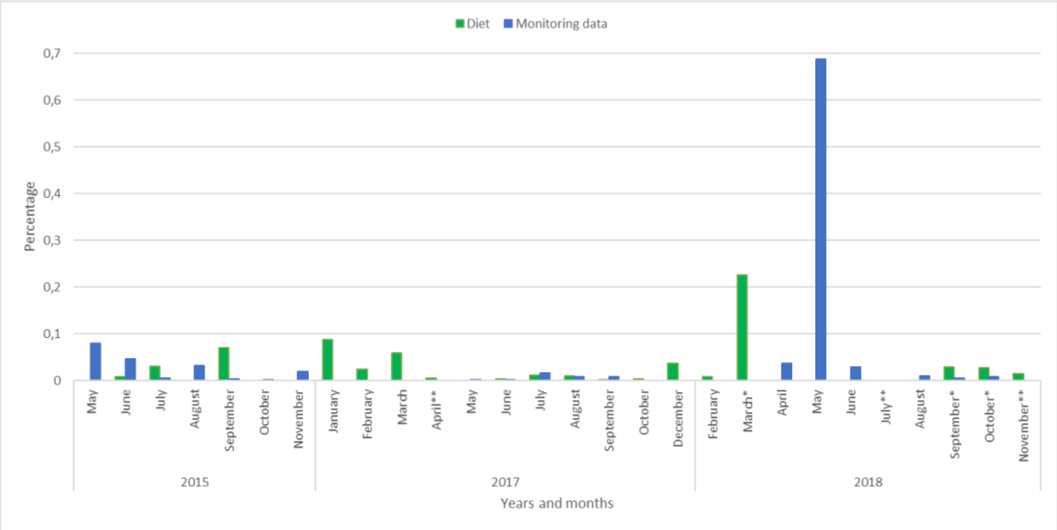

Figure 16: Percentage of Perch in the diet composition of cormorants and monitoring fishing data over the sampled months from 2015-2018. *No record of species in stomach samples, ** No record of species in monitoring samples

3.4 Ivlev's index

In Table 4, negative values of selectivity (red) indicate rejection or inaccessibility of the prey and positive values active selection (green). Division of 0 by 0 is coloured blue. Five species are actively selected for: Herring, Three-spined stickleback, Round goby and Perch. Values near zero implies random feeding (orange) and is the case for Eelpout in July 2015. Values of Eelpout indicate rejection or inaccessibility of prey throughout the recorded dates, except for July 2015 and October-November in 2018. Negative values in June 2015, July and September 2017 are the exception for Perch as all other values indicate active selection. As for the Round goby, negative values are recorded in 2018, but indications of active selection can be found for 2015 and 2017. Three-spined sticklebacks are actively selected for except in September 2017 and no data in September and October 2018. There is no data of Herring in June 2015 and October and November in 2018, however active selection is recorded for July and September in 2015 as well as in June 2017.

Table 4: Species and their measures of selectivity (**E**) calculated from Ivlev's index.

	Herring	**Three-spined stickleback**	**Round goby**	**Perch**	**Eelpout**
2015					
June	-	1,0	0,4	-0,7	-1,0
July	0,4	1,0	0,8	0,7	0,0
September	1,0	0,7	0,4	0,9	-0,8
2017					
June	1,0	1,0	0,4	0,4	-0,8
July	-1,0	0,7	0,2	-0,1	-0,5
August	-1,0	1,0	0,7	0,1	-0,5
September	-1,0	-1,0	0,5	-0,6	-0,8
2018					
September	-1,0	-	-1,0	0,7	-1,0
October	-	-	-1,0	0,6	-
November	-	1,0	-1,0	1,0	-

4. Discussion

Collection of cormorant samples occurred inconsistently over the years, over different seasons and locations. Conductions of monitoring fishing were executed similarly. Despite sampling gaps of both monitoring fishing data and cormorant diet data, the results present a valuable estimation of prey and predator interactions between round goby and cormorants. As the results of prey selection require corresponding months in both data sets, this study provides a limited view of predation on round goby by cormorants over the sampled time course. Interactions between cormorants and round goby during the observed months are still of value from an ecological standpoint. To enhance sampling consistency for future studies, it may be beneficial to conduct the sampling without mainly relying on an external source. By implementing consistency in the sampling, it would be possible to generate sufficient data throughout the season.

Predators such as the Great cormorant have Great adaptive foraging and opportunistic abilities (Johnson et al. 2010). Therefore, the stomach contents can consist of a Great variety of species. Stomach contents of cormorants shows an insight of what the bird recently ate and does not accurately represent the overall diet of cormorants. In this study a broad range of species was found and in order to narrow down the number of species, occurrence of a species in all the samples was looked upon. For selection of which species to further investigate, highly occurring species in the stomachs of cormorants (Table 3) were matched to species occurrence in monitoring fishing. For this study, number of species analysed was narrowed down to five: Round goby, Herring, Three-spined stickleback, Perch and Eelpout. Seeing as many species was excluded, the results only represent a fragment of the collected data.

