Master's thesis

Range expansion of European Flounder *Platichthys flesus* to Icelandic waters. A threat to native salmonids?

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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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Abstract

Warming ocean temperatures have influenced the distribution and abundance of new species to Icelandic waters. The purpose of this study was to identify the potential impacts of emergence of *Plactichthys flesus* on Icelandic salmonids (*Salmo salar, Salmo trutta, salvenlinus alpinus*) by identifying: (1) the distributional range of *P. flesus* in the Westfjords region, Iceland; (2) the relative abundance of *P. flesus* in that area; (3) the diet of *P. flesus* and potential for diet overlap for salmonids; (4) the spatial and temporal overlap between *P. flesus* and salmonids; and (5) prey specific abundance of prey items found in the stomach contents between *P. flesus* and salmonids in estuaries. Including examination on the age distribution of *P. flesus* from fish caught in Önundarförður and Horvik through the months of June-September 2011. *P. flesus* was found throughout the areas of Önundarfjörður, Hornvik, Skálmarfjöður and Norðurföður, Iceland. The highest abundance of *P. flesus* was found in the month of August (CPUE = 4.5833) in Önundarfjörður, where *Gammarus spp.* was the most important prey item of both *P. flesus* and salmonids. In the Hornvik estuary, Chironomidea, had the highest numerical index, while *Idotea emarginata* had the highest occurrence and gravimetrical indices in the relative abundance importance of prey items found in the diet of *P. flesus*. In salmonids, *Gammarus* spp. was the most important prey item for salmonids for all calculated prey indices. The spatial niche overlap between *P. Flesus* and salmonids was 94% in Önundarfjorður where the two groups co-occured, while in Hornvik the two groups co-occurred 45%. The temporal niche overlap results between *P. Flesus* and salmonids in Önundarfjörður showed significant overlap in three methods, while in Hornvik, the temporal niche overlap results also showed a significant overlap in one method. Prey specific abundance of diet items of *P. flesus* and salmonids in Önundarfjörður showed specialized feeding strategies and narrow niche widths. In Hornvik, both species had generalist feeding strategies and broad niche widths. The age of *P. flesus* ranged in Önundarfjörður from 1 to 6 years and in Hornvik between 1 and 5 years. *P. flesus* will likely continue to spread in Icelandic waters, with the potential to compete both spatially and temporally with salmonids.

This thesis is dedicated to my family, friends, teachers and to all those who have supported, believed and inspired me throughout my life, I am truly grateful for all of you.

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1 Introduction

1.1 Effects of climate change on marine ecosystems

Climate change is known as an important element of the past, present and future changes in the distribution of species (Rose, 2005) In marine environments, species richness within fish and invertebrates communities is influenced by a variety of environmental factors, including ocean temperature, salinity, depth, bathymetry and ocean currents (Rose, 2005). It has been demonstrated that marine species respond to ocean warming by shifting their latitudinal ranges, where warming and cooling of ocean temperatures will drive marine fishes to higher and lower latitudes (Rose, 2005; Perry et al, 2005; Litzow, 2006; Portner & Peck, 2010). Latitudinal shifts in marine species will be most predominant in the northern or southern distributional boundaries of a species' geographic range. These shifts in latitudinal range may cause local extinctions of existing species or invasions of new species, both of which will influence the patterns of marine species richness and ecosystem dynamics (Cheung et al, 2009; Portner & Peck, 2010; Perry et al, 2005).

Climate change has been observed and predicted to strongly influence changes in the distribution, abundance in growth, survival, reproduction, population, and changes to trophic levels within marine ecosystems (Portner & Peck, 2010; Rose, 2005; Perry et al, 2005; Hofstede et al, 2010; Philippart et al, 2011). Tropical waters have higher species richness than temperate seas; it is expected that ocean warming will increase species invasions and range expansions in temperate and polar waters (Perry et al, 2005; Rose, 2005; Hofstede et al, 2010; Philippart et al, 2011).

1.2 Effects of climate change on arctic and sub-arctic aquatic ecosystem

Shifts in species composition in response to climate change will increase the number of euryhaline and anadromous species in arctic and sub-arctic estuarine ecosystems (Wrona et al, 2006). These shifts in species composition can potentially cause significant changes in local ecosystems, resulting in competition for food resources with the current inhabitants of these ecosystems (Wrona et al, 2006). Fish and wildlife communities in arctic freshwater and estuarine ecosystems are vital to

local human populations, and represent key components of ecosystems (Wrona et al, 2006) It is known that arctic fish and wildlife will experience first order effects of climate change, which will likely cause increases in growth rate due to warmer temperatures and increased levels of productivity (Wrona et al, 2006). Second order effects of climate change, will potentially cause increased competition among species, with many species extending their distributional range northward (Wrona et al, 2006). These effects on fish and wildlife may cause habitat alterations, which will eventually affect arctic biota, causing changes in the food web (Reist et al 2006a; Wrona et al, 2006). Alterations to higher levels within the trophic system will affect lower levels, therefore altering the ecosystem. These ecosystem changes are expected to be a result from climate change, and may disrupt the balance of fish populations across the arctic environment (Reist, et al 2006a; Wrona, et al, 2006).

Reist et al (2006a), also indicates that upper trophic level animals within arctic ecosystems will be more strongly influenced by climate change, as such species undergo seasonal and annual migrations between habitats and require specific areas for different life history stages.

In sub-arctic to high arctic freshwater ecosystems there are a number of important fish communities present. These fish communities spend their entire lifecycle within freshwater habitats or migrate between freshwater and marine areas. These fish are recognized as diadromous forms, which consist of both anadromous fish species such as salmonids, which spawn in freshwater and feed in the ocean and catadromous fish, which live in freshwater and spawn in the ocean (Reist et al, 2006b).

In arctic marine and freshwater ecosystems, Reist et al (2006b) discusses three ways increased temperature may threaten fish species in the arctic. These include: (1) local extinction caused by thermal stress, (2) a northward shift in geographical range, where ecosystem and dispersive pathway conditions allow and (3) genetic adaptation within the limits of life history traits, and through natural selection.

