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Causes of trends in abundance of mesopredators in the Kattegat Sea

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Orsaker till trender i förekomst av mesopredatorer i Kattegatt

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Contents

List of figures

List of tables

List of Equations

List of abbreviations

Aqua	Department of Aquatic Resources
C	Celsius
CFP	The Common Fisheries Policy
CO_2	Carbon Dioxide
CPUE	Catch Per Unit Effort
DTU	Technical University of Denmark
EU	European Union
GLM	General Linear Model
IBTS	International Offshore Bottom Trawl Survey
ICES	International Council for the Exploration of Sea
Ln	Natural Logarithm
Log	Logarithm
O_2	Oxygen
ppt	Parts per thousand
R1	Ringhals 1
R2	Ringhals 2
R3	Ringhals 3
R4	Ringhals 4
SLU	Swedish University of Agriculture Sciences
SMHI	Swedish Meteorological and Hydrological Institute
SSB	Spawning Stock Biomass
STECF	Scientific, Technical and Economic Committee for Fisheries
TAC	Total Allowable Catch
TDS	Total Dissolved Solids

Abstract

It has come to attention that there is a mesopredator release effect present in the Kattegat Sea (northern Europe, between Sweden and Denmark). The areas in focus here are Ringhals, a nuclear power plant zone, and Vendelsöarna, a undisturbed reference area. Mesopredator abundances like the *Carcinus maenas* (European Shore Crab) have increased over the years; while there have been a noticeable decreased population of *Gadus morhua* (Atlantic Cod) and a sea temperature increase since the 1970s.

The aim of this research in the Kattegat Sea is to analyze the potential causes for increasing abundance of mesopredators that could cause cascading effects and alter the ecosystem itself. Since 1976, data has been collected in the Kattegat Sea region where uni- and multivariate analysis, which can examine the idea that there is a correlation between diminished population of the *Gadus morhua*, (Atlantic Cod) and temperature rise with mesopredator increasing distributions.

Results suggest abundances of mesopredatory fish and crab were highest in areas where there were favourable habitat attributes, eg., in terms of increased temperature. Significant results stating the relationship between increased mesopredator's abundance and Atlantic Cod deceased abundance. Smaller population of the piscivore Atlantic Cod advocates a cascading process. Adjacent areas like the Baltic Sea, have and are also experiencing these effects and results can pose particular challenges for the ecosystem.

Popular Science Summary

A particular interest relies in the Kattegat Sea in northern Europe, located between Sweden and Denmark. Locations like Ringhals, an area exposed to nuclear power plant activity and Vendelsöarna, which is not affected by it, have stimulated a peak of interest for researching an on-going cascading effect known as the "mesopredator release effect". It is hypothesized that Shore Crabs and other mesopredators (organisms which have an intermediate position in the food web) have increased in these regions due to favouring conditions, for instance, decreased predation on species that are preyed upon from Atlantic Cod and increased sea temperatures. A natural predator of the European Shore Crab and other mesopredators is the Atlantic Cod, which has been strongly overfished in the last few decades. High sea temperatures are not favourable conditions for the Atlantic Cod, which is the current status in the Kattegat; according to the results. Although, the Atlantic Cod is slowly recovering in other parts of the Atlantic region, the Kattegat Sea is presumed not to be one of them.

Environmental scientists have growing concern with the increasing "mesopredator release effect". This describes an ecological theory of a dynamic between predators and mesopredators within an ecosystem. If the predator population collapses while the mesopredator population increases, the result is known as a trophic cascade. This effect has already occurred in other regions of the Atlantic and the Baltic Sea. To prevent such incidences, it is necessary that environmental management practices consider such cascading effects.

Narrow near shore environments are classified to be very important because they support connected marine ecosystems. Therefore, the relevance of apprehending the response system of marine species (as well as their in-between relationship) to temperature increase has become an imperative topic in order to understand and accurately predict the impact of induced climate change and human intervention on the ocean. Mesopredatory fish and crab species are key components in coastal food webs, and any alterations in their abundance can cause adverse effects in the marine ecosystem.

1 Introduction

1.1 Purpose of the study and background

A trophic cascade is an indirect effect on the food web occurring when a key species, or a predator population is affected and subdues/alters related to predator or prey (lower trophic levels) populations/behavior (Fig. 1a,b). This is where the "mesopredator release" term comes in effect. This trophic interaction occurs when a top-down control of predator is eradicated and can generate an increase of its prey (smaller predators), which can increase impact on their common prey (Prugh *et al*., 2009). This illustrates an association between decreasing predator abundance and mesopredator overabundance.

Overexploitation of the piscivorous Atlantic Cod (*Gadus morhua*) by fishing companies in the Atlantic has subtly prompted an increasing amount of mesopredator species; causing alterations in the food web structure in offshore and littoral seas (Eriksson *et al.,* 2011 and Bergström *et al.*, 2016). Bergström *et al*. (2016) claims the distribution of mesopredatory fish is determined by habitat variables in a predator-depleted coastal system in nearby waters (Skagerrak).

In the general sense of an impact on predator abundance, this is not the only plausible cause. Multiple studies have brought up the topic of climate change and the effects of temperature relevant to marine species and what future predictions can be attained (Eriksson *et al.* 2011, Carla *et al.* 2015 & Bergström *et al.*, 2016). Climate change and fluctuations in water temperature can have both direct (eg. behavior and migration pattern, mortality rate and reproduction capacity) and indirect (eg. alter composition/structure and productivity of an ecosystem that the fish rely on) effects on fish and crabs.

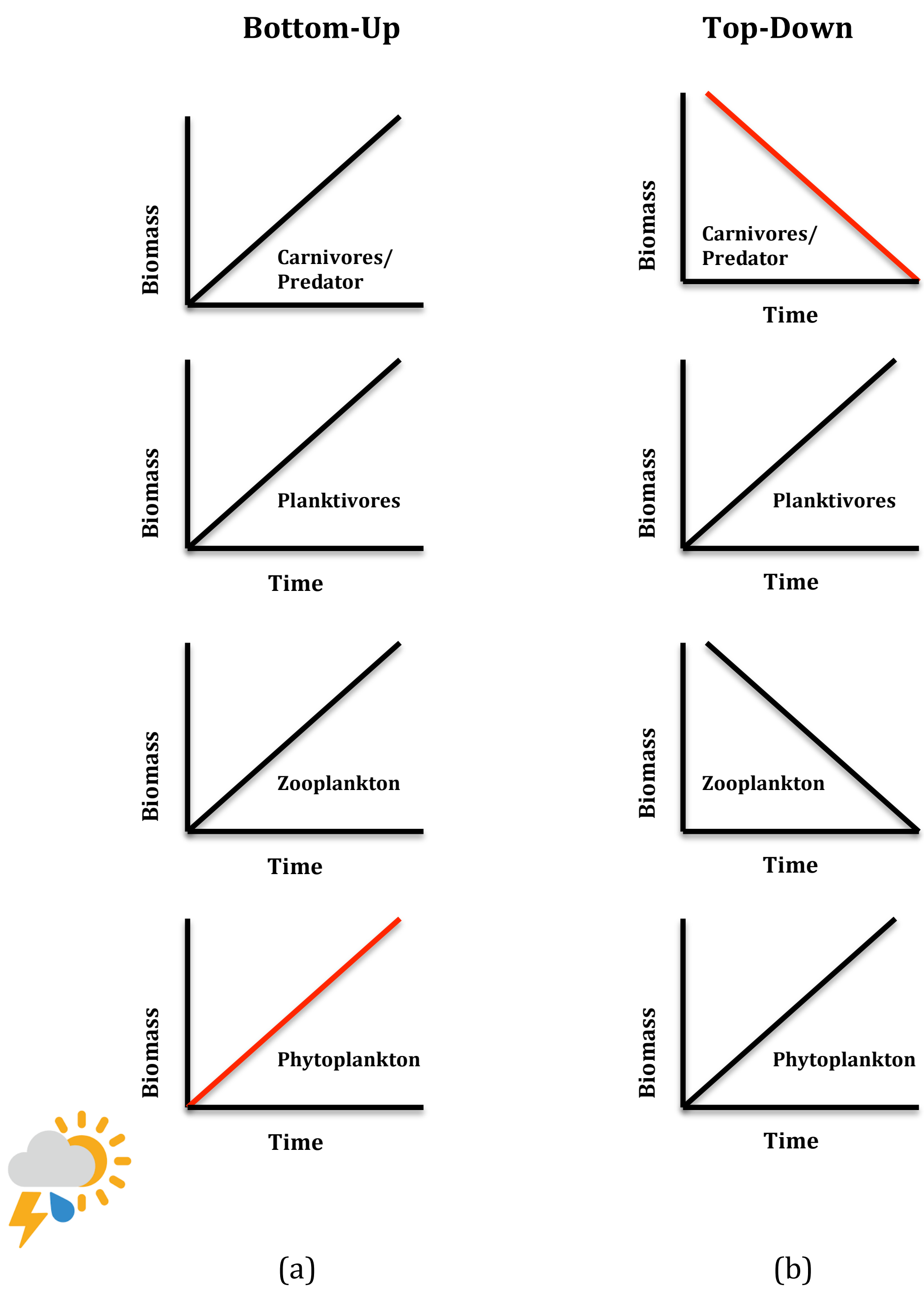

Figure. 1 Types of cascading effects. The effect is directed as the red-line. Bottom-Up (a) which can be inflicted by environmental factors. Top-Down (b) occurs when the predator abundance decreases and prey abundance increases. This, then, leads to a diminution of zooplankton abundance and leads to a reduced grazing pressure on the phytoplankton.

Mesopredator release is common in all types of ecosystems, including terrestrial. One example of the mesopredator release took place in North America during the 20th century, where populations of wolf and cougars were removed by tree overharvesting, excessive hunting, and poisoning by ranchers (Ripple & Beschta, 2005). As a result of these two top-predators being removed, there was an increasing number of mesopredators, such as foxes, raccoons, and coyotes. This disrupted the food chain, jeopardizing species on lower trophic levels, while simultaneously raising mesopredators populations (Ripple & Beschta, 2005). Learning about the consequences of coastal mesopredators on lower trophic levels may in fact be prompted by fishery induced changes in offshore food webs, and how alterations in the food web composition can cause conflicts in coastal ecosystem (Eriksson *et al.*, 2011). The mesopredator release effect can consist of both top-down and bottom-up cascading effects along the food web.

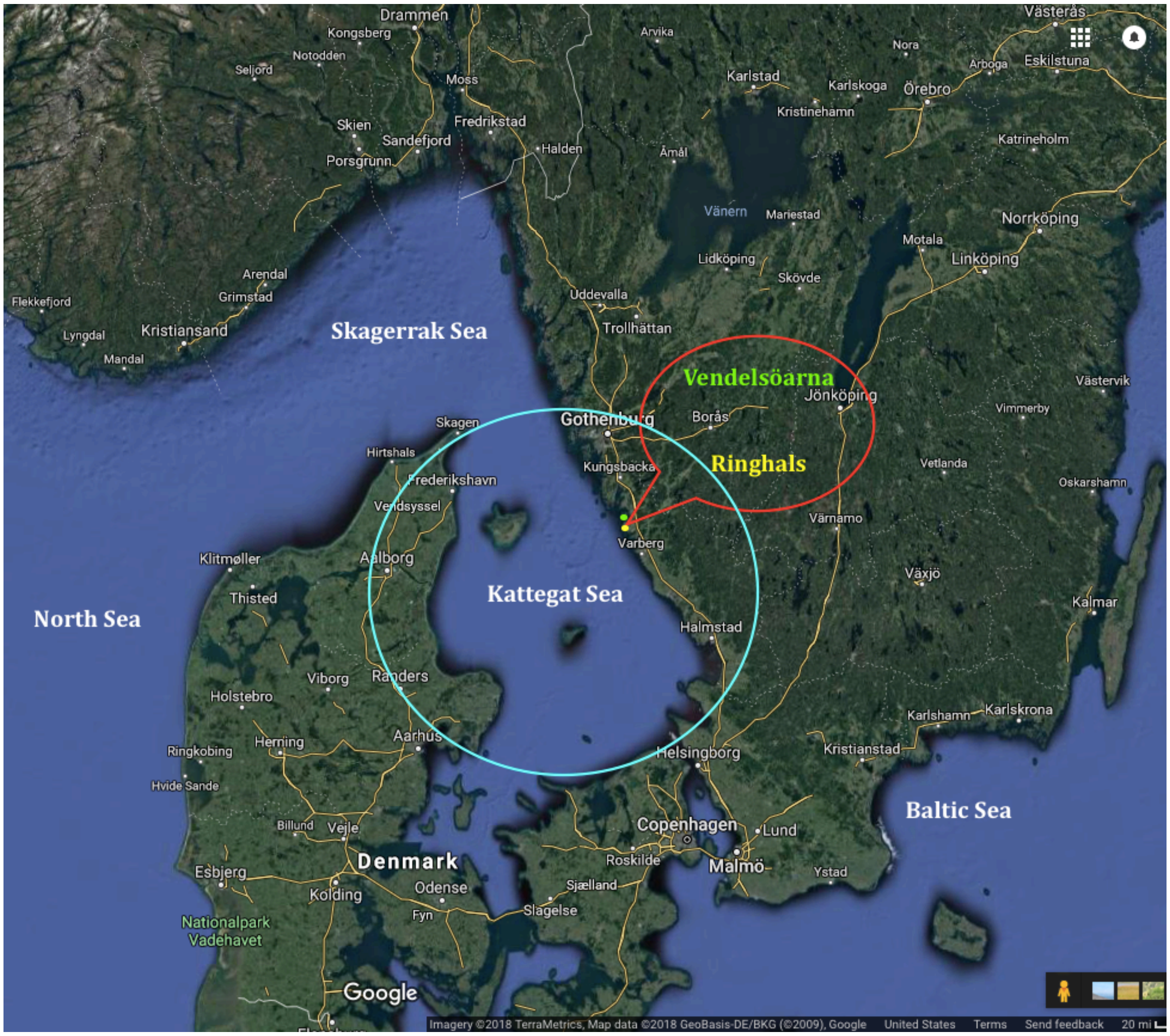

Figure. 2 Locations of the present research are enclosed in the red circle and the Kattegat Sea enclosed within the blue circle. The Baltic Sea is to the lower right, the Skagerrak Sea upper left, and the North Sea lower left. The yellow symbol indicates where Ringhals is located and green represents Vendelsöarna. *Source: Google.maps.com*

The purpose of this study is to explore fluctuations in temperature in the Kattegat Sea region in northern Europe, specifically Ringhals and Vendelsöarna, to explain possible changes in the abundance of the mesopredatory crab *Carcinus maenas* (Shore Crab) and mesopredatory fish species: *Symphodus melops* (Corkwing Wrasse), *Ctenolabrus rupestris* (Goldsinny Wrasse), and *Gobius niger* (Black Goby) and also possibly caused by an increasingly deprived predation by *Gadus morhua* (Atlantic

Cod). This will be done by performing various trend analyses between collected data of species abundance and recorded temperatures.

