

Master's thesis



Impacts of area-based management on the  
population of northern shrimp, *Pandalus*  
*borealis* (Krøyer, 1838), in Isfjorden and  
Kongsfjorden, Svalbard

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*Impacts of area-based management on the population of northern shrimp, Pandalus borealis (Krøyer, 1838), in Isfjorden and Kongsfjorden, Svalbard.*

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## **Declaration**

I hereby confirm that I am the sole author of this thesis and it is a product of my own academic research.

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Anne Kirstine D. Andersen

# Abstract

The Svalbard shelf is identified as one of the chief fishing grounds for the Barents Sea shrimp fishery. While Kongsfjorden has been closed to commercial trawling in order to protect the scientific interests of the area, commercial harvesting continues in Isfjorden. In this study, trawl catches and population structure distributions of northern shrimp (*Pandalus borealis*) were analyzed in an investigation into the impacts of the different management strategies of the two fjords. Additionally, potential predation pressure was explored through abundance estimates of shrimp predators at various locations within the fjords. Stomach contents analysis identified the main predators, namely Atlantic cod (*Gadus morhua*), Greenland halibut (*Reinhardtius hippoglossoides*) and large polar cod (*Boreogadus saida*), but, with the exception of polar cod, there were no significant difference in abundance of these predators between fjords. Mix 3.0 modal analysis of length frequency distributions revealed no clear difference in growth or age at first female maturity between the fjords. However, shrimp in inner Isfjorden, where bottom temperatures are generally lower, exhibited a slight increase in age at female maturity, suggesting reduced growth rates. Generally, there were greater differences in population structure and abundances of both shrimp and predators within the fjords than between them. These results indicate that trawling has no significant effect on the distribution, abundance or population size structure of the shrimp. Instead, heterogeneity in shrimp population structure within each fjord suggested that shrimp utilize different subhabitats at different life stages. Further understanding of such preferences would be useful in the management of the shrimp fishery on the Svalbard shelf.



*This work is dedicated to my little brother  
Who followed me in spirit through every step of this project  
May you rest in peace*





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# Acronyms

ANOVA – Analysis of Variance

CL – Carapace length

CTD – Conductivity, temperature, depth/density

df – Degrees of freedom

EEZ – Exclusive economic zone

ICES – International Council for the Exploration of the Sea

IUCN – International Union for the Conservation of Nature

IMR – Institute of Marine Research

LFD – Length frequency distribution

MPA – Marine protected area

NAFO – Northwest Atlantic Fisheries Organization

NEA cod – Northeast arctic cod

NIPAG – NAFO/ICES *Pandalus* Assessment Group

nm – Nautical mile

NOK – Norwegian krone

PINRO – Polar Research Institute of Marine Fisheries and Oceanography

R/V – Research Vessel

RAPD – Random Amplified Polymorphic DNA

SA – Subarea

SD – Standard deviation

SE – Standard error

UiT – University in Tromsø

UNIS – University Centre in Svalbard





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# 1 Introduction

## 1.1 Background

Marine protected areas have been shown to have substantial positive effects on ecosystems and fisheries in tropical and sub-tropical locations. Notably, such positive effects include increased biodiversity, recovery of depleted fish populations and reduction in physical disturbance by fishing gear (Palumbi, 2001; Russ and Alcala, 2003; Kaiser *et al.*, 2006; Asch and Collie, 2008). However, there is less clear evidence of positive effects of protected areas in Arctic and temperate waters, where seasonal migration of fish species are often observed (Beare *et al.*, 2013). Large-scale closures on Georges Bank in New England have been effective in the recovery of sedentary demersal assemblage of fish (primarily flounders and skates) and bivalve molluscs, but less so for migratory species, such as cod and haddock (Murawski *et al.*, 2000). On the other hand, closing the nursery grounds of plaice (*Pleuronectes platessa*) in the North Sea was deemed an ineffective management strategy for reducing discards of juvenile plaice and increasing biomass of the stock. Since the closure in 1995, the North Sea ecosystem has undergone changes, probably due to eutrophication and changes in temperature, resulting in juvenile plaice moving to deeper waters outside the designated protected area. Although beam trawl effort fell by 90% after the closure, juvenile growth rates of plaice decreased. Landings and total biomass of the stock in the area also declined, resulting in the initial support of the closure being lost from the fishing industry (Beare *et al.*, 2013). Such case studies highlight the importance of evaluating the effectiveness of protected areas against testable objectives and developing adaptive management of these. As such, positive effects may be optimized and conflict reduced.

Marine ecosystems are threatened by a number of factors, such as fisheries, invasive species, eutrophication and climate change. This highlights the need for improved understanding of the current state of systems in order to assess any long-term changes or short-term fluctuations. This has not been a priority in the Arctic, perhaps because the Arctic has typically been an area inaccessible to widespread human exploitation of marine resources, with the exception of the historic European whaling in the waters around

Svalbard (Hacquebord, 2001). There is currently an extensive fishery for northern shrimp (*Pandalus borealis*) on both the western and eastern coasts of Greenland (Hvingel, 2006), and off the coast of Alaska, despite reports of declining stocks (Armstrong et al., 1998; Aschan, 2013). The Svalbard shelf is one of the most important fishing grounds for shrimp in the Barents Sea and is, despite its northern location, an accessible area for conduction of research (Hvingel and Thangstad, 2012b). Investigations of the effects of shrimp fishing on the shrimp population have shown a change in population structure, with reduced proportions of large fecund females, and a subsequent adaptive response of earlier maturation, in the Gulf of Alaska (Charnov, 1981). So far, there have been no similar investigations into the effects of fishing on the population in the Barents Sea and around Svalbard.

Shrimp is the most abundant hyperbenthic invertebrate in the Barents Sea and Svalbard areas (Johannesen *et al.*, 2012a), and the most important shellfish resource in the North Atlantic (Garcia, 2007). It is not a migratory species, even though shrimp larvae travel pelagically with the currents (Aschan and Ingvaldsen, 2009), but they do move in response to local environmental cues. In the Gulf of Alaska, they have been suggested as a potential indicator species of climate change induced regime shifts due to their central position in the trophic structure of the ecosystem and their sensitivity to increasing bottom temperatures (Anderson, 2000). Shrimp hold a similar central position in the Barents Sea ecosystem and the population is surveyed annually (Aschan and Sunnanå, 1997). Predator-prey interactions have been extensively studied in the here, and it has been estimated that the main predator, Atlantic cod (*Gadus morhua*) consume a far greater biomass of shrimp than that caught in the fishery (Berenboim *et al.*, 2000). In several areas of the North Atlantic, there is an inverse relationship between the biomasses of shrimp and cod, attributed to predation (Worms and Myers, 2003; Jónsdóttir *et al.*, 2012, 2013). Predation also has the potential to influence the population size structure of shrimp. Where the fishery selectively targets the large specimens, predation will affect smaller individuals and juveniles. Thus, predation may directly influence recruitment of shrimp to the stock (Aschan and Ingvaldsen, 2009; Jónsdóttir *et al.*, 2012, 2013). Much is known about the biology and ecology of the northern shrimp in the North Atlantic and North Pacific (Shumway *et al.*, 1985; Bergstrom, 2000). However, little is known about what impacts protected areas and different management strategies may have on local Arctic ecology, as

protected areas have not been a management priority. Studying the effects on northern shrimp is an ideal way to investigate such impacts.

## **1.2 Svalbard**

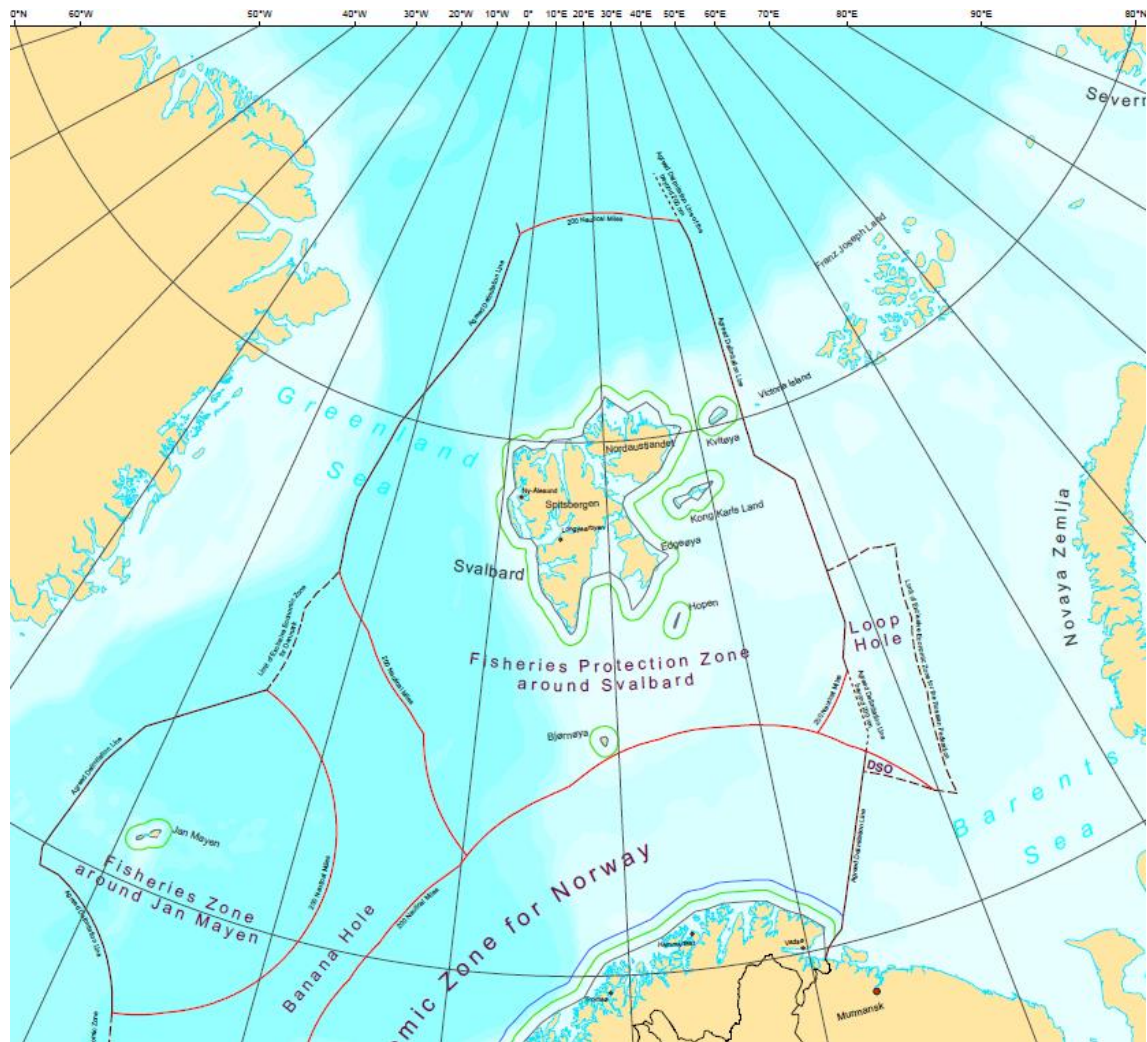
The Arctic archipelago of Svalbard in the northwestern corner of the Barents Sea, just south of the Arctic Ocean, is by many considered to be the most accessible islands in the high Arctic (Kaltenbom and Emmelin, 1993) and an ideal location for scientific study of Arctic ecosystems. The total area is just over 62 700 km<sup>2</sup> and its territorial waters extend 12 nautical miles offshore and comprise approximately 90 700km<sup>2</sup>. The Svalbard Treaty of 1920 gave Norway sovereignty of the islands, and an exclusive economic zone (EEZ), a 200 nautical mile Fisheries Protection zone, was established in 1977 to ensure Norwegian jurisdiction and authority of the area's living marine resources (Figure 1; Churchill and Ulfstein, 2011).

Management of Svalbard's territorial waters is area-based. Area-based management takes a global, cross-sectoral view and seeks to include and sustainably manage all aspects of a site, including ecological, environmental and socio-economic considerations. It is often considered to be the practical application of ecosystem-based management, which focuses on habitats and ecosystem integrity. The areas are often defined by ecological criteria and boundaries are clearly and formally defined. It will typically comprise of different management strategies, such as protected areas, areas for public leisure, temporary or permanent closures, and fishing areas, with the main purpose of ensuring sustainable use of the present resources (Baur *et al.*, 2013). One of the main objectives of management in Svalbard is for the islands to remain as virtually untouched by human impact, protect the vulnerable Arctic flora and fauna, and to promote scientific research of Arctic natural sciences. This is mainly achieved through regulation of public access and the establishment of nature reserves and national parks spanning both marine and terrestrial areas. The Governor is the highest authority on the archipelago and responsible for enforcing these regulations (Churchill and Ulfstein, 2011).

In the same area, there is an international commercial fishery for the northern shrimp. The Barents Sea and Svalbard shrimp fishery has been declining since its peak in the 1980's, but the Svalbard shelf is still one of the main fishing grounds and is targeted by Norwegian, Russian and other European vessels (Hvingel and Thangstad, 2012b) In spite

of the great protective coverage of this territorial sea, trawling for shrimp is permitted within the nature reserves and national parks at depths greater than 100 meters (Reeves, 2000; Forskrift om naturreservater på Svalbard, 1973). No commercial fishery for other species is allowed within the territorial waters of Svalbard.

*Figure 1: Map showing the location of Svalbard in the Barents Sea, its territorial waters (green) and the Svalbard Fisheries Protection Zone (red; Norwegian Military Geographic Service).*



The small research community of Ny-Ålesund is situated in Kongsfjorden, on the northwest corner of Spitsbergen island. It is highly valued as a reference site for research into various disciplines of Arctic earth and marine sciences (Hop *et al.* 2002). The fjord has been closed to commercial trawling since 2002, at which point sonar imageries had already revealed the physical impacts of shrimp trawling in the outer fjord (Shears *et al.*,

1998). A regulation from 2007 strengthened this fishing ban and acknowledged the scientific importance of the area (Forskrift om fiskeaktivitet i Kongsfjorden, 2007), resolving the ongoing conflict between the scientific institutions and the fishery.

Since the fishing ban, no commercial activities have taken place in the fjord. The rationale for the closure was not to protect or replenish a commercial species or habitat, but to ensure an untouched environment in which to conduct scientific research. Although a review is available on the extent of the knowledge of the ecosystem at the time of the closure (Hop *et al.*, 2002), the potential effects of the closure on the ecosystem have not yet been studied. Understanding the impacts of a protected area in the Arctic on a commercially important species, such as shrimp, will not just be useful in the management of similar areas around Svalbard, but may also be extrapolated to other areas off the coast of Greenland and Alaska, where fishing pressure is more intense (Armstrong *et al.*, 1998; Hvingel, 2006; Hvingel and Thangstad, 2012b). Comparing the population in a protected area to that of a nearby fjord, frequented by commercial shrimp trawlers (Hvingel and Thangstad, 2012b), will provide valuable insights into the impacts of both management strategies.

## **1.3 The study**

### **1.3.1 Purpose**

The main purpose of the study was to gain insight and new information regarding the effects of different management strategies, or lack thereof, on the population of the northern shrimp in two fjords in Svalbard. Isfjorden has been open to commercial harvesting with bottom trawls since the 1970s (Garcia, 2007), whereas Kongsfjorden has been closed to commercial trawling activities since 2002 (Forskrift om fiskeaktivitet i Kongsfjorden, 2007). The primary goal was to investigate the effects of trawling and protection on the population by comparing biomass and population size and stage structure of the two fjords. Predator data was also considered to gain a better understanding of the shrimp ecology in the fjords, and perhaps investigate a potential structuring mechanism of the shrimp population. The extensive study of both fjords both assesses the current status of the population, and provides the basis for future studies on the effects of protected areas in the Arctic.

### **1.3.2 Research approach**

The approaches taken to meet the main objectives of this study were:

1. To investigate differences in biomass and population size structure of shrimp between the fjords.
2. To investigate spatial variability of biomass and population size structure of shrimp within the fjords.
3. To model the mean length and proportions of year classes of shrimp to investigate spatial differences in age distribution and growth.
4. To investigate the length and age at which the female shrimp reach maturity and describe potential spatial variability.
5. To identify the main predators of shrimp present in the fjords and investigate if abundance and, thus, predation pressure might differ between the fjords.
6. To investigate if there are any correlations between environmental parameters, such as bottom temperature, salinity and depth, and biomass of shrimp and abundance of predators

To meet the objectives, bottom trawl data from various locations within the two fjords were analyzed on two research cruises in August and September, 2013. The trawl catches were sorted and weighed, and subsamples of shrimp and polar cod, where applicable, were taken. Shrimp biomass, carapace length frequency distributions, and life stage data formed the basis of the statistical analyses. Stomach contents of larger fish were analyzed to identify the potential predators of shrimp and their abundances estimated.

### **1.3.3 Possible scenarios**

Predicting the effects of trawling compared to an area of closure is not straightforward due to the complexity of shrimp ecology and the heterogeneity of hydrographical conditions in the study area (Cottier *et al.*, 2005, 2007). However, three possible scenarios were envisioned. Firstly, if fishing removes large quantities of shrimp from Isfjorden, a reduction in mean biomass at stations might be expected. Further, by selectively targeting larger fecund females, fishing may result in a size and sex structure skewed towards smaller females and males, and perhaps an adaptive response by reducing length at first female maturity (Charnov, 1981). In this scenario, the protected Kongsfjorden would be expected to harbor greater biomass and larger specimens of shrimp. A second scenario



would involve the removal of both shrimp and their predators (in bycatch). Predators target a greater size range of shrimp, and particularly the smaller size classes than the fishery (Aschan and Ingvaldsen, 2009). In this scenario, the population structure would remain unaltered, or perhaps even skewed toward larger individuals. The biomass might remain unchanged or reduced compared to Kongsfjorden. The third scenario proposed that trawling pressure in Isfjorden would be insufficient to obviously impact the population, or that it had unpredicted compensatory artifacts, resulting in complex effects. It has, in fact, been shown that the decapod community in Isfjorden has remained remarkably stable over the past century, which has at least partly been attributed to persistency and resistance to changes (Berge *et al.*, 2009).

### **1.3.4 Scope and limitations**

The project covered bottom trawl stations in Isfjorden and Kongsfjorden in the fall season of 2013 and its conclusions were, thus, limited to this time frame. The seasonal cycles greatly influence the life history and spawning stages of the shrimp, which comprised part of the analysis. Thus, investigations undertaken in different seasons may not be directly comparable. Studying the population in the fall is beneficial when assessing year-classes as the youngest year class will have settled at the bottom and can be sampled by the trawl at this time of year (by a juvenile net; Aschan and Sunnanå, 1997). The project aimed at investigating the current state of the shrimp population, but could make any assessments of temporal changes. Nor was there available data with the appropriate spatial resolution for comparison of Kongsfjorden before and after protection. However, there is some published literature on the ecosystem in Kongsfjorden (Hop *et al.*, 2002) and the shrimp population in the Barents Sea (Aschan, 2000) and around Svalbard (Hansen and Aschan, 2000), which will allow for some comparison and indication of temporal changes. Sampling was limited by the accessibility of the trawl gear, probably resulting in areas not receiving equal representation. Although other methods exist for catching shrimp, the bottom trawl is the main method of surveying around Svalbard and in the Barents Sea (Aschan and Sunnanå, 1997).

### **1.3.5 Organization of the thesis**

This project is presented in a total of six chapters. The first two, the introduction and theoretical overview, will provide the necessary background and current state of knowledge, as well as highlight the main knowledge gaps. The methods and statistical analyses are presented in chapter three, along with suggestions on how to improve upon the chosen methodology. The results are presented in chapter four, before being discussed in chapter five. Concluding remarks are provided in chapter six.

## **2 Theoretical Overview**

### **2.1 Protected areas and area-based management**

#### **2.1.1 Definitions and effectiveness**

Area-based management is said to be the practical application of ecosystem-based management, with the main purpose of ensuring sustainable use of the renewable and non-renewable resources. It will typically comprise of different management strategies, such as protected areas, temporary or permanent closures and fishing areas (Baur *et al.*, 2013). Sustainably managing the commercial fisheries has become a priority as many of the world's fish stocks are depleted or in decline (Pauly *et al.*, 2002). Further, marine fisheries have been identified as the most important factor adversely impacting ecosystems and habitats (Halpern *et al.*, 2008). An important tool in the process of achieving this goal has been the implementation of marine protected areas (MPAs), whose intuitive logic and relative simplicity aims to restore and protect exploited stocks and valuable habitats (Palumbi, 2001; Pauly *et al.*, 2002).

Marine protected areas have been defined by the International Union for Conservation of Nature and Natural Resources (IUCN) as “a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.” This has been further resolved into management categories, ranging from strict nature reserves and wilderness areas to protected areas with sustainable use of natural resources (Day *et al.*, 2012). Their effectiveness can only be judged by how well they meet the set objectives, which generally fall into one of three categories; (1) enhancement of fisheries, (2) preserving ecosystem diversity, or (3) protection of a particular, crucial geographic area (Palumbi, 2001). Such objectives often conflict, particularly in areas where fisheries co-occur with vulnerable habitats. In such cases, trade-offs must be considered and effects continuously monitored and strategically evaluated in order to determine the best possible environmental and socioeconomic outcome (Dichmont *et al.*, 2013).

Changes in community structure and reduction in species richness due to extended physical disturbance by fishing gear has been well established (Murawski *et al.*, 2000; McConnaughey *et al.*, 2000; Kaiser *et al.*, 2006; Asch and Collie, 2008). The recovery of

impacted areas has also, in some cases, been documented. Asch and Collie (2008) found that the benthic fauna on Georges Bank in southern New England, U.S., took two years or more, but mostly recovered after a fishery closure. In the Philippines, the application and subsequent removal of no-take marine reserves on two small coral reef sites was investigated over a 17-year period and compared to two control sites. In total, 11 significant changes in density and biomass of predator fish were recorded, both after the closure and, subsequently, when the protection was removed. Four out of eight increases in density were recorded after the marine reserve status was applied, with three of these requiring 4-6 years of protection. Three significant declines were also observed, all of which occurred after protection was removed. Lastly, two unexpected increases were observed in the non-reserve areas, and suggested explanations for these included (1) a more stringent management plan for the area or (2) a spill-over effect from the nearby reserve (Russ and Alcala, 2003).

Besides marine reserves, national parks and permanent closures, area-based management employs other tools which offer some form of protection of an area. Examples include zoning and temporary closures, which are more widely used in the management of the fisheries sector (Pauly *et al.*, 2002). They may be introduced as a management measure for stationary stocks (such as lobster or seaweed), to protect spawning or juvenile fish, to rebuild a depleted stock, or to protect small-scale fisheries from the competition of large trawlers. Such areas may not have been established with the MPA model in mind, but will provide some level of protection to particular species or habitats (Palumbi, 2001). However, temporary closures do not always meet their set of objectives. For example, seasonal closures on Georges Bank were proven ineffective at protecting the residing ground fish stocks. In 1994, on the other hand, year-round closures of haddock spawning grounds and yellowtail flounder distribution were implemented, and the effects were investigated by Murawski *et al.* (2000). Five years later, these closures were found to provide good protection of the sedentary fishes, whose stock size began recovering. Migratory fish species, such as Atlantic cod and haddock, benefited less directly, but still observed reductions in fishing mortality rates. Further, in the absence of physical disturbance of their habitat, sea scallop (*Placopecten magellanicus*) biomass increased 14-fold and a restricted scallop fishery could be resumed as a result. Although, intuitively, permanent closures and MPAs are established in the belief that they will meet their set

objectives, no such positive effects should be assumed. For instance, the protected area termed the 'Plaice Box' in the North Sea was set up in order to protect juvenile plaice and reduce their bycatch in the flatfish fishery. However, due to ecosystem changes in the North Sea, primarily resulting from eutrophication and increases in bottom temperature, the juvenile plaice shifted to deeper and colder waters outside of the zone of protection. It was concluded that the 17-year long closure had been an ineffective management strategy, highlighting the importance of testing objectives and employing adaptive management in the implementation of such strategies (Beare *et al.*, 2013).

### **2.1.2 Protected areas in Norway**

Since 2011, all areas deeper than 1000 meters in the Norwegian exclusive economic zone (EEZ) have been closed to fishing with bottom gear to protect the potentially vulnerable deep-sea habitats (Forskrift om fiske med bunnredskap i NØS mv, 2011). These comprise a total area about 800 000 km<sup>2</sup> and 38% of the EEZ. The Barents Sea, on the other hand, a continental shelf sea extending beyond the jurisdiction of the Norwegian EEZ, does not have areas protected through this regulation. Here, methods of protection and regulation primarily involve quotas established through international agreements and real time closures of areas to protect juveniles or spawning individuals of commercially important species (Reithe *et al.*, 2004). For instance, when the bycatch of juveniles in one fishery exceeds a critical number, the relevant area is temporarily closed through resolutions passed by the Directorate of Fisheries (Norwegian Directorate of Fisheries, 05.04.13).

Assessments of effectiveness of protected areas and closures using control sites in the north are sparse, but some protected areas in southeastern Norway have been evaluated in terms of their protection of European lobster (*Homarus gammarus*), which has been on the IUCN red list since 2006. Moland *et al.* (2013) investigated the ecological effects of small-scale protected area gear restriction on European lobster and Atlantic cod using a before-after control-impact (BACI) study design. The design involves examining an area before and after an impact, as well as comparing this impact site to a control site. The results showed that, in addition to catch-per-unit-effort and mean size of lobster increasing by 245% and 87%, respectively, in four years, population density and mean length of cod also increased significantly within the protected areas. As well as reporting on these significant results, the authors focused on the great variation of population development between both

individual MPA-sites and control areas. Thus, they concluded that seemingly similar systems produce an inexplicable heterogeneity of protective effects that highlight the need for scientific studies on the topic. This supports the impression that lack of ecological understanding of unique conditions at each site, be it environmental parameters, human extraction of resources, ecological history, or protective measures, poses a significant challenge for comparing sites and predicting outcomes of management strategies.