Climate change will affect arctic anadromous fishes, including: whitefish, cisco, and char species, and their aquatic habitats which they occupy during various life stages, including: fresh water, estuarine, near-shore, marine habitats (Reist et al, 2006a; Reist et al, 2006b). The effects of climate change will have the greatest influence on near shore and marine habitats, which will cause changes in local trophic structures and transfer rates (Reist et al, 2006a; Reist et al, 2006b), The greatest effect

of climate change on anadromous fish will be the impacts to feeding opportunities and their populations (Reist et al, 2006a; Reist et al, 2006b; Wrona, et al, 2006).

Understanding the responses of specific arctic freshwater and estuarine fish species to climate change is of both ecological and economic importance to arctic freshwater ecosystems and human residents of this region (Reist et al, 2006a).

1.3 Effects of climate change on Icelandic aquatic ecosystems

In Icelandic waters there has been a positive increase of temperature and salinity since 1996, with observations of changing distribution and abundance of commercially harvested fish (Anon, 2004; Assthorsson & Palsson, 2006). Warm-water species have increased in abundance and their distribution has shifted north, while cold-water species have been pushed still further north (Assthorsson & Palsson, 2006; Stefansdottir et al, 2010).

Lassalle & Rochard, (2009), indicate that the impacts of climate change on European flounder, *Platichthys flesus (P. flesus),* would be that the species disappears from the areas surrounding the Black Sea, Mediterranean and significant parts of France, and would potentially decline in areas within the southern Baltic, compared to basins surrounding Iceland where habitats would become more favorable.

In September 1999, *P. flesus* was for the first time identified in Icelandic waters when an individual was caught at the mouth of the Olfusa River on the southwest coast of Iceland (Jonsson et al, 2001). Since 1999, the *P. flesus* has been recorded annually throughout many locations around the country, with the exception of the north and northeast coasts, and is rapidly spreading across the coastal waters of Iceland (Astthorsson et al, 2006; Jonsson et al, 2001). The *P. flesus* is a catadromous fish, having the potential to change and alter parts of the Icelandic aquatic ecosystems by competing with native fish populations in both freshwater and marine areas (Jóhannsson & Jonsson, 2008).

A range expansion of *P. flesus* may potentially threaten the local Icelandic economy by threatening populations of salmonids. The tourism sector associated with recreational fishing for salmon provides an estimated USD $30 million per year to the Icelandic economy, from both direct and indirect sources (Jóhannsson & Jonsson 2008; FAO, 2010). Therefore further research is needed to understand and identify the

distribution, range, coastal habitats of *P. flesus* and its effects on salmonid populations within Iceland.

There are no previous studies regarding how the distributional patterns, relative abundance, and diet of *P. flesus* present a potential threat to Icelandic salmonids if they alter the trophic ecology within Icelandic coastal, estuarine and freshwater ecosystems.

1.4 Goals of this study

The aim of this study is to identify the distributional and relative abundance patterns of the European flounder, *Platichthys flesus (P. Flesus)* and evaluate the spatial and temporal overlap with local salmonids within the estuarine and freshwater ecosystems of Önundarfjörður and Hornvik, located in the Westfjords region of Iceland. The questions addressed in this study include:

- What is the distribution of *P. flesus* in the Westfjords of Iceland?
- What is the relative abundance of *P. flesus* in Önundarfjörður and Hornvik in both estuarine and freshwater environments?
- What is the spatial and trophic niche overlap between *P. flesus* and local salmonids in Önundarfjörður and Hornvik estuaries?
- What is the diet of *P. flesus*, and how does it vary by location?
- How much diet overlap is there between *P. flesus* and salmonids in Önundarfjörður and Hornvik in both estuaries?
- What is the prey specific abundance of prey items found in the diet of *P. flesus* and local salmonids in Önundarfjörður and Hornvik estuaries?
- What is the age structure of the *P. flesus* in the Önundarfjörður and Hornvik?

Broadly, this study looks to gain insight and new information regarding the emergence of *P. flesus* in Icelandic water and its potential impacts to ecosystem dynamics, specifically effecting Icelandic salmonids. With this work I hope to provide vital information that will contribute to potential management considerations and foster growth of future studies on the emergence of *P. flesus* in Icelandic waters.

2 Theoretical Overview

2.1 Climate change

Over the last century the earth's climate has warmed approximately 0.6 ^{0}C. This change in climate will cause the natural distributions of many species to extend towards higher latitudes and altitudes (Walther et al, 2002). This is a major concern for aquatic ecosystems as a range expansion of a new species into a new ecosystem can have significant impacts on native fish populations (Lehtonen, 1996; Graham & Harrod, 2009).

Wrona and co-workers (2006), suggest that climate change will contribute to the acceleration of species loss at both regional and global levels. Parmesan & Yohe (2003), discuss that there will be a poleward shift in the latitudinal distribution of species. They conclude that polar species have tended to remain stable or decline in abundance, whereas temperate species at the same sites have increased in abundance and expanded their distributional range.

Temperature range is a strong driving force in ecosystem-level changes in population structures and the composition of marine environments (Porntner & Peck, 2010). The effects of climate change on the North Sea is having detectable impacts on marine fish distributions, with an increased distributional range of 15 marine species caused by warming ocean temperatures and that future distribution shifts in marine environments will be pronounced (Perry et al, 2005). Due to increased warming in the North Sea differential rates of the distributional shifts of marine species, will result in altered spatial overlap among species, potentially disrupting the interactions and compound the effects of climate changes on marine fish (Perry et al, 2005).

Global climate change has already had significant impacts on marine and estuarine fish and fisheries; many studies conclude that the impacts of climate change will likely increase over time as well in severity, with the effects of climate change varying among individuals, populations and communities by the individuals physiological and behavioral responses to environmental factors (Roessig et al 2004; Perry et al, 2005).

Marine species that are limited to spawning in cold water from the Arctic to boreal regions will be affected significantly by climate change and will respond relatively quickly to changing environmental conditions (Rose, 2005). Latitude and

depth are the strongest predictors in changes of species richness; a positive correlation was found in the North Sea, where species found shifting in latitude were also found shifting in depths (Rose, 2005; Perry et al, 2005). In warm, tropical regions there are a greater number of species than colder regions further north; the effecs of climate change has resulted in the warming of northern waters, and has shown more species from southern reaches are invading northern waters; presently there is contraction in the range of fewer numbers of cold water species (Rose, 2005, Perry et al, 2005; Litzow, 2006; Assthorsson & Palsson, 2006).