A similar study has been performed by Eriksson et al. (2011), which only studied mesopredators at Vendelsöarna with a shorter time series. There is a particular interest and monitoring activity in the Ringhals zone because of current nuclear power plant activity. There are four nuclear power reactors in the area with three water-cooled emitters and one (R1) generator that is hydrogen cooled. The method used for cooling water has an impact on the marine environment. The seawater used for condensing the steam to water is taken from the sea and then reverted back into the Kattegat Sea. The temperature in the outflowing is approximately 10 °C higher than in the cooling water intake (Vattenfall, 2012). In addition, climate change may have increased water temperatures. This incidence gives authority for a possible mesopredator release effect. Hence, Ringhals and Vendelsö, in southwestern Sweden, were chosen specifically for this present study.

1.2 Objectives of this study

The main objectives of this study were to assess the relative importance of water temperature and abundances of Atlantic Cod for the abundance of mesopredatory fish and crabs. The objectives were addressed by a vast survey of collected fish data and recorded temperatures over 31 consecutive years on the same day and on the same month (April and August). Data were collected: 1) by fyke nets in the regions of Ringhals and Vendelsöarna, and 2) in trawling surveys, both in the Kattegat Sea. With reference to Eriksson *et al*., (2011), it is hypothesized that mesopredatory fish and crab abundances will:

1. Increase in areas with decreased Atlantic Cod abundance, in this case the Kattegat Sea signaling the “mesopredator release effect”.
2. Increase in areas with highly induced temperatures mainly caused by the nuclear power plant emitters in the Ringhals area and possibly climate change. Eriksson *et al*. (2011) already investigated this, but this present study has access to an additional investigation site, Ringhals and longer

time series. The study will also determine the extent to which the patterns discovered by Eriksson *et al*. (2011) remain.

2 Species status profile

2.1 The European Shore Crab (*Carcinus maenas*)

The Shore Crab can be identified by a number of names, Shore Crab itself, Green Shore Crab, Common Shore Crab, or from its native region, the European Shore Crab (Wolf 1998). European Shore Crabs are found at different locations around the world being California, Washington and Northeastern states, Japan and Australia, but are most common on the Eastern Atlantic coast where they are native (Leignel *et al*., 2014). However, through recent years the Shore Crab is becoming an increasingly abundant species in its native region. In Figure. 3 the distribution of the Shore Crab can be seen and categorized by its abundance.

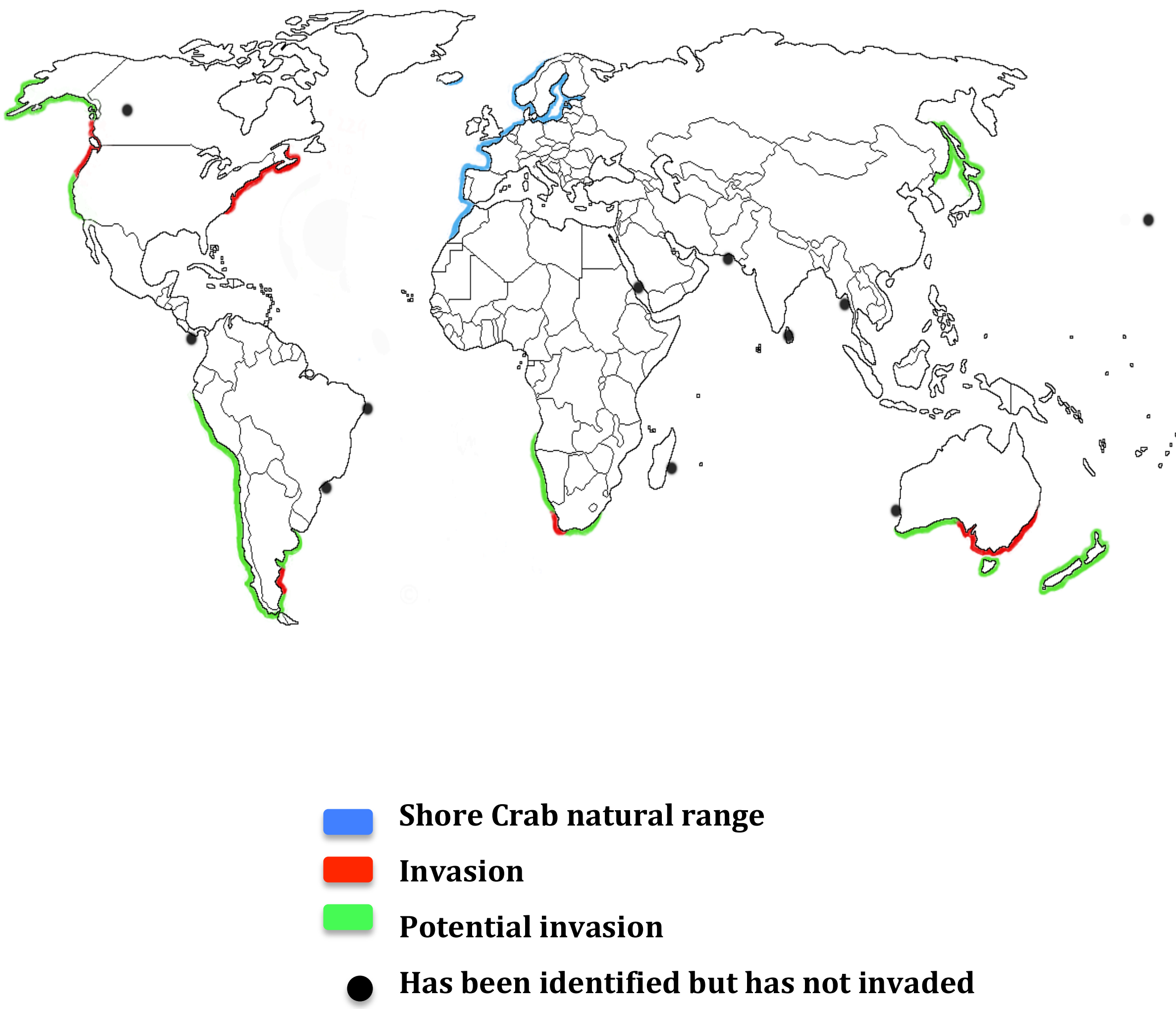

Figure. 3 Distribution of the Shore Crab. **Blue:** Shore Crab natural range. **Red:** Invasion. **Green:** Potential invasion. **Black dot:** Has been identified has not invaded. *Source: British Sea fishing*

The common name, Green Shore Crab, can be deceptive because of the ranging of its color. The morphology of the Shore Crab is variable depending on the molting cycle of the crab. Coloring can range from green to orange and red in certain instances, also depending on their habitat. Especially, juveniles in particular display a variety of patterns during molting. An easy identifiable characteristic is the yellowish spots on the abdomen area (*carapace or shell*) (Washington Dept. of Fish and Wildlife, 2000). The shell is expansive with five serrated teeth on either side and can be no wider than 88.9 to 101.6 mm across (Washington Sea Grant Program, 1998). Another characteristic is the three rounded lobes that lay between the eyes (Washington Dept. of Fish and Wildlife, 2000). The *pereopods* (the front legs) have well-established *chelae* (forceps or pinchers) (Reid *et al*., 1997).

Shore Crabs are found on all types of oceanfronts (for example, sub-littoral, but chiefly shore and shallow waters), from shallow waters to depths up to 60 m, and on rare occasions at depths of up to 200 m (Kraemer *et al*., 2007). They are also commonly found in tide pools, sea-grasses, marshes, and under rocks. The crab can also tolerate a wide range of salinities (Kraemer *et al*., 2007), which will be described below. Shore Crabs are mainly nocturnal; however, their endeavor varies on the tide. Female Shore Crabs can produce up to 80 – 160 million eggs per season (Washington Sea Grant Program, 1998). After hatching, most younglings or larvae take shelter in seaweed and sea-grasses until they reach adulthood (Kraemer *et al*., 2007). According to Moksnes *et al*. (2014), since most Shore Crab larvae displayed nocturnal behavior and the only foreseeable current generating through the micro-tidal Kattegat was sea-land breeze, those larvae have what is called "nocturnal vertical migration" (Moksnes *et al*. 2014). During early stages, Shore Crabs use land breeze to scatter offshore by swimming at the surface only at night, and during later stages they swim at the surface during daytime using sea breeze to go back to settlement areas by the coast (Moksnes *et al*., 2014). Times like the summer are abundant with planktivore predators. Predators like the Atlantic Mackerel (*Scomber scombrus*), Atlantic herring (*Clupea harengus*) and Atlantic Cod that demonstrates a possible rationalization that dominates the ultimate cause for nocturnal migrating behavior. However, since the collapse of the Atlantic Cod and warmer temperatures exerted in the Kattegat, there is more reason for investigating abundances of the Shore Crab. Tidal areas dominating the Kattegat Sea create benefits for the assemblage of Shore Crab to have a better coordinated cross-shelf dispersal and higher recruitment attainment (Moksnes *et al*., 2014). Shore Crabs are classified to be excellent osmoregulating omnivores and a euryhaline species, indicating that they can tolerate a wide range of estuarine and marine ecosystems (Leignel *et al*., 2014). Adults can tolerate temperatures of -2 to 35°C, but prefer 3 to 26°C (Leignel *et al*., 2014). Temperatures less than 10°C will stop the growth and molting and feeding at temperatures of 6 to 7°C. As for salinities, Shore Crabs can tolerate 10 - 33 parts per thousand (ppt) (Grosholz and Ruiz, 2002). They are well adapted and are skillful learning animals, which can rally new improved prey-handling skills, while scavenging with their pinchers. Shore Crabs have a history of previously being suspected to cause the obliteration of the soft-shell clam (*Mya arenaria*) fisheries in New England (Cohen and Carlton, 1995) and a bargain of populations of other commercially vital bivalves involving the Scallop (*Argopecten irradians*) and the Northern Quahog (*Mercenaria mercenaria*) (Pickering & Quijón, 2011). Shore Crabs are native to the Eastern Atlantic, due to their voracious performance; they have an invasive behavior (Leignel *et al*. 2014). While, Shore Crabs feed primarily on crustaceans, worms, mollusks and clams, they are highly adaptable; which makes them very resourceful by eating anything they can get a hold of due to their easily accommodated diets and widespread distribution (Leignel *et al*. 2014). With their voracious behavior, high reproductive rates, the ability to outcompete native species for food resources by consuming anything, even dead organisms, and wide environmental tolerances offers them the capacity to basically alter the community assembly in coastal biota.

2.2 The Black Goby (*Gobius niger)*

Like the Shore Crab, the Black Goby is also prey for the Atlantic Cod. The Black Goby is much bigger compared to other gobies (5 – 7 cm, max 10 cm), with a stout shaped body, round snout, and fused pelvic fins (Miller, 1986). The coloring is usually brown or dark brown, in general dark; however, spawning males are almost entirely black (Miller, 1986). Spawning (reproduction) takes place in the summer, usually in weedy shallows (FishBase, 2017). Its food source is usually small benthic invertebrates. Habitat preference is usually along the coast with a preference for muddy bottoms and bladderwrack cover (Miller, 1986). Referring to depth distribution, Black Gobies are usually found at depths between 1 – 96 m, predominantly at 1 – 50 m, and in a temperature range of 8°C - 24°C (FishBase, 2017).