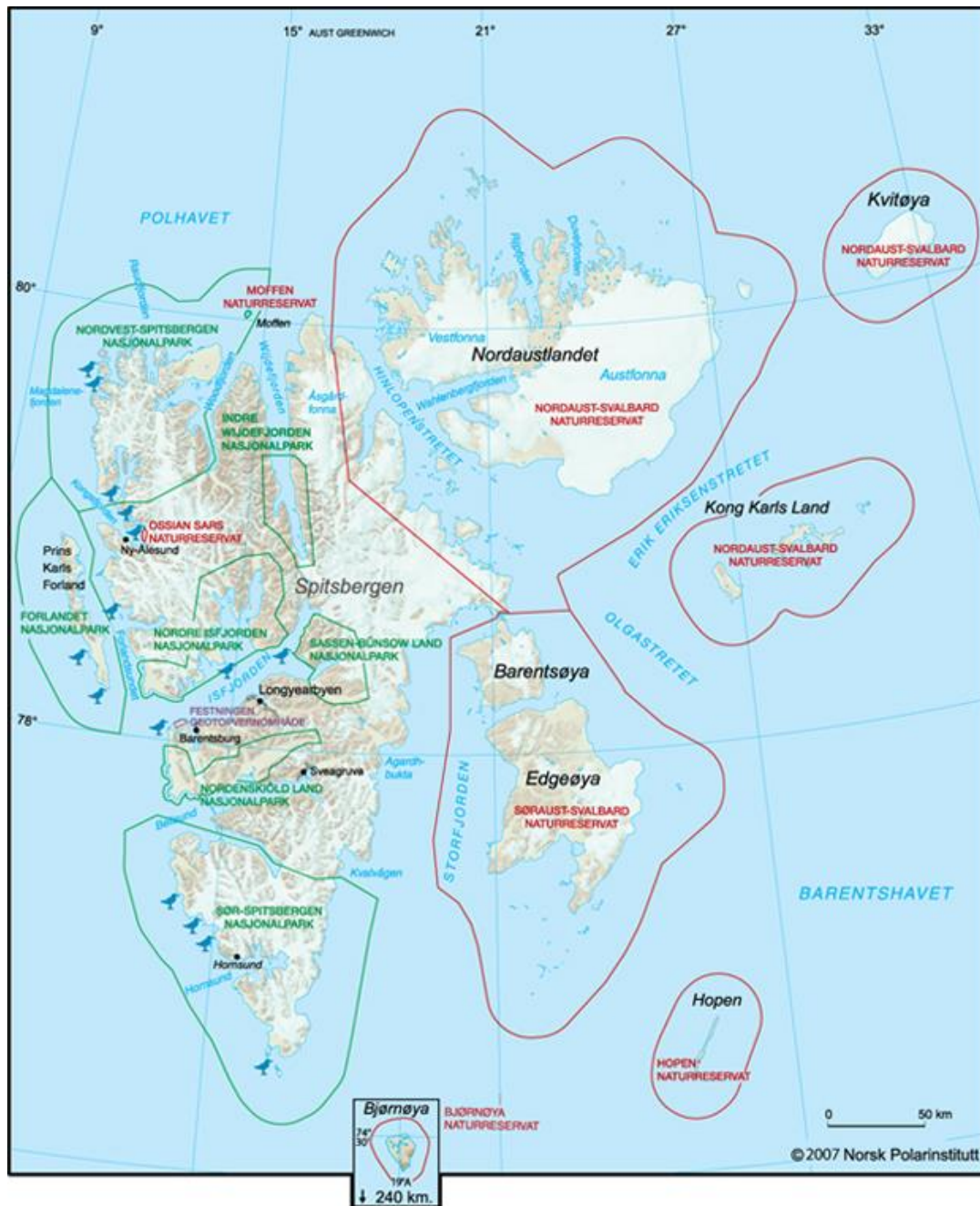
### **2.1.3 Protected areas in Svalbard**

Svalbard has a long standing tradition of protecting its natural environment and acknowledging its intrinsic value – not just its instrumental value to human beings (Forskrift om naturreservater på Svalbard, 1973). Currently, approximately 65% of the land masses and 87% of the water out to the 12-nautical mile territorial limit are protected under the 2002 Svalbard Environmental Protection Act (Svalbardmiljøloven, 2002). These areas are primarily classified as either nature reserves or national parks and span both terrestrial and marine areas. Thus, they are covered by the IUCN definition of marine protected areas. In Svalbard, nature reserves differ slightly from national parks in that they are established to protect a unique or particularly vulnerable species or ecosystems. Overall, however, their overarching objective is to maintain a virtually untouched environment and to protect wildlife, their habitat, and cultural heritage (Svalbardmiljøloven, §1, 2002). In total, there are seven national parks, six large nature reserves, 15 bird sanctuaries and one protected geotope on the archipelago (Figure 2).

In 2007, a fishing ban from 2002 was strengthened through official regulation to protect the area of Kongsfjorden on the northwestern part of Spitsbergen island (Figure 3). The purpose of this closure was to resolve a conflict between the scientific research community and shrimp fishery in the area, and to help strengthen and develop the research in Ny-Ålesund (Forskrift om fiskeaktivitet i Kongsfjorden, 2007). Although representatives of the fishery complained about a potential reduction in income, the research interests in this fjord were weighed heavily due to the available time-series data and the potential for this site as a reference site in investigations into long-term changes in Arctic ecosystems. The importance of retaining the fjord as a largely untouched ecosystem presided over the potential resumption of fishing activities. Neighboring Krossfjorden was closed at the same time, but not through the same regulation. In 2012, the Directorate of Fisheries decided to

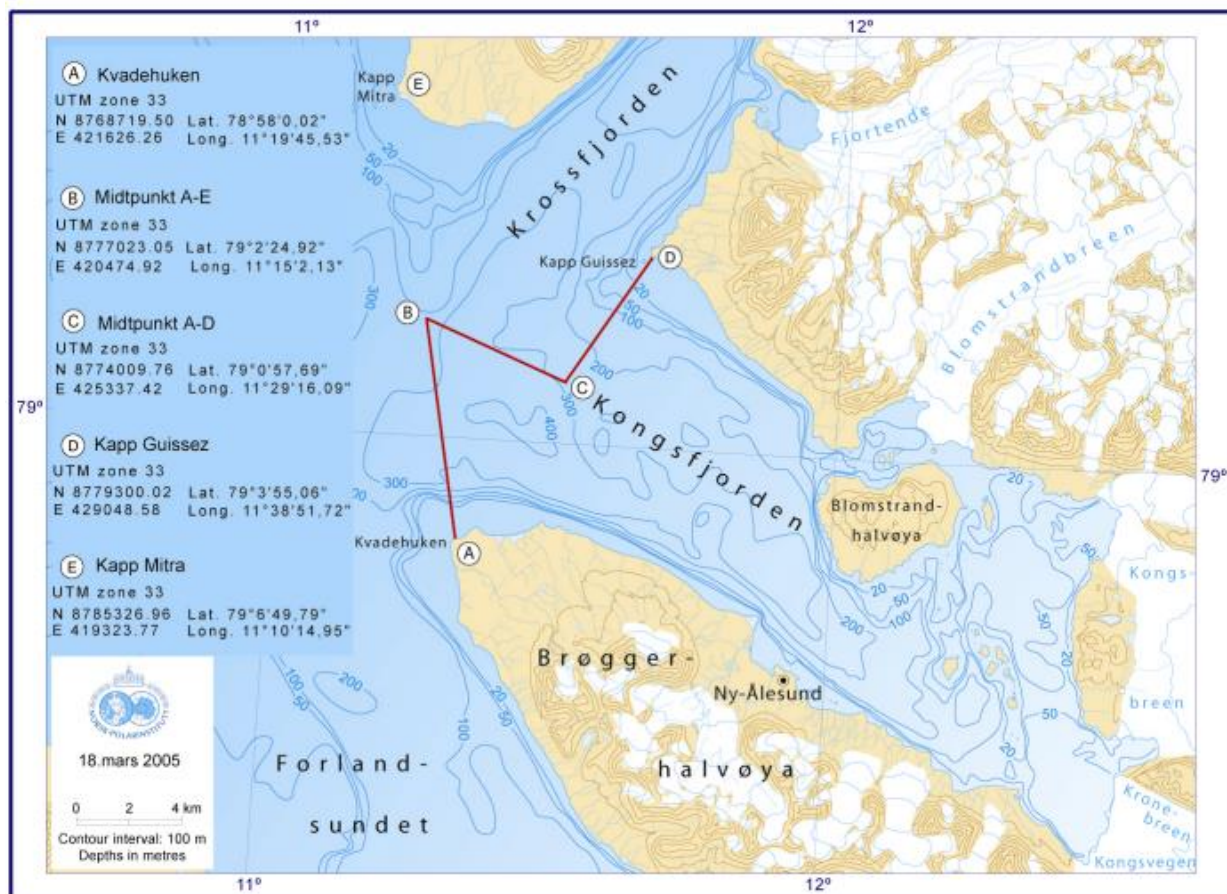
reopen this area (Directorate of Fisheries, 07.05.2012). The impacts of these management policies have not yet been investigated.

Figure 2: Map indicating the protected areas in and around Svalbard as per 2009. Areas marked in green are national parks, whereas those in red are nature reserves (Norwegian Polar Institute, 2009).



- NATURRESERVAT / NATURE RESERVE
- NASJONALPARK / NATIONAL PARK
- GEOTOPVERNOMRÅDE / PROTECTED GEOTOPE
- ✈ FUGLERESERVAT / BIRD SANCTUARY

Figure 3: Map showing Kongsfjorden and a red line, east of which all trawling activities have been prohibited since 2002 (Norwegian Ministry of Justice, 2005).



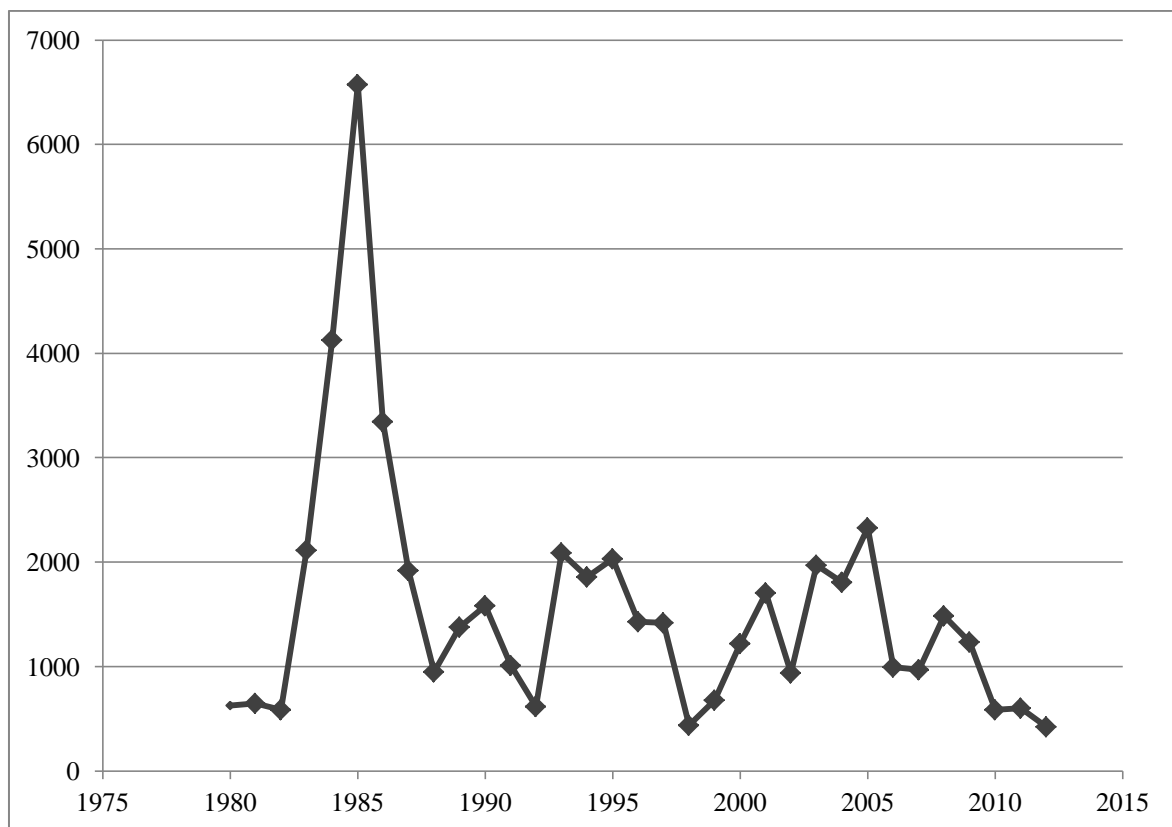
## 2.2 The northern shrimp fishery in the Barents Sea and around Svalbard

The northern shrimp fishery in the Barents Sea and Svalbard area is a multinational fishery, first initiated in 1970 (Garcia, 2007). The main fishing grounds are the Hopen area (central Barents Sea), the Svalbard shelf and the Goosebank area (southeastern Barents Sea; Figure 5). There is no total allowable catch established for the stock (Hvingel, 2012) and the fishery is primarily regulated by effort control, gear restrictions and temporary closures. In the Barents Sea, Norwegian and Russian vessels require licenses, whereas the fleets operating around Svalbard are regulated by numbers of effective fishing days and vessels per country (Hvingel and Thangstad, 2012b). Catches have been fluctuating, but overall declined since the mid 1980's (Figure 4). The total landings in the Barents Sea have

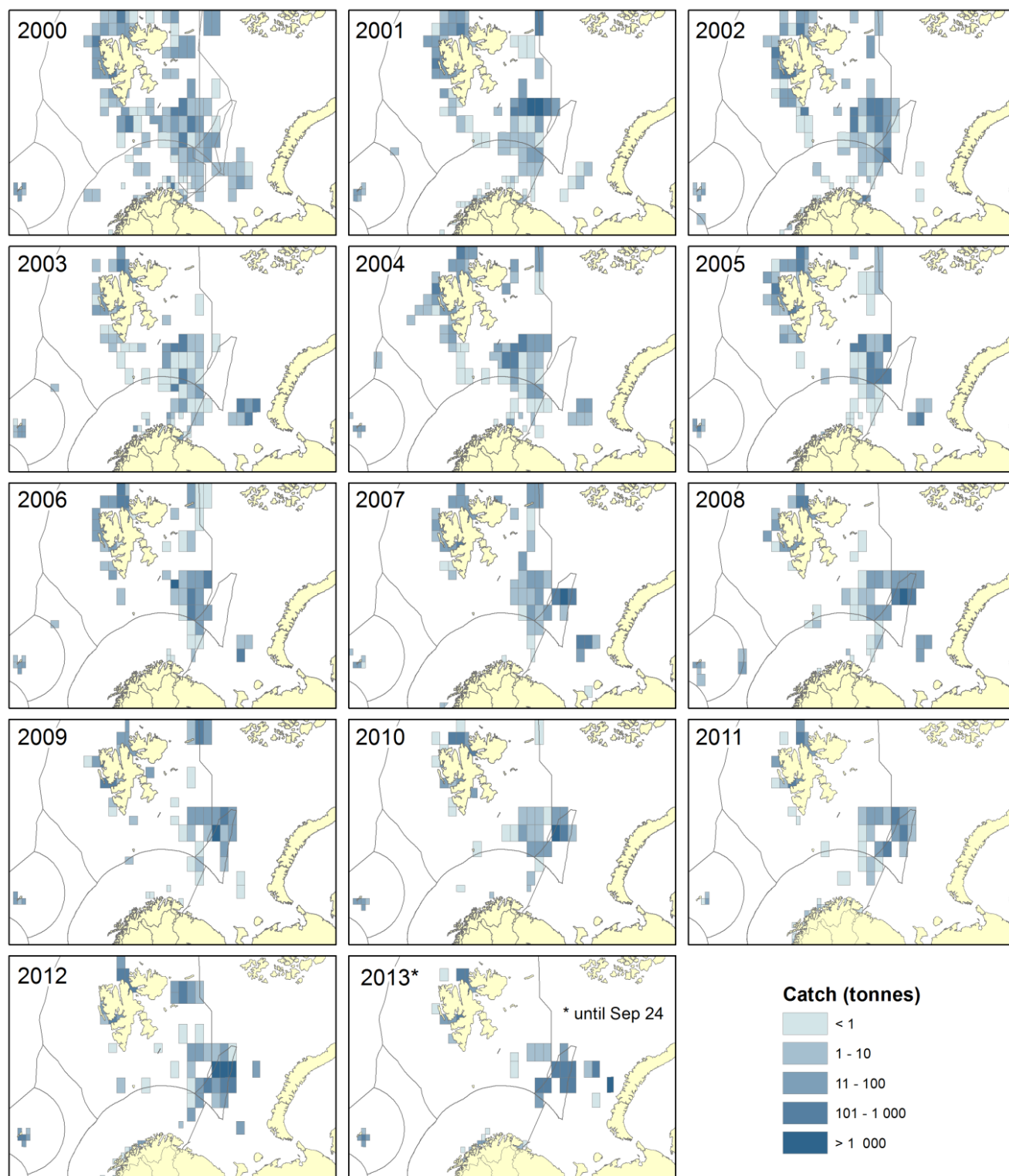


declined from 83 000 tons in 2000, to 23 000 tons in 2013, at least partly due to reduced market prices and increased fuel prices. About 90% of the catch is landed by Norwegian vessels, amounting to approximately NOK 450 million in 2012 (with 18 000 tons; IMR, 2014). In the annual stock assessment, various catch options are considered and their risk of exceeding the maximum sustainable yield. Currently, the biomass of shrimp is thought to be above and the fishing mortality below the value that maximizes yield. The stock is believed to tolerate a total catch of 60 000 tons annually (Hvingel, 2012).

*Figure 4: Shrimp catches from the Svalbard area in tons from 1980-2012. The spatial resolution of the data is unclear, but the relative annual catches have been low since the late 1980's. Data provided by Carsten Hvingel, Head of Research Group Bottom Habitats and Shellfish, Institute of Marine Research (IMR), Tromsø, Norway, personal communication, 20.03.2014.*



*Figure 5: Maps giving an overview of annual shrimp catches in the Barents Sea from 2000 to fall 2013. Total catches and local catches around Svalbard have both decreased significantly (Trude Thangstad, senior engineer at the Institute of Marine Research in Tromsø, pers comm 01.12.2013).*



## 2.3 The biology and ecology of the northern shrimp (*Pandalus borealis*)

### 2.3.1 Identification and distribution

The northern shrimp *Pandalus borealis* (Krøyer, 1838) is a decapod crustacean of pink to red color with a thin shell and slender body (Figure 6). They can reach a total length of up to 16 cm and can easily be distinguished from other shrimp by the morphology of its abdominal somites and spines (Shumway *et al.*, 1985).

*Figure 6: The northern shrimp Pandalus borealis (Krøyer, 1838). The above individual is a spawning female with visible green abdominal roe. Photo provided by Thomas de Lange Wenneck, senior engineer, Institute for Marine Research.*



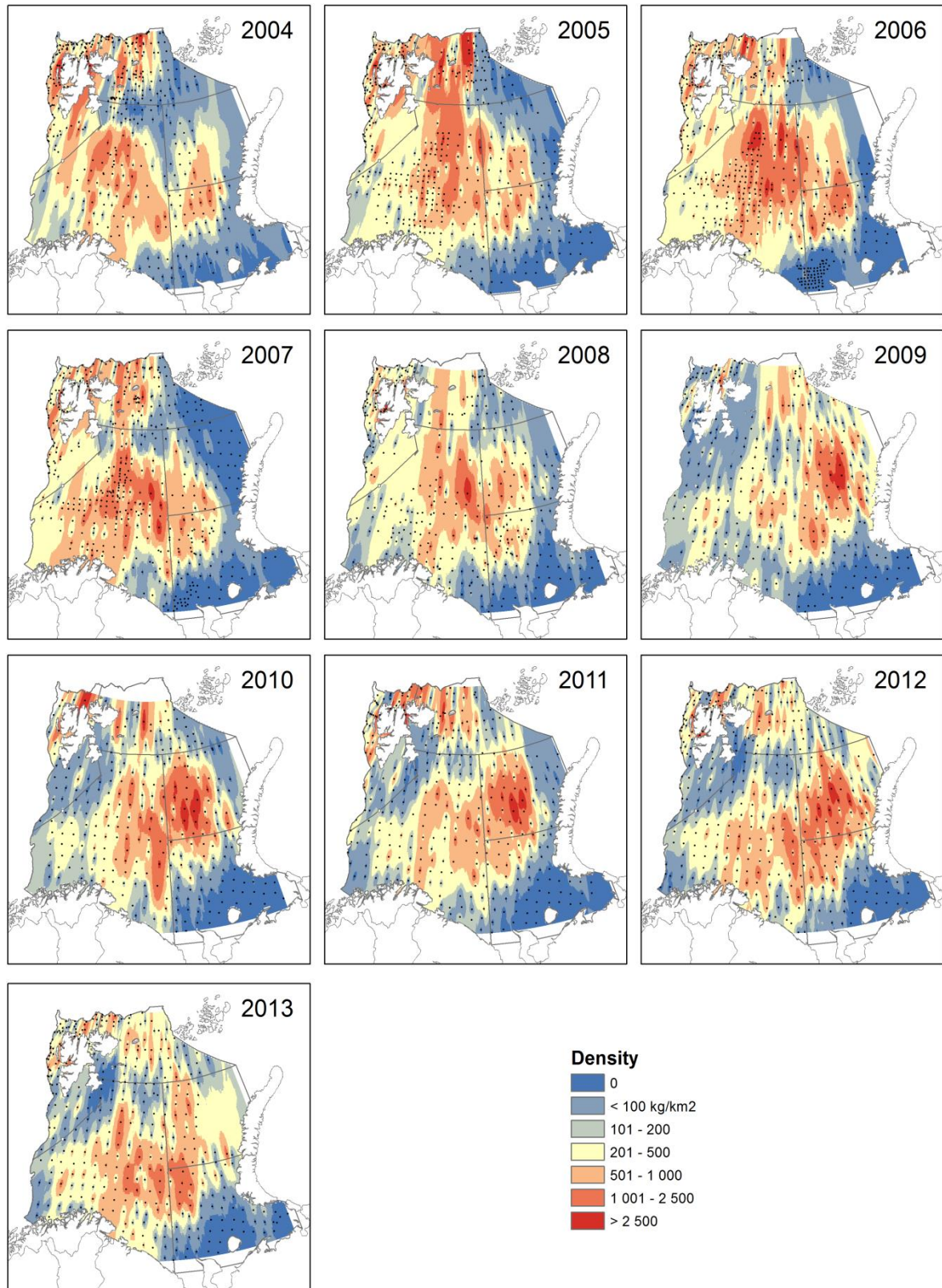
Northern shrimp has a discontinuous circumboreal distribution in the northern hemisphere and is the most abundant benthic-pelagic invertebrate in the Barents Sea and Svalbard areas. They begin their life as pelagic larvae, but past the larval stages, they spend most of their lives in close proximity to the bottom (Shumway *et al.*, 1985, Johannesen *et al.*, 2012a). They are typically found at depths between 50 and 500 meters (Allen 1959), but the distribution extends to as deep as 1500 meters (Shumway *et al.* 1985). In many areas, different life-stages exhibit contrasting vertical distributions, with juveniles and males being more abundant in shallower waters, particularly areas shallower than 300 meters. Females are generally found at greater depths than males. In fact, depth has been identified as the major environmental factor determining spatial size distribution in the Barents Sea (Aschan, 2000). The greater occurrence of juveniles and males in shallower areas may

partly be due to findings of cases where females migrate to shallower areas in the spring and early summer to release their larvae (Shumway *et al.*, 1985; Apollonio *et al.*, 1986). The larvae may travel passively with the currents for up to 330 km while passing thorough five zoeal stages, before settling at the bottom at the sixth, typically within a period of two to three months (Shumway *et al.*, 1985; Aschan and Ingvaldsen, 2009), but the mean distance covered has been modeled to vary between 74 and 122 km (Pedersen *et al.*, 2003). Once settled at the bottom, little is known of their migration patterns besides the females moving inshore to release their larvae (Apollonio *et al.*, 1986), but at least some local migration within the fjords can be assumed as they are active swimmers and responsive to changes in environmental conditions, such as temperature (Anderson, 2000).

Although the shrimp will respond to changes in temperature, it tolerates a broad temperature and salinity range, probably accounting for its wide distribution in the Barents Sea. Preferred temperatures and salinities are generally quoted to be between 0° and 5°C (Shumway *et al.*, 1985) and around 35‰ (Allen 1959), respectively. The highest shrimp density in the Barents Sea is observed between 0° and 4°C. However, the species has been reported in temperatures ranging between -1.6° and 12°C, and salinities anywhere between 23.4 and 35.7‰ (Shumway *et al.*, 1985). At the lower end and below, eggs won't hatch and mass mortalities have been reported (Ingraham, 1981). In the Barents Sea, large concentrations of shrimp are found around the polar front – areas of colliding water masses, upwelling and, thus, great biodiversity (Garcia, 2007).

According to the 2012 NAFO and ICES *Pandalus* Assessment Group (NIPAG) report, the distribution of shrimp in the Barents Sea has shifted eastwards and northwards since 2004 (Figure 7), which may be associated with the increased temperatures observed from the greater inflow of Atlantic water compared to previous years.

Figure 7: Maps from 2004 to 2013, showing distribution and densities of northern shrimp in the Barents Sea based on data from the annual ecosystem surveys performed by IMR and PINRO (Hvingel and Thangstad, 2012a; updated figure including 2013 data provided by Trude Thangstad, senior engineer at the Institute of Marine Research in Tromsø, pers comm 01.12.2013).



### **2.3.2 Population and subpopulations**

The northern shrimp stock in the Barents Sea and around Svalbard and Jan Mayen is considered as one large population. Isolation of shrimp in any area was assumed to be prevented by mixing of subpopulation through larval drift (Berenboim and Lysy, 1987). In more recent years, however, studies have revealed some genetic differences between shrimp of different areas. A population genetic structure analysis by Martinez *et al.*, (2006) showed significant variation and gradients in random amplified polymorphic DNA (RAPD) markers, however, more than 98% of these genetic variations were ascribed to individual differences. Still, subpopulation structures were evident and suggested to be a result of this significant individual diversity responding to regional and local environmental conditions over generations. The shrimp from Svalbard and the Barents Sea displayed variation, but were not significantly different from one another, with the exception of stations near Jan Mayen. In light of this, the Barents Sea and Svalbard shrimp are still considered to be of the same population, and managed as such.

### **2.3.3 Life history**

#### **Feeding, growth and age determination**

Categorized as an omnivore, predator and scavenger, northern shrimp has a varied diet reflecting local food availability (Bergstrom, 2000). A trophic link to the seasonal production cycle has been suggested based on times of egg hatching, bloom initiation and copepod life cycles (Koeller *et al.*, 2009). Studies of fatty acid and lipid composition and stomach contents in Balsfjord in northern Norway found that stomachs of young shrimp (age 1-4) contained chiefly calanoid copepods. A shift in diet was seen at older ages, where stomachs mainly contained euphausiids, fish scales and less frequently remains of polychaetes (Hopkins *et al.*, 1993). Some authors have also reported occurrences of cannibalism of own larvae (cited in Shumway *et al.*, 1985).

Temperature is considered to be the most important factor regulating growth and development (Shumway *et al.*, 1985; Apollonio *et al.*, 1986). Due to the general decrease in bottom temperature with increasing latitude, shrimp in the southern Barents Sea grow faster than those in the central and northern areas (Teigsmark, 1983; Aschan, 2000). Northern populations thus mature later, but enjoy increased longevity (up to 10 years in



Isfjorden in Svalbard; Aschan, 2000). In addition to temperature, individual growth may be reduced in areas of high population density (Koeller *et al.*, 2000).

Growth in shrimp, as in all crustaceans, proceeds step-wise through moulting, with varying rates of growth in their life-time (Parsons *et al.*, 1989) For example, increased rates of growth and repeated moulting is observed during sex change, whereas as females do not grow (moult) for large parts of the year when carrying eggs. In Svalbard, spawning females carry their eggs for approximately 10 months before hatching in the early summer (Koeller *et al.*, 2009). Thus, estimating growth rates and modelling of growth functions pose challenges, but may at least partially be helped by estimating age cohorts in the distribution samples (Hvingel, 2006).

Due to lack of biological age markers (such as otoliths; Bergstrom, 2000), differential growth rates within small geographical areas (Parsons *et al.*, 1989), and methods not constrained by biological realism, age determination is challenging and often imprecise (Hvingel, 2006). Identification of age cohorts is usually performed through modal analysis of the length frequency data. Most commonly, a program called MIX (MacDonald and Pitcher, 1979) is applied to identify cohorts in finite distribution mixtures. However, shrimp length frequency distributions are noisy and results of modal analyses may not represent true cohorts, but instead, be a reflection of sampling bias or shorter-term fluctuations in ecological parameters (Hvingel, 2006). For instance, the modified Campelen shrimp trawl used in the shrimp (now ecosystem) surveys in the Barents Sea (Aschan and Sunnanå, 1997) is designed for optimal sampling of biomass, not length structure (Hvingel, 2006). Small shrimp will often escape through the 40 mm mesh belly of the trawl. Thus, a small 8 mm-meshed 'juvenile bag' was manufactured and attached to the underside of the belly. According to Aschan and Sunnanå (1997), use of this juvenile bag has been standard since 1995. However, it was not employed on the 2013 ecosystem survey around Svalbard, from which part of this project's data arrived. Aschan and Ingvaldsen (2009) found a good correlation ( $R^2=0.80$ ) between the recruitment indices of the shrimp age 2 caught in the codend and the juvenile bag, but the smallest (age 1) shrimp were not sufficiently sampled with the trawl alone, and it was concluded that the juvenile bag is essential for sampling of the age 0 and age 1 shrimp.

Alternative methods of age determination have been attempted. For instance, Bluhm *et al.* (2001) investigated the potential for using the autofluorescent pigment, lipofuscin, as an age marker in polar crustaceans. Although showing some promise for certain species, it was deemed an inappropriate method for *P. borealis*. More successfully, Fournier *et al.* (1990, 1991) developed and applied the MULTIFAN model to quantitatively assess time-series of length frequency data, but the method never achieved wide-spread application, so MIX continues to be the most frequent approach (Hvingel, 2006).