Porntner & Peck (2010) and Cheung et al (2009) discuss how extreme temperatures limits and thermal tolerance ranges change with latitude. They note that species inhabiting high latitudes have the most narrow tolerance range. Thermal tolerance is, relatively narrow for species in lower latitudes, and tends to be widest for fish in mid-latitudes, where seasonal variation are on average greater than in higher and lower latitudes.

The thermal threshold for a species and the capacity to adapt or perform will affect the productivity of a species within a given ecosystem, as well as influence the species' interactions among other species. Whether they be predator-prey and or competitive interactions, these interactions may alter community composition which can lead to significant effects on the ecosystem (Porntner & Peck, 2010).

Overall, the impacts of climate change on the structure and dynamics of aquatic food webs is poorly understood, and further research is needed to understand how arctic food webs will respond both indirectly and directly to climate change (Wrona et al 2006).

2.2 Climate change in Iceland

Iceland is located between of the Mid-Atlantic Ridge and Greenland-Scotland Ridge, south of the Arctic Circle and it is surround by two primary water masses of different properties and separate origins (Astthosson et al, 2007). The primary water mass originates far south in the North Atlantic and consists of warm and saline Atlantic water brought northward towards the southern coast of the country, flowing westward along the Irminger Current, and then northward along the west coast (Astthosson et al, 2007). The majority of the water then turns west towards Greenland and flows southward along the slope of Greenland. A small current branch travels

northwards along the Icelandic shelf area known as the North Icelandic Irminger Current (Astthosson et al, 2007). In the southern reaches of Iceland, ocean temperatures range between 6 to 11 ^{0}C depending on the seasonality, with salinity ranges between 35.0 ppt and 35.2 ppt (Astthorsson et al, 2007;Valdimarsson & Malmberg, 1999). Polar water is the second primary water mass surrounding the Iceland. The polar water which comes from the Arctic Ocean and consists of lower salinity (<34.5ppt) and lower temperatures (<0 ^{0}C) water (Astthorsson et al, 2007). The polar water flows from the Arctic Ocean through the Fram Strait between Spitsbergen and Greenland as the East Greenland Current (Astthorsson et al, 2007). These water masses mix throughout Iceland, and the Atlantic waters cool when they come into contact with colder, polar waters. During the summer salinities are low in coastal regions because of by freshwater run-off, which circulates clockwise around Iceland (Astthorsson et al, 2007).

Long term monitoring throughout Icelandic waters has shown a continuous increase in temperature and salinity since 1996 (Anon, 2006). This increase in temperature and salinity have been seen in the large scale trends observed in the North Atlantic Ocean over recent years (Anon, 2004). The ocean temperatures in the North Atlantic Ocean have significantly increased in the North Sea, Celtic Sea and the central area west of Scotland and are expected to rise with an increase of 2 C^0 over the next 100 years (Hofstede et al, 2010; Philippart et al, 2011). These changes are caused by changes in the North Atlantic Oscillation (NAO), which affects the circulation of ocean waters and air-sea exchange of heat and freshwater (Sarafanov, 2009). Which has resulted in the changes in hydrographic conditions and the intensity of the deep convection in the sub-polar North Atlantic and Nordic seas (Sarafanov, 2009).

Associated with this warming of Icelandic waters are changes in the distribution and abundance of commercially exploited fishes (Astthorsson & Palsson, 2006; Bjornsson & Palsson, 2004; Stefansdottir, et al, 2010). Many new species of fish have been reported in Icelandic waters, and rare southern species have increased in abundance and and moving northward (Astthorsson & Palsson, 2006; Bjornsson & Palsson, 2004; Stefansdottir, et al, 2010; Astthorsson et al, 2007).

Between 1996 and 2006, 22 new species of fish previously unrecorded within the Icelandic 200 mile EEZ were reported, with a recent trend suggesting a decrease in new arrivals, as no new species were found between 2003 and 2005 (Astthorsson & Palsson, 2006).

Similar to the global view of Wrona et al (2006), Assthorsson et al (2007), concludes that it is important for fisheries in Iceland to conduct future research on understanding the marine environments, especially in the northern waters surrounding Iceland where climatic events may have the most significant effects, as very little is known to date.

2.3 Impacts of novel species

Invasive species can often lead to potential declines in population and extinctions of native species. Understanding of the cause and affect of invasive species will help scientists and resource managers to minimize the effects on native populations (Mills, et al, 2004)

Global climate change is predicted to favor invasive species and increase the potential impacts of invasive species on ecosystems worldwide (Dukes & Mooney, 1999; Lehtonen, 1996; Graham & Harrod, 2009). Dukes and Mooney (1999), describe these impacts as competitive effects, whereby the invading species have the potential to (1) reduce resources available to native species and (2) alter fundamental properties of the ecosystem. These impacts have the potential to affect and contribute to global change of biodiversity.

The number of negative interactions on native species is dependant on the rate and size of colonization that the invasive species has when both species are of similar body size. This is caused by species perceiving the environment in similar ways, if they are of similar size and mobility (Mill et al, 2004; MacArthur & Levins, 1964).

Thermal guilds are used to classify fish species based on temperature tolerance: coldwater species have physiological optimums <20 ^{0}C, coolwater species have physiological optimums between 20-28 ^{0}C, and warm water species have physiological optimums >28 ^{0}C (Magnuson et al, 1999). For example, a thermal environment <20 ^{0}C might prevent warmwater adapted species from expanding and establishing a self-sustaining population (Rahel and Olden (2008). As water temperatures increase, the effectiveness of the coldwater filter will diminish, allowing for the spread of warmwater species into new areas.