2.3 The Goldsinny Wrasse (*Ctenolabrus rupestris)* and Corkwing Wrasse *(Symphodus melops)*

Both Goldsinny Wrasse and Corkwing Wrasse are classified as labridae species and are associated with marine reefs. Goldsinny Wrasses are found at depths similar to Corkwing Wrasses, depth range of 1 – 50 m, but preferably between 1 – 20 m (FishBase, 2017b). Corkwing Wrasses have an adult size range between 7 – 10 cm (FishBase, 2017c), while the Goldsinny Wrasse has an adult size range of 11 – 18 cm (FishBase, 2017b). Goldsinny Wrasse prefer rocky and weed covered shores and larger fish occur at deeper areas (FishBase, 2017b). Their diet consists of crustaceans, gastropods and bryozoans. Reproduction also takes place during the summer (ibid). The Corkwing Wrasse is a very territorial fish that thrives in the littoral zone (FishBase, 2017c). Other areas that this fish can be found are in eelgrass beds, lagoons and near rocky areas (ibid). Besides having similar feeding habits as the Goldsinny Wrasse, the Corkwing Wrasse consumes mollusks, hydroids and worms (ibid). For commercial uses, both labridae species are used as cleaner fish in salmon farms (ibid).

2.4 The Atlantic Cod *(Gadus morhua)*

Atlantic Cod is a cold water demersal species that can live up to 25 years (European Commission, 2016). They can be found on continental shelves and throughout the north Atlantic along coastal waters (ibid). Cod prefer to live near seabeds that are no more than 200 meters deep, but in places like the Baltic Sea, which suffers from oxygen depletion at lower depths, their behavior is more pelagic (ibid). A behavior response study from the Atlantic Cod to temperatures was performed by Freitas *et al*. (2015). It was discovered that Cod have a "diel vertical migration" pattern behavior, which signifies a behavior of swimming towards the epipelagic zone in shallow feeding habitats at night. Under fortunate conditions (favorable temperatures), cod ascend and select vegetated habitats to feed in (Freitas *et al*., 2015). This behavior was most common at night. This migration can concur with the nocturnal vertical migration of the Shore Crab. It has also been determined that there may be a clear association between sea surface temperatures and vertical position during winter and summer seasons (ibid.). Freitas *et al*. (2015) proposed that cod reflected physiological constraints towards escalated sea temperatures, especially in the summer time. At this time of the year, cod were detected in profound depths whenever temperatures rose (ibid.). Water temperatures ranging from -1.5 to 19°C are optimal for cod (Freitas *et al*., 2015). Conversely, the thermal preference of cod were at temperatures starting from 15°C and below and vary depending on their size, hemoglobin genotype, and dissolved oxygen concentrations (Freitas *et al*., 2015). For example, during growth stage, preferred temperatures are between 9 and 15°C, also varying the fish body size (Freitas *et al*., 2015). Idiosyncrasies in temperature that are beyond thermal limits for cod can swift an unsuitable situation in their performance. Temperatures that are 20°C and higher can veer high mortality rates (Freitas *et al*., 2015). In one of the Freitas *et al*. (2015) experiments, it was discovered that the Atlantic Cod veered to deeper waters when temperatures increased over 15°C. The Atlantic Cod plays an important role in the Baltic Sea and North Sea ecosystems, but so does the Kattegat Sea cod stock population. There is genetic evidence that the Kattegat stock contrasts from other local populations from the North Sea and Skagerrak. That is, the Kattegat population is possibly separate from other surrounding seas (André *et al.*, 2016).

The European Union's (EU) Common Fisheries Policy (CFP) has prompted recovery plans for cod stocks. Each plan varies between different stocks/fisheries covering the Skagerrak/Kattegat, North Sea and Eastern Channel (Paisley *et al*., 2010). Furthermore, new recovery and management plans are under development to reduce the collapse of cod industries that have impacted social and economic systems, and the marine ecosystems. Over the last couple of years, records have indicated that many cod stocks are recovering, but in smaller stock sizes (ICES, 2017). Movement of cod is still not fully understood and can vary from different regions. Nevertheless, what certainly governs their movement behavior is fairly well known. These qualities are sustainable fishing pressure, food availability, appropriate spawning spots and favorable water temperatures (André *et al*., 2016). Spawning does occur in the Kattegat area; however, a major spawning spot is located in the North Sea (ibid). Currents from the North Sea transport eggs and larvae to Skagerrak and further into the Kattegat Sea. According to André *et al*. (2016) the forte and course of larval drift are possibly directed by an interaction between size and location of spawning spots in the North Sea and sea currents from the North Sea to Skagerrak and Kattegat (André *et al*., 2016). Findings from tagging studies could suggest that juvenile cod reaching maturity at the age of two and three that grow up in coastal areas (Kattegat and Skagerrak) have a behavioral governing mechanism of natal homing (André *et al*., 2016), which means the Kattegat has local natal populations. The natal homing or philopatry refers to the behavior of an adult animal (in this case, the cod), which returns to its birthplace to procreate (André *et al*., 2016). Understanding these migratory behaviors and oceanographic processes could help develop an improved management approach for the cod stock.

2.5 History of the collapse of the Atlantic Cod (*Gadus morhua*) in reference to the Kattegat Sea

The decrease of Atlantic Cod was due to improved fishing methods using trawls and nets. When fishing, fishermen collected more than what was supposed to be caught. According to new laws after the crash in the 1980s, if the catch was higher than the allowed quota, the rest of the cod was dumped back into the sea (ICES, 2017). Moreover, young Atlantic Cod, which did not follow size requirements, were also dumped back dead into sea because they were not eligible for landing and sale. Since 2005, the recovery plan for cod was to reach a maximum sustainable yield and a deadline to reach the target by increasing the quantities of mature fish and reduce fishing mortality. To achieve the target, the measurements implemented to the multiannual plan included appropriate methods for the establishment if the level of the total allowable catches (TACs) and a system that does not exceed the TAC. New multiannual plans were regulated in accordance to Article 6, 9 and 12, and advice was received by scientists from the International Council for the Exploration of Sea (ICES) and the Scientific, Technical and Economic Committee for Fisheries (STECF). As of the year of 2008, the Swedish fishery minister and the general director for the Swedish Board of Fisheries in cooperation with Danish ministers agreed on closing areas in the Kattegat Sea using national regulations (Fig. 4).

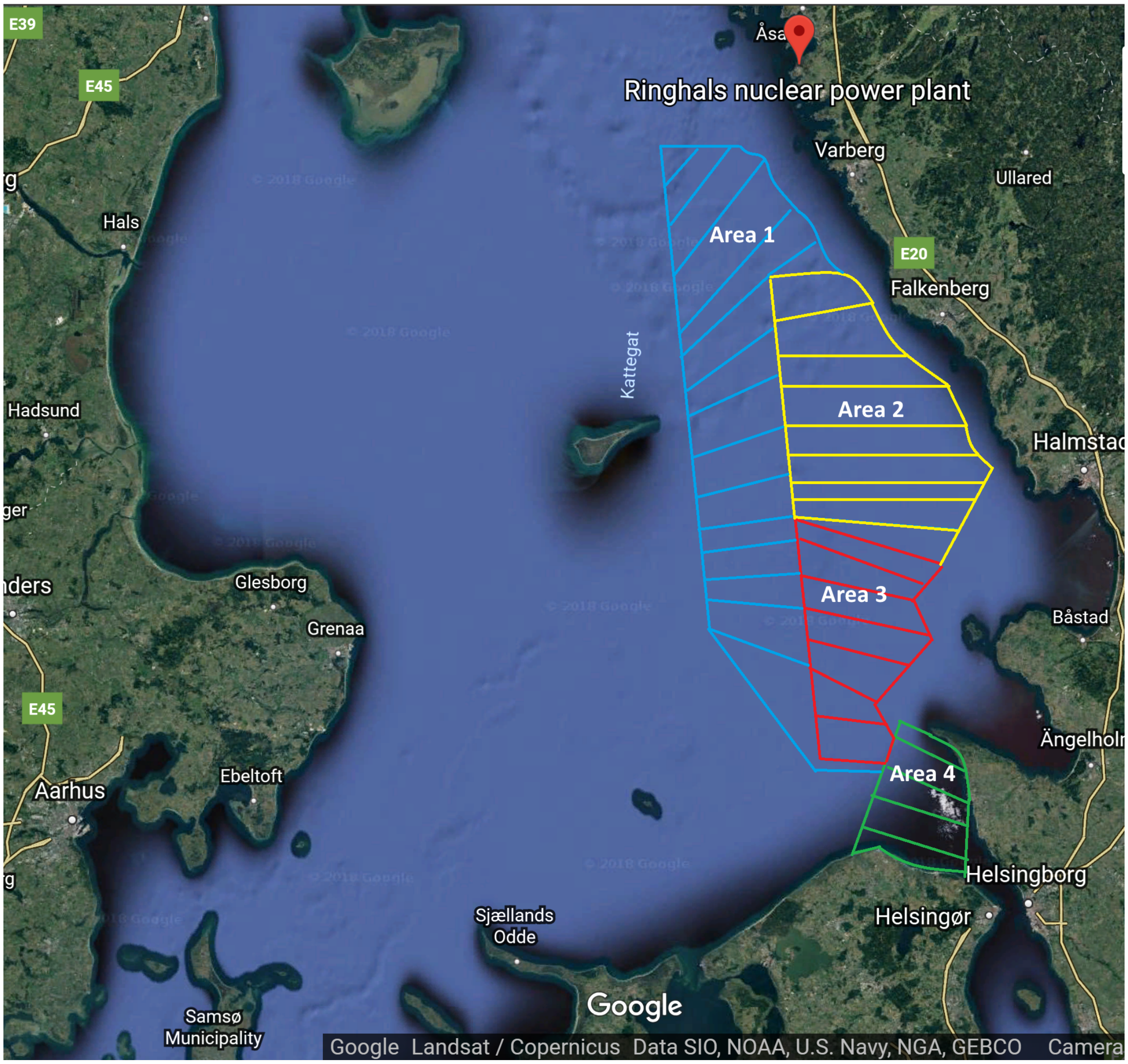

Figure. 4 Established grounds restricting fisheries to increase the cod stock biomass. **Area 1 (blue)** (January 1st – March 31st) Seasonally closed in the exception with only selective gear with low cod-catchability. **Area 2 (yellow)** Closed all year except for the use of selective gear. **Area 3 (red)** Closed all year for all fisheries (even recreational). **Area 4 (green)** Seasonally closed (February – March) in the exception for the use of selective gear. *Source: Google.maps.com*

Cod stocks in some areas in the Atlantic Ocean have overcome the collapse, or are recovering slowly, but still have progressed. The case in the Kattegat is quite different because cod stocks have recovered to a certain degree but it is still considered to be an area classified as threatened due to the low population and reduced body size. The current protection that the Atlantic Cod in the Kattegat was initiated as a governmental agreement by the 1st of January 2009 (SLU Aqua 2011). The EU negotiations in the Council of Ministers for Fisheries in the Kattegat Sea in 2008 were not considered constructive with regard to the highly threatened cod stock; therefore, new respective national legislations were enforced. New rules were the following:

1. A well-established joint working group to evaluate existing fish equipment and develop new gear to reduce cod mortality, reduce the TAC and improve selectivity, such as using the seltra trawl (no more than 90 mm mesh size) (DTU, 2011). This means coercing fishers to fit special sorting grids in their trawling nets, allowing adult cod to swim away from the net, while lobster is the main catch.
2. Introducing induced spatial protection by limiting fisheries during spawning seasons and in key areas; mainly the south-eastern part of the Kattegat Sea, proposing a three-zone closure.
3. Continue strengthening the collaboration between Sweden and Denmark associations to improve fisheries in the Kattegat area.

A preliminary evaluation had been carried out in spring 2011 by the EU: the Commission's Scientific Council (STECF), on a basis prepared by the Sea Fisheries Laboratory and DTU Aqua. Political agreements were discussed between the respective responsible fisheries ministers, in cooperation between the Sea Fisheries Laboratory and Denmark's counterpart, DTU Aqua, by performing consistent surveys by commercial contracted fishing vessels and sampling that is carried out by scientific staff from each institute (SLU Aqua 2011). In addition, a development work is carried out with hydroacoustic studies (echo soundings and recordings) in parallel to develop other non-lethal methods for collecting stock data, which locate spatial distributions of fish stocks in the Kattegat Sea (SLU Aqua, 2011).

The evaluation shows that the protection areas and the use of selective gear in zones around the fully closed area have contributed to reducing fishing mortality by about 14% compared with 2007 (SLU Aqua 2011). The use of the no-take zone has benefited as well as a useful management practice by increasing the abundance and body size (Bergström *et al.*, 2016). Recruitment in the stock is unfortunately still very poor, despite the fact that there was new legislation to reduce the catch of cod. Over recent years, there have been numerous reports stating that the status of the cod in the wider is doing quite well in many areas, with the exception that the cod caught are smaller than 24 years ago and ICES (2017) encourages a cautious approach. Unfortunately, the regional improvement has not been reflected in the Kattegat Sea, according to ICES (ibid). About 17 years ago the cod quota in Kattegat was set at 852 tons, but since 2012, it has not been recommended to fish cod directly (ibid.). The quota is only for accidental catches, or bycatch of fisheries targeting other species; for example, whiting and haddock.

Cod in the Kattegat Sea is mainly taken as bycatch in the Norway Lobster (*Nephrops norvegicus*) fishery, which are fished by using demersal trawls such as, Swedish grid trawls. Where the rate of disposal has been high but constant between 2013 and 2015 (ICES 2017). Trawling for the Norway Lobster has actually has had an impact on mitigating the cod population. Cod is known to be traditionally caught alongside and illegal practices were discovered in 2015 for purposely catching the cod on fishing vessels (The Black Fish, 2015). This was done by modifying trawl nets by either detaching steel grids to create openings under the grid, or using chains to weigh down the opening of the net to make the fitted grid impractical (ibid.). An example is the demersal trawl, which is dragged on the seabed. In accordance to the European Parliament a field study was performed to compare similar adjacent marine ecosystems: the Kattegat Sea and Öresund Sea. It was concluded that due to different technical regulations there is much better performance of the cod stock in Öresund due to the absence of trawling (European Parliament 2010). Demersal trawling is what dominates the exploitation pattern in the Kattegat, despite that cod is not fished (ibid.). In Öresund, fish stocks are exploited by gill netting.