## **Reproduction**

Northern shrimp are protandric hermaphrodites – they are born and reproduce as males before going through a short phase of intersex and then changing sex and reproducing as females. Males and females are easily distinguishable by external structures on their first and second pair of pleopods, often used in combination with the presence or absence of sternal spines on their abdominal somites (Allen 1959; see Appendix A for diagrams). Warner (1975) explains the potential benefits of protandry in a size-advantage model where the smaller males produce less energetically demanding sperm than the larger metabolically demanding female eggs.

Spawning in northern areas occurs once annually, in the fall, and some females are found to skip the spawning season. The eggs are carried on the female abdomen through winter until hatching larvae in the early summer. Fecundity is proportional to body mass (Clarke *et al.*, 1991) and egg incubation time is generally negatively correlated with temperature, and estimated to approximately 9-10 months around Svalbard (Brillon *et al.*, 2005; Koeller *et al.*, 2009). The birth date of shrimp in this area is often taken to be June 1<sup>st</sup> (Nilssen, 1990).

Carapace length at first female maturity, an indication of sex change, has been reported to range between 18.9 to 27.9 mm in the North Atlantic, corresponding to ages between 3 and 8 years (Skúladóttir, 1998). Work by Charnov (1979; 1990) and Charnov and Anderson (1989) suggest that Pandalid shrimp, including *P. borealis*, display environmentally cued sex change. The size and age of change has been associated with size distribution of the breeding population in their immediate environment, in accordance with the sex allocation theory (Charnov, 1979). More specifically, size at female maturity in Pavlov Bay, Alaska, was positively correlated with mean size of breeding population, implying that these



adaptive changes are of a rapid nature. The differences in size distributions were attributed to different mortality rates (for example through fishing) and recruitment (Charnov and Anderson, 1989). In other words, the sex allocation theory suggests that shrimp rapidly adapt to compensate for a small breeding population of females by decreasing the size at which they change sex. More recent work by Bergstrom (1997), Wieland (2004) and Koeller et al. (2000), indicate no such relationship and rapid adaptive response. Instead, they indicate that the length at sex change and maturity is genetically determined over generations. The literature is conflicting and mechanisms are unclear. It is perhaps more likely that the heterogeneity among populations and habitats will support these proposed driving mechanisms in varying degrees, not allowing for generalized conclusions to be drawn.

## **Predation**

Parsons (2005) has compiled the published research on shrimp predation in the North Atlantic and produced a list of 26 predators. These include mammals, seabirds and predator fish, primarily Atlantic cod (*Gadus morhua*), Greenland halibut (*Reinhardtius hippoglossoides*) long rough dab (*Hippoglossoides platessoides*), redfish (eg. *Sebastes mentella*), haddock (*Melanogrammus aeglefinus*) and cusk (*Brosme brosme*). One of the major generalist predators in the Barents Sea is the northeast Arctic cod stock of the Atlantic cod, whose diet reflects local prey availability (Parsons, 2005; Johannesen *et al.* 2012b). In 2013, the northeast Arctic cod stock had the “highest observed” spawning stock biomass ever recorded (ICES, 2013), and a total biomass of approximately 3.7 million tons (Arneberg *et al.*, 2013). The stock has a wide spatial overlap with shrimp in the Barents Sea (except in the deepest areas; Johannesen *et al.*, 2012b), where this prey-predator interaction has been well documented (Albers and Anderson, 1985; Bogstad and Mehl, 1997; Michaelsen and Nedreaas, 1998 ; Dalpadado and Bogstad, 2004; Parsons, 2005). In the Barents Sea and several other areas in the North Atlantic, the inverse relationship found between shrimp and cod biomasses support the “top-down” control hypothesis (Worms and Myers, 2003). Using multispecies and virtual population analysis (VPA) models, Berenboim *et al.* (2000), suggest that cod predation, along with shrimp recruitment, is one of the most important factors influencing shrimp population dynamics. In fact, cod biomass will also directly influence recruitment to the shrimp stock through predation on juvenile shrimp (Aschan and Ingvaldsen, 2009; Jónsdóttir *et al.*, 2012, 2013). Further, stomach

contents analysis showed size-dependent predation; that the importance of shrimp in the diet starts high, but declines with age, and that cod aged 3 to 6 years consumed the greatest biomass of shrimp. All length groups of shrimp are available to cod at length 30 cm and above. The relative importance of shrimp as a prey item varies between sites, study and year (Parsons, 2005), probably reflecting the local availability of shrimp or other preferred species (such as capelin), but is generally found to contribute 10-12% by weight to the diet of young cod (age 1-4). This number decreased to less than 2% for 12 year old cod. In the Barents Sea, the biomass of shrimp consumed by cod is estimated to far exceed that caught in the fishery (Berenboim *et al.*, 2000). There is no published literature outlining predation by cod in the fjords and areas around Svalbard specifically, but as the species' distributional ranges are expanding and shifting, and the spatial overlap between cod and shrimp is increasing (Aschan, 2013), research will undoubtedly continue on this topic.

Other species may also impact shrimp populations through predation in the Barents Sea. Michaelsen and Nedreaas (1998) concluded that shrimp is the third most important prey species of Greenland halibut in the Barents Sea and East Greenland waters, with the percentage by weight in the stomach samples ranging from 2.3 to 12.9%. Greenland halibut is widely distributed in the waters around Svalbard and in the Barents Sea (Høines and Gundersen, 2008). Due to increases in stock size in recent years, it now supports a fishery with a total allowable catch of 15 000 tons (IMR, 2013). Research in the fjords of Svalbard, including Isfjorden, found shrimp to be a preferred prey for larger specimens of Greenland halibut (Vollen *et al.*, 2004).

Polar cod (*Boreogadus saida*) was not included in the list published by Parsons (2005) as there are limited studies on polar cod diet and none indicating them as a major predator of shrimp. Polar cod has a broad distribution in the water column, and larger individuals are often caught in bottom trawls (Hop *et al.*, 2002). Younger, more pelagic fish is also assumed to undertake some diurnal migrations towards the bottom (Falk-Petersen *et al.*, 2008; Benoit *et al.*, 2010). A study of polar cod diet around Svalbard categorized the species as an opportunistic feeder and found evidence of at least some predation on shrimp in the area (Ajiad and Gjøseter, 1990). As the overlap between boreal and arctic species distributions has increased (Renaud *et al.* 2011), as indicated by the increased distributional overlap of shrimp and polar cod, the potential for predation may also have increased and will, thus, be investigated in this study.

## **2.4 Gaps in knowledge**

There are a number of knowledge gaps with regards to Arctic marine systems and their function, particularly when assessing outcomes of management strategies. The impression is that there is a lack of ecological understanding of unique conditions at each site, for example in environmental parameters, human extraction of resources, ecological history, or protective measures. Inadequate understanding of these may pose a significant challenge for comparing sites and predicting outcomes of management strategies.

The impacts of management strategies of Svalbard have not before been investigated. Kongsfjorden is the first area having been closed to all trawling activities. Similarly, the effects of fishing on the Isfjorden shrimp population or whole ecosystem have not been considered, in spite of comprehensive temporal surveying. There is also little information available on fjord populations of shrimp.

Lastly, ecological interactions, particularly predation on shrimp in the fjords, are not fully understood. For instance, polar cod is not generally mentioned as a potential predator of shrimp. However, as their distributions overlap around Svalbard, this is a potential interaction that ought to be investigated.



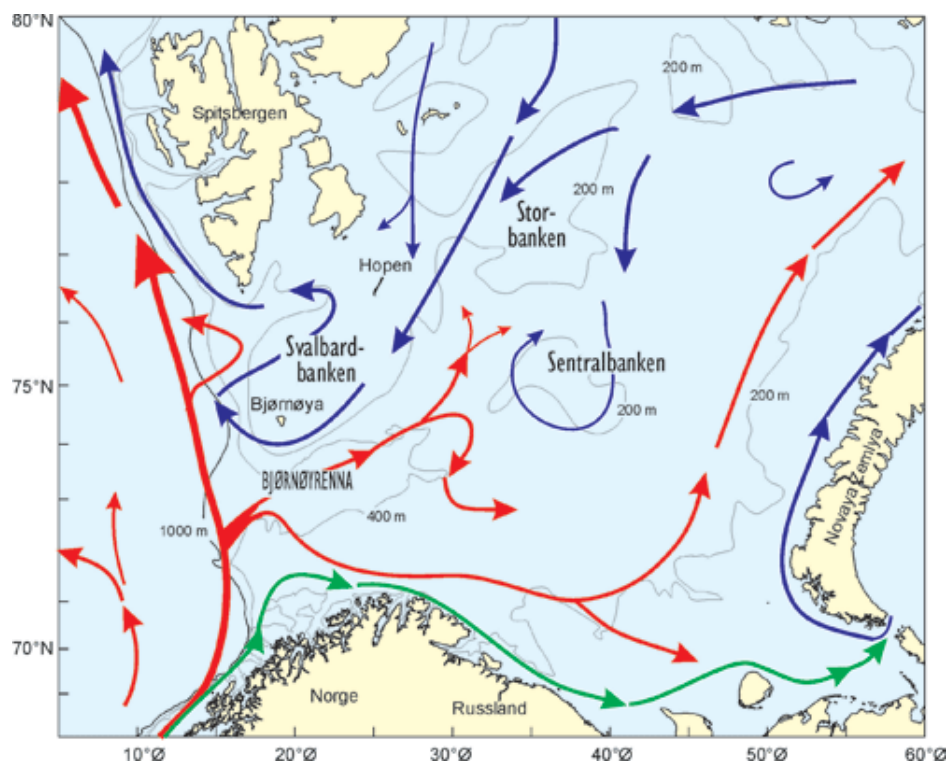
## 3 Research Methods

### 3.1 Study sites

#### 3.1.1 Svalbard

The Arctic archipelago of Svalbard sits in the northwestern corner of the Barents Sea, just south of the Arctic Ocean and comprise the islands located from 74° to 81° north, and from 10° to 35° east. The total area is just over 62 700 km<sup>2</sup> and its territorial waters extend 12 nautical miles offshore and comprise approximately 90 700 km<sup>2</sup>. The west coast is characterized by a narrow continental shelf, the West Spitsbergen shelf, deep fjords and great interannual variations in hydrographical conditions. The major current system in the Barents Sea and Svalbard involves warm Atlantic water traveling north with the Gulf Stream and interacting with cold Arctic water entering from the northeast. (Figure 8; Loeng, 1991). Thus, the west coast of Svalbard receives a significant Atlantic influence through the West Spitsbergen Current carrying warm and saline Atlantic water north, through the Fram Strait, to the Arctic Ocean (Cottier *et al.*, 2005; Nilsen *et al.*, 2008).

*Figure 8: Map indicating the prevailing ocean circulation patterns and depth isolines in the Barents Sea and around Svalbard. Red arrows indicate Atlantic water, blue arrows Arctic water, and green arrows the Norwegian coastal current (Norwegian Institute of Marine Research, 2005).*



### 3.1.2 Isfjorden

Isfjorden is positioned between 78° 7' N to 78° 27' N with side-fjords extending as far as 78° 50' N), and the permanent human settlements, Longyearbyen and Barentsburg, are located in side-fjords to the west of the main fjord axis. Nordre Isfjorden National Park covers the northern land areas, as well as the entire area of Nordfjorden. Isfjorden is unsilled, but some of the side fjords have shallow sills separating them from the main fjord axis. These inner silled basins were not sampled. Isfjorden is more than 100 km long and the largest fjordic system on the west coast of Spitsbergen island (Figure 9). The influx of Atlantic Water in the fjord varies interannually (Nilsen *et al.*, 2008), resulting in an alternation between Atlantic and Arctic conditions. The extent of Atlantic Water penetration depends in part on wind forcing and prevailing wind conditions (Cottier *et al.*, 2007), but also on the density of the cooler coastal water, separating the Atlantic water from the water in the fjord (Figure 8). These factors influence the variability between years and seasons. Some winters, extensive sea-ice formation results in production of dense brine, resulting in near or below 0°C bottom temperatures in inner parts of Isfjorden. The resulting Arctic conditions are offset by the greater occupation by Atlantic water in the summer, resulting in bottom temperatures of up to 5 °C (Cottier *et al.*, 2005; Nilsen *et al.*, 2008).

### 3.1.3 Kongsfjorden

Also unsilled, Kongsfjorden is located further north along the west coast of Spitsbergen, between 78° 45' N and 79°20' N (Figure 10). It is the location of the small research community of Ny-Ålesund and forms a two-armed complex with Krossfjorden, sharing a common mouth. Similar to Isfjorden, the annual and interannual hydrographical conditions are dominated by the balance of Atlantic and Arctic water. Compared to Isfjorden's 100 km, Kongsfjorden and Krossfjorden are significantly smaller; approximately 20 and 30 km long, respectively. This allows for greater dissemination of Atlantic water at all times of the year and less sea-ice forming in the winter (Cottier *et al.*, 2005). In addition, the presence of two glaciers at the head of the fjord, Kongsbreen and Kongsvegen, at the head of the fjord influences the local hydrography through input of cold fresher water, and through larger sources of inorganic sediment.

Figure 9: Map outlining the bottom trawl sampling stations in Isfjorden, Svalbard. The numbers refer to the stations in Table 1, the triangles to stations covered on the August cruise, and circles to stations covered in September.

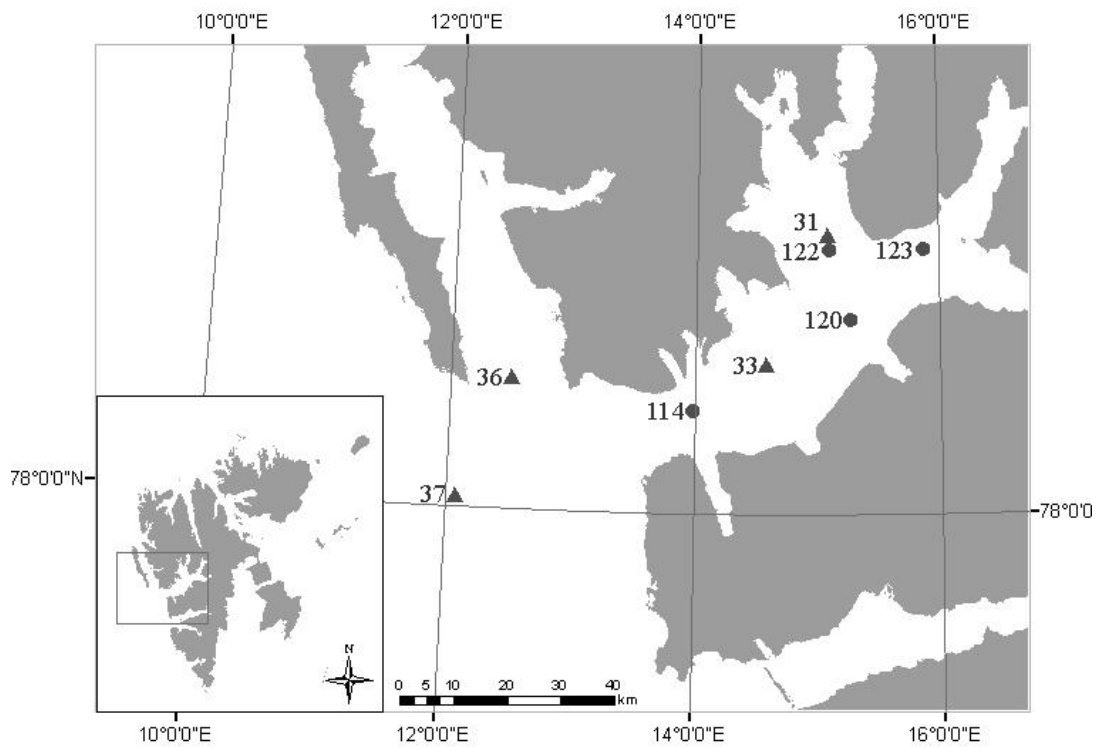
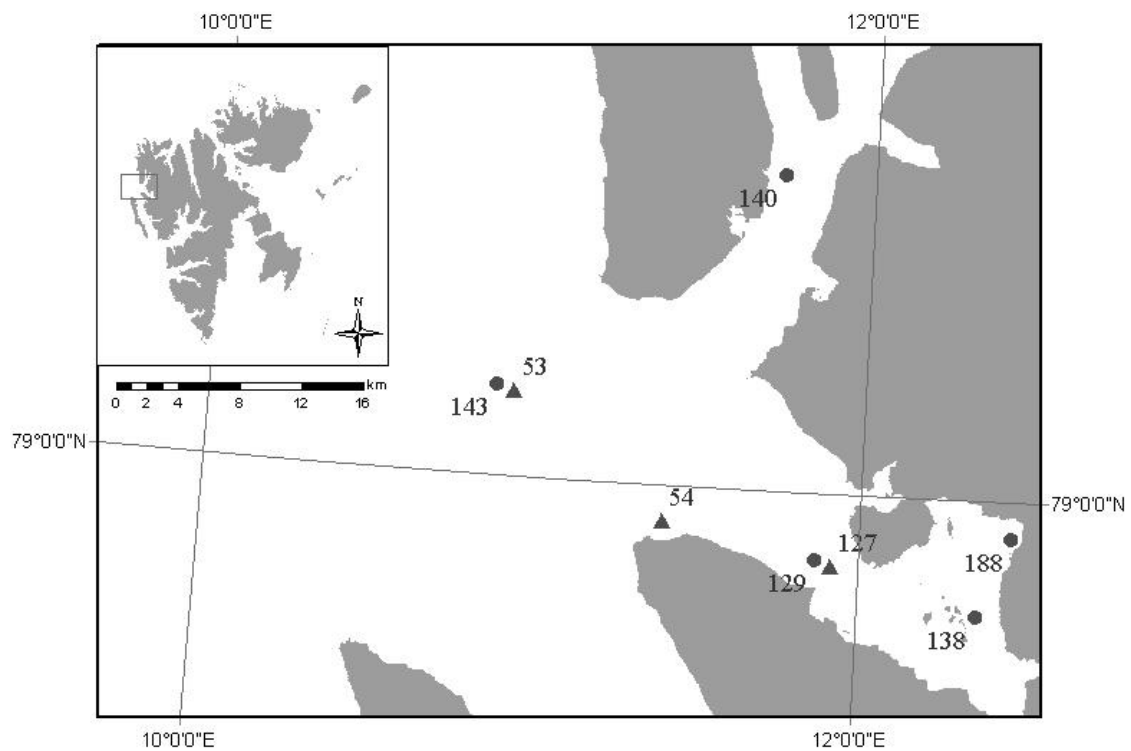


Figure 10: Map outlining the bottom trawl sampling stations in Kongsfjorden, Svalbard. The numbers refer to the stations in Table 1, the triangles to stations covered on the August cruise, and circles to stations covered in September.



## 3.2 Sampling method

Sampling was conducted between 19 August and 4 October 2013, on two 14-day research cruises on board R/V Helmer Hanssen. These were attended as a registered student at the University Centre of Svalbard (UNIS). Each cruise lasted two weeks and were spaced three weeks apart. The August cruise was part of the annual Norwegian-Russian Barents Sea ecosystem survey, jointly undertaken by Norwegian IMR and Russian PINRO. The station grid attempted to be area and depth stratified, but was limited by the accessibility of the trawl gear. A total of seven stations were sampled in Isfjorden and Kongsfjorden. The September cruise, a student cruise organized by UNIS, sampled more deeply into the fjords and trawled a total of nine stations. Several of these stations were approximately the same stations sampled in August, thus allowing analysis of some temporal resolution in population structure. The locations were chosen based on the fjord bathymetry and accessibility of the trawl gear, as well as the need for adequate cover of the hydrographical and geographical range in the fjords. Station data and locations are summarized in Table 1 and visualized in Figures 9 and 10.

The bottom trawl used in the sampling was a modified Campelen 1800 shrimp trawl with rockhopper gear; the standard sampling gear employed in the annual ecosystem survey since 2005. It used a stretched mesh size of 80 mm in the front and 22 mm in the codend. The horizontal and vertical openings were 17 m and 4-5 m, respectively, and the door spread was about 45-50 m. On the second cruise, a 1 by 1 m juvenile net with a mesh of 8 mm (previously described in section 2.2.3) was attached to the bottom of the trawl in order to better sample the younger year classes (Aschan and Sunnanå, 1997). The gear was towed at the bottom for approximately 15 minutes, at  $3 \text{ kn h}^{-1}$ , covering a distance of approximately 0.75 nautical miles. However, due to the nature of the bottom, this time was reduced at three locations in inner Kongsfjorden. At most sites, temperature and salinity data were recorded using a conductivity, temperature and density (CTD) probe taking measurements at 1 meter intervals from the surface to the near bottom. Depth was also recorded by an acoustic echo sounder.



*Table 1: Sampling Stations in Isfjorden and Kongsfjorden, Svalbard. Stations in Isfjorden are positioned above the horizontal line. Distance and speed refer to that of the ship towing the trawl gear.*

St. No.	Date	Latitude (°N)	Longitude (°E)	Depth (m)	Trawl time (min)	Distance (km)	Speed (kn)
31	19.08.13	78.467	15.083	176	16	0.80	3.0
33	19.08.13	78.250	14.580	279	15	0.75	3.1
36	20.08.13	78.220	12.500	264	16	0.80	2.9
37	20.08.13	78.020	12.080	260	16	0.80	2.9
114	24.09.13	78.171	13.984	316	18	0.87	2.9
120	24.09.13	78.325	15.277	256	17	0.88	3.1
122	25.09.13	78.440	15.098	214	16	0.83	3.1
123	25.09.13	78.441	15.879	188	16	0.85	3.2
53	21.08.13	79.050	10.930	325	14	0.70	3.1
54	21.08.13	78.980	11.400	345	15	0.75	3.1
127	30.08.13	78.959	11.917	355	15	0.74	3.2
129	26.09.13	78.962	11.873	335	14	0.72	3.1
138	26.09.13	78.933	12.363	52	9	0.47	3.1
140	27.09.13	79.183	11.723	338	9	0.48	3.2
143	27.09.13	79.052	10.879	349	17	1.07	3.2
188	04.10.13	78.979	12.464	134	7	0.30	2.6

In the lab, trawl catches were first sorted by species and total weights were recorded. For fish species where samples totaled fewer than 200 animals, all individuals were measured (total length) and weighed. For larger catches, such as shrimp and polar cod, random subsamples were taken, counted and weighted in order to establish total abundance. Total lengths of all individuals from the subsamples were also recorded. Fish length measurements were made electronically using a fish board on the August cruise and manually on the September cruise. Shrimp subsamples were generally in an excess of 400 individuals, randomly chosen and weighed to determine shrimp abundance and biomass, before being set aside for later analysis. Total abundance was calculated by first dividing the weight of the subsample by the subsample count to find mean weight per shrimp. The total catch weight of shrimp was subsequently divided by this number to estimate the total

number of shrimp in the trawl. The same procedure followed for large polar cod samples. Where subsamples were taken, these were in excess of 200 individuals. All polar cod with a total length greater than 14 cm from the entire sample on the September cruise were collected for stomach-content analysis. Stomachs were also collected from specimen with a total length greater than 20 cm of species assumed to predate on shrimp (Parsons, 2005). These included Atlantic cod (*Gadus morhua*), Greenland halibut (*Reinhardtius hippoglossoides*), long rough dab (*Hippoglossoides platessoides*) and beaked redfish (*Sebastes mentella*). Other species caught by the trawl, typically smaller fish species, crustaceans and other taxa belonging to the benthos or hyperbenthos, were identified to species level, weighed and counted. These have not been included in any further analysis, but a complete list is found in Appendix B

Using the trawl time and average speed in knots, obtained from the ship log, distance was calculated using the equation  $distance\ (nm) = speed\ (knots) \times time\ (hrs)$ . The data from the ship log was compared to the depth data provided by the Scanmar sensor on the trawl recording time at bottom. Where these values differed, averages were made. Distance calculations allowed for catch weights and abundance numbers to be standardized to catch per nautical mile by dividing the values by the distance (in nautical miles) covered by the trawl.

### **3.3 Shrimp subsampling**

A random subsample of at least 400 shrimp was taken at each station. A few individuals from each subsample (<5%) were recorded as present in the subsample, but were unable to be measured due to damage to the carapace. Before each shrimp from a subsample was measured, it was sorted according to maturity stages 2-8 based on the presence of sternal spines combined with the morphology of the endopodites on the first pair of pleopods (Mjanger *et al* 2006). More specifically, this included first separating the subsample according to presence or absence of roe. The group without roe was subsequently separated into males (stage 2) and resting females (stage 7) based on the presence or absence of sternal spines on their abdomen, respectively. The morphology of the endopodites also identified a low number of intersex (stage 3) shrimp among the males. The second large group comprised the spawning females with conspicuous roe. Females with abdominal roe

(fertilized eggs) have already spawned and are classified as stage 5. It was not possible to determine whether these are first- or second-time spawners (primi- or multiparous) as the sternal spines were covered by eggs, and thus likely to already have had their appearance affected. The females with head roe were classified as either primiparous (stage 4) or multiparous (stage 8) spawners based on the presence or absence of sternal spines. As expected, females with hatched eggs (stage 6), seen in spring, were not found (Shumway et al., 1985; Nilssen, 1990). See Appendix A for a schematic view and flow chart of the staging process.

The standard accepted length measurement for shrimp is carapace length. This is measured from the posterior end of the eye opening to the posterior dorsal edge of the carapace. This was done with an accuracy of 0.1 mm using Mitutoyo USB digital sliding calipers, regularly calibrated to ensure accurate measurements recorded directly to a laptop computer.

### **3.4 Stomach contents analysis**

In order to assess potential predators of shrimp present at this time of year, on the September cruise (eight stations), fish with a total length of more than 20 cm and large polar cod (*Boreogadus saida*) (above 14 cm) were dissected and their stomach contents analyzed. The species meeting this criterion included Atlantic cod (*Gadus morhua*), Greenland halibut (*Reinhardtius hippoglossoides*), long rough dab (*Hippoglossoides platessoides*) and beaked redfish (*Sebastes mentella*). Within an hour of the trawl arriving on deck, the potential predators were identified, weighted and measured. The stomachs were carefully removed, labelled and placed in jars containing solutions of at least 70% ethanol. The fullness of the stomachs as a quartile percentage was noted. Analysis was carried out within the next two days by placing the stomach on a petri dish, cutting it open with scissors and flushing out the contents with alcohol solution. Care was taken to identify and remove shrimp and other prey items obviously swallowed in the trawl, as indicated by the location, color and absence of decomposition of the animals. The presence of these shrimp consumed was recorded, but not included in the analysis. Using a Leica stereoscope, prey items were typically identified to family, genus or species level, but decomposition sometimes made this impossible. Thus, a category of “unidentified prey”

was included in the data. Numerical and volumetric assessments of contents were noted to increase the resolution of the analysis, but contents are presented in the results section based simply in the Occurrence Index (Hyslop 1980). The occurrence method involves recording the number of stomachs containing one or more individual shrimp, and presenting these as a proportion of the total. Empty stomachs were excluded from the contents analysis as they offered no indication of whether these specimens would consume shrimp, but the percentage of empty stomachs was recorded and are presented in Appendix E. The analysis was simple and did not give any indication of relative importance of prey items. Indeed, a more detailed analysis was not judged to be necessary as the objective was simply to determine which species predate on the local shrimp population.

### **3.5 Data analysis**

Visualization of data and statistical analyses were carried out in Microsoft Excel (2010), Primer 6, Statistica and R (R Development Core Team, 2008).

#### **3.5.1 Carapace length data**

All the length data was recorded as a list in a text file using the Mitutoyo USB digital calipers (Mitutoyo, Japan) and subsequently imported into an Excel spreadsheet. In order to distinguish between the stages, they were measure in ascending order with a line of “0.00” separating them. In Excel, these separations were removed and stages assigned to the length data in a separate column. Subsequently, these were summarized in tables of length frequencies using the frequency function with defined length classes of 0.5 cm, chosen from the literature (Skúladóttir and Pétursson, 1999; Aschan, 2000; Wieland, 2004). Maturity stages were included in the resulting bar charts using the stacked column function in Excel.