Changes in thermal regimes can mediate the impact of established invasive species on native species through shifts in the competitive dominance between species and overall survival (Reeves, et al, 1987). Causing increased consumption by invasive

species on native prey species and increased parasite exchange between invasive and native species (Rahel & Olden, 2007). Increase in ocean temperatures may therefore exacerbate the impacts of invasive species on native species (Rahel & Olden, 2007). In some areas where native trout populations occur, migration barriers have been built to limit the influence of non-native species on the native populations as water temperatures increase (Cooney et al, 2005).

Hellman et al (2007) describe three impacts that climate change can have on invasive species. The first impact is a decreased persistence of the native species because of climatic factors, while the invasive species may be able to survive and colonize the new environment. Secondly the invader may tolerate the climate, overcome biotic constraints on their growth, and establish a prelavent population under climate change. The third impact is a "lag phase" phenomenon, where a non-native species may establish a small population under normal conditions but become invasive if climate change increases their competitive ability or spread (Crooks & Soule 1999). These are impacts are based on the native species ability to adapt to changing local environmental conditions (Crooks & Soule 1999).

The impact of an invasive species depends on the size and the range occupied by the invader, its average abundance within that area, and its per capita impact on that environment (Hellman et al 2007). The potential impact of an invasive species is dependent on the native species population and resources that can all be affected by climate change (Hellman et al 2007 & Parker et al. 1999).

Byers (2002), predicts that climate change scenarios may give native species disadvantages against changes in environmental conditions as they will no longer have ranges of environmental variables that suit their environment, allowing for the invasive species to move in and colonize new environments.

While there is a wealth of published literature on invasions in general, there is a significant lack of information on the potential threats of invasive species on native populations of Icelandic fish, specifically salmonids.

2.4 Icelandic salmonids

Anadromous Atlantic salmon, *Salmo salar,* Arctic charr, *Salvelinus alpinus*, and Brown trout, *Salmo trutta* populations, co-occur throughout many rivers and estuarine systems in Iceland, northern Norway, and on the Kola Peninsula of Russia (Gronvik & Kelmetsen 1987; Gudbergson, 2011).

Salmon provide the highest economic value of all fresh water species within Iceland, generating an estimated USD $30 million in both direct and indirect revenue from tourism and recreational fishing opportunities (Jóhannsson, et al, 2008; Gudbergson, 2011; FAO, 2010). In addition to the salmonids, threespine stickle back, *Gasterosteus aculeatus*, European eel, *Anguilla anguilla* (Gudbergsoon, 2011, Icelandic Fisheries, 2011), and the American eel, *Anguilla rostrata* round out the native species, with a recent appearance of the European flounder, *Platichthys flesus* in Iceland (Gudbergsoon, 2011; Icelandic Fisheries, 2011; Astthorsson & Palsson 2006). Arctic char, which is the most common species of fish in Northern-latitude freshwater environments, have poor adaptations as a resource competitor against invasive or sympatric fish species (Kelmetsen et al, 2003), indicating that the recent occurrence of European flounder may cause troubles for the char.

Gudbergson, (2011), documents considerable fluctuations among years in salmon catch rates throughout Iceland; salmon rivers within the same geographic regions often show similar fluctuations as a result of environmental factors. The number of salmon in each river is a function of the amount smolts produced each year and their survival in the river, and their survival at sea. It has been proposed that climatic factors have the greatest influence on salmon in Iceland; there is a significant correlation between the number of grilse caught and ocean temperatures during the migration of smolts during spring and early summer (Scarnecchia, 1984; Antonnson et al, 1996).

Brown trout catch statistics over the past decade in Iceland have shown that the population has remained stable. This is in contrast to arctic char populations, which showed a decline between 2001-2007. Arctic char are overall currently thought to be on the rise, with the exception of rivers in the southwest regions of Iceland (Gudbergsson, 2011). Declines in arctic char catch rates have been attributed to impacts of climate change (Gudbergsson, 2011). There have been significant declines in arctic char populations across northern Europe and the British Isles, as a result of

the introduction and invasion of new species, as well a number other anthropogenic and natural ecological disturbances (Nilsson 1965; Winfield et al, 2010; Gudbergsson, 2011). Arctic char represent an essential component of the aquatic ecosystems in the Arctic, acting as an important indicator species on the general health of ecosystems from a local and global perspective (Reist, et al, 2006b; Reist & Sawatzky, 2010).

There is a number of local and global stressors impacting arctic char populations including commercial subsistence, and recreational fishing; industrial development, eutrophication, habitat alteration and loss, chemical contamination; species introduction and colonization, and barriers to migration caused by hydrological shifts from climate change (Reist et al, 2006b; Reist & Sawatzky, 2010). Salmon, trout and char of subarctic regions may eat similar prey in near-shore, surface oriented environments during summer months (Gronvik & Kelmetsen, 1987). Arctic char and brown trout are known to feed in shallow, near shore areas at sea during different life stages (Pemberton, 1976; Klemetsen et al, 2003; Rikardsen, & Amundsen, 2005). Gronvik and Kelmetsen (1987), conclude that the feeding ecology of arctic char, brown trout and salmon are closely related in near shore marine environments, where small salmon are more specialized as mid water fish predators, brown trout have the ability to feed on a variety of fish species of different sizes and some invertebrates. Arctic char feed on a variety of prey items in their diet and are able to exploit more prey resources within their common habitat (Gronvik & Kelmetsen, 1987).

Levings et al (1994) examined the importance of estuaries as a determining factor of the year-class survival of a year class. The diet of smolts consisted of fresh water invertebrates, estuarine gammarid amphipods as the general majority of the diet in fjordal environments. In some populations, salmon can rear up to 3 years in the estuaries and brackish water, where they can reach sexual maturity migrating to freshwater to spawn (Klemetsen et al, 2003). During these rearing years they feed dominantly on gammarid amhipods, capelin eggs, and insect larvae (Robitaille, 1984; Robitaille et al, 1986).

Anadromous brown trout, feed most heavily during early autumn in the sea, and feeding usually quickly drops upon entering freshwater. Many trout feed minimally and use stored energy reserves to live during winter months. Brown trout feed on marine crustaceans, polychaetes, fish and surface insects (Gronvik & Klemetsen, 1987; Klemetsen et al, 2003), but diets tend to vary depending on season,

fish size and age (Gronvik & Klemetsen, 1987; Klemetsen et al, 2003). Brown trout are opportunistic and can also exhibit specialization temporarily when a specific prey item becomes more available (Klemetsen et al, 2003).