Monitoring fishing data sets from 2015-2017 indicate high frequency of round gobies caught in the fyke nets, especially during June-September. Correspondingly, in the stomach contents of cormorants, round gobies become more common during the same months. During fall to spring, (October-April), lower values of round gobies are noticed for both monitoring and diet samples. While round gobies are found in lower percentage, Three-spined stickleback, Herring, Perch and Eelpout were more prominent. However, in 2018 the previous pattern of round gobies cannot be applied. For monitoring fishing catch, round gobies started at a relatively high percentage between 10-15%, decreased to below 10% in June and then abnormally low percentages from July-November (Figure 14). In 2015 and 2017, percentage of round gobies were among the highest of all species during May-November. As for the diet in 2018, Round goby was consumed in March, but not during any of the other months. During the same time period, Round goby was barley caught in the monitoring fishing. However, for 2018 there were no collection of cormorants from May-September due to absence of protection hunting in the area. Meaning, there are no stomach contents to analyse. In the catch there were low percentages of round gobies from May-August and if the cormorants diet responded with low levels of round gobies in their diet during this time, is unknown. Although, there are samples of cormorant's diets during late autumn in 2018. Round goby was recorded in October 2017 and not in 2018. During November in 2018, there were records of Perch and Three-spined stickleback, at approximately the value (5%). In 2017, there are no samples taken in November but in December, samples of Perch and Three-spined stickleback was recorded at about <5% in the diet. This implies that cormorants eat similarly during late autumn, regardless of occurrence of Round goby. An explanation could be seasonal diets of cormorants.

Seasonal differences in the cormorant's diet can be observed for round goby, seeing as percentage of round goby generally are high during the summer months (June-September) whereas values are generally lower during the rest of the year. During winter, spring and autumn water temperatures are lower. Round goby has a seasonal pattern, during colder months they live on deeper depths (Behrens et al. 2022). Lower values of goby might be due to fishing gear not being placed below 25 meters and cormorants not feeding at those depths. The forecast is that seasonal trends of cormorants diet are still occurring in Karlskrona, compared to the Great Lakes where the seasonal trends vanished due to diets predominantly consisting of gobies (Johnson et al. 2010). In order to obtain a greater understanding of seasonal differences of round goby in the diet of cormorant's, supplementary samples throughout the year is needed.

In Ivlev's test (Figure 7), the relative abundance of prey fish (p_i) was calculated according to the results of monitoring fishing. Choice of fishing gear, fyke nets, are placed along the ocean floor and therefore only allows for certain species to be caught in the nets. The two types of nets, standard and fine-mesh might catch different types of species, which was not taken into consideration in this study. The catch from fyke nets inaccurately represent the reality of fish dispersal in the ocean. For a more accurate representation, further investigations can incorporate different fishing gears or investigate which fishing gear most accurately represents the diet of cormorants.

In order to calculate active selection, a species must be found in both diet and catch. Hence, a broader range of species found in the diet and monitoring fishing was cut down to fewer species. On top of that, only a few months could be used to calculate active selection. Reason being that data from several months in one data set must have corresponding months in the other one. Therefore, the results of active selection are not as extensive.

In 2018 something caused round goby to dramatically decrease during the abnormally warm summer, and no one knows for certain what may have caused this. Consequently, the results of 2018 are deemed atypical. The only corresponding months in 2018 in order to calculate Ivlev's index were: September, October and November. From previous years in September, percentages were usually high of round goby in both catch and diet, which is not the case for 2018. For catch samples in October values of 1% in 2018 (Figure 12) can only be compared to values from 2015 (Figure 8), which were below 2%. As for November, there is only data from 2015 at approximately 8% and 1% in 2018. However, seeing as there is barley a 1% difference in October from 2015 compared to 2018, round gobies might just not be captured during this month. Probably due to the fact that Round goby migrates to lower depths and therefore more uncommon in the diet of cormorants. There is however no certainty that values in October weren't unusually low in 2015, seeing as levels are at 8% in November.

As for stomach samples, percentages of Round goby in October are only observed at approximately 6% in 2017 (Figure 11) and 0% in 2018 (Figure 13). For November, there is only stomach samples from 2018 at 0% (Figure 13). Compared to previous years, values in September-November are lower than previous years with an exception in October. Unfortunately, values in 2018 can only be compared to one previous year. A consolidation of data from all years (2015-2018) would represent a more reliable comparison.

The extremely low values of Round goby in 2018 (Figure 12-13) results in a negative value in Ivlev's index. A negative value indicates inaccessibility or rejection of prey. Positive values, active selection, for round gobies is noted for 2015 (June, July, September) and 2017 (June-September). A higher percentage of Round goby in data sampling on top of active selection from previous years can argue that inaccessibility of prey, is the case for 2018.