Conversely, in 2016, the discard rate declined, thus, the average discard rate between 2013 and 2015 was used for the catch advice from ICES (ibid.). International Council for the Exploration of Sea (ICES) concluded in an assessment, the "Advice on fishing opportunities, catch, and effort Greater North Sea European," that the cod stock development over time has improved since 2009 from a "historical low level" and the rate-level of mortality is still undetermined due to prominent variances between the catch data (discarded and landing data) and the total exclusions from the stock assessed within the model (ICES 2017).

3 Materials and Methodology

The material and methodological approach was divided into where and how sampling was performed, what material and programing was used to perform the numerical data in order to comprehend the logical perspective.

3.1 Study area

The Kattegat Sea is a bay-like sea basin in the southern Scandinavian region that is in the transition zone (Figure. 1) between the estuarine Baltic Sea and the more marine North Sea (Encyclopedia Britannica, 1998). It is part of the only gateway between the North Sea and the Baltic Sea. The Kattegat has a mean depth of 20 meters and the eastern region, which is closest to the Swedish coast; has larger depths compared to other parts of the Kattegat (Jonsson *et al*. 2016). The Kattegat Sea covers an area of 25,485 km^2, 220 km long, and varies in width from approximately 60 to 142 km (Encyclopedia Britannica, 1998). Because the salinity is higher than in the Baltic Sea, biodiversity is also higher (Carlsson, 1998). The Kattegat Sea has salty currents coming from the Jutland Coast that originate in the southern parts of the North Sea and German Bight (Jonsson *et al*. 2016). The flow coming from the North Sea to Kattegat Sea has saltier water and the Baltic Sea contributes with lower salinity water surfaces draining through by ways of the Great and Little Belt and Öresund (*ibid*). In addition, there are several freshwater tributaries: Rivers Gudenå, Grenå, Lagan, Nissan, Ätran, Viskan and Göta Älv. Vertical mixing in profound depths takes place by winds. This is due to the differences between the salinity coming from different flow directions, which creates stratification. At depths of 13 to 15 meters in the halocline, salinity can be 25 - 30 and reinforced in the summer by a thermocline (Ærtebjerg *et al.* 2003). The two sampling areas were at Vendelsöarna and Ringhals. Ringhals is a Swedish nuclear power plant with four reactors, two of which were built in the 1970s and two in the 1980s. Out of the four reactors there is only one boiling water reactor (R1) and three pressurized water reactors (R2, R3, R4) (Vattenfall 2017). It is situated on the Värö Peninsula in Varberg Municipality, approximately 60 km south of Gothenburg (Vattenfall 2017). Vendelsöarna is located a few km northeast of Ringhals. The sampling areas where the fish and temperature surveys were assessed have a good oxygen status and no harmful eutrophication status (Maria Jansson, pers. comm.). However, the areas have been disturbed by the long-term overfishing habits, initiating substantial depletion of many piscivorous fish, mainly gadoids (e.g., Atlantic Cod).

3.2 Fyke net sampling

Data were collected from 1976 to 2016 in a monitoring program to observe the annual changes in abundance of species and their trends, as well as temperatures throughout. When collecting the data, the abundance of the fish species were monitored using fish traps called fyke nets. Fyke nets are cone-shaped passive traps used for catching fish (Fig. 6). Fish swimming along the bottom encounter the net fence and get diverted into the trap. There are a series of funnels directing the fish into the trap until they end up in the last chamber, and when the net is pulled out, the fish are sorted out (Fig. 6). The Vendelsöarna zone is classified as a reference location in the Ringhals monitoring program and is studied as an area that is not affected by release of cooling water from the nuclear power plant (Andersson *et al*. 2016). The Vendelsöarna, as well as the Ringhals area, were sampled and compared in two different periods. One phase was in April beginning at waters below 12°C and the other in August (warm water), well above 12°C (ibid.). In doing so, cold water and warm water species could be monitored consistently (Andersson *et al*. 2016). Additionally, for this research the data from the International Bottom Trawl Survey (IBTS; catch per unit effort, CPUE was monitored as catch in numbers per trawl hauling hour) was used as an additional reference system for the Atlantic Cod in the Kattegat Sea. These data were used and compared with the results from what was caught with the fyke nets. The reason to use these data was because results and catch regarding cod is more accurate with IBTS than with a fyke net, while mesopredators are more representatively caught in fyke nets than in trawls. Other differences between the fyke net and trawl data is that the trawl data refer to the entire sea of Kattegat, while the fyke net data are referred to Ringhals and Vendelsöarna areas specifically. Also, the IBTS data (IBTS: data supplied by the International Council for Exploration of the Seas, ICES) were monitored during January/February that consisted Atlantic Cod from age group 1 and older (age 6) (ICES, 2016).

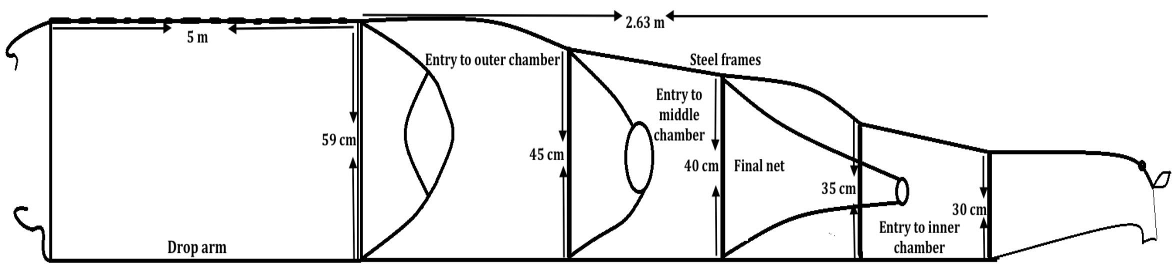

Figure. 5 A picture of the fyke net that was used for this research. It is composed of three sections: the arcs that make up the body are made up acid-resistant spring steel, the arm that guides the fish and finally the net that encloses the fish (Swedish Agency for Marine and Water Management, 2015). The network is made with 18 mm mesh size in arm and 11 mm in the outermost fish house. As for the yarn quality, a 210/12 braided knotless nylon is used. *Source: Swedish Agency for Marine and Water Management, 2015*

The Vendelsöarna, as well as the Ringhals area, were fished at six stations repeatedly twelve times (one night each) in each period (Andersson *et al*. 2016). From 1998 onwards, fishing efforts were reduced to nine days during each fishing period (Andersson *et al*. 2016). Each station involved two individual fyke nets located between 0 to 6 m depths. For the first fyke net, the “arm” was deployed closest to land. As for the second fyke net, the arm was connected to the edge of the inner chamber of the first net, so that both arms pointed towards the shore. The fish swim along the arm and are trapped in the fyke net chambers which is the tunnel closed at the end (Andersson *et al*. 2016). The fyke nets were fished at a straight angle from land. The average depth at the inner part of the net is 0.5 to 1 meter and 5 to 6 meter at the outer part (Andersson *et al*. 2016). The fyke nets were placed approximately at 10 a.m. and were collected at 10 a.m. the following day. At each station, bottom water temperatures were measured where each individual in the catch was measured in centimetres. Each individual in the catch was measured and checked for visible illness symptoms or injuries, and the weight was also recorded for each species at the station. If several individuals were caught from the same species, they were weighed together (Andersson *et al*. 2016). When fish were captured, measurements were made proximately from nose to tail and for crabs the width of carapax was accounted for measurement (Andersson *et al*. 2016). Each catch was registered as catch per unit effort (CPUE/catch in numbers per fyke net and night). In 1969 the Kattegat Sea was included in the survey trawl area by the ICES (ICES, 2016). Different trawls and tow durations varied through-out the years on commercial vessels (ibid). Recent survey carried annually since 2010, uses the same standard bottom trawl net type GOC-73 on a scientific fishery boat, tow duration and data collection (ibid). The biological data that was recorded were the weight, length, gender, mauturaity and classified the age groups (age 0 – 6) as well for the IBTS data (ibid).

3.3 Data treatment

The collected data was used for several analyses to track developments on the fish community and to determine, whether there are any differences between recipient and reference areas. The analysis for each different track was based primarily on the average number of fish per fyke net and IBTS haul; CPUE. Afterwards, data was transmitted to a Microsoft Excel Sheet 2011, where each data set was organized in accordance to each year. For all CPUE calculations, before transforming data into Natural Logarithm (Ln), the CPUE of each species for each year was multiplied by 1000. When it is a low CPUE, which was the case for the majority of the data, performing the Ln function, the outcome is negative. The purpose was to avoid any negative numeration for the R 3.0.1 program; otherwise it would have consistently classified it as an error. Hence, each CPUE was transformed into milliCPUE (this was also performed with the trawl data). With the ICES trawl data (note again that CPUE is defined differently than in the fyke net fishery); because there were different age groups (age: 0 – 6+) for the Atlantic Cod, the SUM function was used to add all age groups together. The statistical analysis software, Brodgar 2.7.4, was used to perform General Linear Models (GLM), which is similar to the Ln function for fitting linear models. A GLM determines if there were trends over time using a $p \leq 0.05$ significance level. Estimated trend lines through the residual points provide a visual support for discovering significant patterns, and denoting deviation from zero means. Implementing the R 3.0.1 program with Brodgar 2.7.4 completed this task. When performing the GLM procedure the probability distribution that was used for this analysis was Gaussian. Previously, when performing this analysis the Inverse Gaussian distribution was used with $1/mu^2$ link function, but results were a faliure. Results were unaccurate providong responses that were not intelligible. Therefore, the probability distributuion, Gaussian was used with the log link function. Ideally, graphs (residual vs. fitted plots) should have points scattered with no particular pattern, where the estimate states where it begins on the y-intercept. Another useful plot for diagnostic purposes is the Normal Q-Q plot. This plot should have a linear line, having points fall roughly along the line, indicating that the residual follow a normal distribution, but due to variability in marine biology it was decided that Normal Q-Q plot is not relevant for this research.

Equation (1):

$$Y \times 1000 = milliCPUE$$

where:

$\boldsymbol{Y}$ is the dependent variable; CPUE in this case

Afterwards, transforming milliCPUE into a Natural Logarithm (Ln) occurs in the following explanation:

If an exponential form is $y = b^x$, then the logarithm form is $x = log_b y$. A natural logarithm is a special type of logarithm, where a natural logarithm is logarithm with a base "e",

where:

$$e \approx 2.71828183....$$

If $y = e^x$, then $x = log_e y \rightarrow x = Ln\ (y)$ leading to the formula,

Equations (2):

$$log_e x = Ln(x)$$

3.4 Biophysical model

Data was tested (R 3.0.1 programming) using the general linear model (GLM) function using the univariate and multivariate relationship between environmental variable (temperature) and the CPUE Atlantic Cod as the explanatory variables versus the abundance of mesopredatory fish as the response variable. The GLM equation is described as the following:

Equation (3): $\mathrm{Y} = \beta_0\ \beta_1\mathrm{X} + e$

In the model, the variables are described as the following,

where:

- **Y** is the dependent variable; response
- $\boldsymbol{\beta_0}$ is the intercept
- $\boldsymbol{\beta_1}$ is the coefficient or slope
- **X** is the independent variable; explanatory
- $\boldsymbol{e}$ is error

The error terms and Y are assumed to be normally distributed, homoscedastic (the same variance at every X), and multiple univariate tests with the same design matrix. (PennState.edu, 2018).

Each figure demonstrates residual versus fitted plots using the GLM procedure. Naturally, each figure should have a straight line running through the dotted lines at zero value; however, due to variability in marine biology lines will not be completely straight. It is difficult to obtain complete accurate results in the field of marine biology because of its unpredictability, measurement uncertainties and large natural variability's. Therefore, it is important to perform as many experiments and collect as much data in different sections to obtain the optimal outcome of the research. For each plot, every point denotes for one day, where the x-axis entails the predicted response made by the model, in other words the fitted values and the y-axis is the accuracy of the prediction, the residual values (STATWING). Subsequently, the rule for observing these plots is by the following formula:

Equation (4):

Residual = Observed – Predicted

Where:

1. By indicating that the distance from the line at zero value is how accurate the prediction is.
2. Values at zero indicate that the predicted value is identical as the observed. However, there could be other errors, for example, sampling errors that can cause the observed value to be varying from the true value.
3. Values on the positive side of the plot imply that prediction was too low and
4. Vice versa (too high) for values on the negative side of the plot (STATWING).

Each plot should have the points as scattered as possible and no visual pattern. Indicating that these residual plots give no indication that assumption of our model is false, but our main interest was on the p-values that were obtained from these tests. In Figure. 6, is an example of a fitted versus residual plot from the attained results.