The arctic char is the northern most freshwater fish, having a circumpolar distribution; and are known as a generalist and opportunistic species with the ability to utilize many different habitats and diets (Dempsen et al, 2002; Amundsen et al, 2008; Eloranta et al, 2011).

Anadromous arctic char make generally short duration migrations to sea, usually ranging from 30-70 days; this is dependent on fish size, maturity, environmental conditions and availability of prey (Dempson et al, 2002). Amphipods are the dominant prey species in the diet of anadromous arctic char in some locations (Johnson, 1980; Dempson et al, 2002), while in others fishes were the majority of prey in diets (Gronvik & Klemetsen 1987). In Dempson et al (2002), the six major prey taxa of char include: fish, mollusks, annelids, crustaceans, insects and chaetognaths.

Arctic char demonstrate a high level of dietary plasticity when confined to food resources by introduced species, as they are inferior to compete with pelagic resources used by an introduced competitor like the European whitefish (Eloranta et al 2011). Further research is needed to understand and evaluate the combined effects of climate change and new species on salmonid populations in Iceland, and there is a specific lack of information regarding salmonids within the Westfjords region of Iceland.

2.5 Flatfish biogeography overview

There are two major lineages occurring in flatfishes, recognized as: the Psettoidei, which is comprised of the Psettodidae family; and Pleuronectoidei, consisting of all remaining flatfish groups (Chapleau, 1993; Cooper & Chapleau 1998; Munroe, 2005b). Flatfishes can be found from the southern reaches of the Arctic Ocean to the continental seas off Antarctica; occupying a vast number of environments from shallow marine and freshwater habitats to deep marine waters up to 2000 meters in depth (Munroe, 2005a). Most commonly, flatfish assemblages inhabit estuaries and marine waters from coastlines to the outer reaches of the continental shelf. The diversity of flatfish in polar environments, freshwater systems

and in bathyal depths below 1500 meters show significant lower levels compared to other aquatic environments throughout the world (Munroe, 2005a). Post-metamorphic flatfish migrate into a benthic feeding lifestyle and habitat; lying on the bottom on their blindside on top of the substratum or partially buried under a thin layer of sand or silt with eyes exposed above the substratum (Munroe, 2005a). Flatfish are commonly found in a variety of substrata including: silt, mud, sand, sand-shell and rocky and pebbly bottom types; with different species having specific preferred strata types (Allen & Baltz 1997; Phelan et al, 2001; Munroe, 2005).

The distribution of flatfishes is influenced by water temperature, salinity, depth, sediment type, prey distribution and the degree of habitat specialization (Gibson, 1994; McConnaughey & Smith, 2000; Munroe, 2005a; Able et al, 2005). The distribution of a particular flatfish species requires knowledge of both phylogeny and geographic information regarding the history of the region (Munroe, 2005a). Understanding the historic lineages of species over time and how a species has responded to biogeographic events is required to understand how the present-day distribution of flatfish assemblages has occurred throughout different regions of the world (Munroe, 2005a).

2.6 Flatfish trophic ecology

Flatfish are known as important predators and critical components in benthic communities around the world (Link et al, 2002; Link et al, 2005). Flatfishes feed primarily on two general prey types; the majority of flatfish feed largely on either polychaetes or small benthic crustaceans while the larger, wider-gaped flatfish eat almost entirely fish and squid (Link, et al 2005). Other prey types commonly consumed but of less significance in the diet are: harpacticoid copepods, bivalves, echinoderms, oligochaetes, insect larvae (chironomids), decapods, mysids, euphausids and similar shrimp species (Link et al, 2002; Vinagre et al, 2005; Link et al, 2005). For the majority of flatfish species, polychaetes and amphipods can comprise 40-70% of prey consumed but polychaetes can be up to >90% of a flatfish's diet (Pearcy & Hancock, 1978, Link et al, 2005; Vinagre, 2005). Amphipods and similar small crustaceans are the majority of the diet when polychaetes are otherwise limited (Link et al, 2005). Spatial differences in prey availability and habitat type are significant driving factors of flatfish diets, as flatfish can exist in coastal rivers, estuaries,

exposed and protected bays, and across depth strata along continental shelves (Percy & Hancock, 1978; Link et al 2005; Vinagre et al, 2005; Freitas et al, 2009).

2.7 Flatfish competition

Llink et al, (2005), document four requirements to show competition among species: spatio-temporal overlap, similar resource utilization, limiting resources and evident population impacts of interaction between taxa. They suggest that organisms that have the same prey will have the potential for competition and note that many species that consumes benthic invertebrates or forage fishes has the potential to compete with flatfish (Link et al, 2005; Vinagre et al, 2005).

Research gaps within flatfish ecology include a lack of knowledge about competition between flatfishes and benthic invertebrates. Flatfish diets are dependant on morphology, ontogeny and spatio-temporal availability of prey items, and diets will primarily consist of worms, small crustaceans, fishes and squids, and echinoderms (Link et al, 2005). Depending on prey items, flatfish can have weighty impacts on the overall populations of prey resources consumed (Link et al, 2005). Further research is needed to understand impacts and influences of flatfish on prey populations, focusing on the influences of flatfish predation on ecologically valuable species of polychaetes and amphipods (Piet, et al, 1998; Link et al, 2005; Vinagre et al, 2005). There is strong potential for competition amongst flatfishes species and between other species as documented in Georges Bank, in the northeast United States (Link et al, 2005; Garrison & Link 2000a, b); therefore this area should be examined in future studies and assessments examining competition and population-level impacts of flatfish (Link et al, 2005).

2.8 European flounder, *Platichthys flesus*

The European Flounder, (*P. flesus),* is a pleuronectid flatfish, which is a broad and diverse family of flatfishes having an amphi-boreal distribution in the North Atlantic and North Pacific marine and estuarine environments. A large concentration of the pleuronectids occurs in Arctic-boreal and cold temperate seas (Cooper & Chapleau, 1998; Munroe, 2005). Ten species of pleuronectids are endemic to Atlantic waters with a geographic range from the Barents Sea, Iceland and Greenland Straight, southward along the European Continental shelf to the Mediterranean and from the

western Greenland coast southward along the North American Continental shelf to the coastline of North Carolina (Wheeler, 1969; Cargenelli et al, 1999; Periera et al, 1999; Munroe, 2005).