#### **3.5.2 Spatial distribution**

In order to identify and visualize stations of similar length frequency distributions, a cluster analysis of the counts of the length frequency distributions, using Bray-Curtis similarity, was performed using Primer 6. This was similarly done for counts of three categories; males (stages 2 and 3), spawning (stages 4, 5 and 8) and resting females (stage 7) in each sample.

### 3.5.3 Cohort analysis

The cohort analysis was done with the Mix 3.0 modal analysis in R statistical environment, using the *mixdist* package. The package is based on the original program by MacDonald and Pitcher (1979), who developed a method for analyzing distribution mixtures. The program uses a number of algorithms to identify and estimate parameters (year classes or cohorts) in finite mixture distributions, such as length frequency distributions.

The length frequency data were first compressed into bins of 0.5 mm. The stations were grouped into areas based on the LFD cluster analysis in order to increase the sample size ( $n$ ). If the sample size was too small for a given cohort, actual means were given, as done by Aschan (2000). The Mix program required the number of cohorts to be defined prior to analysis and this number was determined by visual examination of the length frequency distributions, with due consideration given to assumed biological limits. The Mix was first run without constraint on the standard deviation, but if this was outside the acceptable range of 0.6 to 1.1 (as advised by Professor Einar M. Nilssen, University of Tromsø, personal meeting, 22.11.2013), it was fixed at the top end for the given year class. Mix 3.0 was not run with equal standard deviations of all the cohort means in each group. The curves were fitted by least squares and iterations; the goodness of fit given by a chi-squared value. An example of the R code used in the analysis is seen in Appendix D. The model provided mean a length at age, proportion standard error of mean and standard deviation (sigma) of each cohort in the sample.

### 3.5.4 Length at maturity

In order to investigate potential differences between the areas and fjords with respect to the size and at maturity, maturity ogives were modelled and fitted in R. Due to the protandrous nature of this Pandalid species, maturity ogives are given for females. Female maturity ogives are cumulative distribution curves of proportions of mature female in each size class. (Skúladóttir and Jónsson, 1980). For each station, the proportion of mature females was plotted for each 0.5 cm length group. Sigmoidal logistic curves were fitted by least squares and iterations, according to the formula given by Skúladóttir and Pétursson (1999),

$$P_i = \frac{1}{1 + e^{-(a + bx_i)}}$$

where  $P_i$  is the proportion of mature females and  $x_i$  the length group.  $a$  and  $b$  were values provided by the logistic model in R, and correspond to the y-intercept and slope of the curve at the inflection point. The inflection point,  $L_{50}$ , is the length at which 50% of the specimens are mature females. An example of the code used for the analysis can be seen in Appendix D. Mature females included those with either head or abdominal roe, as well as those in a resting stage (stages 4-8). The estimations of length at maturity were compared to the cohort analysis to approximate the age at maturity. Lastly, an ANOVA was run to compare lengths at maturity between the fjords.

### **3.5.5 Predator data**

Predator data, primarily weights, lengths and abundances, were recorded and standardized to per nautical mile for comparison between areas and fjords. Non-parametric correlation analyses were carried out in Statistica in order investigate relationships between the predator abundance, shrimp catch weight and environmental parameters. ANOVAs were also performed to reveal any statistical differences in catch weights and abundances between the sampling sites and fjords.

## **3.6 Limitations and improvements of methods**

### **3.6.1 Sampling method**

The analyses assume that the available sampling data is representative of the actual population. The areas sampled, however, were limited to those where use of trawl gear was possible, thus sampling could not be random within the fjord. Secondly, there is considerable variation in distribution on both temporal and spatial scales, as seen by the resampling of certain stations and the variability within the fjords. Consequently, through uneven representation of areas, these factors possibly skewed the results. For instance, over or under representation of areas with particularly high or low densities of either shrimp or predators would subsequently result in the mean biomass value of a fjord being neither accurate nor precise. In other words, the fjords were not necessarily sampled representatively. Furthermore, the difference in size, and potentially habitat heterogeneity, between the fjords was probably not fully captured by the limited number of trawls in each fjord. Still, the experience of crew and researchers on board the research vessels ensured

that the major habitats in each fjord were sampled. In light of this, the biomass or abundance estimates will not represent absolute values of the species in the fjords, but will instead form a starting point for comparison between and within the fjords.

Further, some diurnal vertical migration has been demonstrated in shrimp populations off the coast of Alaska, resulting in lower abundances near the bottom at night (Barr, 1970). Some of the stations for this project were sampled at night, but there were still good light conditions due to the midnight sun at such a northern latitude. Thus, none of the stations were sampled in the dark, but the light conditions did, however, somewhat vary between the times of day. To what extent this may have influenced biomass or size composition of the catch is unknown. Ideally, all stations would have been sampled close to the same time of day in order to minimize this potentially influencing factor.

A juvenile net with a mesh size of 8 mm is now part of the standard sampling gear in the ecosystem survey, designed and introduced to catch the first two year-classes of shrimp, which are poorly sampled by the trawl (Aschan and Sunnanå, 1997). The trawl is, in fact, biased in its selection of larger shrimp, but there is no reason to believe that this bias differed among stations. The juvenile net was absent on the first cruise and did not catch more than a handful of the first and second year-class on the second. These were excluded from the analysis. Whether the gear malfunctioned or the young of year shrimp had not yet settled at the bottom is unclear. Time between hatching and settling at the bottom has been reported to range between two (Aschan and Ingvaldsen, 2009) and four (Pedersen et al., 2002) months, so it is possible that there were few shrimp of this size class at the bottom. However, the second-year shrimp were not sampled by the juvenile net, either, even in areas where they were caught in the codend. Successful sampling by the juvenile net would have allowed for an estimation of the length of the first year-class, as well as give an indication of its distribution, and a better estimation of the length at age of the second year-class, which was poorly sampled by the trawl.

Lastly, due to limitations of time and resources, only one subsample of shrimp was analyzed per trawl. Ideally, two or three repeated subsamples would ensure that the population structure is a better representative of the total catch. Larger subsamples than those taken would also give more precise estimations of cohorts, particularly at stations dominated by young shrimp.

### 3.6.2 Statistical analysis

The challenges associated with age determination of shrimp have previously been described in section 2.2.3. Grouping of stations based on length frequency distributions provided greater sample sizes for the model, but this method did not work optimally for all stations. In outer Isfjorden, the two stations displayed differences in mean length at age resulting in an excess of noise in the length frequency distribution. A modal analysis fails to accurately distinguish the modes in such pooled data as the modes end up blending due to different patterns. Thus, as the modes in the size distributions did not overlap due to differential growth, the data from each fjord could not simply be pooled and compared, but had to be analyzed separately.

The Mix analysis only illustrates how well the function fits the histograms or overall data. The program is not sensitive to overlapping modes unless the parameters in the test are constrained (Du, 2002). Thus, biological realism was a priority when fitting the curves, particularly when placing these constraints on the parameters. Choosing the most realistic model was a time-consuming and complicated trade-off between best fit (based on the chi-square value) and biological realism, and was achieved through trial and error. Biological realism implied constraining standard deviation to not exceed 1.1 (as advised by Prof. Einar. M. Nilssen, University of Tromsø, 22.11.2013), considering realistic growth between cohorts and being aware of the presence of weak cohorts. The end result was successful, but more time and experience would undoubtedly produce even more accurate results and better fit. The relative age at length was estimated from the literature and length frequency distributions and had to be included in manually included in the analysis. Lastly, there does not appear to be an effective statistical procedure to compare the results of modal analyses (Parsons *et al.*, 1989). Thus, the comparison of length at age is descriptive only.

A second concern regarding the analysis was in the assessment of the length at female maturity. According to the Icelandic method by Skúladóttir (1998), the  $L_{50}$  represents the length at which 50% of the population is mature females. According to the author, this includes egg bearing females, but excludes females with abdominal spines. The confusion arises because the method assumes that females about to spawn undergo a moult where these spines disappear. However, this does not appear to be the case around Svalbard



where primiparous (stage 4) females containing head roe still had spines shortly before spawning. Based on these findings, the females appeared to moult just at the time of spawning, as indicated by observation of large numbers of stage 5 (egg bearing) females with soft carapaces. Thus, stage 4 shrimp with spines were considered “mature” in this analysis, as indicated by the presence of head roe.

This method should be modified and standardized before being applied to analysis of Svalbard shrimp in order to allow for meaningful spatial and temporal comparison. A study using data from 1992-98 (Hansen and Aschan, 2006) excluded the stage 4 shrimp from the analysis. This likely skewed the results as the primiparous, yet mature, females were not included in the calculation. How the results were skewed is determined by the proportions of females in stages 4, 5 and 8. If most of the stage 4 females had transitioned to become stage 5, it would have had little effect. If, on the other hand, sampling occurred before the onset of spawning, it can be presumed that the calculated  $L_{50}$  is significantly greater than what would have been estimated otherwise. The method chosen in this study focused on including all females with roe in the category “mature females”. In the future, a standardization of this method should be a priority in order to produce comparable results.



## 4 Results

### 4.1 *Pandalus borealis* population structure

#### 4.1.1 CTD and catch data

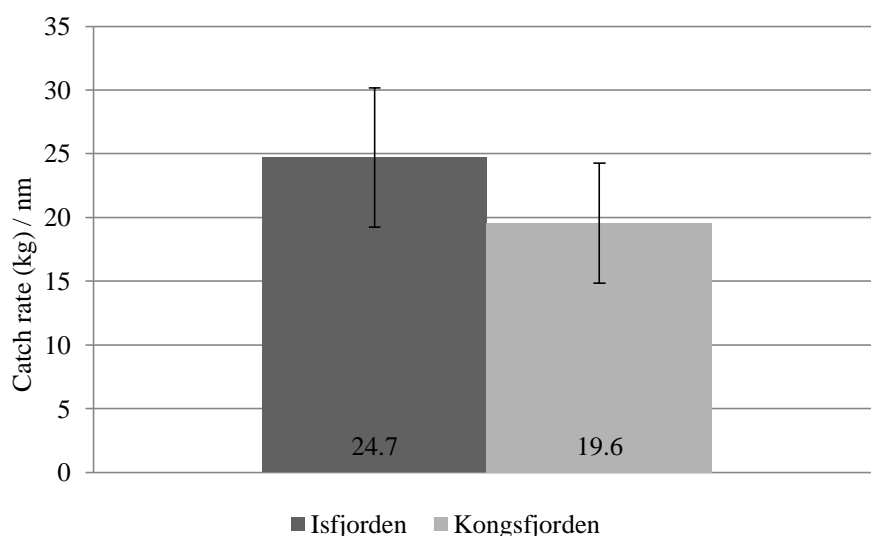
All stations were sampled in daylight on the given dates (Table 2). Due to a faulty Scanmar temperature sensor on the trawl, temperature and salinity data from four stations (37, 53, 54, 127) were interpolated from the constructed maps of isolines, made available by the IMR (Appendix C). The measured bottom temperatures ranged from 0.0° in inner Isfjorden to 5.1° near the glacier (Kongsbreen) in inner Kongsfjorden. The salinity ranged between 34.0‰ near the glacier in Kongsfjorden to 35.0‰ at the outer stations in both fjords.

*Table 2: Standardized catch (per nautical mile) of northern shrimp and CTD results for the sampled stations in Isfjorden and Kongsfjorden. Temperature and salinity data from stations 37, 53, 54 and 127 were interpolated from constructed maps of temperature and salinity isolines (provided by Thomas de Lange Wenneck, IMR; Appendix C)*

St. no.	Location	Date	Time	Catch weight /nm (kg)	Abundance /nm	Depth (m)	Temperature bottom (°C)	Salinity bottom (‰)
31	IF Nordfjorden	19-Aug	16:11	47.38	21269	176	0.8	34.7
33	IF Middle	19-Aug	20:29	18.03	3954	279	0.5	34.8
36	IF Rekesøyla	20-Aug	02:39	36.38	7029	264	3.4	34.9
37	Isfjordrenna	20-Aug	04:42	10.35	2131	260	4.0	35.0
53	Kongsfjorddjupet	21-Aug	16:29	23.77	5862	325	1.0	34.9
54	KF Kvadehuken	21-Aug	17:51	22.61	4898	345	1.0	34.9
127	KF middle	30-Aug	19:24	44.76	9449	355	1.0	34.9
114	IF outer	24-Sep	08:03	16.18	2748	316	2.7	34.8
120	IF middle	24-Sep	16:46	13.16	3443	256	0.0	34.8
122	IF Nordfjorden	25-Sep	08:13	11.52	3545	214	1.5	34.8
123	IF inner	25-Sep	14:40	44.63	12272	188	1.1	34.8
129	KF middle	26-Sep	10:18	22.23	5019	335	2.3	35.0
138	KF O. Sarsfjellet	26-Sep	19:25	6.19	1920	52	4.4	34.5
140	Krossfjorden	27-Sep	08:15	5.24	1476	338	0.1	35.0
143	Kongsfjorddjupet	27-Sep	16:37	6.64	1450	349	1.8	35.0
188	KF Kongsbreen	04-Oct	18:55	25.05	6613	134	5.1	34.0

The catch rates of shrimp varied by a factor of nine; from 5.24 kg/nm at station 140 in Krossfjorden, to 47.38 kg/nm in Nordfjorden (inner Isfjorden). In Nordfjorden (inner Isfjorden; 31 and 122), the catch rate fell from 47.38 kg/nm to 11.52 kg/nm between sampling dates, five weeks apart. Similarly, stations in Kongsfjordjupet (outer Kongsfjorden; 53 and 143) and middle Kongsfjorden (127 and 129) fell from 23.77 to 6.64 kg/nm and 44.76 to 22.23 kg/nm, respectively, in the same time period. Although the mean catch rate in Isfjorden is greater than that in Kongsfjorden (Figure 11), the difference is not statistically significant ( $p > 0.48$ , t-Test assuming unequal variances,  $df = 14$ ) Catch rate was neither correlated with temperature nor salinity. The depths sampled (52-355m) were within the species' known distributional range (Shumway *et al.*, 1985) and, similarly, showed no correlation.

*Figure 11: Mean northern shrimp catch rate per nautical mile (kg) at bottom trawl stations in Isfjorden and Kongsfjorden. Error bars represent the standard error of the means (SE = 5.5 and 4.2,  $p > 0.48$ )*



#### 4.1.2 Length frequency distributions

A total of 7122 shrimp (3453 from Isfjorden and 3669 from Kongsfjorden) were stage determined and measured at the 16 stations. These data are summarized as length frequency distributions in Figures 12 and 13. Samples from inner stations comprise a greater proportion of males (stage 2) than from more outer areas of the fjords, evident in stations 31, 33, 120 and 123 in Isfjorden, and stations 138 and 188 in Kongsfjorden. Stations sampled on the second cruise, in September, include a greater proportion of egg-bearing females (stage 5) than those sampled in August (Table 3).

Figure 12: Length frequency distributions of carapace lengths (0.5 cm bins) and life-history stages of northern shrimp samples from bottom trawl stations in Isfjorden.

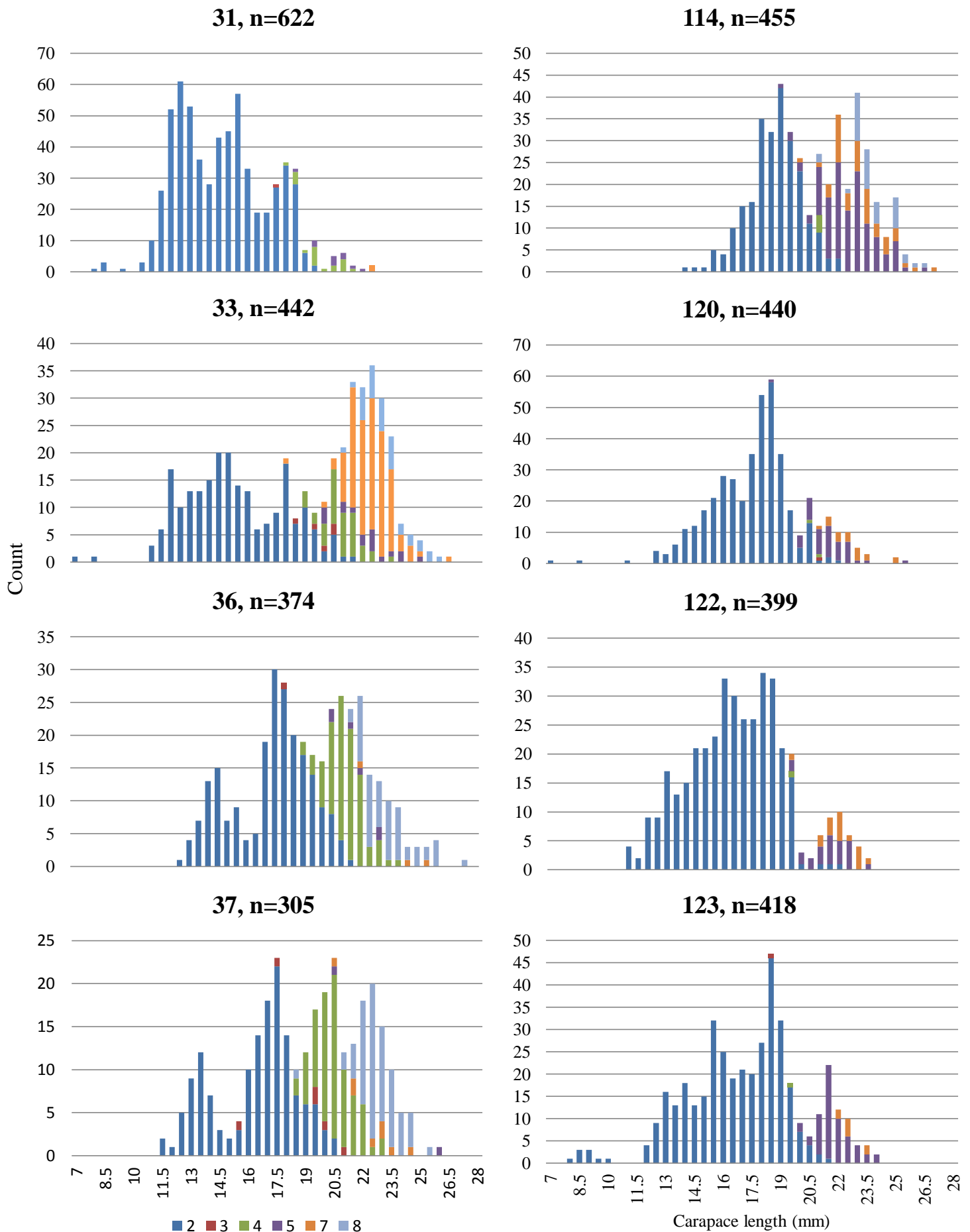
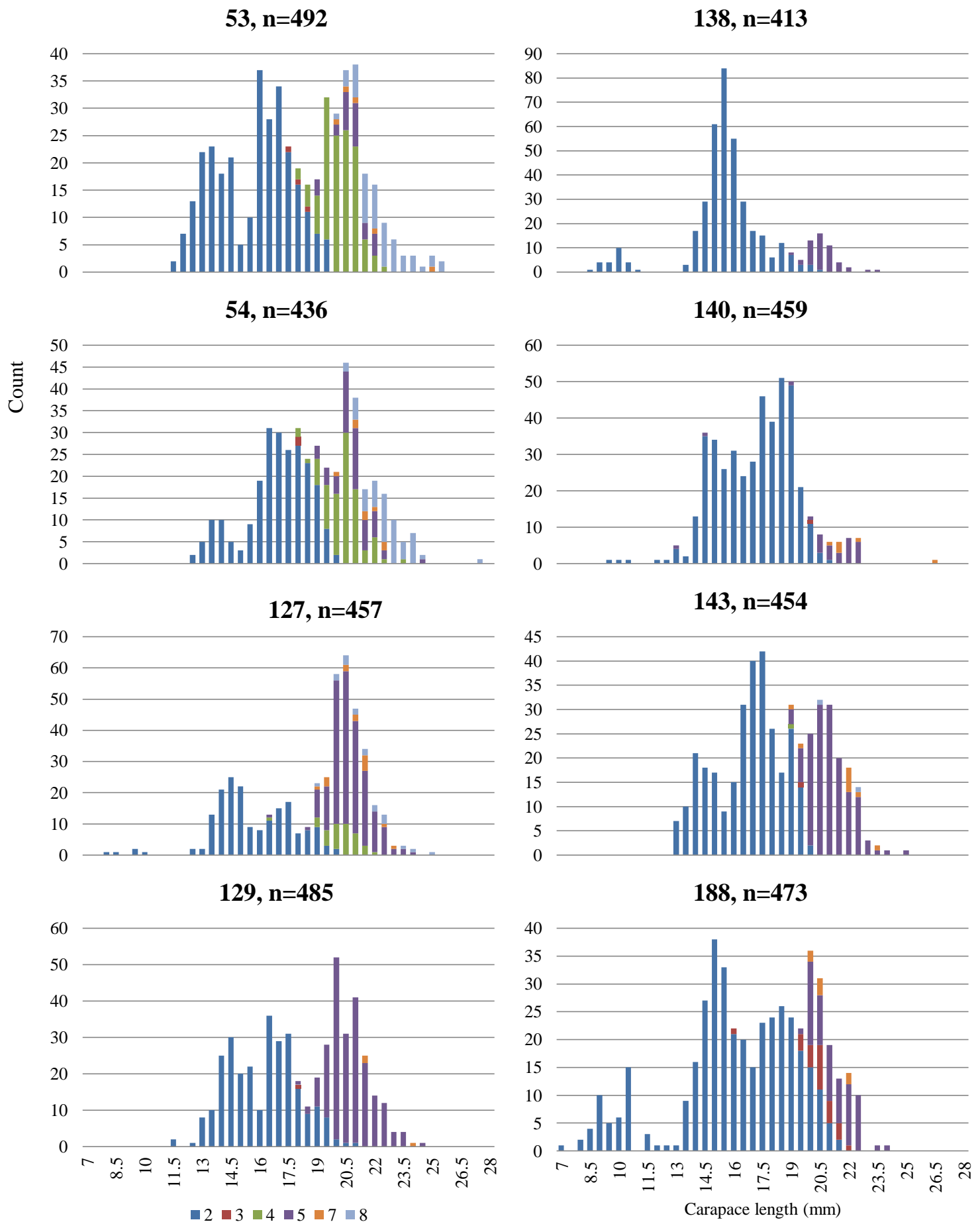


Figure 13: Length frequency distributions of carapace lengths (0.5 cm bins) and life-history stages of northern shrimp samples from bottom trawl stations in Kongsfjorden.



The proportions of males (stages 2 and 3) and females (stages 4-8) differed greatly among stations (Table 3), from 49.8 to 94.8% males in Isfjorden, and from 39.2 to 92.4% in Kongsfjorden. Between the fjords, however, it was not a significant difference ( $p > 0.73$ , t-test assuming unequal variances,  $df = 14$ ).

*Table 3: Proportions (given in per cent) of life history stage, also summarized into sexes, of northern shrimp at stations in Isfjorden and Kongsfjorden. Stations in Isfjorden are positioned above the horizontal line.*

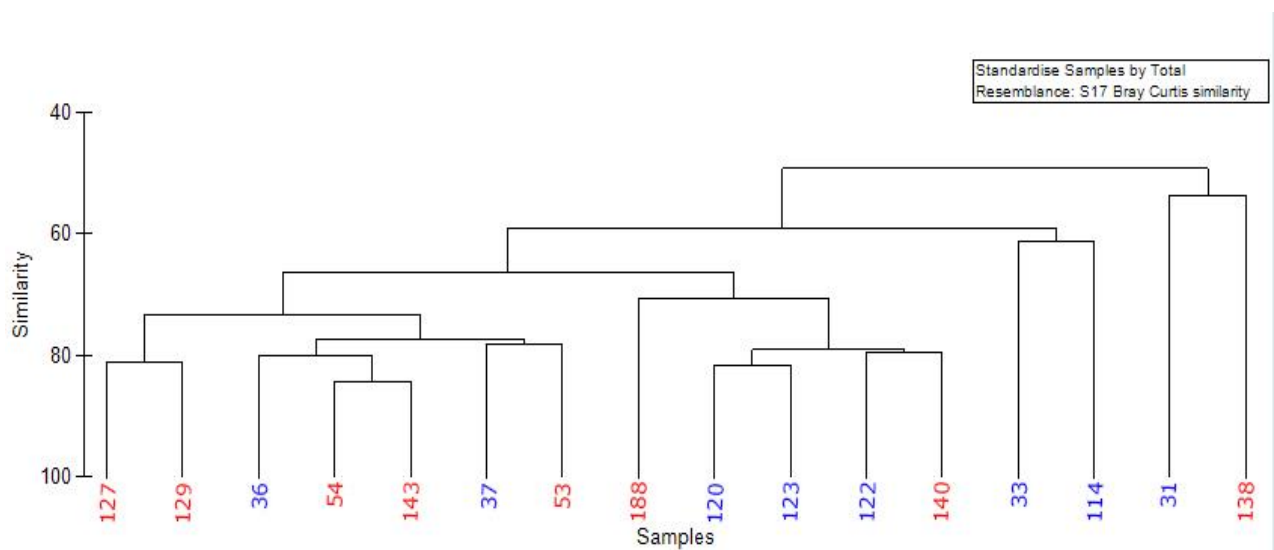
Station	Life history stage (%)							Totals (%)	
	2	3	4	5	6	7	8	Males	Females
<b>31</b>	94.7	0.2	3.2	1.6	0.0	0.3	0.0	94.8	5.2
<b>33</b>	49.3	1.1	9.3	3.8	0.0	28.5	7.9	50.5	49.5
<b>36</b>	57.2	0.3	24.3	1.6	0.0	0.8	15.8	57.5	42.5
<b>37</b>	47.9	2.0	24.9	0.7	0.0	2.6	22.0	49.8	50.2
<b>114</b>	53.0	0.0	0.9	27.0	0.0	10.5	8.6	53.0	47.0
<b>120</b>	84.8	0.2	0.5	10.5	0.0	4.1	0.0	85.0	15.0
<b>122</b>	89.5	0.0	0.3	6.0	0.0	4.3	0.0	89.5	10.5
<b>123</b>	83.7	0.2	0.2	13.9	0.0	1.9	0.0	84.0	16.0
<b>53</b>	57.3	0.6	25.0	5.5	0.0	1.0	10.6	57.9	42.1
<b>54</b>	52.3	0.5	20.9	12.6	0.0	1.8	11.9	52.8	47.2
<b>127</b>	39.2	0.0	8.3	45.3	0.0	3.3	3.9	39.2	60.8
<b>129</b>	56.1	0.2	0.0	43.1	0.0	0.6	0.0	56.3	43.7
<b>138</b>	88.6	0.0	0.0	11.4	0.0	0.0	0.0	88.6	11.4
<b>140</b>	92.2	0.2	0.0	6.3	0.0	1.3	0.0	92.4	7.6
<b>143</b>	65.0	0.2	0.2	32.2	0.0	2.0	0.4	65.2	34.8
<b>188</b>	79.5	5.1	0.0	14.0	0.0	1.5	0.0	84.6	15.4

### 4.1.3 Spatial analysis

A cluster analysis of the carapace length frequency distributions allowed for grouping of stations for further analysis (Figure 14). The analysis revealed a greater similarity among stations located in similar areas (inner/middle/outer) across the fjords than within them.

Outer stations 36, 37, 53, 54 and 143 were just under 80% similar. Two stations (127 and 129) sampled four weeks apart at the same location in middle Kongsfjorden were over 80% similar. Inner stations 120, 122, 123, 140 and 188 were approximately 70% similar. Inner stations 31 and 138 were less than 60% similar, but they were more similar to each other than the rest of the group. The same was revealed for middle stations 33 and 114 (60% similarity). Two stations (127 and 129) sampled in the same location in middle Kongsfjorden, four weeks apart, were, in contrast just over 80% similar.