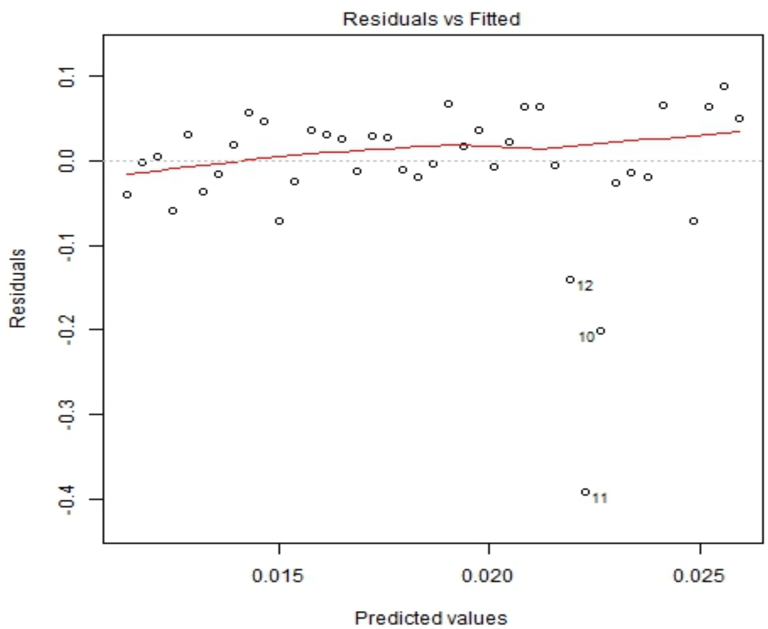

Figure. 6 Residual (year) versus Fitted (response) plot of a GLM containing temperature and Shore Crab CPUE at Vendelsöarna in April.

It tests the null hypothesis about the effects of other variables on the means of various groupings of a single dependant variable/s (IBM, 2013). The general ruling is based on whether the null hypothesis is supported or rejected. The null-hypothesis is no correlation between X and Y, for example, CPUE and temperature.
If the p-value is less or equal to 5% (0.05), the null hypothesis is rejected, which entails there is a correlation between X and Y.

4 Results

The aim of this research was to check the relative importance of the Atlantic Cod and temperature on mesopredators. The assumption was based on the hypothesis that mesopredator abundance is increasing based on potential trends throughout the years since 1976. If there is a connection to the increasing temperatures near Vendelsöarna and the Ringhals area (nuclear plant cooling water system) and climate change effects, as well as the decreased population of the Atlantic Cod.

4.1 Thermal Environment

Average sea temperatures were recorded at the bottom of the fyke net (0 to 6 m depth). At the Ringhals area, temperatures remained from 4.58 – 11.15 °C in April and 17.17 – 24.13 °C in August (Fig. 7). As for Vendelsöarna, temperatures ranged from 3.66 – 8.82 °C in April and 15.22 – 21.44°C in August. Thus, the average differences between the two locations are 2.38°C in April and 1.99°C for August. August Temperatures (Fig. 7b) have a trendline denoting a slight increase over time, but in April (Fig. 7a) there is a definite increase over time. What is also clearly shown in both scattered line graphs (August and April) is that temperatures are higher at Ringhals than at Vendelsöarna. As previously mentioned, temperatures in these waters around Ringhals, having nearby generating cooling water system from the nuclear power plants (see section 2.1) are considerably higher.

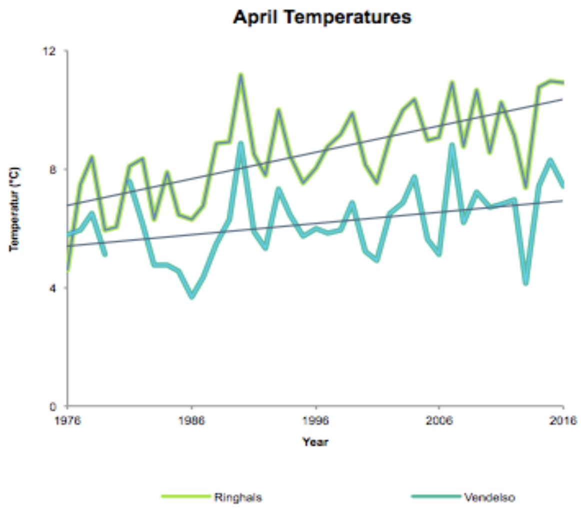

Figure. A

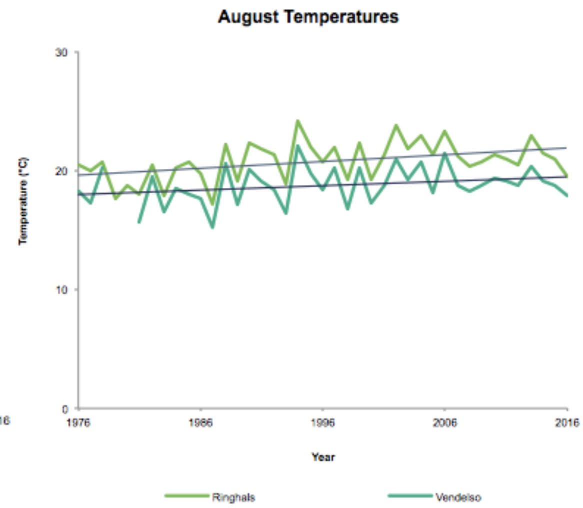

Figure. B

Figure. 7 The change in temperature from 1976 – 2016, both Ringhals and Vendelsöarna in (a) April and (b) August.

4.2 Mesopredator trends over the years

Figures 8 and 9 illustrates a generally higher abundance of Shore Crabs in comparison with other investigated mesopredators. Corkwing Wrasses is the second most abundant among the studied mesopredators throughout the years. However, its abundance remains lower in Vendelsöarna than at Ringhals. The same pattern can be observed for the abundance of the Shore Crab.

As for the Atlantic Cod, there is no indication of increased or decreased pattern in the graphs; however, it can be observed that at Vendelsöarna Atlantic Cod abundances are higher compared to Ringhals. For example, Ringhals has an average CPUE of 70 and Vendelsöarna has a CPUE of 182.7 in April. This is the same case as well for Goldsinny Wrasse and Black Goby. Goldsinny and Corkwing Wrasses vary during this season (April), but – as for Black Goby – continue to be particularly low compared to the rest of the mesopredators. It should be noticed that gaps in the graph indicate missing data, mainly if there was no catch on those days. For the year of 1980, however, no data was collected.

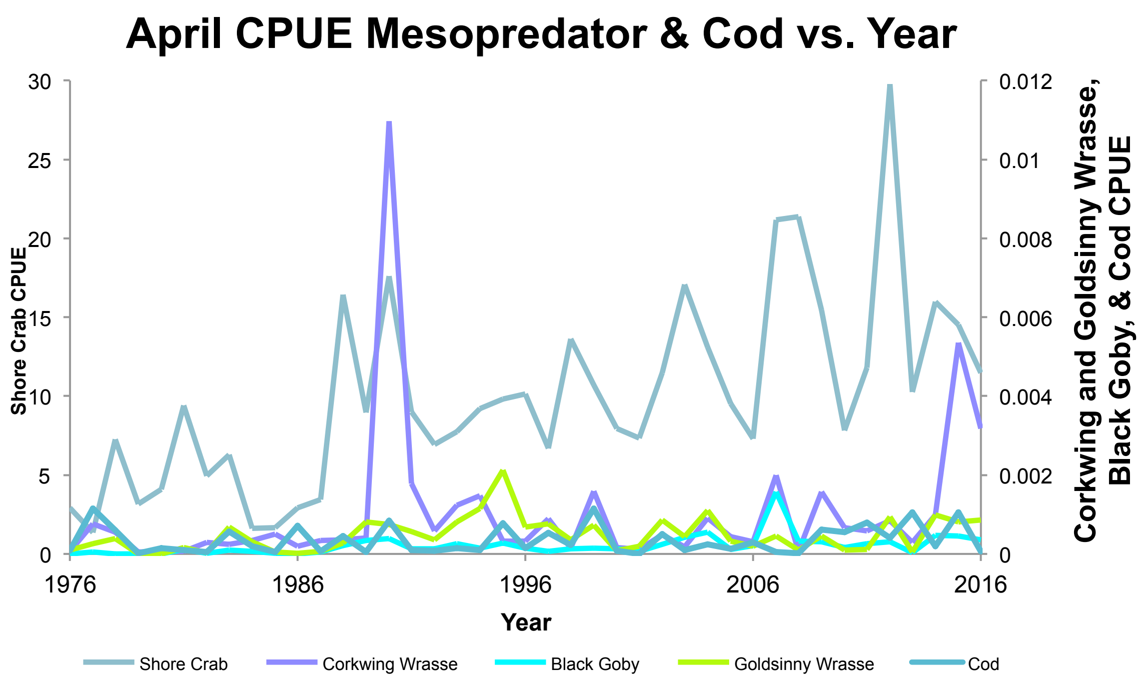

Figure. 8 The CPUE of each species is the response variable (y-axis) and the year is the explanatory variable (x-axis) in April at Ringhals. There are two axes representing different species due to large variations in the CPUE.

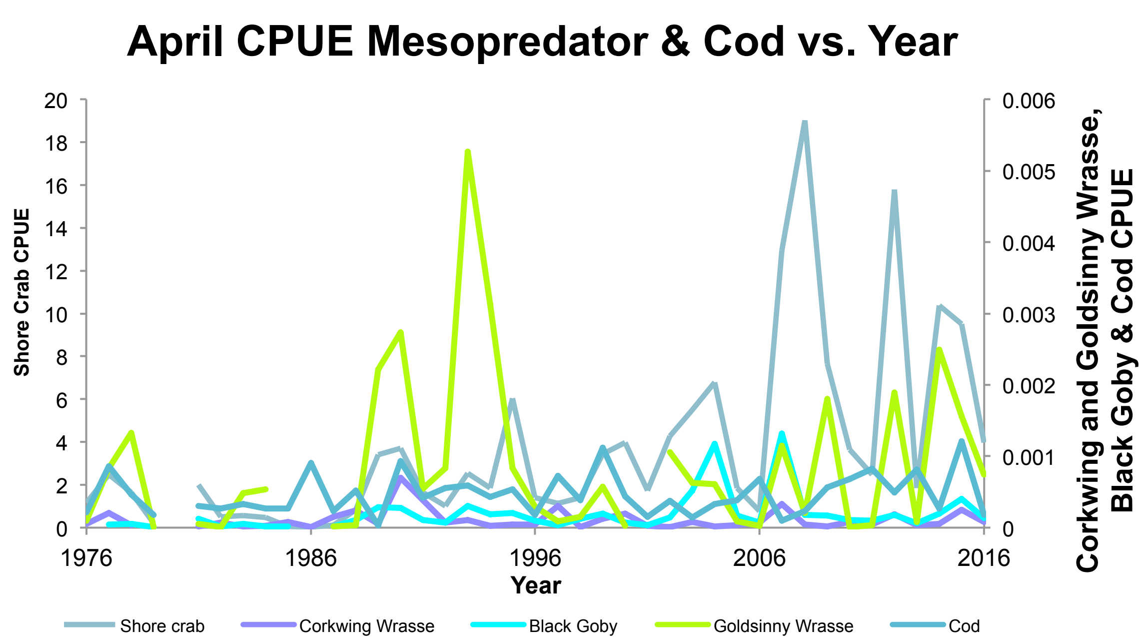

Figure. 9 The CPUE of each species is the response variable (y-axis) and the year is the explanatory variable (x-axis) in April at Vendelsöarna. There are two axes representing different species due to large variations in the CPUE.

As for August graphs (Fig. 11 & 12) there was an obviously lower abundance of Atlantic Cod at the Ringhals location during the summer time compared to Vendelsöarna. There have been also sudden increases in the mid 80s, 90s and early 2000s of Atlantic Cod at Vendelsöarna, which continued to have lower abundances throughout the years. The Shore Crab continued to have a higher abundance at both locations in August and Corkwing Wrasses had the second highest abundance. In Vendelsöarna, Black Goby had a very low CPUE; not noticeable in the line graph. The highest CPUE for Black Goby was 0.85 (catch in numbers per fykenet and night) in 2013 in Ringhals. As for Goldsinny Wrasse, there was a switch up where abundances are higher at Ringhals than at Vendelsöarna. Again, gaps in the line graph illustrate missing data due to no catches on that year or because data were not collectable.

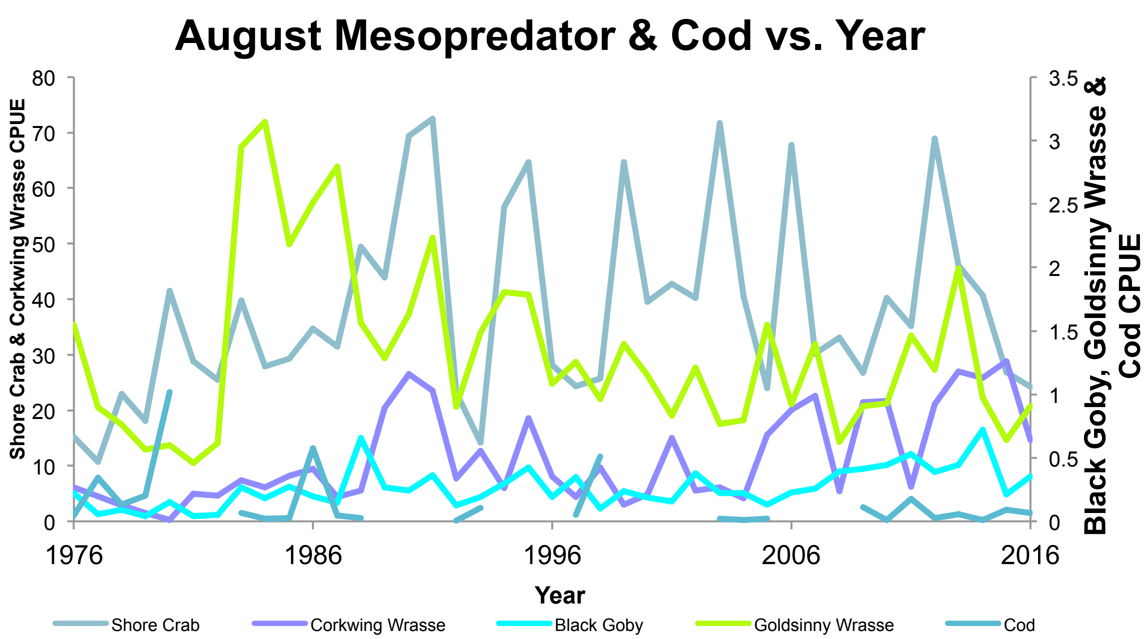

Figure. 10 The CPUE of each species is the response variable (y-axis) and the year is the explanatory variable (x-axis) in August at Ringhals. There are two axes representing different species due to large variations in the CPUE.