Platichthys flesus, has an extensive geographic distribution across the Black Sea, Mediterrean Sea, the European Atlantic coasts, which include the British Isles and Ireland, the North Sea, the Baltic, the Barents Sea, the White Sea and recently *P. flesus* has been found in Iceland's coastal waters (Larsen et al, 2007; Hylland et al, 1996; Bos, 1999; Lassalle & Rochard, 2009; Astthorsson et al, 2006; Jonsson, & Johannsson, 2001). *Platichthys flesus* can tolerate salinities from 0-33ppt, and is distributed throughout marine, estuarine, brackish waters and coastal environments throughout Europe (Bos, 1999; Andersen et al, 2005; Larsen et al, 2007). *Platichthys flesus* are considered a facultative catadromous species of fish, and are most commonly found within a 50 m from the shore, usually in estuaries and other areas of low salinity (Summers, 1979; Hemmer-Hanson et al, 2007; Skerritt, 2010). *Platichthys flesus* can be found in freshwater but cannot spawn in these areas, as the egg development will not occur; therefore the species returns to the ocean to spawn. *Platichthys flesus* can migrate over significant distances but rarely travels within the deep-sea environments; the average annual migration of the *P. Flesus* is approximately up to 32km (Wheeler, 1969; Summers, 1979; Hemmer-Hanson et al, 2007). This migration waters between 20-50m usually corresponds with spawning months of January and February, depending on geographic location and ocean conditions; February to June is known as the overall spawning period for *P. flesus* (Berghahn, 1984; Rijnsdorp & Witthames, 2005).

After metamorphosis and the end of the pelagic phase, in the spring, a large portion of the new recruits migrate to fresh water, and the adult population return to the estuary and shallow coastal areas for feeding (Berghahm, 1984). In the fall juveniles disperse into other coastal nursery grounds (Berghahm, 1984; Morais et al 2011).

The average length of a *P. flesus* at the end of year one is 80mm, 140mm after two years, 190mm after three years and 240mm after four years (de Vlas, 1979; Summers, 1979). Males reach sexual maturity approximately at the 110mm and females at 170m, either in their second or third year of age (Summers, 1979; Bos, 1999; Dres et al, 1999). In sub-populations specifically in the Baltic Sea, the age of maturity and life history strategies can differ depending on genetic divergences

among populations (Dres et al, 1999; Nissling et al, 2002). There is still limited research conducted on population dynamics and distribution of *P. flesus*, and there to date has been no work interactions of *P. flesus* with other species in Iceland's fresh and marine water ecosystems.

2.9 *Platichthys flesus* trophic ecology

Shallow sandy areas in estuaries, brackish waters and coastal rivers are used by juvenile *P. flesus* where they feed on 90% meiofauna, predominantly harpacticoid copepods (Aarnio et al, 1996). When *P. flesus* grows larger than 50 mm, diet shifts to macrobenthic prey (Aarnio et al, 1996).

Research suggests that juvenile *P. flesus* are opportunistic feeders and adapt their feeding strategies to what prey assemblages that are present within their environment (Aarnio et al, 1996; Beaumont & Mann, 1984; Link et al 2005; Andersen et al, 2005; Vinagre et al, 2005). During periods of low prey diversity diets will be dominated by a specific species that is abundant, usually amphipods species and supplemented by small portions of other prey (Summers, 1980; Andersen et al, 2005; Link et al, 2005). Because P. flesus is new to Iceland and has high potential overlap with native species, there is a need for further research into the impact of *P. flesus* might have on the native Icelandic fauna.

2.10 European flounder in Iceland

Lassalle & Richard (2009) suggest that due to climate change, *P. flesus* would eventually disappear from the areas surrounding the Black Sea, Mediterranean and significant parts of France, while Icelandic habitats would become more suitable.

Twenty-two new species of fish have been discovered in Icelandic waters since 1996 (Anon, 2006; Astthorsson & Palsson, 2006). In September 1999, *P. flesus* was discovered near the mouth of the Olfusa River on the south west coast of Iceland. Local farmers also caught a strange looking plaice or dab, near the Olfusa River, though the fish was not brought to the Marine Research Institute for proper identification (Astthorsson & Palsson, 2006). Since 1999 *P. flesus* has been annually documented throughout Iceland, with evidence supporting the rapid distribution throughout coastal waters of Iceland, except in the north and northeast coast and (Jonsson et al, 2001; Gudbrandsson et al, 2005; Astthorsson & Palsson, 2006;

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Eirkíksson et al, *in press*). A juvenile *P. flesus* was identified in the Síki River near Norðurfirði in the Northeast region of the Westfjords in 2005 (Gudbrandsson, et al, 2005) the first documentation of *P. flesus* in this part of the country. In September 2011, nine juvenile *P. flesus* were identified in the Skálmardalsá region of the Westfjords by Eirkíksson et al (in press).

2.11 Niche overlap theory

Niche overlap is a method used by ecologists to analyze numerical data arranged in ecological categories to understand the degree of how two or more different species use a common resource or resources within a given community (Colwell & Futuyma, 1971). This method is used to answer questions on how different species partition resources within a community; data is collected pertaining to animals or plant abundances and by the number of individuals or equivalent units of measure. These units of measure can vary in type from prey items, habitat types, substrates, environmental conditions and climatic factors (Colwell & Futuyma, 1971; Donovan & Welden, 2002). Species that have shown high levels of niche overlap have the potential to influence the populations of competing species for resources within a community (Krebs. 1999). Biologists have determined that for species to co-exist within a community, species must show different ecological requirements by a minimal amount to avoid competition (Pianka, 1974).

MacArthur and Levins (1967) discuss how biodiversity can be limited by three circumstances. The first describes that there must be lower limit to the abundance of each species within a community, which in turn sets the upper limit on the number of given species. Secondly there is an upper limit to the abundance of each species in a community, which can be set by a number of factors including predation and disease, which can influence the ability for more species to increase. Thirdly environmental factors can set limits to the degree of specialization of a species within a community, where competition may or may not set a limit to the similarities of coexisting species.