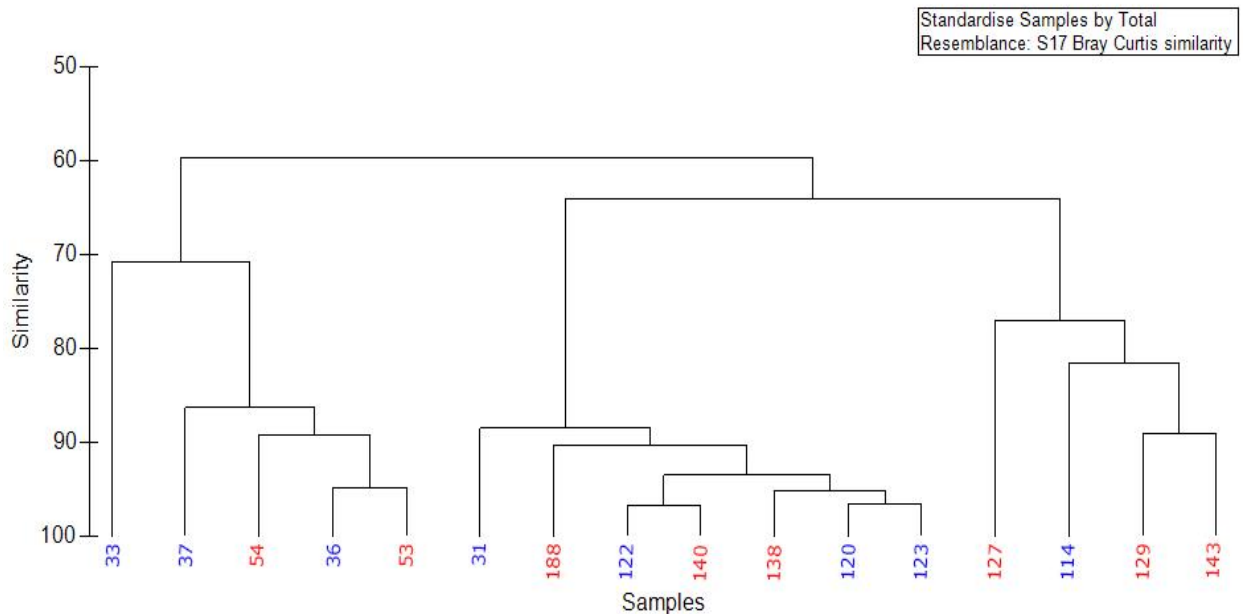
*Figure 14: Dendrogram from the cluster analysis used to combine samples of shrimp based on the similarity of their LFDs in Isfjorden (blue) and Kongsfjorden (red).*



A similar dendrogram was constructed based on the proportions of males, spawning females and resting females (Table 3; Figure 15). Again, it showed that the region within the fjord better determined population structure than did the fjord identity. The dendrogram revealed two main clusters with >75% similarity. Inner stations (31, 120, 122, 123, 138, 140, 188) were >90% similar. Middle and outer stations (36, 37, 53, 54, 114, 127, 129, 143) were >80% similar. Inner station 33 comprised of a relatively large proportion of resting females (stage 7; Table 3), setting it aside from the rest.



Figure 15: Dendrogram from the cluster analysis used to combine samples of shrimp based on the similarity of their maturity stages (male, spawning or resting female) in Isfjorden (blue) and Kongsfjorden (red).



#### 4.1.4 Cohort analysis

Modal analysis using Mix 3.0 (MacDonald and Pitcher, 1979) revealed a maximum of six year classes in the samples. The stations were grouped based on their location and similarities of length frequency distribution (Figure 14). In spite of being almost 80% similar in the LFD cluster analysis, stations 36 and 37 in outer Isfjorden were too dissimilar in their modes for fitting the model and had to be analyzed individually. The modelled curves and output data are summarized in Table 4 and Figure 16. The goodness of fit was given by a chi-square ( $\chi^2$ ) value, which ranged from 10.11 to 46.74 – typical values for this analysis (Hoxmeier and Dieterman, 2011). Lower values correspond to a better fit.

Table 4: Mean carapace length (mm) of year classes of northern shrimp, estimated by Mix 3.0 modal analysis (Figure 16), in Isfjorden and Kongsfjorden. The goodness of fit is given by the  $\chi^2$ -value. Means in italics indicate where sample size was too small for Mix. Standard errors are given in parentheses and values in bold are visualized in Figure 17.

Cohort																
Area/Station	SD	I		II		III		IV		V		VI		n	$\chi^2$	
		CL (mm)	%	CL (mm)	%	CL (mm)	%	CL (mm)	%	CL (mm)	%	CL (mm)	%			
Isfjorden	Inner	0.81-0.94	8.62	0.9	12.78 (0.13)	21.0	15.56 (0.08)	32.1	18.33 (0.07)	35.0	21.65 (0.10)	10.7	24.92	0.3	1877	22.95
	Middle	0.72-1.10	7.53	0.2	12.26 (0.26)	4.6	14.98 (0.24)	14.8	18.73 (0.14)	32.0	22.32 (0.13)	43.0	24.61	5.4	897	26.58
	36	0.78-1.10	-	-	14.42 (0.12)	15.5	18.09 (0.11)	37.5	21.38 (0.17)	38.0	24.64 (0.34)	9.0	-	-	376	21.59
	37	0.74-0.97	-	-	13.24 (0.15)	12.9	17.20 (0.24)	32.1	19.94 (0.22)	24.2	22.47 (0.24)	30.8	-	-	303	10.11
Kongsfjorden	Inner	0.83-1.10	9.83 (0.11)	5.6	15.24 (0.06)	43.7	18.07 (0.17)	33.2	20.62 (0.24)	17.3	24.22	0.2	-	-	1345	46.74
	Middle	0.76-1.1	10.01	0.9	14.48 (0.09)	22.3	17.16 (0.10)	21.2	20.33 (0.14)	47.8	23.95	7.8	-	-	942	13.86
	Outer	0.79-1.10	-	-	14.42 (0.12)	15.6	18.05 (0.11)	36.2	21.39 (0.17)	40.6	24.43	7.7	-	-	1526	22.75

Figure 16: Length frequency distributions of northern shrimp caught at 16 stations in Isfjorden and Kongsfjorden, fall 2013. Overlaying green lines are best fitting mixture models and red lines are age groups. Mean length at age values are represented by triangles.

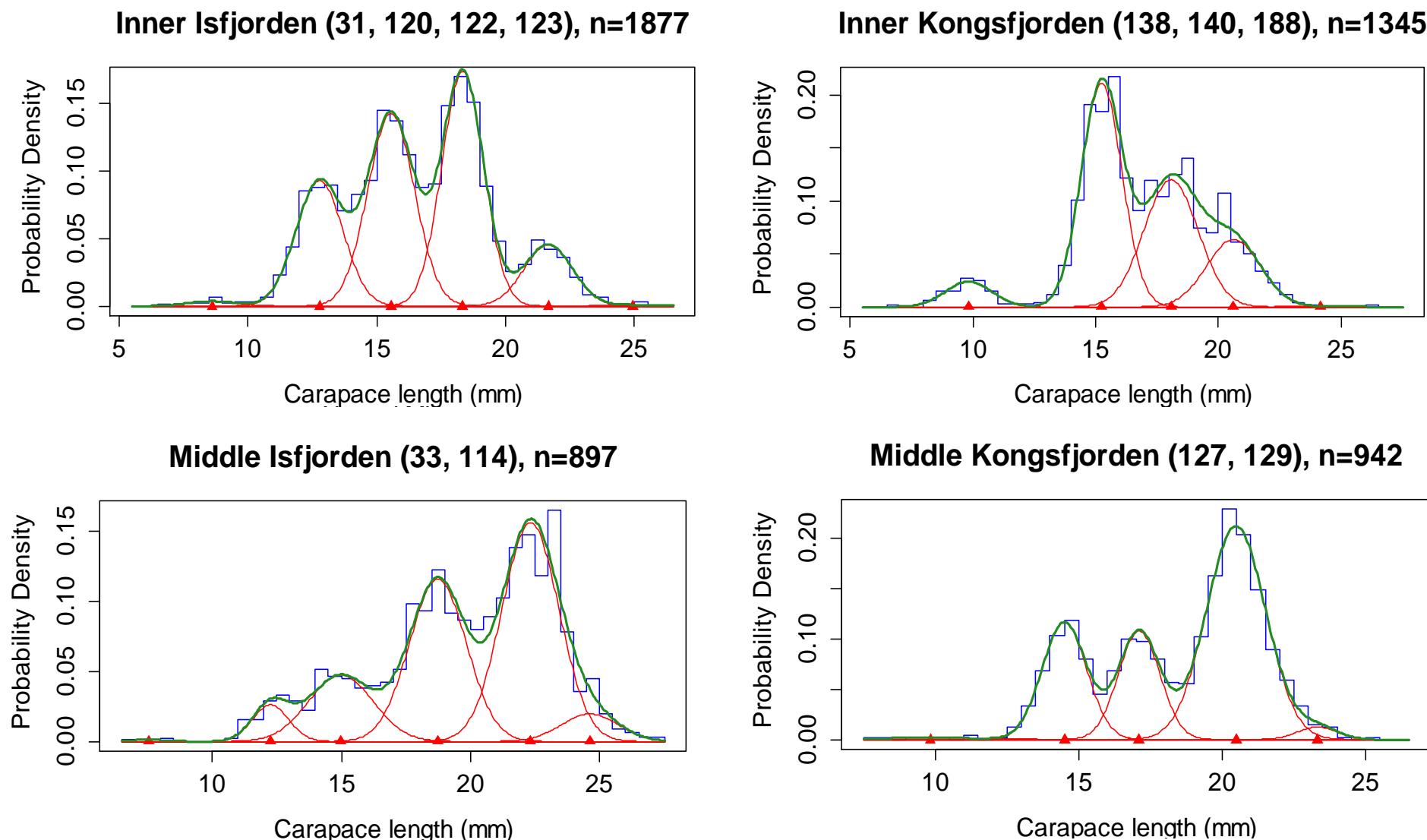
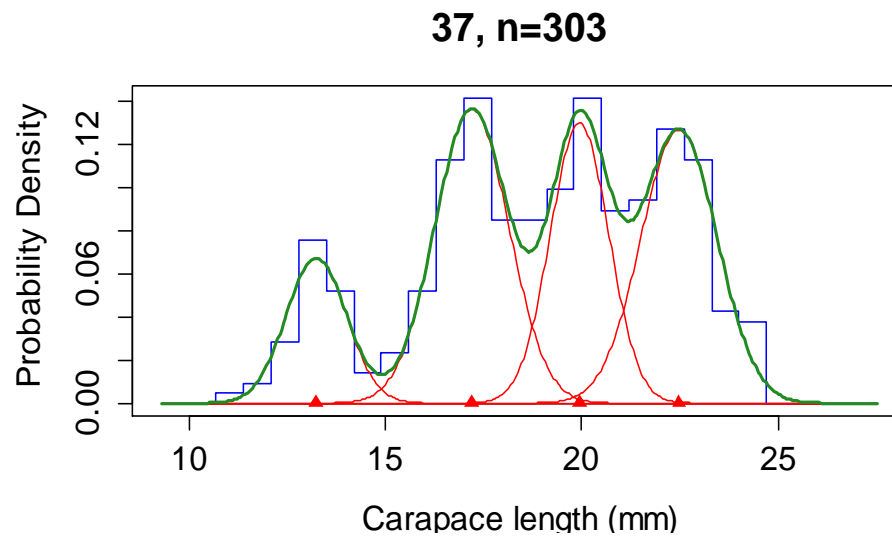
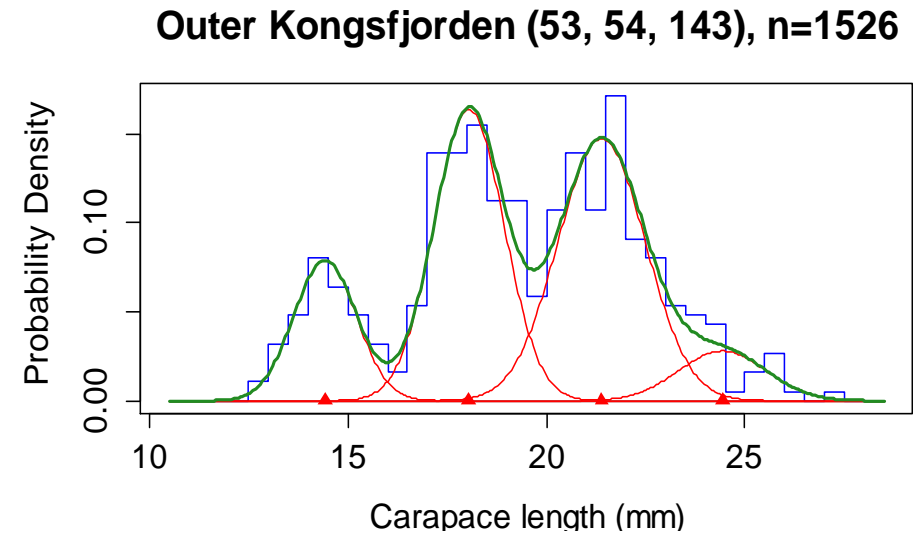
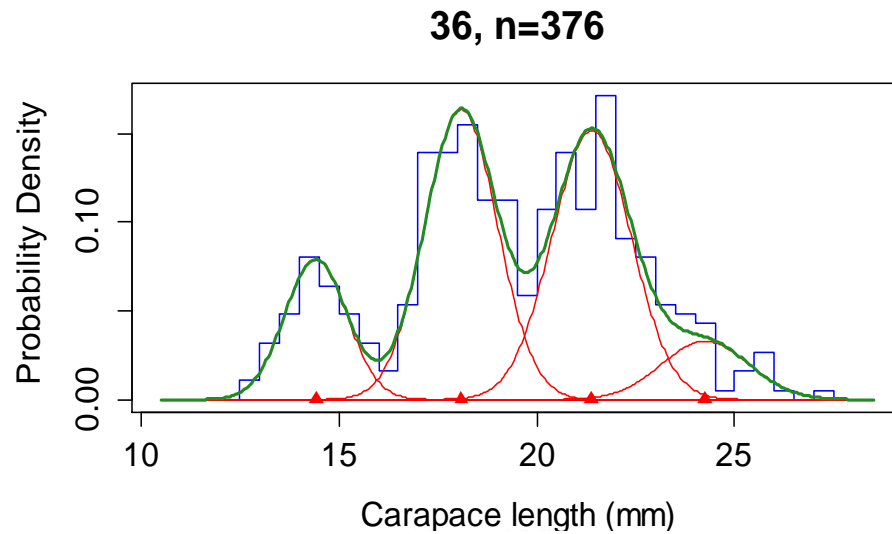
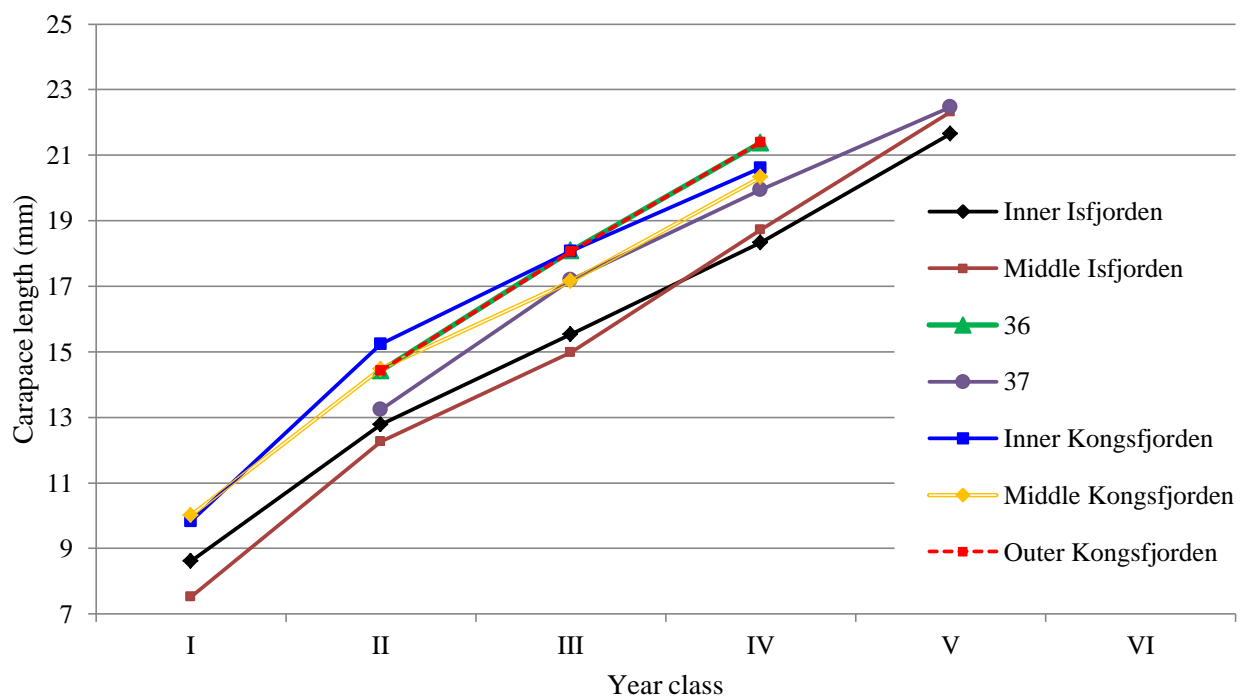


Figure 16 (cont.): Length frequency distributions of northern shrimp caught at 16 stations in Isfjorden and Kongsfjorden. Overlaying green lines are best fitting mixture models and red lines are age groups. Mean length at age values are represented by triangles.



The youngest cohort caught in the trawl was 7-8 mm CL in Isfjorden and 9-10 mm CL in Kongsfjorden. The length at age of shrimp in Kongsfjorden did not vary between areas, and was generally slightly greater than the length at age in Isfjorden. The output data from the models is visualized in Figure 17 and suggests a slight reduction in length at age at the inner and middle stations in Isfjorden (black and brown lines) compared to similar locations in Kongsfjorden (blue and yellow lines). However, the outer stations in both fjords show similar lengths at age.

*Figure 17: Modelled lengths at age using modal analysis (Mix 3.0) of northern shrimp sampled in Isfjorden and Kongsfjorden.*



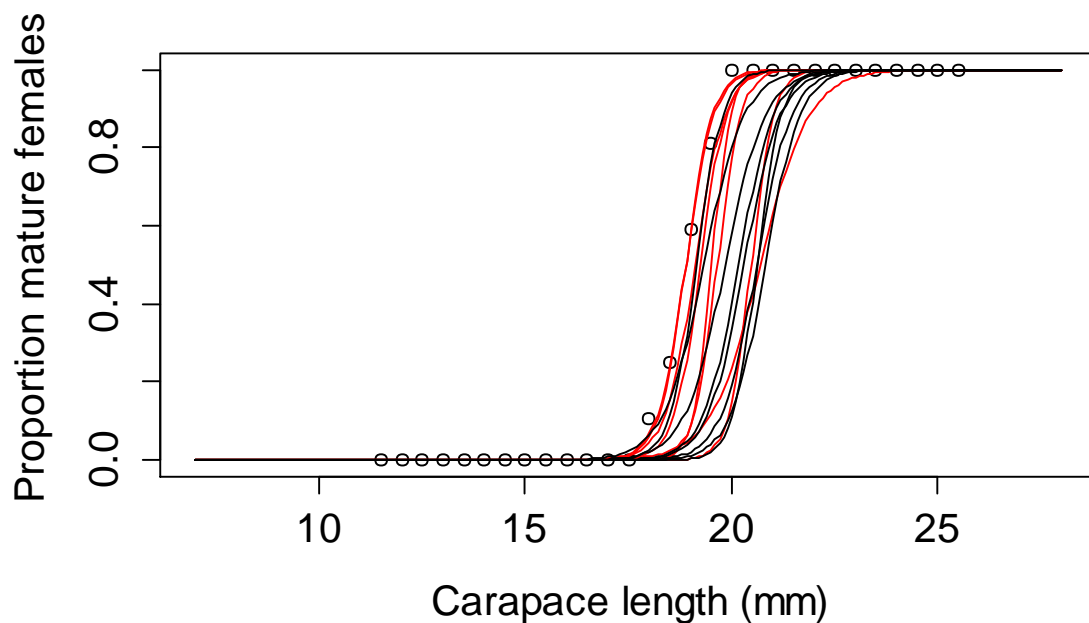
#### 4.1.5 Length and age at maturity

The findings reveal that there are no significant differences in length at maturity for shrimp at the sample sites (Table 5;  $p > 0.12$ , t-test assuming unequal variances,  $df = 14$ ). The inflection point of the maturity ogives for female shrimp, i.e. the length at which 50% of specimens comprised mature females, ranged from carapace length 18.89 to 20.82 mm. Shrimp in inner and middle Isfjorden, where temperatures are generally lower, are estimated to mature as females around the age of 5, one year later than at the other sites. Maturity ogives for all the stations are given in Figure 18.

Table 5: Summarized length and age at maturity of northern shrimp at various locations in Isfjorden and Kongsfjorden based on fitted maturity ogives (Figure 18) and cohort analyses (Table 4). Stations in Isfjorden are positioned above the horizontal line. SE represents the standard error and AIC (Akaike information criterion) the relative quality or fit of the logistic curve to the data. A small value suggests a better fit.

Station	$L_{50}$ (mm)	SE	AIC	Est. Age
31	19.1	0.13	16.8	5
33	19.8	0.14	29.2	5
36	20.2	0.10	24.1	4
37	19.3	0.13	27.9	4
114	20.8	0.10	28.2	5
120	20.6	0.12	29.1	5
122	20.3	0.18	23.9	5
123	20.6	0.13	15.9	5
53	18.9	0.09	20.9	4
54	19.2	0.08	23.7	4
127	18.9	0.10	27.9	4
129	19.1	0.09	26.2	4
138	19.7	0.13	13.5	4
140	20.5	0.13	16.4	4
143	19.5	0.07	18.0	4
188	20.7	0.12	42.1	4

Figure 18: The female maturity ogives of 16 stations in Isfjorden (black lines) and Kongsfjorden (red lines) as proportions of mature females by length class (0.5cm) were used for the calculations of  $L_{50}$  (length at which 50% of specimens are mature females). The plotted data points are from station 53 and exemplify the data used to fit the curves.



## 4.2 Potential predators

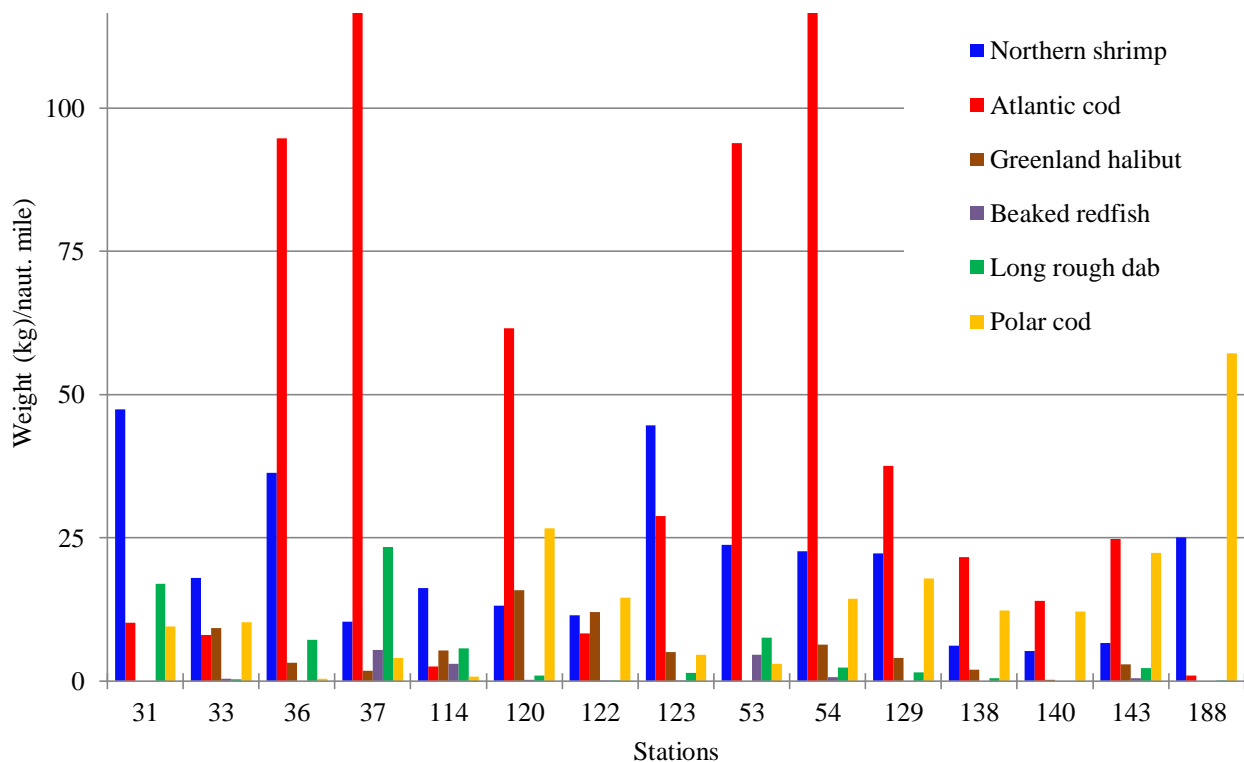
### 4.2.1 Catch data

The trawl catch data, including that of shrimp and the potential predators, are summarized and visualized in Figure 19. A complete list of species and biomass is found in Appendix B. It reveals highly variable catch rates among stations; both of total catch and catch of individual species. Total catch rates per nautical mile were greatest in the outer fjord areas, at 163.2 and 168.3 kg nm<sup>-1</sup>, at stations 36 and 54, respectively. In contrast, the smallest catches were made in middle fjord areas, at 33.4 kg nm<sup>-1</sup> at station 114 in Isfjorden, and 31.4 kg at station 140 in Krossfjorden. This constitutes more than a five-fold difference in total catch. The species comprising the greatest overall biomass was Atlantic cod (*Gadus morhua*). In contrast, haddock (*Melanogrammus aeglefinus*) was mostly absent from the trawl samples. Polar cod (*Boreogadus saida*) was caught at a relatively moderate rate of 9.5 to 26.6 kg nm<sup>-1</sup>, with the exception of station 188, next to Kongsbreen glacier, (57.2 kg nm<sup>-1</sup>) and stations 36, 114 and 53 (0.4, 0.7 and 3.0 kg nm<sup>-1</sup>). Stations 31 and 122 in Isfjorden and stations 53 and 143 in Kongsfjorden were sampled in the same location, but five weeks apart. The results reveal a halving of total catch rates at both locations. The greatest differences are seen in catch rates of shrimp (Isfjorden) and cod (Kongsfjorden). Lastly, there were no significant correlation between abundance of predators, biomass of shrimp and environmental parameters (Table 6).

Table 6: Spearman Rank Order Correlations of biomass and abundance of shrimp, environmental parameters depth, bottom temperature and salinity, and abundance of predators, from stations in both Isfjorden and Kongsfjorden.

Variable	Spearman Rank Order Correlations (Spreadsheet1)								
	MD pairwise deleted Marked correlations are significant at p < .05000								
	kgnm	nmm	depth	btemp	bsal	pred-pcod	pcod	allpred	atlcod
kgnm	1.000000	0.973529	-0.070588	-0.079646	-0.264208	0.135714	-0.277033	-0.125000	-0.060714
nmm	0.973529	1.000000	-0.188235	-0.085546	-0.320297	0.114286	-0.234138	-0.146429	-0.046429
depth	-0.070588	-0.188235	1.000000	-0.327435	0.715872	-0.264286	-0.076854	-0.089286	-0.003571
btemp	-0.079646	-0.085546	-0.327435	1.000000	0.005922	0.110813	0.245081	0.466488	0.134048
bsal	-0.264208	-0.320297	0.715872	0.005922	1.000000	0.019678	-0.114593	0.023256	0.307693
pred-pcod	0.135714	0.114286	-0.264286	0.110813	0.019678	1.000000	-0.361037	0.100000	0.764286
pcod	-0.277033	-0.234138	-0.076854	0.245081	-0.114593	-0.361037	1.000000	0.779268	0.032172
allpred	-0.125000	-0.146429	-0.089286	0.466488	0.023256	0.100000	0.779268	1.000000	0.300000
atlcod	-0.060714	-0.046429	-0.003571	0.134048	0.307693	0.764286	0.032172	0.300000	1.000000

Figure 19: Catch rate of northern shrimp and the most abundant fish species, in kilograms per nautical mile, from bottom trawl stations in Isfjorden and Kongsfjorden.