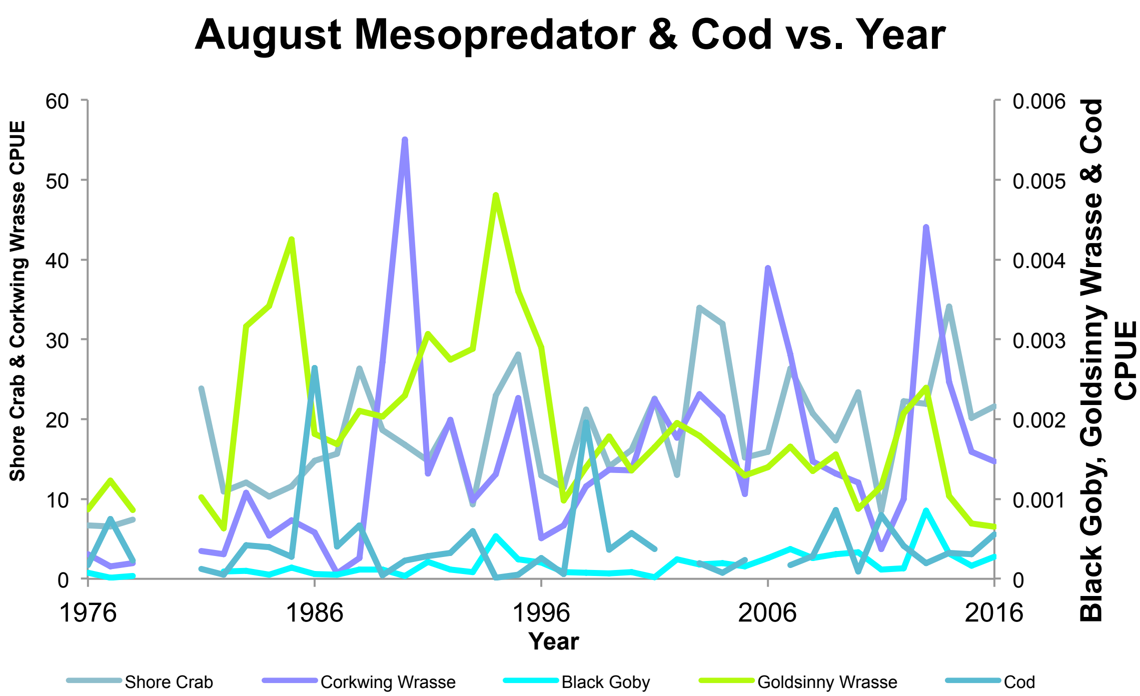

Figure. 11 The CPUE of each species is the response variable (y-axis) and the year is the explanatory variable (x-axis) in August at Vendelsöarna. There are two axes representing different species due to large variations in the CPUE.

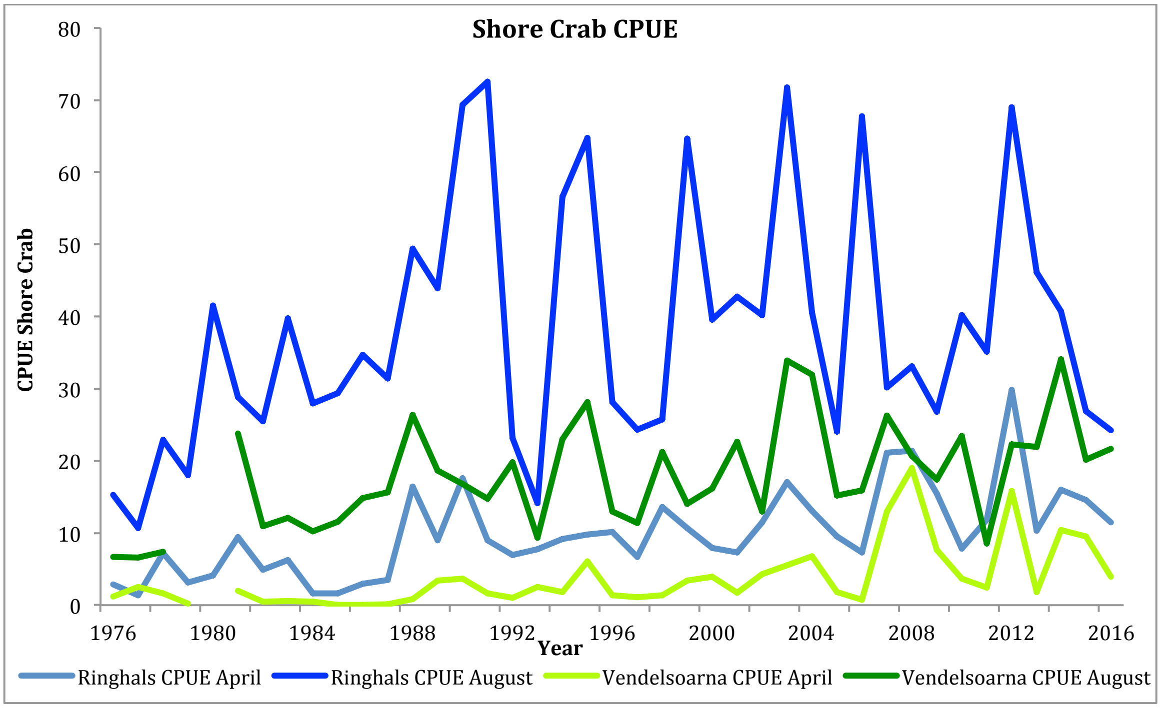

Figure. 12 CPUE of the European Shore Crab in April and August at Ringhals & Vendelsöarna.

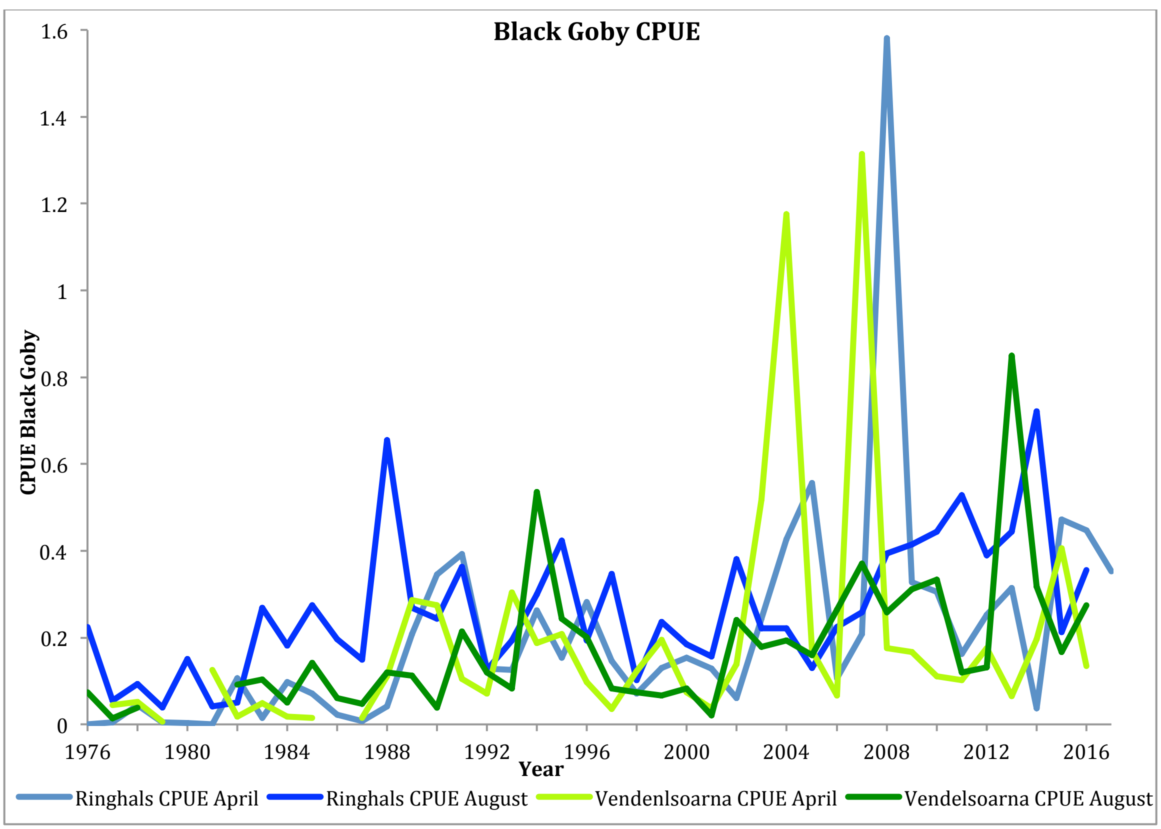

Figure. 13 CPUE of Black Goby in April and August at Ringhals & Vendelsöarna.

4.3 Trends and Associations

Atlantic Cod had only insignificant results (ns). Positive signs (+) indicate that there is a relationship between the response and explanatory variables (Atlantic Cod vs. year). The negative signs (-) implies a negative relationship; however, because of all the p-values being non-significant, Atlantic Cod is not increasing over time, nor was there a relationship between Atlantic Cod versus year. The ns signifies that there is inadequate evidence about the significance of the relationship between the variables. The p-value does not designate positive or negative relationship, but the level of confidence; the estimate value is what determines the negative or positive relationship. This pattern is also observed for Goldsinny Wrasse (ns) and a negative response during August at Vendelsöarna. This indicates that neither fish species is increasing over time. Although, Figure. 9 (April – Vendelsöarna) indicates otherwise, demonstrating that during the last decade Goldsinny Wrasse has increased slightly. Corkwing Wrasse yielded significant trends except for April - Vendelsöarna Table 1.). For Shore Crab and Black Goby trends were all significant (Table 1.) (except in August for Shore Crab), with the assumption that there is a general increase of these mesopredators throughout the years. The Black Goby significance can be compared with results from the previous figures. For example, Figure. 9 demonstrates that Black Goby abundance is very low compared to the other fish species. However, from observing the raw data that were collected and the results from the statistical analysis performed in the present study, Black Goby has indeed increased over the years in the catches. Due to its comparable lower abundance from the other mesopredators, independent graphs were designed to view its true abundance. It can also be viewed in Figure. 13, where Black Goby abundances are higher at Ringhals location compared to Vendelsöarna.

Table 1. The p-values of each species (response variable) versus the year (explanatory variable) from April and August both in Ringhals and Vendelsöarna. All Ln CPUE fish data were used for the statistical analysis. The signs of the trends ($+ or -$) are indicated for significant trends. ns: not significant, $*: p < 0.05$; $**: p < 0.01$; $***: p < 0.001$.

	April				August			
	Ringhals		Vendelsöarna		Ringhals		Vendelsöarna	
	P	**R²**	**P**	**R²**	**P**	**R²**	**P**	**R²**
Corkwing Wrasse	+*	0.151	ns	0.005	+**	0.315	+**	0.325
Goldsinny Wrasse	ns	0.090	ns	0.022	ns	0.015	-*	0.043
Shore Crab	+***	0.476	+***	0.364	ns	0.105	ns	0.299
Black Goby	+***	0.416	+***	0.283	+***	0.352	+***	0.386
Atlantic Cod	ns	0.035	ns	0.018	ns	0.08	ns	0.004

Positive significant values are an indication that there is a correlation between increasing temperatures and increasing mesopredator. As the explanatory variable temperature increases, the response variable (mesopredator) increases and as the Atlantic Cod decreases, mesopredator responds in a decreasing matter. Results obtained for the associations between temperature and Atlantic Cod versus Corkwing Wrasse were significant (Table 2 & 3.). Significant results were observed for Table 2., and in the month of April for Vendelsöarna (Table 3.); the rest of the values were insignificant. Although, for the month of August (Table 3.) the p-value was $p = - ***$ this indicated that the relationship is negative. This means that as Atlantic Cod decreases, mesopredator increases.

Goldsinny Wrasse has significant values in April and August temperatures at both locations, ($p \leq 0.001$), with the implication that Goldsinny Wrasses are increasing with increasing temperatures. With this statement being said, results for Shore Crab were all ($p = + ***$) and Black Goby as well, except ns in April – Ringhals and August – Vendelsöarna (Table 2.). Black Goby populations are higher in August than in April at Ringhals; this contrast can clearly be seen in Figure. 13. As for the comparison versus the Atlantic Cod (Table 3.), there were no non-significant (ns) results found. All were ($p = - ***$), except during the month of April – Ringhals ($p = + ***$) for Shore Crab and Black Goby. The results for Atlantic Cod (Table 2.)

demonstrate significant values; $(+)$ in April and $(-)$ values in August. As the temperature increases the Atlantic Cod decreases.