In this study, I apply niche overlap theory to identify potential competition between the *P. flesus* and Icelandic salmonids. I also examine the possibilities and consequences of *P. flesus* presence on Icelandic salmonids in light of MacArthur and Levins (1967) predictions. I specifically examine the distributional range of *P. flesus* in the Westfjords region, Iceland; the relative abundance of *P. flesus* in that area; the

diet of *P. flesus* and potential for diet overlap for salmonids; the spatial and temporal overlap between *P. flesus* and salmonids; and prey specific abundance of prey items found in the stomach contents between *P. flesus* and salmonids in estuaries.

3 Research Methods

3.1 Study area and sampling stations

The Westfjords region of Iceland (Figure 1) is a landscape consisting of deep fjords cut into a sequence of basaltic lava flows of Miocene age (-15 Ma); mountain sides of the range rise from sea level to 700m (Conway et al, 2010). The annual temperature of the Westfjords ranges from -5 to 10 ^{0}C with annual precipitation of approximately 2000mm/year (Conway et al, 2010). The ocean temperatures surrounding Iceland range between 6-11 ^{0}C, and salinity ranges typically from 35.0-35.2 (Astthorsson et al, 2007;Valdimarsson & Malmberg, 1999). The freshwater river ecosystems of the Westfjords are run-off systems with shallow lakes and wetlands near the origins and direct run-off systems on tertiary basalt (Gardarsson, 1979; Olafsson, 2002)

Önundarfjörður is located in the Westfjords region along the Northwest Peninsula of Iceland. Önundarfjörður is approximately 118 km^2 from the head of the fjord to the end of the estuary of Vöð. The approximate size of the estuary is 6 km^2; two river systems drain into the base of the estuary, the Korpa located on the northern end, and Hestá to the south end of the estuary

Hornvik is located in Hornstradir Nature Reserve in the northernmost part of the Northwest region of Iceland on the Westfjords peninsula of Iceland. Hornvik has a northwest trending basin, with depths in the bay from 50-100 meters (Hjort et al, 1985). Hornvik is approximately 24 km^2 from the head of the fjord to the end of the Hafnarós estuary. The approximate size of the estuary is <1 km^2; the Vatnið River system drains into the base of the estuary and is located on the north end of the estuary, which receives large tidal influences (Jonsson, 2011).

The tides in Iceland are mainly semidiurnal type, which are 12 hours and 25 minutes between consecutive floods. The tidal wave arrives in the south and rotates clockwise around Iceland. The mean speed of the wave is approximately 150km/hour (Jonsson, 2011). The tidal elevations are greatest along the west coast, with a difference between ebb and flood for ranging from 1-4 meters. The typical tidal currents have amplitude of approximately 10cm/s (Jonsson, 2011).

Figure 1   Westfjords region. Overview in lower left shows relation to Iceland.
                (Map modified from original source, (ja.is, 2011)).

Fourteen stations were sampled between the periods of June 2011 to September 2011 (Table 1). Stations 1 to 7 were located in Önundarfjörður near the end of the estuary of Vöð stations 8 to 11 were located in the Korpa River above the tidal limit of the estuary, and stations 12 to 14 were located in the Hestá River above the tidal limit of the estuary (Figure. 2)

Eight stations were sampled in July 2011 (Table 1). The Stations 15 to 20 were located in Hornvik along the estuarine area of Hafnarós at the mouth of the Vatnið River. Stations 21 to 23 were located in the Vatnið River above the tidal limit of the estuary (Figure. 3).

Table 1   The sampling stations in Önundarfjörður with station number
            (Figure.2), sample method, name of location, and brief description of
            the macro-habitat.

Station #.	Sample method	Name	Macro habitat	Sampling Date
1	Gill net	Vöð	Estuary	June-September 2011
2	Gill net	Vöð	Estuary	June-September 2011
3	Gill net	Vöð	Estuary	June-September 2011
4	Gill net	Vöð	Estuary	June-September 2011
5	Gill net	Vöð	Estuary	June-September 2011
6	Gill net	Vöð	Estuary	June-September 2011
7	Water parameters	Vöð	Estuary	June-September 2011
8	Electro-fishing	Korpa	Freshwater River	June-September 2011
9	Electro-fishing	Korpa	Freshwater River	June-September 2011
10	Water parameters	Korpa	Freshwater River	June-September 2011
11	Temperature Probe	Korpa	Freshwater River	June-September 2011
12	Electro-fishing	Hestá	Freshwater River	June-September 2011
13	Electro-fishing	Hestá	Freshwater River	June-September 2011
14	Water parameters	Hestá	Freshwater River	June-September 2011
15	Gill net	Hafnarós	Estuary	July 2011
16	Gill net	Hafnarós	Estuary	July 2011
17	Gill net	Hafnarós	Estuary	July 2011
18	Gill net	Hafnarós	Estuary	July 2011
19	Gill net	Hafnarós	Estuary	July 2011
20	Water parameters	Hafnarós	Estuary	July 2011
21	Electro-fishing	Vatnið	Freshwater River	July 2011
22	Electro-fishing	Vatnið	Freshwater River	July 2011
23	Water parameters	Vatnið	Freshwater River	July 2011

Figure 2   Vöð estuary, Korpa and Hestá River. With 14 sampling stations. Korpa located on the northern end and Hestá to the south end of the estuary. Overview in upper right shows Vöð estuary, Korpa and Hestá River in relation to Önundarfjörður and the North Atlantic Ocean (Map made in (Garmin: MapSource, 2012)).

Figure 3   Hafnarós estuary, Vatnið River. With 9 sampling stations. Overview of in upper right
                 shows in relation to Hornstrandir Nature Reserve and the North Atlantic ocean (Map
                 made in (Garmin: MapSource, 2012)).

3.2 Sampling techniques and water parameter equipment

Multiple sampling techniques were used to catch flounder and salmonids of different sizes in different habitats during the data collection of the present study to identify distribution and abundance of flounder populations throughout the sampled area.