#### 4.2.2 Stomach-contents analysis

The percentage of non-empty stomachs containing shrimp is given for each fish species in Table 7. In Isfjorden, 25 to 100% of cod stomachs contained shrimp. In Kongsfjorden, these numbers were slightly lower, ranging from 19.6 to 66.7%. A total of 42.4% (n=30) of cod stomachs from individuals exceeding 20 cm in length contained shrimp. In Kongsfjorden, the percentage was lower, 28.8%, but the sample size greater (n=73). Smaller samples of Greenland halibut, long rough dab and beaked redfish were analyzed, and some contained shrimp, establishing them as potential predators, but they had far lower frequencies of occurrence than Atlantic cod. Polar cod was also considered as a potential predator at lengths above 14 cm and was frequently caught at high rates in the bottom trawl (Figure 19). The frequency of occurrence in stomachs was similar between fjords, at 9.7% (n=31) in Isfjorden and 10.9% (n=119) in Kongsfjorden.



Table 7: Percentage of non-empty stomachs from potential predators that contained shrimp from trawl stations in Isfjorden and Kongsfjorden. 'n/a' implies that no specimens were caught in the trawl, whereas '-' indicates where no stomach samples were analyzed.

Potential predator	<u>Isfjorden</u>				<u>Kongsfjorden</u>			
	114	120	122	123	129	138	140	143
Atlantic cod >20cm	25	37.5	100	45.5	66.7	19.6	50	50
Greenland halibut >20cm	40	0	20	50	n/a	n/a	n/a	0
Long rough dab >20cm	0	-	n/a	0	50	0	n/a	0
Beaked redfish >20cm	0	n/a	n/a	n/a	n/a	n/a	n/a	33.3
Polar cod >14cm	-	-	0	18.8	22.2	8.8	16.7	3.8

### 4.2.3 Potential for predation

Abundance per nautical mile for potential predators of length greater than 20 cm (NEA cod, Greenland halibut, beaked redfish and long rough dab) and 14 cm (polar cod) at each station are given in Table 8. Data is missing at station 127 where only shrimp catch was recorded and analyzed. Abundances greatly varied between stations and the spread mirror the catch rates in kilograms in Figure 19. Comparisons of mean abundance per nautical mile of potential predators in each fjord are given in Figures 20-23. Due to the great variation within each fjord, the apparent differences were not statistically significant ( $p>0.05$ ) for Atlantic cod or when the species were grouped. The abundance of large polar cod (>14cm), on the other hand, was significantly greater in Kongsfjorden (296 individuals average) and Isfjorden (15 individuals average) with the Mann-Whitney U-test giving a p-value smaller than 0.01 (Figure 23).

Table 8: Abundance of potential predators standardized per nautical mile. Stations in Isfjorden are positioned above the horizontal line.

Station	Atlantic cod	Greenland halibut	Beaked redfish	Long rough dab	Polar cod
31	6.3	0.0	0.0	95.0	18.8
33	2.7	20.0	1.3	1.3	0.0
36	31.3	5.0	0.0	27.5	2.5
37	40.0	2.5	30.0	63.8	15.0
114	1.1	8.0	13.8	17.2	0.0
120	18.2	20.5	1.1	4.6	30.7
122	2.4	9.7	0.0	0.0	25.4
123	15.2	7.0	0.0	3.5	23.4
53	30.0	0.0	8.6	20.0	12.9
54	30.7	6.7	1.3	5.3	78.7
129	12.4	4.1	0.0	4.1	136.9
138	105.4	2.2	0.0	4.3	236.6
140	4.2	0.0	0.0	0.0	62.5
143	6.6	2.8	1.9	7.5	151.9
188	0.0	0.0	0.0	0.0	1391.2

Figure 20: Mean abundance per nautical mile of all potential predators of shrimp (including >14cm polar cod) at stations sampled in Isfjorden and Kongsfjorden. Error bars represent the standard error of the mean ( $SE = 15.5$  and  $180.0$ ,  $p > 0.19$ ).

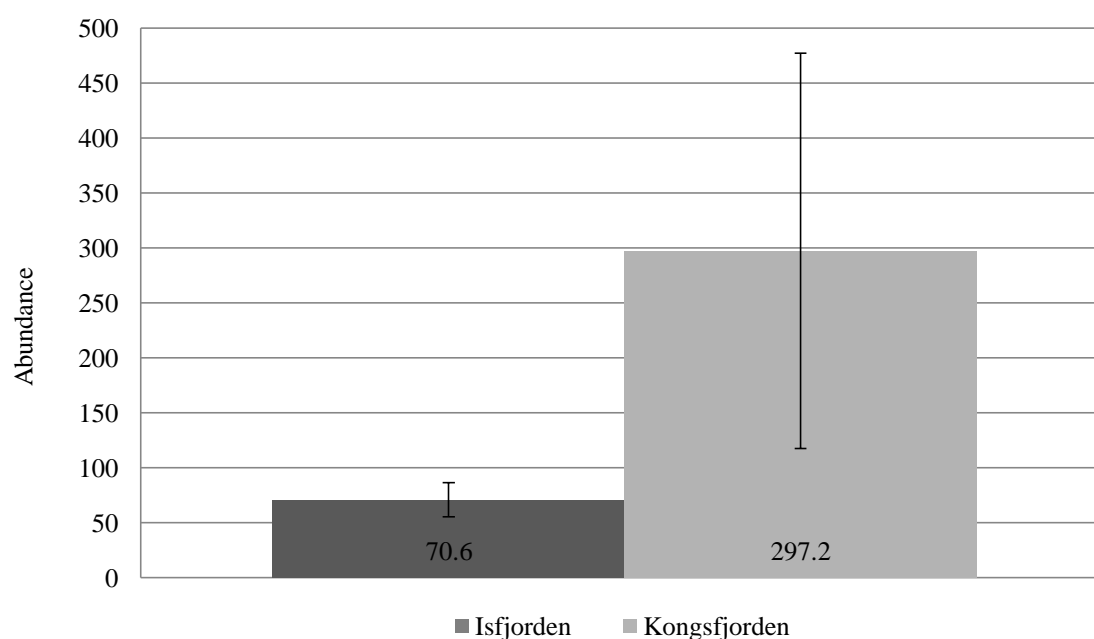


Figure 21: Mean abundance per nautical mile of potential predators of shrimp (excluding >14cm polar cod) at stations sampled in Isfjorden and Kongsfjorden. Error bars represent the standard error of the mean ( $SE = 15.1$  and  $14.8$ ,  $p > 0.36$ ).

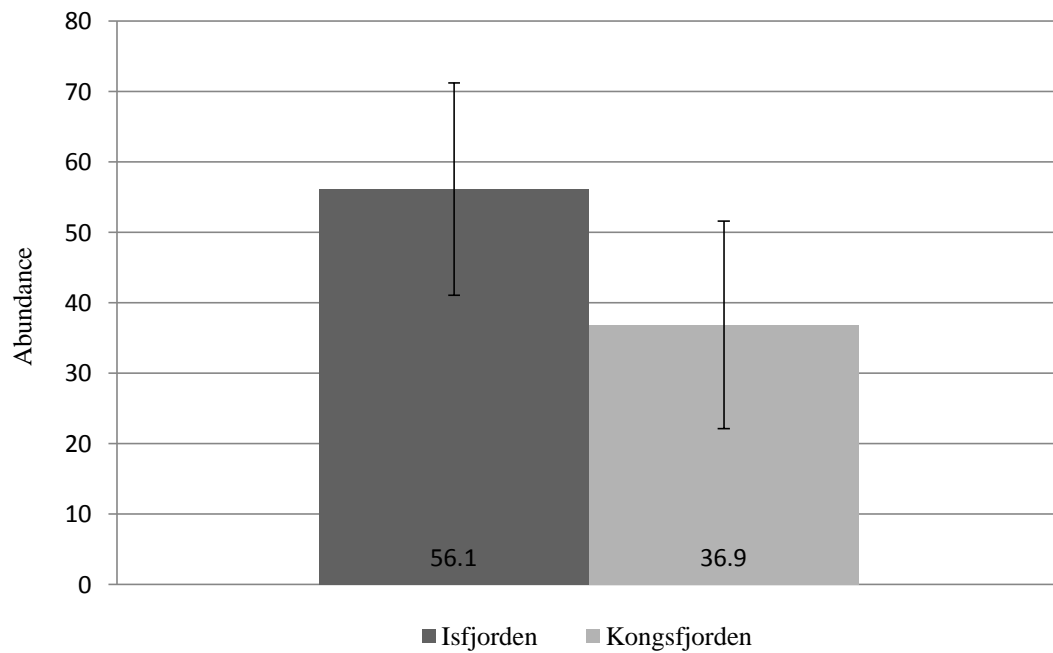


Figure 22: Mean abundance per nautical mile of Atlantic cod (*Gadus morhua*) >20cm at stations sampled with bottom trawl in Isfjorden and Kongsfjorden. Error bars represent the standard error of the mean ( $SE = 5.1$  and  $13.8$ ,  $p > 0.42$ ).

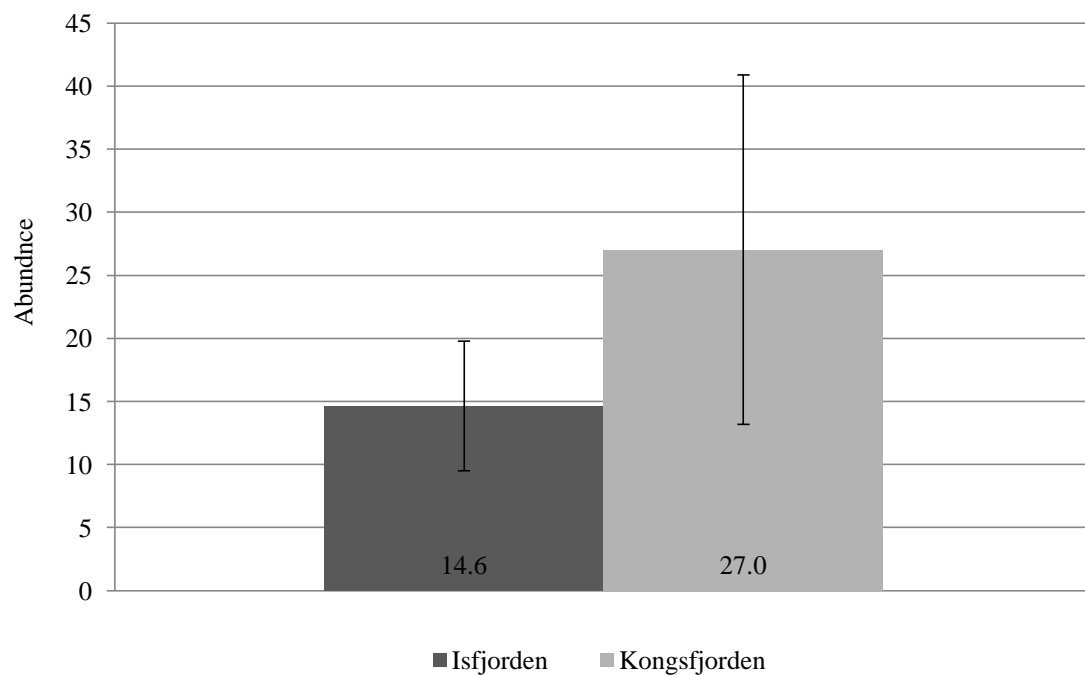
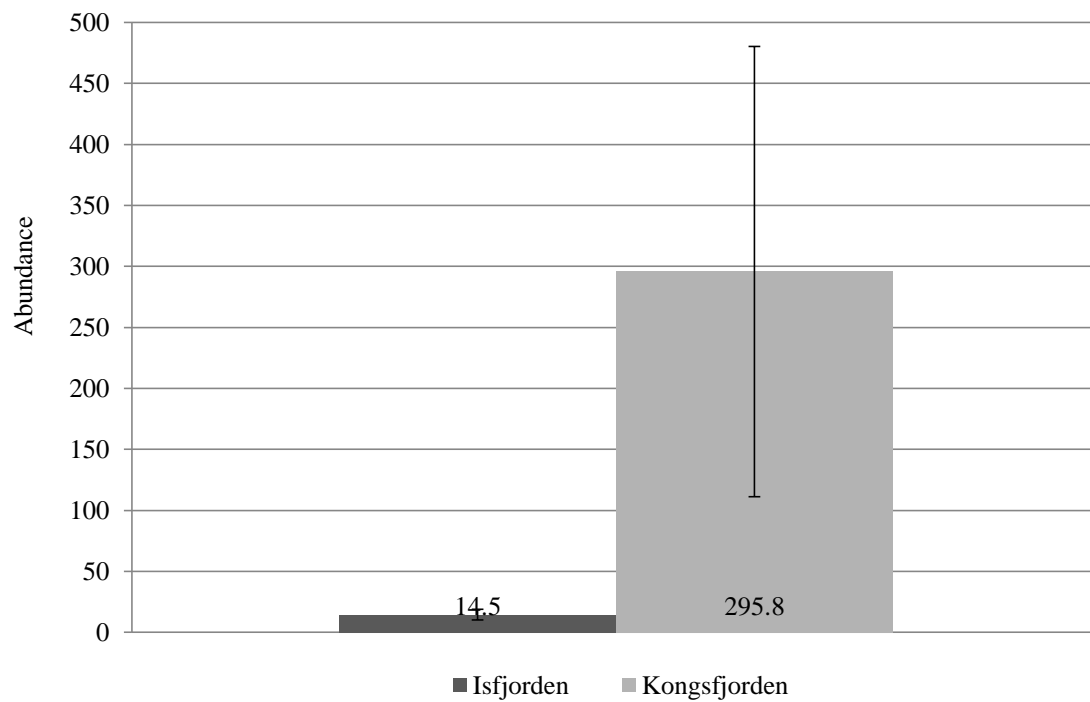


Figure 23: Mean abundance per nautical mile of polar cod (*Boreogadus saida*) >14cm at stations sampled with bottom trawl in Isfjorden and Kongsfjorden. Error bars represent the standard error of the mean ( $SE = 4.3$  and  $184.6$ ,  $p < 0.01$ ).



## 5 Discussion

### 5.1 Spatial variability between fjords

#### 5.1.1 Biomass and size structure

The results showed large catches of shrimp in both fjords, confirming the species' central position in the food web (Johannesen et al., 2012a). There was large spatial variation in mean biomass of shrimp both within and between fjords. This resulted in no statistically significant contrasts, despite a moderately higher biomass in Isfjorden (Figure 11). The biomass of shrimp in the trawl, albeit standardized to catch per nautical mile, likely did not give true biomass estimates of the fjords, or perhaps even reliable relative estimates. As outlined in section 3.5, the fjords were not sampled equally and the choice of locations was limited by the accessibility of the trawl gear. Still, the trawl catches provide some means of comparison of the fjords – at least in the deeper basins where northern shrimp dominates the decapod community (Berge *et al.*, 2009), but rather than revealing differences between them, they highlight variation among locations within each fjord (see Section 5.2.1).

Similarly, it was concluded that there were no major differences in the population size structure between the fjords as the cluster analysis of carapace length frequency distributions showed that the stations did not cluster and separate by fjords (Figure 14). The proportions of males and females differed largely among stations, but there were no significant difference between the fjords (Table 3). Using length frequency data from 1992-98, Hansen and Aschan (2006) showed that Isfjorden had larger proportions of smaller shrimp than any other area around Svalbard. It was suggested that this might have been due to lower temperature or fishing pressure. Trawling selectively removes the large females from the population and the fishing pressure exerted on the Isfjorden shrimp population was relatively high in 1990 (Figure 4). However, the general decline of fishing since then may have allowed for the population to recover in the past decade. Further, the current modest fishing pressure may not be sufficient to have impacted the population size structure in any significant way (Carsten Hvingel, Institute of Marine research, Tromsø, pers. comm., 15.11.2013). Further, the 2000 study showed that there was greater interannual variation in length frequency distributions within Isfjorden than the other six areas sampled. The other areas were within each degree latitude from 75° to 81° N. The data was collected during the annual trawl survey (now ecosystemsurvey; Aschan and

Sunnana, 1997). The exact locations of the stations were not disclosed, but they are not generally within fjords (with the exception of Isfjorden), and they often change between years as the survey grid is under constant evaluation (Knut Sunnana, Senior Scientist, Institute of Marine Research, Tromsø, pers. comm.). The variability within Isfjorden may have been due to unequal sampling of areas due to changing locations, and it highlights the heterogeneity of fjord systems, which have not previously been discussed. Kongsfjorden did not fall wholly within an area, but was split by the 79° N line of latitude. Both areas had less interannual variability in length frequency distributions and greater proportions of larger shrimp than Isfjorden. These results differ significantly from those presented in this study, and are not easily explained. It is possible that no other fjord than Isfjorden was sampled in Hansen and Aschan's study, suggested by the consistency of the LFDs in the other areas, making them irrelevant for comparison to this study. It is likely that smaller shrimp is typical for fjords in general, as suggested by this study, rather than just for Isfjorden.

### **5.1.2 Length at age and female maturity**

The length and age at female maturity is also not significantly different between fjords. The difference in  $L_{50}$  among stations was smaller than the overall annual length increment of the cohorts. Thus, it is concluded that shrimp in Isfjorden and Kongsfjorden mature as females at the same length, but at different ages, dependent on growth rate. Fishing, by impacting population size structure has in some areas, such as the Gulf of Alaska, been thought to result in an altered length at female maturity in order to compensate for the resultant loss or gain of overall population fecundity (Charnov, 1981). According to this theory, removing the large fecund females results in a reduction of size at sex change and mean length of primiparous females. Such an adaptive response was not evident in Isfjorden; either because the population here does not display such plasticity in response to their environment, or because the mortality of the larger size classes of the population is insufficient for such a response. As there was no significant variation in size structure between fjords, it might be assumed that the fishing pressure is not sufficient to test the presence of such an adaptive response.

Once the cohorts were identified from the Mix-analysis, they were compared to the literature and assigned an age. Assuming the birth date of the shrimp to be June 1<sup>st</sup>

(Nilssen, 1990), they would at the time of sampling be in the process of settling at the bottom (Aschan and Ingvaldsen, 2009). The sixth and last zoeal stage of the shrimp larvae, while still in its pelagic phase, were found to have a mean carapace length of approximately 3.75 mm off the coast of West Greenland (Pedersen *et al.*, 2002). This size class can therefore be assumed to be the 0+ year class. They were too small to be sampled by the trawl in this study, but the presence of such a size class is assumed based on current knowledge about reproduction in relevant populations described above. The next cohort, also generally too small to be sampled by the trawl (Aschan and Sunnanå, 1997), was assigned the 1+ year class. Some specimens of this length class (around 9 mm) were retained by the trawl, but in insufficient frequencies for the Mix program. The next cohorts were adequately sampled by the trawl and assigned year-classes as far as 6+ years, a smaller number than was first expected based on published literature. Hansen and Aschan (2006) had previously identified as many as ten cohorts in Isfjorden and eight on the Spitsbergen shelf. This discrepancy may be a result of increasing interannual variations or long-term increases in temperatures (Klyashtorin *et al.*, 2009) due to increased Atlantic Water influence, and subsequently growth rates in the areas. It may also be due to bias or difference in the method of data analysis, such as the manual input of cohorts and pooling of LFDs from several stations (as previously discussed in section 3.5). Further, due to the suspension of growth of spawning females and the relatively small proportions of larger size classes in the samples, make the older cohorts difficult to clearly differentiate.

When comparing the middle and interior parts of the fjords, growth rate in Isfjorden appears to be somewhat lower than in Kongsfjorden. The outer fjord basins, however, were similar in their length at age and were assumed to have a similar growth rate. These differences and similarities are descriptive only as there does not appear to be an effective statistical procedure to compare the results of modal analyses (Parsons *et al.*, 1989). Combining the results from the modal analysis and lengths at sex change, it appears that shrimp in Isfjorden are one year older when they change sex; 5 instead of 4. Temperature and density-dependence are frequently quoted as the main determinants of growth in shrimp (Wieland, 2004). As biomass per nautical mile between the fjords did not significantly differ (Figure 11), it was not an influencing factor on the growth rate. The lower temperature in Isfjorden (Table 2) might have resulted in somewhat reduce growth rates here and perhaps also extended the lifespan of individuals. It should, however, be

noted these results are only suggestive and that in order to make any firm conclusions on the growth of shrimp in the two fjords, both temporal data from the same locations and a growth model (for example von Bertalanffy growth curves) need to be employed.

### 5.1.3 Predation

It is suggested that predators, particularly Atlantic cod in the Barents Sea (Berenboim *et al.*, 2000), has the potential to influence the population structure of shrimp. Where the fishery selectively targets the large specimens, predation will affect smaller individuals and juveniles. Thus, predation may directly influence recruitment of shrimp to the stock (Aschan and Ingvaldsen, 2009; Jónsdóttir *et al.*, 2012, 2013). Even so, the mean abundance of all species exerting a potential predation pressure on the shrimp, based on the stomach contents analysis, did not differ significantly between the fjords (Figures 21-24). These results were consistent whether or not polar cod was included in the analysis and suggests that predation pressure between the fjords is of similar strength. However, in isolation, the abundance of polar cod was found to be, on average, 20 times greater in Kongsfjorden (Figure 23); a significant result. The results have also demonstrated a great overlap in distributions of shrimp and large polar cod. Thus, in large abundances, polar cod may have a significant influence the population structure of shrimp. It is possible that the different species exert variable predation pressure on the shrimp population, and that they target different size classes. The greater abundance of polar cod in Kongsfjorden may have offset the effects of fishing in Isfjorden. Yet, the size of polar cod included in the analysis, generally between 14 and 25 cm in total length, limit the size of prey available to them. Polar cod has a large standing biomass in the Barents Sea ( $0.5-1.5 \times 10^6$  tons) and is associated with Arctic Water masses (Hop and Gjørseter, 2013). It is a dominant species in both Kongsfjorden and Isfjorden (Hop *et al.*, 2002; Renaud *et al.*, 2013), but its biomass caught by bottom trawl has decreased significantly in 15 years. In August of 1997-98, 35.6 and 24.4 kg of polar cod were caught in the inner and middle/outer areas, respectively (Hop *et al.*, 2002). These were in 20 minute hauls, which constitutes 1 nautical mile if traveling at a speed of 3 knots  $\text{h}^{-1}$ . In comparison, the biomass of polar caught at inner stations in this 2013 study ranged between 12.4 and 57.2 kg  $\text{nm}^{-1}$ . In the same review by Hop *et al.*, no data was provided for Atlantic cod in the middle and outer basins, but a biomass of 11.3 kg was given for the inner area. The catch rates of the inner area in this study ranged between 1.0 and 21.6 kg  $\text{nm}^{-1}$ , giving the same mean. The catch of Greenland



halibut reversed from being greater in inner versus outer basins in 1997-98 (4.3 versus 1.0 kg), to being greater in the outer basin in 2013 (up to 6.3 kg nm<sup>-1</sup> versus up to 2.0 kg nm<sup>-1</sup> in the inner basins). However, the stations sampled in these two studies were not in the same locations within the fjord, and as it has already been shown that there is great variation within the fjords, these are not directly comparable. They do, however, give an indication of temporal change and it can probably still be concluded that predator biomass in Kongsfjorden has not changed appreciably since the closure in 2002.

## **5.2 Spatial variability within the fjords**

### **5.2.1 Biomass and size structure**

Although the results do not point to any significant differences in shrimp population biomass or size structure between fjords, they clearly demonstrate differences among sites within the fjords (Tables 2-3, Figures 12-15). Further, a similar pattern of differences along the fjord axis were observed in both fjords, suggesting that this may be a general pattern in western fjords on Svalbard.

The catch data displayed an uneven distribution of shrimp biomass within the fjords (Table 2), which could not in any large degree be explained by temperature, depth or other species catch data (Figure 19). Thus, it is speculated that it could be caused by other abiotic data, such as bottom structure, or by biotic factors, such as zoogeographical distribution, food availability and habitat preferences. Three locations were sampled on both cruises, showing significant temporal variation; indicative of at least some degree of short-term migration. Long-term persistence in distribution has been demonstrated in Isfjorden as a whole over the last century, even if the distribution within the fjord varies between years (Berge *et al.*, 2009).

Population size structure also greatly differed between the sites, based on the results of the cluster analyses. Similar trends were seen within both fjords; small male shrimp congregated in the inner regions of the fjord, with the proportion of larger males and females increasing towards the mouth. The clustering of stations into three groups; inner, middle and outer, regardless of fjord, provides further evidence of the heterogeneous nature of fjord habitats. Inner stations varied significantly in temperature between fjords, ~ 0.5° in Isfjorden and ~ 5° in Kongsfjorden, yet they both supported large concentrations of

juveniles and males. Observing such a similar trend between the fjords is interesting, especially considering that Isfjorden is about five times longer than Kongsfjorden and temperatures and glacial presence differs as well. It may suggest favorable conditions for juveniles in these locations, such as food availability, habitat or absence of certain predators (such as cod). However, the extent of migration at this life stage is unknown. It is possible that they concentrate here because of the current system in the fjords transporting them during their pelagic larval stage. It is known that shrimp are sensitive to environmental cues, such as temperature (Anderson, 2000) and probably food availability, but the extent of migration of juveniles and males is not known. Offshore populations of female shrimp have in other areas been found to migrate near shore to release their larvae in the spring (Apollonio *et al.*, 1986), so it is plausible that they might migrate inside fjords to hatch their eggs, resulting in a natural concentration of larvae and, subsequently juveniles, here. More thorough investigations are required in order to gain a better understand this trend.

No evidence of depth stratification of the LFDs and male/female proportions was found within the sampled range of this study (52-355 m; Table 1), although this has been observed in offshore populations in the Barents Sea. It has previously been found that small and medium sized shrimp (usually males) congregate in shallower areas with a depth range of 200-350 m, whereas larger shrimp (females) are more commonly found at a deeper range between 350 and 500 m (Aschan, 2000). Within the sampled range of this study, although great variation in size frequencies, this trend was not obvious. This suggests that more complex and dynamic conditions of these fjords provide more important factors determining distribution than depth and temperature alone.

### **5.2.2 Length at age and maturity**

The length at age of shrimp in Isfjorden differed between outer and middle/inner stations (Table 4). The shrimp from inner and middle basins were smaller than those in the outer basin. The outer stations exhibited similar lengths, and thus growth, to the shrimp in Kongsfjorden. The slightly elevated temperatures in Kongsfjorden and outer Isfjorden suggest a greater Atlantic Water influence in these areas and could potentially result in increased growth rates in these areas. Although there are both annual and seasonal variation in the extent of Atlantic water penetration in Isfjorden, the sheer length of the

fjord (>100 km) will slow and reduce the influence on inner locations. Kongsfjorden is significantly shorter and will not experience the same gradient of temperature (Cottier *et al.*, 2005, 2007; Nilsen *et al.*, 2008). As the length at female maturity did not vary significantly among stations and between fjords (ranging from 18.9 to 20.8 mm; Table 5), it can be assumed that it is length, and not age, that determines the onset of sex change. This result is expected as size is crucial considering reproductive fitness and fecundity (Shumway *et al.*, 1985). No evidence was found that shrimp in these two fjords have lower size at female maturity in areas of low female abundance in order to compensate for decreased reproductive potential (Charnov, 1981).

The cohort analysis revealed no evidence of weaker cohorts at any of the locations, suggested from the proportions of the cohorts in the sample (Table 4; Figure 16). Weak cohorts are usually a result of poor recruitment at the pelagic larval stage (Shumway *et al.*, 1985; Anderson, 2000), but may also result from being targeted by fisheries, and would have caused gaps in the cohort analysis. No such gaps were apparent, but there were obvious differences in the proportions of the various year classes in different areas. Although the proportions varied within the fjords, there was not one cohort with consistently lower proportions than expected among the stations. Based on the data, these local variations are perhaps more likely caused by migration of the shrimp within the fjord rather than any particular cohort being weaker than another. The absence of the juvenile net on the first cruise, and its poor sampling of small shrimp on the second cruise, resulted in few specimens of the 1+ year class, and none of the young of the year shrimp just settling at the bottom. It is unknown if the juvenile net failed or if the youngest cohort had not yet settled. However, as the juvenile net sampled no other cohorts, it is possible that it was inappropriately attached and did not open under water. Either way, this made the length at age estimation impossible for the first cohort and imprecise for the second. Similarly, sample size of the oldest cohort in most of the locations was too small to be considered accurate for the Mix analysis. Exceptions for this were found at inner fjord stations and station 37 in outer Isfjorden, where sample sizes were sufficient for estimation of cohort size.