Table 2. The p-values of each species (response variable) versus temperatures (explanatory variable) from April and August both in Ringhals and Vendelsöarna. All Ln CPUE fish data were used for the statistical analysis. The signs of the correlations $(+\ or\ -)$ are indicated for significant trends. ns: not significant, $*: p < 0.05$; $**: p < 0.01$; $***: p < 0.001$.

	April				August			
	Ringhals		Vendelsöarna		Ringhals		Vendelsöarna	
	P	**R^2**	**P**	**R^2**	**P**	**R^2**	**P**	**R^2**
Corkwing Wrasse	+***	0.151	+***	0.099	+***	0.097	+***	0.137
Goldsinny Wrasse	+***	0.090	+**	0.248	+***	0.008	+***	0.006
Shore Crab	+***	0.476	+***	0.022	+***	0.232	+***	0.030
Black Goby	ns	0.416	+***	0.548	+***	0.236	ns	0.154
Atlantic Cod	+***	0.035	+***	4.723×10^{-5}	-***	0.316	-***	0.180

Table 3. The p-values of each mesopredator (response variable) versus Atlantic Cod (explanatory variable) from April and August both in Ringhals and Vendelsöarna. All Ln CPUE fish data were used for the statistical analysis. The signs of the correlations $(+\ or\ -)$ are indicated for significant trends. ns: not significant, $*: p < 0.05$; $**: p < 0.01$; $***: p < 0.001$.

	April				August			
	Ringhals		Vendelsöarna		Ringhals		Vendelsöarna	
	P	**R^2**	**P**	**R^2**	**P**	**R^2**	**P**	**R^2**
Corkwing Wrasse	+***	0.155	+***	0.021	-***	0.231	-***	0.039
Goldsinny Wrasse	+***	0.038	-**	0.0005	-***	0.033	-***	0.006
Shore Crab	+***	0.012	-***	0.002	-***	0.173	-***	0.042
Black Goby	+***	0.010	-***	0.0004	-***	0.178	-***	0.127

Another different series of statistical analysis tests (multivariate) were implemented to see if there was any significant association together between both Atlantic Cod and temperature versus mesopredator. It is imperative to perform these tests to gain a grasp of the situation, if both explanatory variables of Atlantic Cod and temperature play an important role together or not. Table 4 displays the results between Atlantic Cod and temperatures versus mesopredators. During April, only temperatures for Ringhals are significant for each mesopredator species; as well as for Vendelsöarna. As for the response towards the Atlantic Cod, all results came back insignificant ($p \geq 0.05$) for both locations, in the exception for Corkwing Wrasses in April – Ringhals ($p = +* \ \& \ +***$). Results for August, responses were all insignificant ($p \geq 0.05$), indicating there were no trends at all.

Table 4. The p-values of each mesopredator (response variable) versus both Atlantic Cod and temperature (explanatory variable) from April and August both in Ringhals and Vendelsöarna. All Ln CPUE fish data were used for the statistical analysis. The signs of the trends ($+ \ or \ -$) are indicated for significant trends. ns: not significant, $*: p < 0.05$; $**: p < 0.01$; $***: p < 0.001$.

	April				**August**			
	Ringhals		Vendelsöarna		Ringhals		Vendelsöarna	
	P	**R^2**	**P**	**R^2**	**P**	**R^2**	**P**	**R^2**
Corkwing Wrasse	+* & +***	0.512	ns & +*	0.142	ns & ns	0. 256	ns & ns	0.102
Goldsinny Wrasse	ns & +***	0.322	ns & +**	0.249	ns & ns	0.087	ns & ns	0.009
Shore Crab	ns & +***	0.520	ns & +***	0.492	ns & ns	0.209	ns & ns	0.061
Black Goby	ns & +***	0.599	ns & +***	0.560	ns & ns	0.277	ns & ns	0.314

As previously mentioned, the IBTS data was used to compare data with the fyke net data. Result for explanatory variable year vs. IBTS Atlantic Cod (trawl net data) was negatively significant ($p = -***$). This means that the Atlantic Cod abundance has sharply decreased throughout time. In Table 5., results of mesopredator (fyke net) versus Atlantic Cod (trawl net), Atlantic Cod (trawl net) vs. temperature (fyke net) show the following:

Table 5. The p-values of each mesopredator (response variable) versus Atlantic Cod (explanatory variable), Atlantic Cod vs. temperature from IBTS data collected during January/February. All Ln CPUE fish data were used for the statistical analysis. The signs of the trends ($+ \ or \ -$) are indicated for significant trends. ns: not significant, $*: p < 0.05; **: p < 0.01; ***: p < 0.001$.

	April				**August**			
	Ringhals		Vendelsöarna		Ringhals		Vendelsöarna	
	P	**R^2**	**P**	**R^2**	**P**	**R^2**	**P**	**R^2**
Corkwing Wrasse	-***	0.056	-*	0.002	-***	0.191	+***	0.119
Goldsinny Wrasse	-***	0.022	-**	0.059	+***	0.061	+***	0.036
Shore Crab	-***	0.190	-***	0.256	+***	0.0002	+***	0.093
Black Goby	-***	0.130	-***	0.116	-***	0.233	ns	0.314
IBTS Atlantic Cod vs. Temperature (explanatory)	-***	0.170	-***	0.111	-***	0.099	-***	0.064

As explained beforehand, the IBTS data only concerns with Atlantic Cod data during the months of January/February and refers to the entire Kattegat Sea; therefore, that is the why there is only one result for Atlantic Cod vs. year. For temperature (explanatory), both locations were negatively significant. The mesopredator vs. IBTS Atlantic Cod outcomes were also all significant, but only Goldsinny Wrasse in August for both locations and Shore Crab at Ringhals – August were ($p = +***$). This means when cod decreases, so does the mesopredator. Moreover, the multivariate analysis was also performed, since the IBTS cod-catch is more accurate. Although results came back more responsive; for example, Black Goby was significant and Shore Crab in April - Vendelsöarna. But, results were not strong either.

Table 6. The p-values of each mesopredator (response variable) versus both IBTS Atlantic Cod and temperature (explanatory variable) from April and August both in Ringhals and Vendelsöarna. All Ln CPUE fish data were used for the statistical analysis. The signs of the trends ($+ \ or \ -$) are indicated for significant trends. ns: not significant, $*: p < 0.05; **: p < 0.01; ***: p < 0.001$.

	April				August			
	Ringhals		Vendelsöarna		Ringhals		Vendelsöarna	
	P	R^2	P	R^2	P	R^2	P	R^2
Corkwing Wrasse	ns & +***	0.508	ns & +*	0.116	-* & ns	0.202	ns & +*	0.230
Goldsinny Wrasse	ns & +***	0.327	ns & +**	0.252	ns & ns	0.067	ns & ns	0.058
Shore Crab	ns & +***	0.540	-* & +***	0.059	ns & +**	0.230	ns & ns	0.107
Black Goby	ns & +***	0.659	ns & +***	0.595	-* & +*	-9.199	-*** & +*	0.421

Additional trend analysis was performed using year as the explanatory variable and temperature as the response variable. As predicted, there were positive (+) significant trends for both locations in both April and August. These results can be seen in Table 7.

Table 7. The p-values of each recorded temperatures from the bottom of fyke net (response variable) versus year (explanatory variable) from April and August both in Ringhals and Vendelsöarna. All temperature data were used for the statistical analysis. The signs of the trends ($+ \ or\ -$) are indicated for significant trends. ns: not significant, $*: p < 0.05$; $**: p < 0.01$; $***: p < 0.001$.

	April		August	
	P	R^2	P	R^2
Ringhals	+***	0.452	+**	0.173
Vendelsöarna	+*	0.136	+*	0.078

5 Discussion

5.1 Catch Per Unit Effort (CPUE) and Fitted vs. Residual Results

It is well established (André *et al*., 2016, Andersson *et al.,* 2016) that the North Sea's temperature is increasing and have increased of an estimate of 1.67 C° in the last 45 years (DW.com). This circumstance has also amplified a sudden peak of interest in nearby waters, essentially the Kattegat Sea, which is settled in the specific study areas of Vendelsöarna and Ringhals. From the results it is clear that there are marginally increasing temperatures over time (Fig. 7a & 7b.), as indicated by the trend-line. The average estimate increase for each month is 3.584 °C in April & 2.288 °C in August for Ringhals and 1.528 °C in April & 1.492 °C in August for Vendelsöarna. There is a clear indication that these increasing temperatures are more visible in the month of April (also August) and at the Ringhals location compared to Vendelsöarna. This can be explained feasibly by the presence of the nuclear power plant and its associated cooling water system in the area. Marginal increases in temperatures were also detected in Vendelsöarna. It is to be noted again that Vendelsöarna is not affected by cooling water. Established by the results for the extant of this study, April continues to display significant trends (Table 7.). Conversely, Eriksson *et al*. (2011) explains Vendelsöarna – August temperatures have "marginally significant trends" but not during April. The water temperature in Vendelsöarna in August resembles an approximate increase of a 0.5°C per decade (ibid). It is likely that significant temperature changes are more probable in April because of stronger winds during the spring circulation, while August is characterized by stratification (Rasmussen, 1995). Essentially, both locations demonstrated that there is a rise of sea temperatures over the years from the results. Aside from the presence of the nuclear power plant, another feasible explanation for the warmer temperatures is climate change. Worldwide, climate change is gradually increasing sea temperatures (HELCOM, 2007); and this also appears to be the case at the two investigated sites (Fig. 7). Environmental factors play an important role in the behaviour of marine species. Environmental variabilities, such as temperature, oxygen, salinity, wind and current, even time of day are these factors. Not only environmental variabilities play a role, but also the presence of predators. Since the collapse of the Atlantic Cod industry, it has come into favour for other marine species that are at lower trophic levels in the food web (Eriksson *et al*., 2011). Allowing their abundances to increase and move up in the food chain. It is not doubtful that overexploitation in the past had an effect on the mesopredator release effect. As explained in the equation, Y is dependent; therefore, the abundance during a specific year ahead is dependent on abundances from previous years.

From the results (Fig. 8 – 11), it can be observed that the Shore Crab has increased over the years during the months of April and August and at both locations

(Ringhals & Vendelsöarna). Conclusively, Shore Crab furthermore has the highest mesopredator abundance compared to others. Yet, there is also a clear indication (Fig. 7a & 7b) that higher temperatures come into favour for the Shore Crab. The indication suggests that Shore Crab abundances were higher during the month of August and at Ringhals from Fig. 12 and abundances remained higher than Atlantic Cod (Table 3.). However, from Table 5. there is a controversy with the IBTS Atlantic Cod, meaning that Shore Crab abundances were higher during April. Possible differences between the two locations are favouring factors supporting the fact that higher temperatures in the Ringhals zone fit to the nuclear power plan activity that surrounds the environment.

Figure. 12 shows how there's a clear difference between the two months at Ringhals and how high-temperature differences can come into favour for the Shore Crabs due to their high-adaptability mechanism. Results (Fig. 8 - 11) indicate that Corkwing Wrasse is the second most strongly increasing mesopredator, especially at Vendelsöarna during August (Fig. 11).

Goldsinny Wrasse displayed non-significant results (Table 1.). However, abundances remain higher compared to Atlantic Cod in August and interestingly in Vendelsöarna – April (Fig. 8 – 11 & Table 3.). The explanation for the insignificant results could be that Goldsinny Wrasse has increased slightly in the last couple of years, but not in greater amounts. Therefore, it is possible since Goldsinny Wrasse is "slightly" increasing (not in large abundances) p-values are not low enough for significant results. Goldsinny Wrasses have slower growth rates compared to other wrasses, but have a long life expectancy; this could explain the insignificant values. An interesting fact that wrasses, during the summer, are commonly spotted in beds of seaweed and during winter they occur in deeper waters. A fact is that "several species of wrasse (*Labridae*) are used as cleaner fish to remove salmon lice from farmed Atlantic salmon" (Skiftesvik *et al*., 2014). At low cost and a natural effective practice, there is a downside. Despite that there is a mutualistic relationship between the wrasses and lice from the skin of farmed salmon and reduces the use of pesticide that could be harmful for marine life. Fishing wildly these sea lice peckers (wrasses) has began to expend existing populations (Halvorsen *et al.*, 2017).

Fishermen may have spread their fishing grounds and performed their commercial fishing for wrasses in the area in recent years (Håkan Wennhage, pers. comm.). Although in this context it is worth repeating that wrasses CPUE tended to increase, or be stable over time. Comparing with Eriksson *et al.* (2011), wrasses and Shore Crab catches remained higher compared to other mesopredators as well as in August (5 - 20 X higher precisely) (Eriksson *et al.,* 2011).

The catchability of gobids is relatively low in fyke nets. There was a notable associated pattern for the results from the Black Goby. Results all came back significant versus explanatory variables, temperature and Atlantic Cod (Table 2. & Table 3.); except during April – Ringhals and August - Vendelsöarna (vs. explanatory variable, temperature). This remark is compatible with results from Eriksson *et al.* (2011). This observation supports furthermore a relationship with warmer temperatures and the Atlantic Cod. Black Goby can reproduce in multiple seasons, between May and August. Nevertheless, in the presence of Atlantic Cod, even for juveniles (age 2-3), which is the current dominating life stage in the Kattegat Sea area, it is difficult to build nests, demonstrating predator avoidance behaviour (Magnhagen, 1990). Thus, Black Goby populations were higher in August than in April at Ringhals (Fig. 13). This contrast is clearly displayed in Figure 13.