Round goby is seen as a valuable prey for the Great cormorant in the Baltic Sea (Almqvist et al. 2010; Kornis et al. 2012; Rakauskas et al. 2013; Ovegård et al. 2016; Oesterwind et al. 2017). Studies suggests that native predators, such as the

Great cormorant can combat the invasion of Round goby (Ovegård et al. 2016). A Greater number of predators, could possibly regulate the population of Round goby (Rakauskas et al. 2013). Therefore, one possible solution to hinder the expansion and decrease the number of round gobies is conservation of Great cormorant.

As Round goby is of high appearance in the stomach of cormorants, an impression of distinguished predator-prey interactions is conveyed. Higher percentages of Round goby in stomachs of cormorants could indicate that Round goby substitutes or reduces predation on native species. However, this is not proven in Karlskrona, but it has been observed at different locations (Corkum et al. 2004; Oesterwind et al. 2017). To analyse if predation of native species decreased, data of diet composition of cormorants before and after the invasion of Round goby is crucial. A potential approach to conduct a more in-depth analysis is to divide round gobies into different size classes. In that case, investigations of prey selection by cormorants towards certain size classes of Round goby could be conducted. Collection of round gobies included size sorting but analysing methods of Round goby in stomach contents did not allow for this.

In conclusion, this study shows an indication of active selection on round gobies by cormorants. To better understand the dynamics between cormorants and round gobies in the archipelago in Karlskrona, further monitoring of both fish stocks and cormorant diet is required.

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Appendix

Table 5: Frequency of occurrence for prey species in diet samples of cormorants from 2015.

2015		
Prey, common name	**Prey, latin name**	**Frequency of occurrence**
Lesser sand eel	*Ammodytes tobianus*	0,15
Herring	*Clupea harengus*	0,22
Cyprinidae	*Cyprinidae*	0,02
Pike	*Esox lucius*	0,02
Cod	*Gadus morhua*	0,02
Three-spined stickleback	*Gasterosteus aculeatus*	0,41
Ruffe	*Gymnocephalus cernua*	0,10
Shorthorn sculpin	*Myoxocephalus scorpius*	0,02
Round goby	*Neogobius melanostomus*	0,68
Unknown		0,02
Perch	*Perca fluviatilis*	0,41
European flounder	*Platichthys flesus*	0,02
Pomatoschistus sp	*Pomatoschistus sp.*	0,05
Roach	*Rutilus rutilus*	0,15
Spinachia	*Spinachia spinachia*	0,02
Sprat	*Sprattus sprattus*	0,05
Eelpout	*Zoarces viviparus*	0,05

Table 6: Frequency of occurrence for prey species in diet samples of cormorants from 2017.

2017		
Prey, common name	**Prey, latin name**	**Frequency of occurrence**
Common bleak	*Alburnus alburnus*	0,01
ammodytes sp.	*ammodytes sp.*	0,03
Lesser sand eel	*Ammodytes tobianus*	0,01
Silver bream	*Blicca bjoerkna*	0,01
Herring	*Clupea harengus*	0,04
Clupeidae	*Clupeidae*	0,03
Lumpfish	*Cyclopterus lumpus*	0,01
Cyprinidae	*Cyprinidae*	0,17
Cod	*Gadus morhua*	0,03

Gasteroidae sp.	*Gasteroidae sp*	0,24
Three-spined stickleback	*Gasterosteus aculeatus*	0,37
Gobiidae	*Gobiidae*	0,13
Ruffe	*Gymnocephalus cernua*	0,17
Round goby	*Neogobius melanostomus*	0,37
Perch	*Perca fluviatilis*	0,49
Pleuronectidae	*Pleuronectidae*	0,03
Pomatoschistus sp.	*Pomatoschistus sp.*	0,03
Ninespine stickleback	*Pungitius pungitius*	0,04
Roach	*Rutilus rutilus*	0,03
Saduria	*Saduria entomon*	0,03
Zander	*Sander lucioperca*	0,03
Spinachia spinachia	*Spinachia spinachia*	0,01
Sprat	*Sprattus sprattus*	0,01
Unknown		0,04
Eelpout	*Zoarces viviparus*	0,07

Table 7: Frequency of occurrence for prey species in diet samples of cormorants from 2018.

2018		
Prey, common name	**Prey, lain name**	**Frequency of occurrence**
Silver bream	*Blicca bjoerkna*	0,06
Herring	*Clupea harengus*	0,06
Clupeidae	*Clupeidae*	0,06
Common whitefish	*Coregonus lavaretus*	0,03
Cyprinidae	*Cyprinidae*	0,35
Pike	*Esox lucius*	0,06
Cod	*Gadus morhua*	0,03
Gasteroidae sp.	*Gasteroidae sp*	0,09
Three-spined stickleback	*Gasterosteus aculeatus*	0,12
Gobiidae	*Gobiidae*	0,21
Ruffe	*Gymnocephalus cernua*	0,35
Round goby	*Neogobius melanostomus*	0,03
Perch	*Perca fluviatilis*	0,82
European plaice	*Pleuronectes platessa*	0,03
Pomatoschistus sp.	*Pomatoschistus sp.*	0,09
Ninespine stickleback	*Pungitius pungitius*	0,03
Unknown		0,06
Eelpout	*Zoarces viviparus*	0,03

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