When compared to a similar investigation using data from 1992-98 (Hansen and Aschan, 2006), it is evident that there is little overlap of findings. For instance, the previous study had identified ten cohorts in Isfjorden, where this study only identified a possible six

(including the cohorts poorly sampled). The average mean length at age ranged from 7.37 to 25.33 mm in their study - similar to the range sampled in this study; 7.53 to 24.92 mm. In the six other areas on the Spitsbergen shelf, up to eight cohorts were identified in their study, but with larger specimens recorded (up to 28.26 mm). Although, in our study, it was concluded that it was not reasonable to pool length frequency data from whole fjords, it was the method employed for the previous study. Pooling the length frequencies of a whole fjord with such varied hydrological conditions may have resulted in the appearance of extra cohorts where it may simply have been one cohort with differential growth rates (Hvingel, 2006). However, when pooling was attempted with the data, still no more than six cohorts were visible (this limitation was explored in section 3.6.2). This suggests that there might have been some changes in the population structure in the approximately two decades between the two assessments. These differences, both between Isfjorden and the other areas, and between the two studies, might be attributed to differences or changes in growth rate with potentially increasing temperatures. In the Hansen and Aschan study (2006), the mean summer bottom temperatures were reported at 1.4°C in Isfjorden and between 0.8° and 2.0°C on the shelf between 1992 and 1998. When compared to the temperatures recorded in this study, the highest being 4.4 and 5.1°C in inner Kongsfjorden, they appear to have increased in this time. The temperatures in outer Isfjorden were similarly quite high, 3.4 and 4.0°C, which could begin to explain the differential growth seen in Isfjorden between the two studies. The temperatures at the middle and inner stations, on the other hand, were similar to the 1.4°C average given by Hansen and Aschan (2006). A more thorough investigation into the temperature fluctuations over the past two decades is required to confirm or reject this suspicion.

A comparison of the length at first female maturity revealed a significantly greater length (and hence age) in the Hansen and Aschan study (2006). The inconsistency of the methods have previously been outlined in section 3.5, but even with adapting the same method as Hansen and Aschan (2006), by excluding the stage four (primiparous) shrimp from the definition “mature females”, the results continue to suggest a reduction in size at first female maturity in our study compared to theirs. In Isfjorden, it appeared to have been reduced from a carapace length of 23.1 mm in the 1990s to between 19.1 and 20.8 mm in 2013. Similarly, in the areas west and north of Isfjorden, the length had previously been reported at a 24.3 and 24.1 mm, respectively. Attempting to explain these differences is

largely speculation, but it is possible that either one of the datasets have been subjected to some bias, either at the point of sampling or analysis. It could for example have been an error in random sampling, faulty measuring calipers or a large number of specimens of a certain size class being excluded from the analysis, perhaps due to a soft or broken carapace which cannot be measured (as a result of moulting). No information was provided on the spatial resolution or exact location of the stations, or the dates or times of sampling, in the Hansen and Aschan study (2006). It is only known that they were sampled in the summer months, and it is likely this was during the annual shrimp survey (between April and September; Aschan and Sunnana, 1997). Thus, if the sampling occurred before any considerable spawning had begun, which is quite likely as sampling took place in the summer, the primiparous females would have been almost completely excluded from the analysis. In which case, their  $L_{50}$  would represent the length at which 50% of the specimens were second-time spawners, and not technically the “age at first female maturity”. Due to the timings of the sampling in this project, particularly on the second cruise, there was no way of distinguishing between first- and second-time spawners, nor was it deemed necessary as they are all “mature females” in this condition. The  $L_{50}$  is, according to Skúladóttir (1998), the length at which 50% of the specimens in the sample are mature females.

It is of course possible that the length at maturity has declined in two decades. In fact, in the north Atlantic, the reported spread in length at maturity range from 18.9 mm in Ísafjardardjúp in the Westfjords in Iceland, to 27.9 mm in the Denmark Strait (Skúladóttir, 1998). Thus, it is biologically feasible for the shrimp to have undergone this change. Skúladóttir also demonstrated that inshore populations, such as fjord populations, appear to be distinctively smaller at the age of maturity than offshore populations. Unless the sampling occurred at the same time of the year, these results are not directly comparable, but they may still give some indication of how the population has changed. Biomass and locations of samples would have been useful in this comparison. Whether there are significant changes in densities of either shrimp or predator species is not known, but the density of shrimp has since 2004 been declining on the Spitsbergen shelf (Figure 6). Known predators, such as Atlantic cod, are also reported to have increased in abundance in the same area (Renaud *et al.*, 2012). Thus, more detailed information is necessary in order to make a meaningful temporal comparison.

### **5.2.3 Predation**

The biomass and abundance of predators also differed among areas of the fjords. Most notably, the biomass of Atlantic cod was much greater at the outer stations. This finding is in accordance with the belief that cod is an Atlantic species preferring warmer water (Drinkwater, 2009), and would, thus, refrain from penetrating the fjords too deeply in large if temperatures are lower here. The abundance of cod greater than 20 cm in length, somewhat surprisingly, was greatest at one of the inner stations in Kongsfjorden (station 138). The sample here consisted mostly of small specimens of less than 30 cm, so the biomass was not significantly higher than other stations. Perhaps smaller cod will congregated there due some favorable factor, such as high food availability. There was, on the other hand, no cod at a nearby station (station 188), adjacent to the glacier, which also accommodated a large number of small shrimp. Polar cod, on the other hand, was found in large concentrations at this inner station in Kongsfjorden. Neither the abundance nor biomass of predators could account for the differential distribution of shrimp biomass in the fjords. Predator interaction was not considered in this study, but it is possible that it represents one of the factors determining community structure of predatory fish.

## **5.3 Areas of further research**

This project, along with the above discussion, has highlighted a number of interesting areas for future research in order to reach a more complete understanding of the fjord systems. These results provide only a snapshot of the conditions in the specified areas. Gaining a better understanding of the local fjord and shelf currents and the ontogenetic movements of the shrimp larvae will begin to explain the differential distribution of length classes observed in the fjords. A more thorough stock assessment and growth modeling, particularly using temporal data would prove or disprove some of the central findings in this thesis, such as insignificant catch differences between the fjords. Temporal data from several locations in the fjords would also give an indication of whether the observed spatial trends holds true over time, particularly at different times of year. Potential in-fjord migration of females could be investigated by a trawl survey in late spring, around the time of hatching. Larval concentrations in the water column could be sampled at the same time by various plankton samplers (for example MIK or Bongo), and could be used to reassess if the birth date of Svalbard shrimp should maintain the 1<sup>st</sup> of June, as suggested by Nilssen

(1990). Egg incubation time is negatively correlated with bottom temperature (Koeller *et al.*, 2009), implying that increasing temperatures might result in earlier hatching, or perhaps later spawning. Time of hatching may be adaptive, but this might ultimately result in hatching being uncoupled from the time of the spring bloom and copepod life cycle. Lastly, pelagic trawls and stomach contents analyses would identify the major predators of shrimp larvae in the area, which largely dictate year class strength (Pedersen *et al.*, 2002). Understanding the current shrimp ecology in the fjords will provide a strong basis for studies into future impacts of varying Atlantic water influence and even climate change. If large predators of shrimp, such as Atlantic cod, keep increasing in abundance and expanding their distributional range, they will undoubtedly impact the population. Continued annual surveying of the areas, but with even greater penetration in Kongsfjorden, will provide data for such impact analyses. Currently, the annual ecosystem survey only samples outer Kongsfjorden.

As stressed both above and in section 3.5, there is a need for standardization of methods of assessing maturity in females. The data is adequately collected, but analysis is not performed in such a way as to provide meaningful comparisons of data sets. Fortunately, it is simply a matter of reassessing the data, if time and resources allow for it.

The focus of future research should be on providing managers with sufficient data to make effective management decisions. Further, continuous monitoring is necessary in order to ensure that they have access to new and updated data in order to assess the effects of these management strategies.

## **5.4 Implications for management**

Currently, shrimp fishing in Isfjorden does not exert a threat to the local shrimp population. However, there is large potential for growth in the areas around Svalbard, especially if the shrimp distribution keeps shifting northward (Figure 7). The area around Svalbard is identified as one of the most important fishing grounds for the Barents Sea fishery (Hvingel and Thangstad, 2012b). The potential for future conflict is considerable, as several locations in Svalbard also possess a high scientific value, as exemplified by the regulated closure of Kongsfjorden in 2007. Long time-series datasets are available for sites in both Kongsfjorden and elsewhere on the archipelago. This alone makes these habitats worth protecting, allowing for investigations into the effects of, for instance, climate

change. Even though effects of current trawling pressure on shrimp are negligible, the trawling gear is likely to cause habitat destruction and impact community structure and function (Shears *et al.*, 1998; Kaiser *et al.*, 2006), aspects of the ecosystem not investigated in this study. Thus, the more global effects of trawling are still unclear.

Protecting the environment simply for its intrinsic value has generally been the philosophy behind protective legislation in Svalbard . Leading up to the protection of Kongsfjorden in 2007, a hearing in 2005 concluded not to change §4 of the Svalbard Environmental Protection Act (Svalbardmiljøloven, 2002) with the rationale that protection for research is less important than conservation (Ministry of Justice, hearing document, 22.03.2005). Ensuring the continued protection of Kongsfjorden is important to maintain the proven valuable scientific research in the area. The fjord may also in the future function as control sites to investigate effects of trawling if fishing intensify in Isfjorden.

Avoiding conflict between the fishing industry and the scientific research community may be achieved by managing prioritized areas for both fishing and research through zoning. In many cases, the areas of interest to these stakeholders are not in conflict. For instance, protecting fjords should not pose a great threat to the fishery as the larger shrimp targeted have been found to concentrate in the outer fjords and on the shelf (Hansen and Aschan 2000). Protecting inner fjords may also be beneficial to the stock if they are indeed utilized as nursing areas for young shrimp.

It is important that the management of both the shrimp stock and protected areas consider subhabitat value. Understanding how the various habitats within the fjords support different life stages of shrimp, as well as their early ontogenetic movement, is important to their management. This study suggests that there are such differences in subhabitat utilization within the fjords, but the mechanisms driving them are not adequately accounted for and need to be investigated further. At the moment, understanding the ways in which shrimp utilize the different areas in the fjords does not have direct implications to the management. However, certain parallels may be drawn between the Barents Sea population and more southern populations in the more traditional North Sea and Skagerrak fisheries (IMR, 2010). Understanding the ecology within the distribution area and how it changes over time is essential to the successful adaptive management of these stocks.



Anderson (2000) suggested that Pandalid shrimp might be a good indicator species of marine regime shifts off the coast of Alaska, particularly due to their sensitivity to warming temperatures. Further, they are not a migratory species and are very abundant in the hyperbenthos, making them easy to sample. The eastward and northward shifts in distribution in the Barents Sea over the past decade (Figure 7) is consistent with an increased inflow of warm Atlantic water and may be indicative of a slow regime shift. The annual ecosystem survey cruises already performs extensive shrimp sampling in the Barents Sea, acknowledging them as an important species in the Barents Sea and around Svalbard. Thus, gaining a better understanding of habitats and ecosystems of the complicated fjord systems could be used to optimize sampling programs in the fjords, where the typical grid depth stratification does not work due to the heterogeneity of hydrographical conditions (Cottier *et al.*, 2005, 2007). Improved sampling resolution would provide more valuable information about the stock and the state of the ecosystem.

A relatively fine spatial resolution is necessary in order to detect changes in stock status on the Svalbard shelf. Hansen and Aschan (2006) suggest dividing the area into seven strata based on length at age and age at maturity data. However, as the results of that study differed considerably from those presented in this thesis, it is clear that the shrimp stock dynamics are ever changing and that there is a strong need for standardization of methods (as outlined in section 3.5) to adequately capture this change. The methods employed in estimating age at maturity vary between using the  $L_{50}$  value (Skúladóttir, 1991; Hansen and Aschan, 2006) and calculating mean lengths of primiparous females (Parsons *et al.*, 1989). There is also occasional confusion of terminology, such as which stages are considered a “mature female”. As a result of these confusions, coupled with the time of year of sampling, findings may not be directly comparable, even in the same area. Even so, they are often presented as comparable. Communication, cooperation between countries and institution, and sharing of data and methods will help resolve such confusions and prevent them from reoccurring.

Lastly, in order to choose effective management strategies, this study highlights the importance of setting testable objectives and monitoring managed areas. In order to do this, managers are dependent on new and updated data from research, surveys and the fishing industry. Bridging the gaps between these institutions in order to improve communication and help identify knowledge gaps, should be one of the main priorities in the future.



## 6 Conclusions

### 6.1 Summary of findings

Based on comparison with untrawled Kongsfjorden, trawling does not appear to have significantly impacted the biomass or population size structure of the shrimp population in Isfjorden, consistent with the third possible scenario presented in section 1.3.3. The likely explanation for this is the current low fishing pressure, but community resilience might also be considered. The decapod community in Isfjorden has remained remarkably stable over the past century, which has at least partly been attributed to persistency and resistance to changes (Berge *et al.*, 2009). Moreover, analysis suggests that the predator abundance and identity is variable, and that the large (>14 cm) polar cod abundance is significantly greater in Kongsfjorden. The predator identity is not likely to have changed appreciably since the establishment of the closure. Within the fjords, Atlantic cod was found to dominate outer basins, whereas polar cod showed a more variable distribution.

The catch data also displayed a variable distribution of shrimp biomass within the fjords, which could not in any large degree be explained by temperature, depth or other species catch data. It is speculated that it could be caused by other abiotic data, such as bottom structure, or by biotic factors, such as zoogeographical distribution, food availability and habitat preferences. Similar pattern of differences along the fjord axis in population size and stage structure was observed in both fjords, highlighting the heterogeneity of fjord systems, and suggesting that this may be a general pattern in western fjords on Svalbard. Small male shrimp congregated in the inner regions of the fjord, with the proportion of larger males and females increasing towards the mouth. The shrimp also mature as females at the same length, but at different ages, dependent on growth rate. Growth rate was found to be slightly lower in middle and inner basins of Isfjorden compared to the other areas.

The great variability observed highlights the importance of continued research into how the heterogeneity of fjord systems impact populations, and how and why different areas are utilized at different life stages.



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## Appendix A

### Figures outlining the stage determination process of northern shrimp

Figure A: Diagram showing the location of the first and second pair of pleopods, as well as the carapace region measured (Shumway et al., 1985)

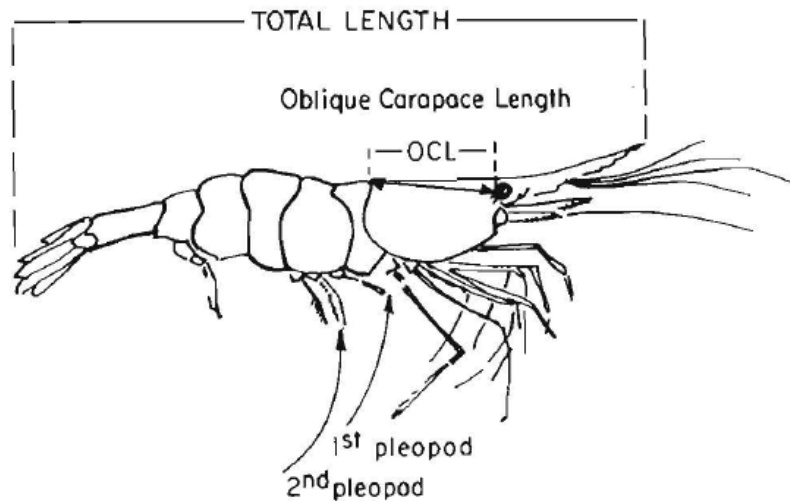


Figure B: Diagram showing the sternal spines and how they differ between males, intersex and female shrimp (Grimsno, 1993)

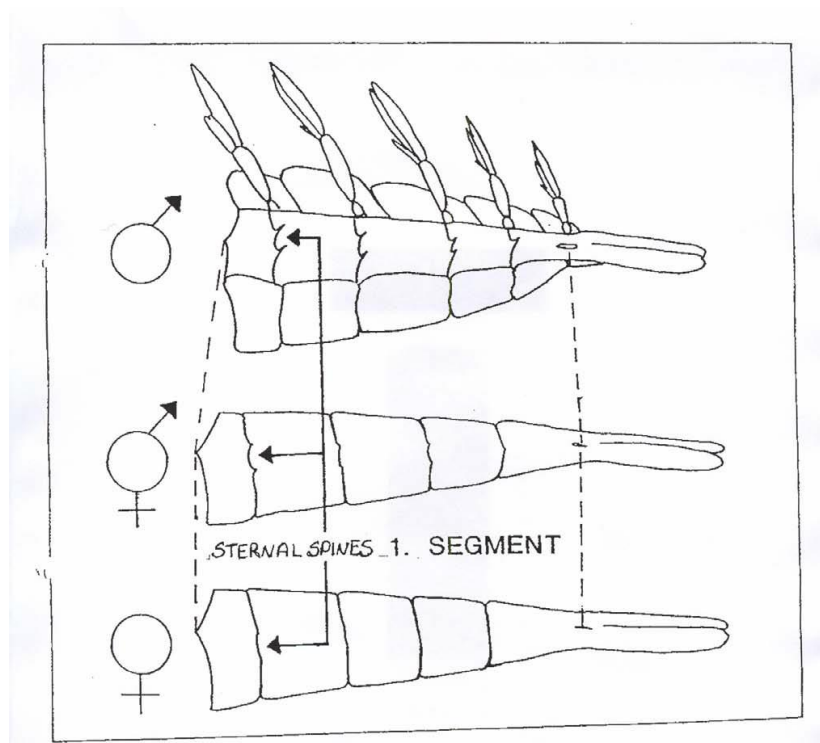


Figure C: Codes used for the maturity stages of northern shrimp in the study (Grimsmo, 1993).

### ***Pandalus borealis* maturity stages – codes**

<b>Maturity stage</b>	<b>Code</b>
Juvenile	---
Male	2
<ul style="list-style-type: none"> <li>• Sternal spines prominent (Fig. 3)</li> <li>• Male structure of the endopod of the 1. pleopod (Fig. 2B)</li> </ul>	
Intersex (transitionals)	3
<ul style="list-style-type: none"> <li>• Sternal spines prominent</li> <li>• Intersex/female structure of the endopod of the 1. pleopode (Fig. 2B)</li> </ul>	
Female (first time spawning)	4
<ul style="list-style-type: none"> <li>• Sternal spines prominent</li> <li>• Head roe clearly visible</li> <li>• Female structure of the endopod of the 1. pleopode (Fig. 2B)</li> </ul>	
Female	5
<ul style="list-style-type: none"> <li>• Sternal spines reduced</li> <li>• Extruded eggs under the abdomen</li> <li>• Head roe may be presence</li> </ul>	
Female	6
<ul style="list-style-type: none"> <li>• Sternal spines reduced</li> <li>• With setae and remains of eggs/hatching eggs</li> <li>• Head roe may be presence</li> </ul>	
Female (resting stage)	7
<ul style="list-style-type: none"> <li>• Sternal spines reduced or disappeared</li> <li>• No setae or eggs</li> </ul>	
Female (second time spawning)	8
<ul style="list-style-type: none"> <li>• Sternal spines reduced</li> <li>• Head roe distinct</li> </ul>	



Figure D: Diagram showing the endopodite on the first pair of pleopods and how it develops with age, from male, intersex, and to female (Grimsmo, 1993).

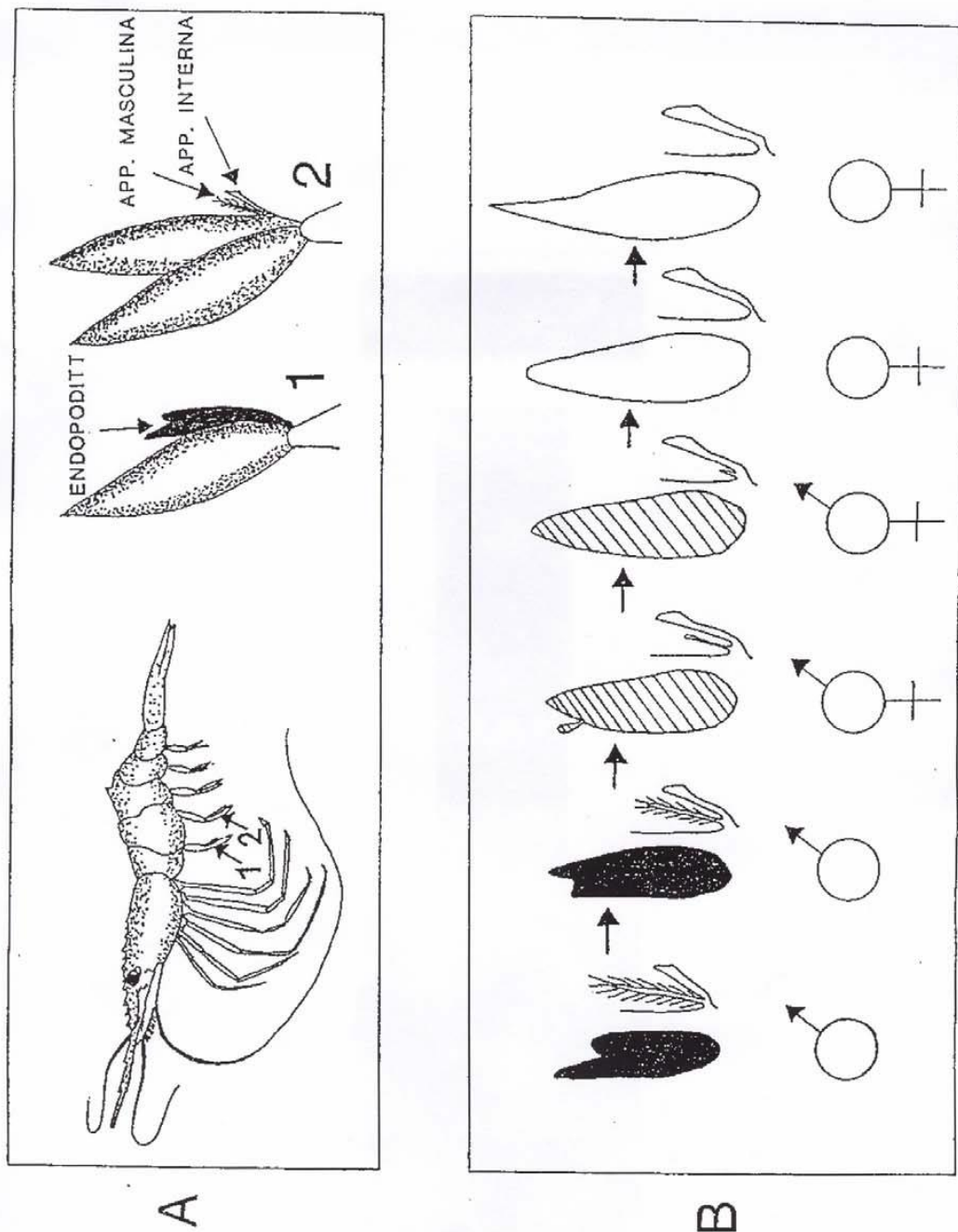
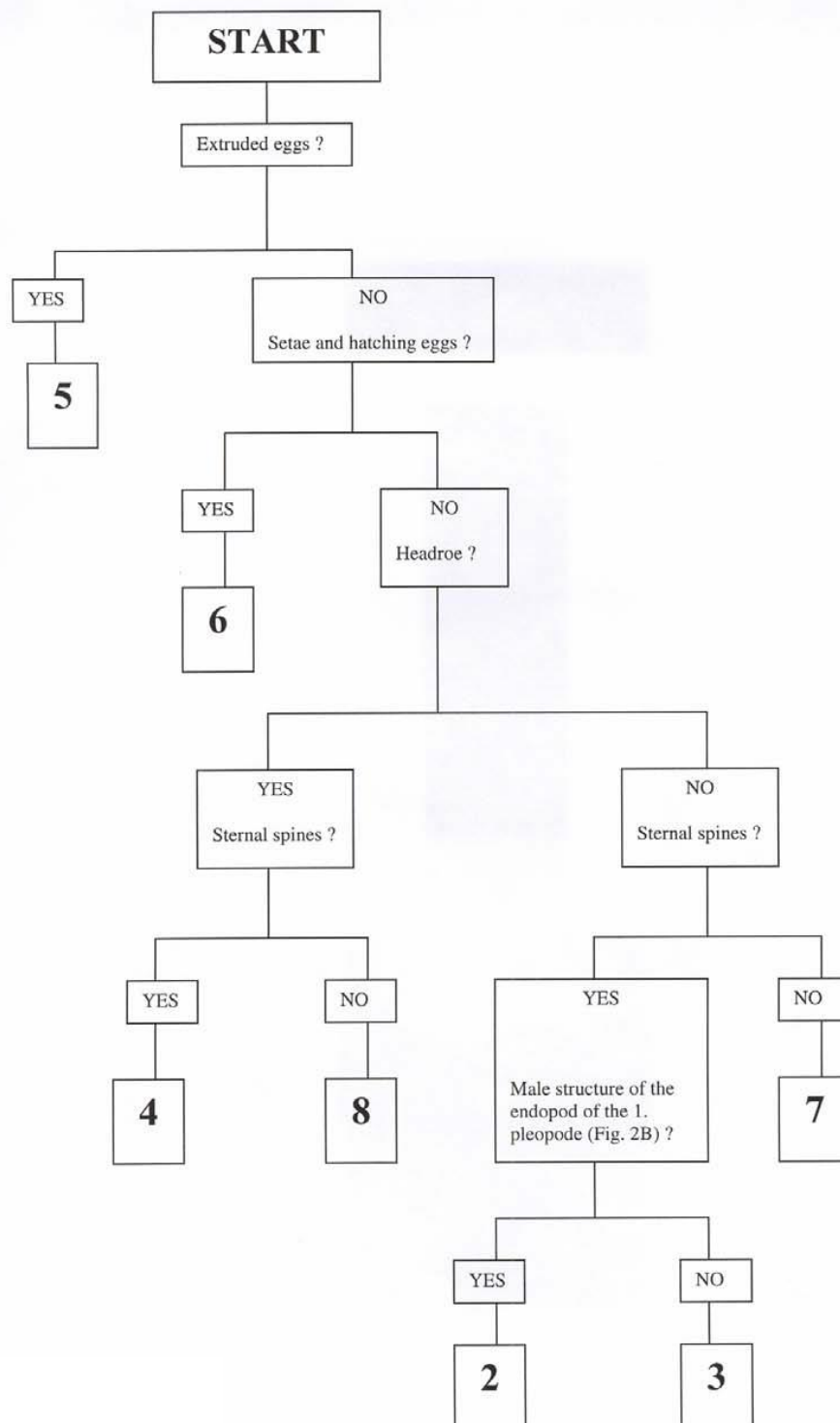


Figure E: A flow chart of the staging process of northern shrimp (*Grimsno, 1993*).



# Appendix B

## Total species list and standardized biomass of trawl catches

Table A: Total species list and standardized biomass of trawl catches from Isfjorden.