The ICES International Bottom Trawl Survey of demersal fish (Atlantic Cod) data in January/February was used to perform the GLM statistical analysis in Table 5. Distinctive pattern in the results for Atlantic Cod was discovered as well. During the month of April and August for Table 5. outcomes were (—) significant. As in Table 2. For the fyke net cod catch, results were significant as well, but with the signal that Atlantic Cod abundances decrease as temperature rise (August) and increase with lower temperatures (April). As for the IBTS cod-catchability there is a decreasing pattern. Temperature as the explanatory variable vs. IBTS Atlantic Cod do not support results in Eriksson et al. (2011). Environmental key factors, for example, temperature and season could explain the role of the Atlantic Cod. There is a definite pattern with the association of warmer temperatures, the Ringhals area and the Atlantic Cod. This could possibly verify that when temperatures are higher, especially at the Ringhals location due to the nuclear power plant - cooling water system raises sea temperature. As well as other statements concluded by previous studies performed in other related fields of interest, that the Atlantic Cod is not attracted to warm waters; especially during the summer season (Drinkwater, 2005; Andersen *et al*. 2009; Rose, 2009). It is assumed that due to higher temperatures in summer, Ringhals has a low CPUE of Atlantic Cod compared to Vendelsöarna. Cod is classified as a cold-water species. In the summer time, cod travel to lower depths where the water is colder to avoid warmer surfaces, or in general warm areas (Andersen *et al*. 2009). Abnormalities in temperature can cause an imbalance between the oxygen demand and supply (ibid.). In return, this effect can become lethal for the organism performance (Andersen *et al*. 2009). However, this is not the case in the investigated areas. According to a report by the Swedish Meteorological and Hydrological Institute (SMHI), the Kattegat Sea is classified as a "problem area" (Skogen *et al*. 2009). This means that the oxygen status is not stable. However, the SMHI report also states that the parameters of this study (Vendelsöarna and Ringhals) are classified as a "potential problem area" (ibid.), which means that the oxygen status is stable.

However, the oxygen content is stable in our study area (Maria Jansson, pers. comm.). Optimal temperatures for cod are between 3 to 15°C and 9 to 15°C for growth range (Andersen *et al*. 2009). Anything above will cause the cod to veer towards deeper waters, especially larger cod. Therefore, besides the overexploitation of Atlantic Cod, this variability in temperature could possibly partially explain the reasoning why juvenile cod abundances were higher than adult cod. Additionally, temperatures during August at both locations were at an average between 17 and 24°C, which is not optimal for the cod. Although results from the fyke net data did not significantly explain any variations throughout the years (Table 1.) This could, furthermore explain that cod abundances in fyke nets are continually low compared to mesopredators. Table 2. also suggests as temperatures in August for both locations increased, Atlantic Cod decreased; a negative correlation.

Table 3. also suggests significant trends versus mesopredators; however, during the month of April at Ringhals there was an interesting discovery of positive trends.

As for the fyke net data, the trawl data were compiled and used to perform the analysis if there were any strong associations between mesopredator vs. IBTS Atlantic Cod. Trawl data (Table 5.) demonstrated strong responses, same as fyke net data, although with slight differences. Positive significant correlation were discovered in Table 3. for April – Ringhals and vice versa in Table 5. The same can be said about IBTS Atlantic Cod versus temperatures. While there is a difference between the cod-catch in fyke nets and IBTS data. Offshore abundances of cod-catch is more accurate in IBTS data, thus trawl net data due to the differences between the nets. However, it is to be kept in mind that the IBTS data was collected during winter season (January/February), which is not comparable to the months of April and August. It is also to be noted, location accuracy plays an important function role in this analysis. Conversely, the accuracy of locations is different between fyke net and trawl data because fyke nets as previously mentioned is in reference to the exact locations of this present study, Ringhals and Vendelsöarna. Data was collected separately for Ringhals location and is not considered in the IBTS. As hypothesized, Ringhals location was classified as a particular situation due to the effects of the nuclear power plant. IBTS data represents the entire Kattegat, including Vendelsöarna. It can be said that the high temperatures at Ringhals can furthermore define the hypothesis that temperature is the main environmental driving force playing a key role of where these marine species migrate. Moreover, mesopredatory fish migrate to areas where there is favourable habitat quality and is encouragingly associated to the abundance of piscivores.

The association between Atlantic Cod and temperature versus mesopredator (Table 4 & 6), as mentioned previously demonstrated that there was in fact no strong observed association between the two. For the month of August, the insignificant results could represent the fact that during August, temperatures are warmer compared to April. While, results are not that all different, there was somewhat stronger results using the IBTS data for the multivariate analysis compared to Table 4. This included that Black Goby and Shore Crab have a relationship with the explanatory variables Atlantic Cod and temperature. However, even though using the IBTS cod data like how Eriksson *et al.* (2011) used in their research, Table 6 results do not assemble with their research, which had strong significance association between the explanatory variables Atlantic Cod and temperature vs. mesopredator. Additionally, as mentioned before, there is a difference between our studies. The present study had access to longer time series, which demonstrates the true variance throughout time.

5.2 Rationalization

Indications from this current study suggest that Atlantic Cod abundances are still continuously low in the Kattegat Sea. ($p \leq 0.05$ for trends; also see Figures 8 – 11). Marginal slopes viewed in Figures 8 - 11 are normal in the sense of the unpredictability of marine biology. There will be sudden increases due to unexpected favouring conditions, for instance, a drop in temperature during a specific term of the season. Indications from an assessment of the ICES (2017) states that the Spawning Stock Biomass (SSB) of cod has increased since 2012, and the possibility that mortality rates have declined extensively since 2008 in Kattegat. However, "the increase in SSB should be considered in the historical light of the much higher SSB seen in the 1970s" (ICES 2017). Although seltra trawls have benefited with reducing the discard rates of cod, ICES leans more towards in the disagreement about how positive the trends are. Some analysts interpret data as if some spawning biomass had improved dramatically and increased fishing could be allowed. According to ICES, if and when the "precautionary approach is applied, catches in 2018 should be no more than 772 tonnes" (ICES 2017). New precautious measurements have to be considered for new marine management plans. Special attention should be placed in the Ringhals area. Despite the fact that the Ringhals nuclear power plant reactors R3 and R4 have been planned to be decommissioned into the 2040s, much can occur during that time period. Even though the current oxygen status is stable, cautious measures are to be taken into consideration due to marginally increasing temperatures in both areas (Vendelsöarna is not affected by the warm waters coming from the nuclear reactors), especially in the Ringhals area. Temperature fluctuations can have great influence on an ecosystem. Figure. 14 show's what environmental factors, or elements could be affected by temperature. As there is an apparent mesopredator release effect in the present study areas, there are also similar coastal and littoral ecosystem statuses in nearby areas such as, the Swedish Baltic Sea and the Atlantic Coast.

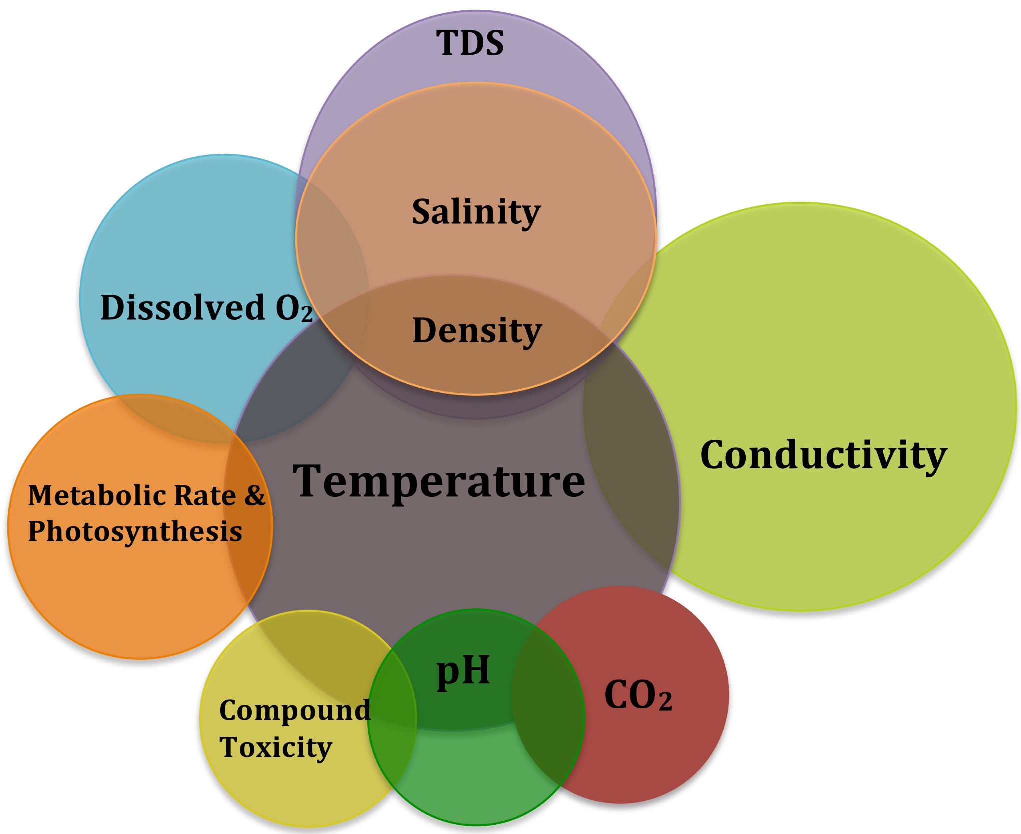

Figure. 14 Temperature as the center mechanism, which can have an effect on each surrounding bubble. If a bubble is merged with another bubble this implies that there is a relationship between. TDS stands for total dissolved solids.

There is a strong connection between the effect of the warm water emissions from the power plant and climate change effect, and the decreased abundance of Atlantic Cod. The diversity of the fish community has developed differently in the two areas during the cold season, as Ringhals shows a decrease in diversity, where warm water species have been observed in the recipient area and Vendelsöarna is stable (Andersson *et al*. 2016). This is an indication that the Ringhals nuclear power plant zone with the cooling water systems does indeed have an association with these occurrences in abundances. Also, while Eriksson *et al.* states that together with increasing sea temperatures and decreased predation pressure by Atlantic Cod contributed to the increase of mesopredator abundance along the coast (Eriksson *et al.,* 2011). Moreover, there are also other threats in the other parts of the Kattegat that have the possibility to develop in the area of interest in this filed study, including: oxygen depletion, new developing invasive species [eg., *Hemigraspus sanguineus* (Asian Shore Crab)], eutrophication and hazardous substances and cascading effects causing algal blooms (Skogen *et al.,* 2009 and SLU Aqua, 2011). By performing this assessment, it is clear that collaboration between respective authorities and interested communities is important. Regular comprehensive evaluation testing for fish in the Kattegat for stock analyses, the Sea Fisheries Laboratory in cooperation with DTU Aqua, Swedish and Danish professional fishing are continually managing cod quotas to improve their abundances and size, and avoid bycatch. An important fact is the "discrepancy between stock assessment values and our Ln-CPUE estimates suggests that in order to better understand the dynamics of fish stocks, biomass estimation should be performed at regional and local scales and implemented using as many data sets as possible" (Casini *et al*. 2005).

6 Conclusion and Outlook

Since the collapse of the Kattegat cod stock in the 1970s (ICES, 2016), there has been an increase in interest pertaining to how this event has affected the ecosystem. In recent years, many studies have been published concerning the effect of this event on biological populations (Eriksson *et. al*., 2011), showing a strong correlation between mesopredator and Atlantic Cod populations. Though there was a visual on the analysis of the unvariate regression between IBTS and fyke net data collected by our group between mesopredator and Atlantic Cod populations; observations from Table 1. illustrated no trends of Atlantic Cod increasing over the years. Correlations suggest that the decrease in population size are currently being caused by other factors that are not associated with the overexploitation in the past. However, it is not to be ignored that the past overexploitation of the cod did have an effect on the ecosystem (eg. food chain/cascading effects) and the cod population itself.

This constant cause may be because of the increasing sea temperatures. Due to rising sea temperatures, the diel vertical migration behaviour is becoming common among smaller cod (Rose, 2009). During the winter season, these migrations consist of both larger and smaller fishes; however, during summer, the migration of smaller fishes becomes more abundant. Such a shift in equilibrium seems to be detrimental for local populations like those in the Kattegat Sea, causing larger cod to travel deeper into non-vegetated rocky bottoms and sandy environments (Freitas *et al*. 2015). This suggests that that Atlantic Cod is forced into a trade-off of food availability versus satisfying temperature environments. It has been discovered that Atlantic Cod thrive when temperatures are between 3 to 15°C, which was not the case during August, particularly at Ringhals. Noticeably, there is a different status/significance from the findings of Eriksson *et al.* and those presented in this study. We have found a stronger association between decreasing Atlantic Cod population size with increasing temperatures, especially in the Ringhals area. Such rapid increase in mesopredator populations, can force sudden changes in the structure of ecosystems as these animals assume new roles and greater influences, the “mesopredator release effect.”

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