		Standardized biomass (kg) per nautical mile							
		Isfjorden							
Common name	Scientific name	31	33	36	37	114	120	122	123
<u>Fish and northern shrimp</u>									
Northern shrimp	<i>Pandalus borealis</i>	47.38	18.03	36.38	10.35	16.18	13.16	11.52	44.63
Atlantic cod	<i>Gadus morhua</i>	10.18	8.03	94.75	123.30	2.49	61.61	8.30	28.83
Polar cod	<i>Boreogadus saida</i>	9.50	10.30	0.35	4.05	0.74	26.64	14.54	4.62
Greenland halibut	<i>Reinhardtius hippoglossoides</i>		9.23	3.21	1.81	5.36	15.85	12.00	5.06
Beaked redfish	<i>Sebastes mentella</i>	0.05	0.35		5.43	2.96	0.23	0.08	0.01
Long rough dab	<i>Hippoglossoides platessoides</i>	17.00	0.29	7.15	23.38	5.68	0.91	0.04	1.43
Haddock	<i>Melanogrammus aeglefinus</i>	0.00		1.95					
Capelin	<i>Mallotus villosus</i>	1.71	0.09	1.43	0.11	0.03			
Thorny skate	<i>Raja radiata</i>	0.70	0.59	1.35	4.08				
Northern wolffish	<i>Anarhichas denticulatus</i>			13.92					
Atlantic wolffish	<i>Anarhichas lupus</i>				0.00				
Daubed shanny	<i>Leptoclinus maculatus</i>	6.08	0.07	0.06	0.02	0.13	0.14	0.75	2.07
Shakeblenny	<i>Lumpenus lampretaeformis</i>	0.38		0.02					
Lumpsucker	<i>Cyclopterus lumpus</i>	0.01							
Atlantic poacher	<i>Leptagonus decagonus</i>	0.12	0.02			0.01			0.05
Moustache sculpin	<i>Triglops murrayi</i>				0.01				
Atlantic hookear sculpin	<i>Artediellus atlanticus</i>	0.15							0.02
Ribbed sculpin	<i>Triglops pingelii</i>	0.02							
	<i>Lycodes gracilis</i>								
Threespot eelpout	<i>Lycodes rossi</i>	0.01					0.06	0.01	

Pale eelpout	<i>Lycodes pallidus</i>		0.03					
Variegated snailfish	<i>Liparis gibbus</i>		0.01			0.05		
Gelatinous snailfish	<i>Liparis fabricii</i>		0.01			0.00		0.00
Sea tadpole	<i>Careproctus spp</i>		0.01					
Unknown jellyfish			0.51	0.18	0.54			
Foreign objects		0.33	0.15					
<u>Other benthos and hyperbenthos</u>		kg/nm						
Annelida	<i>Euchone papillosa</i>			0.000				
Annelida	<i>Harmothoe sp.</i>				0.001			
Annelida	<i>Maldane arcica</i>			0.010	0.012			
Annelida	<i>Nephtyidae g. sp.</i>		0.000		0.006			
Annelida	<i>Nereis pelagica</i>	0.000						
Annelida	<i>Pectinaria hyperborea</i>		0.001	0.002				
Annelida	<i>Phyllodoce sp.</i>		0.000					
Annelida	<i>Polynoidae g. sp.</i>		0.003					
Annelida	<i>Protula tubularia</i>							
Annelida	<i>Sabellidae g. sp.</i>							
Annelida	<i>Spiochaetopterus typicus</i>	0.000		0.011				
Annelida	<i>Thelepus cincinnatus</i>				0.001			
Arthropoda	<i>Acanthostepheia malmgreni</i>							
Arthropoda	<i>Cirripedia g. sp.</i>		0.000					
Arthropoda	<i>Diastylis goodsiri</i>					0.002		
Arthropoda	<i>Epimeria loricata</i>			0.001				
Arthropoda	<i>Eualus gaimardii</i>	0.001					0.005	0.002
Arthropoda	<i>Hyas araneus</i>		0.021					
Arthropoda	<i>Lebbeus polaris</i>					0.002		
Arthropoda	<i>Meganyctiphanes norvegica</i>	0.000			0.000			
Arthropoda	<i>Nymphon longitarse</i>				0.000			
Arthropoda	<i>Nymphon spinosum hirtipes</i>							

Arthropoda	<i>Nymphon stroemi</i>								
Arthropoda	<i>Ornatoscalpellum</i>								
Arthropoda	<i>stroemii</i>								
Arthropoda	<i>Pandalus montagui</i>								
Arthropoda	<i>Paramphithoe hystrix</i>	0.001							
Arthropoda	<i>Pontophilus</i>								
Arthropoda	<i>norvegicus</i>								
Arthropoda	<i>Rhachotropis</i>								
Arthropoda	<i>aculeata</i>								
Arthropoda	<i>Sabinea</i>	1.536	0.299	0.024	0.068	0.136	0.043	0.210	0.532
Arthropoda	<i>septemcarinata</i>								
Arthropoda	<i>Spirontocaris spinus</i>								
Arthropoda	<i>Stegocephalus</i>		0.004			0.002			
Arthropoda	<i>inflatus</i>								
Arthropoda	<i>Themisto abyssorum</i>				0.000				
Arthropoda	<i>Themisto libellula</i>					0.002			
	<i>Thysanoessa inermis</i>								
	<i>Thysanoessa raschii</i>								
Brachiopoda	<i>Terebratulina retusa</i>								
Bryozoa	<i>Alcyonidium sp.</i>								
Bryozoa	<i>Myriapora coarctata</i>								
Bryozoa	<i>Rhamphostomella sp.</i>	0.001							
Bryozoa	<i>Stegohornera</i>								
	<i>lichenoides</i>								
Cnidaria	<i>Diphasia fallax</i>								
Cnidaria	<i>Drifa glomerata</i>	0.397	0.008						
Cnidaria	<i>Duva florida</i>								
Cnidaria	<i>Gersemia rubiformis</i>								
Cnidaria	<i>Grammaria abietina</i>								
Cnidaria	<i>Hormathia digitata</i>			0.001	0.002				
	<i>m. parasitica</i>								
Cnidaria	<i>Lafoea sp.</i>								
Cnidaria	<i>Monobrachium</i>	0.001		0.000					
	<i>parasitum</i>								
Cnidaria	<i>Umbellula encrinus</i>	0.003				0.011			
Echinodermata	<i>Ctenodiscus crispatus</i>	0.005		0.590	0.514				
Echinodermata	<i>Eupyrgus scaber</i>								
Echinodermata	<i>Henricia sp.</i>								

Echinodermata	<i>Icasterias panopla</i>				0.291			
Echinodermata	<i>Ophiacanta bidentata</i>	0.014	0.052	0.003				
Echinodermata	<i>Ophiopholis aculeata</i>	0.000						
Echinodermata	<i>Ophiura sarsi</i>	0.008	0.005	0.010	0.006			
Echinodermata	<i>Poliometra proluxa</i>							
Echinodermata	<i>Poraniomorpha hispida</i>	0.033	0.069					
Echinodermata	<i>Strongylocentrotus droebachiensis</i>							
Mollusca	<i>Arctinula greenlandica</i>							
Mollusca	<i>Astarte crenata</i>	0.022						
Mollusca	<i>Bathyarca glacialis</i>	0.002		0.002	0.037			
Mollusca	<i>Bathypolypus arcticus</i>							
Mollusca	<i>Buccinum elatior</i>			0.009				
Mollusca	<i>Buccinum hydrophanum</i>			0.006	0.004			
	<i>Buccinum polare</i>					0.002		
Mollusca	<i>Chlamys islandica</i>							
Mollusca	<i>Clinocardium ciliatum</i>	0.450	0.029	0.015	0.016			
	<i>Ciliatocardium ciliatum</i>							0.002
Mollusca	<i>Colus islandicus</i>					0.005		
Mollusca	<i>Cryptonatica affinis</i>				0.003			
Mollusca	<i>Cryptonatica affinis</i>							
Mollusca	<i>Cuspidaria arctica</i>	0.009						
Mollusca	<i>Gonatus fabricii</i>							
Mollusca	<i>Margarites costalis</i>							
Mollusca	<i>Propebela turicola</i>							
Nemertini	<i>Nemertini g. sp.</i>		0.002					
Porifera	<i>Halichondria sp.</i>							
Porifera	<i>Haliclona sp.</i>							
Porifera	<i>Histodermella sp.</i>							
Porifera	<i>Phakellia sp.</i>	0.014						
Porifera	<i>Porifera g. sp.</i>							

Porifera	<i>Suberites ficus</i>			0.018					
Sipuncula	<i>Phascolion strombus</i>			0.002	0.006				
Sipuncula	<i>Sipunculidea g. sp.</i>		0.000						
	<i>Oedicerotidae sp</i> ( <i>Arrhis phyllonyx</i> )					0.002			
	<i>Neptunea sp</i>					0.009			
	<i>Cyanea capillata</i>					0.513	0.059	1.737	0.779
	<i>Urasterias eincarii</i>								
	<i>Black snotfish</i>								
	<i>Casaproctus sp</i>								

Table B: Total species list and standardized biomass of trawl catches from Kongsfjorden.

Standardized biomass (kg) per nautical mile

Kongsfjorden									
Common name	Scientific name	53	54	127	129	138	140	143	188
<u>Fish and northern shrimp</u>									
Northern shrimp	<i>Pandalus borealis</i>	23.77	22.61	44.76	22.23	6.19	5.24	6.64	25.05
Atlantic cod	<i>Gadus morhua</i>	93.89	116.93	No data	37.55	21.63	14.00	24.83	0.98
Polar cod	<i>Boreogadus saida</i>	2.99	14.38	No data	17.89	12.34	12.17	22.37	57.23
Greenland halibut	<i>Reinhardtius hippoglossoides</i>		6.31	No data	3.98	1.96	0.20	2.93	
Beaked redfish	<i>Sebastes mentella</i>	4.63	0.70	No data				0.51	
Long rough dab	<i>Hippoglossoides platessoides</i>	7.55	2.36	No data	1.54	0.49		2.21	0.00
Haddock	<i>Melanogrammus aeglefinus</i>			No data	0.01	0.42	0.01	0.01	
Capelin	<i>Mallotus villosus</i>	0.04		No data	0.10			0.03	
Thorny skate	<i>Raja radiata</i>	6.07		No data		1.66			
Northern wolffish	<i>Anarhichas denticulatus</i>		9.17	No data					
Atlantic wolffish	<i>Anarhichas lupus</i>			No data					
Daubed shanny	<i>Leptoclinus maculatus</i>			No data	0.04	1.90	0.10	0.03	0.37
Shakeblenny	<i>Lumpenus lampretaeformis</i>			No data		0.06			

Lumpsucker	<i>Cyclopterus lumpus</i>			No data					
Atlantic poacher	<i>Leptagonus decagonus</i>			No data	0.03				
Moustache sculpin	<i>Triglops murrayi</i>			No data					
Atlantic hookear sculpin	<i>Artediellus atlanticus</i>			No data					
Ribbed sculpin	<i>Triglops pingelii</i>			No data				0.03	
	<i>Lycodes gracilis</i>			No data					0.12
Threespot eelpout	<i>Lycodes rossi</i>			No data					
Pale eelpout	<i>Lycodes pallidus</i>			No data					
Variegated snailfish	<i>Liparis gibbus</i>		0.06	No data	0.04			0.02	1.09
Gelatinous snailfish	<i>Liparis fabricii</i>			No data					
Sea tadpole	<i>Careproctus spp</i>		0.11	No data					
Unknown jellyfish		0.91	0.69	No data	1.29	4.04	3.32	1.70	1.27
Foreign objects									
<u>Other benthos and hyperbenthos</u>									
Annelida	<i>Euchone papillosa</i>								
Annelida	<i>Harmothoe sp.</i>	0.000							
Annelida	<i>Maldane arctica</i>								
Annelida	<i>Nephtyidae g. sp.</i>								
Annelida	<i>Nereis pelagica</i>								
Annelida	<i>Pectinaria hyperborea</i>	0.002							
Annelida	<i>Phyllodoce sp.</i>								
Annelida	<i>Polynoidae g. sp.</i>								0.013
Annelida	<i>Protula tubularia</i>	0.000							
Annelida	<i>Sabellidae g. sp.</i>	0.000							
Annelida	<i>Spiochaetopterus typicus</i>								
Annelida	<i>Thelepus cincinnatus</i>								
Arthropoda	<i>Acanthostepheia malmgreni</i>	0.011	0.002		0.008		0.008		
Arthropoda	<i>Cirripedia g. sp.</i>								
Arthropoda	<i>Diastylis goodsiri</i>								



Arthropoda	<i>Epimeria loricata</i>							
Arthropoda	<i>Eualus gaimardii</i>					0.002		
Arthropoda	<i>Hyas araneus</i>							
Arthropoda	<i>Lebbeus polaris</i>						0.017	
Arthropoda	<i>Meganctiphanes norvegica</i>				0.036	0.002	0.079	
Arthropoda	<i>Nymphon longitarse</i>							
Arthropoda	<i>Nymphon spinosum</i>	0.000	0.008					
Arthropoda	<i>hirtipes</i>							
Arthropoda	<i>Nymphon stroemi</i>		0.003					
Arthropoda	<i>Ornatoscalpellum stroemii</i>	0.000						
Arthropoda	<i>Pandalus montagui</i>	0.008						
Arthropoda	<i>Paramphithoe hystrix</i>		0.002					
Arthropoda	<i>Pontophilus norvegicus</i>	0.006	0.019					
Arthropoda	<i>Rhachotropis aculeata</i>	0.001						
Arthropoda	<i>Sabinea septemcarinata</i>	0.082	0.232		0.100	0.030	0.117	0.40
Arthropoda	<i>Spirontocaris spinus</i>		0.005					
Arthropoda	<i>Stegocephalus inflatus</i>							
Arthropoda	<i>Themisto abyssorum</i>	0.000				0.002		
Arthropoda	<i>Themisto libellula</i>				0.001			
	<i>Thysanoessa inermis</i>					0.085	0.004	
	<i>Thysanoessa raschii</i>					0.011	0.017	
Brachiopoda	<i>Terebratulina retusa</i>	0.000						
Bryozoa	<i>Alcyonidium sp.</i>		0.001					
Bryozoa	<i>Myriapora coarctata</i>	0.001						
Bryozoa	<i>Rhamphostomella sp.</i>							
Bryozoa	<i>Stegohornera lichenoides</i>	0.000						
Cnidaria	<i>Diphasia fallax</i>		0.002					
Cnidaria	<i>Drifa glomerata</i>		0.017					
Cnidaria	<i>Duva florida</i>	0.003	0.004					
Cnidaria	<i>Gersemia rubiformis</i>		0.004					
Cnidaria	<i>Grammaria abietina</i>	0.000	0.001					

Cnidaria	<i>Hormathia digitata</i>	0.000						
Cnidaria	<i>m. parasitica</i>							
Cnidaria	<i>Lafoea sp.</i>	0.001	0.003					
Cnidaria	<i>Monobrachium</i>							
Cnidaria	<i>parasitum</i>							
Cnidaria	<i>Umbellula encrinus</i>							
Echinodermata	<i>Ctenodiscus crispatus</i>	0.018				0.004		0.007
Echinodermata	<i>Eupyrgus scaber</i>	0.001						
Echinodermata	<i>Henricia sp.</i>		0.006					
Echinodermata	<i>Icasterias panopla</i>							
Echinodermata	<i>Ophiacanta bidentata</i>	0.001	0.005					
Echinodermata	<i>Ophiopholis aculeata</i>	0.018	0.003					
Echinodermata	<i>Ophiura sarsi</i>	0.066	0.037					
Echinodermata	<i>Poliometra proluxa</i>	0.001						
Echinodermata	<i>Poraniomorpha</i>							
Echinodermata	<i>hispida</i>							
Echinodermata	<i>Strongylocentrotus</i>		0.026					
Echinodermata	<i>droebachiensis</i>							
Mollusca	<i>Arctinula</i>	0.001						
Mollusca	<i>greenlandica</i>							
Mollusca	<i>Astarte crenata</i>							
Mollusca	<i>Bathyrca glacialis</i>	0.001	0.004					
Mollusca	<i>Bathypolypus arcticus</i>	0.093						
Mollusca	<i>Buccinum elatior</i>	0.003						
Mollusca	<i>Buccinum</i>	0.006						
Mollusca	<i>hydrophanum</i>							
Mollusca	<i>Buccinum polare</i>							
Mollusca	<i>Chlamys islandica</i>		0.006					
Mollusca	<i>Clinocardium</i>	0.004						
Mollusca	<i>ciliatum</i>							
Mollusca	<i>Ciliatocardium</i>							
Mollusca	<i>ciliatum</i>		0.008					
Mollusca	<i>Colus islandicus</i>							
Mollusca	<i>Cryptonatica affinis</i>	0.004						
Mollusca	<i>Cryptonatica affinis</i>	0.004						
Mollusca	<i>Cuspidaria arctica</i>							
Mollusca	<i>Gonatus fabricii</i>	0.005						
Mollusca	<i>Margarites costalis</i>		0.003					

Mollusca	<i>Propebela turicola</i>		0.008					
Nemertini	<i>Nemertini g. sp.</i>							
Porifera	<i>Halichondria sp.</i>	0.002						
Porifera	<i>Haliclona sp.</i>	0.009						
Porifera	<i>Histodermella sp.</i>	0.001						
Porifera	<i>Phakellia sp.</i>							
Porifera	<i>Porifera g. sp.</i>	0.115						
Porifera	<i>Suberites ficus</i>							
Sipuncula	<i>Phascolion strombus</i>	0.001						
Sipuncula	<i>Sipunculidea g. sp.</i>							
	<i>Oedicerotidae sp</i> <i>(Arrhis phyllonyx)</i> <i>Neptunea sp</i>							
	<i>Cyanea capillata</i>							
	<i>Urasterias eincarii</i>						0.017	
	<i>Black snotfish</i>						0.050	
	<i>Casaproctus sp</i>							0.080



# Appendix C

## Temperature and salinity maps from IMR/PINRO ecosystem survey, August 2013

Figure F: Map outlining CTD stations (left) and bottom temperature isolines around Svalbard, August 2013. Provided by Thomas de Lange Wenneck, engineer, IMR.

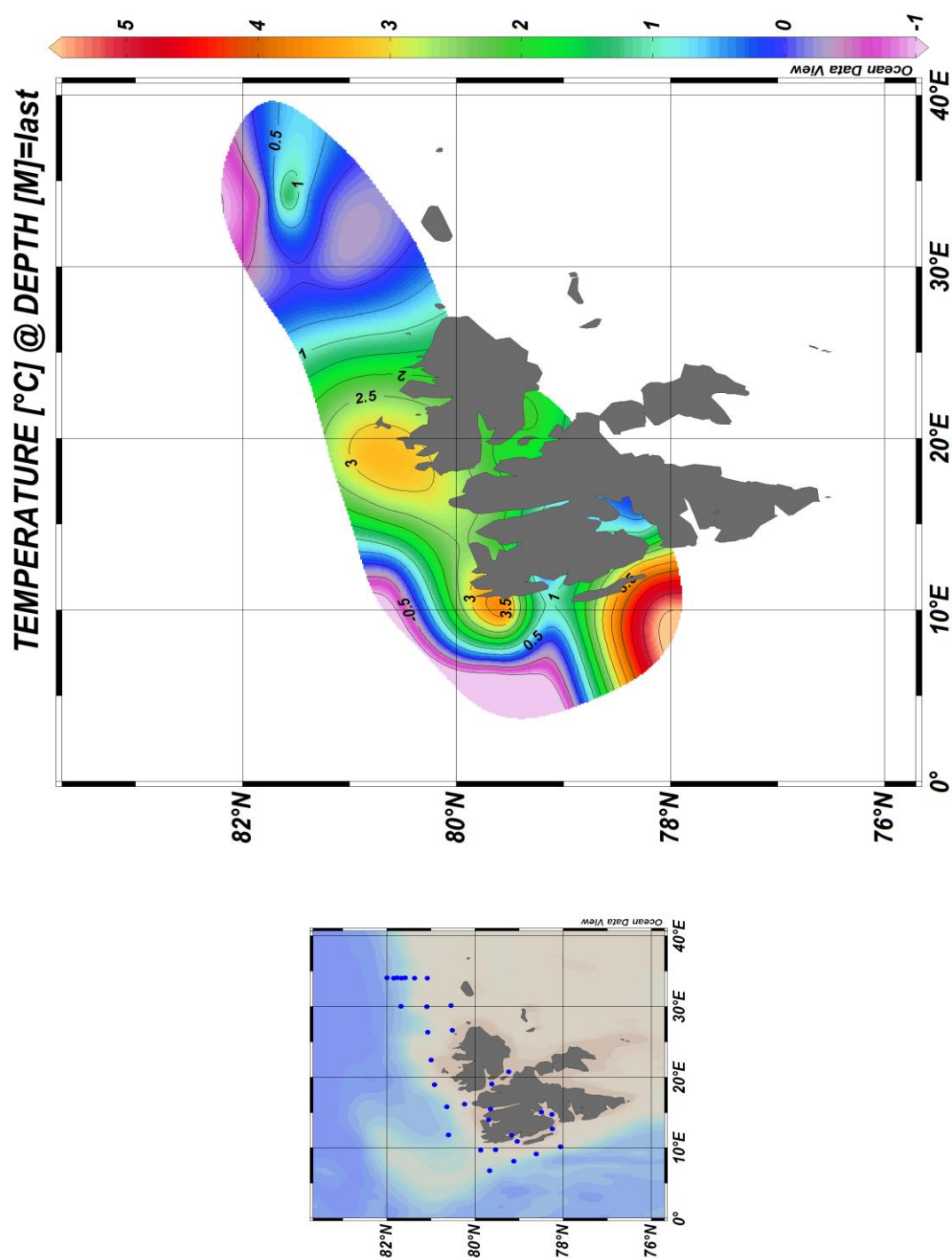
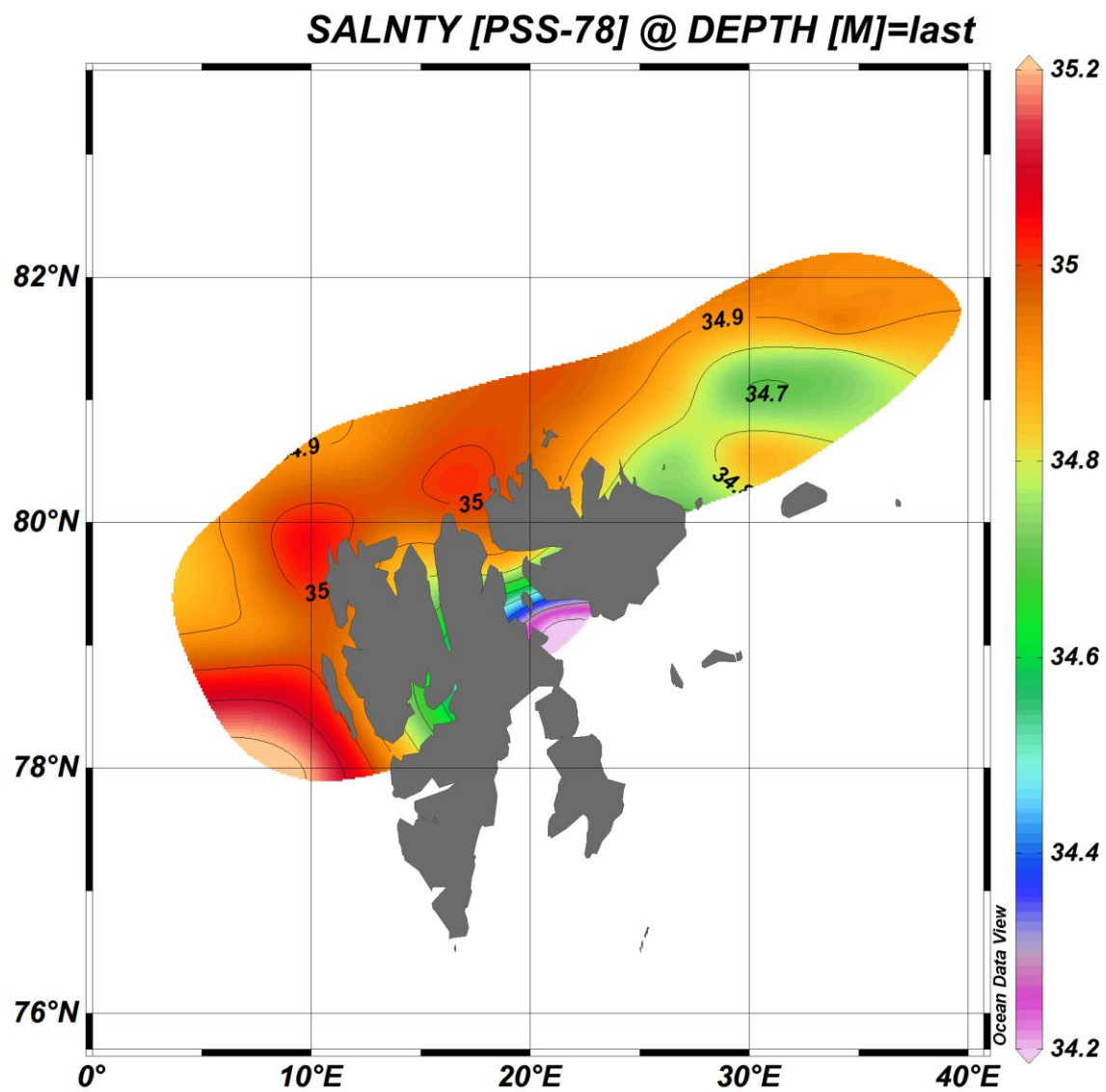


Figure G: Map outlining bottom salinity isolines (ppt) around Svalbard, August 2013.  
Provided bu Thomas de Lange Wenneck, engineer, IMR.



# Appendix D

## Example of R codes

*Figure H: Example of R code used in the modal analysis of length frequency data.*

```
## Open mixdist
library(mixdist)

#Read the file
x <- read.table("36 n=376.txt")
x <- x[,1]

summary(x)

## Breaks forthe histogram
breaks <- seq(from = 11, to = 28, by= 0.5)

hist(x, breaks)

## Define mix groups.
mixgroups <- mixgroup(x, breaks = breaks)

## Define mixparameters.
mixpars <- mixparam(mu=c(13.5, 17, 21, 25), sigma=c(1, 1, 1.1, 1.1))

## Run the mix analysis
fit <- mix(mixgroups, mixpars , dist = "norm", constr = mixconstr(conpi = "NONE",
  conmu = "NONE", consigma = "SFX", fixpi = NULL, fixmu = NULL,
  fixsigma = c(FALSE, FALSE, TRUE, TRUE), cov = NULL, size = NULL),
  emsteps = 1, usecondit = FALSE, exptol = 5e-06, print.level = 1)

plot(fit, main="36, n=376", xlab="Carapace length (mm)")

summary(fit)
```

*Figure 1: Example of R code used for the logistic curve and inflection point in the analysis of length at female maturity.*

```
st33<-read.delim("L50 st33.txt")
st33
attach(st33)
y = cbind(Females, Males)
model.results = glm(y~CL,binomial)
summary(model.results)
library(MASS)
dose.p(model.results,p=0.5)
plot(CL,(Females / (Males + Females)), main="33",
      ylab = "Proportion mature females", xlab = "Carapace length (mm)")
logisticline = function(z) {eta = -40.690 + 2.051 * z;1 / (1 + exp(-eta))}
# add intercept and CL
x=seq(7,28,0.1)
lines(x,logisticline(x),new = TRUE)
```



## Appendix E

### Percentage of empty stomachs recorded in stomach-contents analysis

*Table C: Percentages of empty stomachs, with sample size given in parenthesis, recorded in the stomach-contents analysis at stations in Isfjorden and Kongsfjorden.*

		Atlantic cod >20cm	Greenland halibut >20cm	Long rough dab >20cm	Beaked redfish >20cm	Polar cod >14cm
Isfjorden	<b>114</b>	0.0 (1)	28.6 (7)	66.7 (5)	60.0 (15)	n/a
	<b>120</b>	0.0 (16)	38.9 (18)	75.0 (4)	100.0 (1)	51.7 (29)
	<b>122</b>	0.0 (2)	37.5 (8)	n/a	n/a	28.6 (21)
	<b>123</b>	8.3 (12)	66.7 (6)	33.3 (3)	n/a	20.0 (20)
Kongsfjorden	<b>129</b>	0.0 (9)	n/a	33.3 (3)	n/a	0.0 (18)
	<b>138</b>	4.1 (49)	100.0 (1)	100.0 (1)	n/a	11.1 (54)
	<b>140</b>	0.0 (2)	n/a	n/a	n/a	0.0 (18)
	<b>143</b>	14.3 (7)	66.7 (3)	25.0 (8)	50.0 (2)	21.2 (33)



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