3.2.1 Electro-fishing equipment

Single-pass electro-fishing was conducted, using a shoreline based portable electro-fishing unit designed by Vaki Aquaculture systems LTD, with a voltage of 300-600 V (DC) in all freshwater river sample sites in Hestá, Korpa, and Vatnið. Each electro-fishing station was measured to a 250m length, and was located above the brackish water and tidal limit of the estuaries. The width of each station was measured in five locations in meters. Electro-fishing took place in Hestá and Korpa each month between June and September 2011. Electro-fishing in Vatnið took place in the month of July 2011. GPS points were taken for each start and end location along Hestá, Korpa, and Vatnið. During electro-fishing one person would fish, while the second would collect paralyzed fish for sampling.

3.2.2 Gillnetting

Gill nets of different mesh sizes were used in sampling *P. flesus* and salmonids, in the Vöð estuary during the months of June, July, August and September. In the month of June, six gillnets were set randomly set across the estuary using 1m x 20m gillnets, with varying mesh sizes of 17.5 mm, 22.5 mm, 24.5 mm, 28.5 mm, 31.5, and 43.0 mm (measured between knots). The nets were set perpendicular to shoreline at 50-100m intervals during low tide and fished over one full tidal period of approximately 12 hours. Each net was checked for fish after each tidal period. This occurred over 4 tidal periods in June.

In the months of July, August and September, five gillnets were set randomly across the estuary using 1m x 20m gillnets, with varying mesh size of 17.5mm, 22.5mm, 24.5mm, 28.5, 31.5mm, and 35.0 mm (measured between knots). The nets were set perpendicular to shoreline at 50-100m intervals during low tide and fished over one full tidal period of approximately 12 hours. Each net was checked for fish

after each tidal period. This occurred over 4 tidal periods in each month over July, August and September 2011.

In the month of July five gillnets were set randomly across Hafnarós estuarine area near the mouth of the Vatnið River estuary using 1m x 20m gillnets, with varying mesh sizes of 17.5mm, 22.5mm, 24.5mm, 28.5, and 31.5mm, mesh sizes (measured between knots). The nets were set perpendicular to shoreline at 50-100m intervals during low tide, and fished over one full tidal period of approximately 12 hours.

In both Hafnarós and Vöð estuaries, location was recorded using a handheld GPS and the time of each net set and net check was recorded. If fish were caught, the net number and mesh size was recorded and kept separately according to mesh size and net. Each fish collected was identified, measured for total length (1 mm precision), fork length (salmonids; 1 mm precision), weighed (wet weight with 0.1 g precision), gutted and weighed (wet weight with 0.1 g precision), gonads, stomach, and livers removed and weighed (wet weight with 0.1 g precision), and sagittal otoliths (flounder) and scale samples (salmonids) collected. Stomach fullness was estimated in percentage, the location of eye registered (*P. flesus*), caudal fin clips collected (*P. flesus*) and for salmonids, signs of parasite infection were documented. Stomachs were kept and frozen for later analysis from all *P. flesus* and salmonids.

3.3 Sample collection and processing

3.3.1 Otolith analysis

Otoliths were removed from both *P. flesus* and salmonids, cleaned with water, and placed in paper envelopes or plastic otolith cases. Each set of otoliths were identified by fish number, station and location. Both right and left otoliths from *P. flesus* were used to determine age. Age estimates using otoliths are primarly used in flatfish populations as the majority of species examined display clear and unambiguous increments, with the exceptions of a few species (Nash & Geffen, 2005).

To prepare otoliths for aging analysis, otoliths were removed from storage and soaked in 90% glycerin prior to examination to improve light penetration. Otoliths were then mounted onto a black slide. The slide was then sprayed with a small amount of glycerin to help with light penetration and reading. Otoliths were read under a Wild Heerbrungg stereoscope at 60x power. Ageing accuracy was determined by selecting 20 otolith sets and having a first reader repeatedly count rings and decide on the age, followed by a second age analysis by a second, experienced reader. The otoliths sets were then sent to The Icelandic Marine Research Institute Laboratory in Reykjavik, where age was validated by an experienced reader. Following this three step validation process the remaining flounder otoliths were read by the first and second readers at the Icelandic Marine Institute Laboratory in Ísafjörður, Iceland. After discussion and comparison between both readers, a decision was made on the age of each fish and the assigned age recorded (Figure 4).
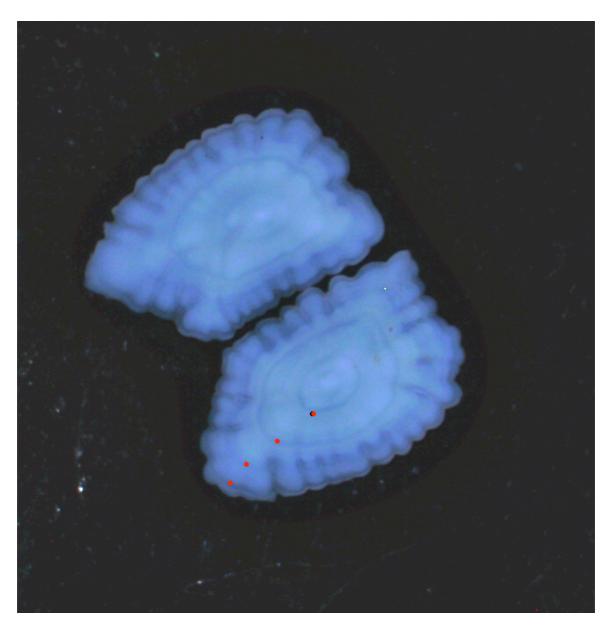
Figure 4   Otolith from Platichthys flesus. Önundarfjörður, July 2011

3.3.2 Stomach content analysis

All stomachs collected were frozen and placed into individual zip-lock bags, and labeled by fish number, net number, location, and date. With a few exceptions of some individual juvenile *P. flesus*, which stomach contents were not sampled, due to difficulties in sampling conditions.

Frozen stomachs were thawed in a refrigerator at approximately 5^0C. Once thawed, stomachs were placed in a sorting tray and, using a surgical scalpel blade (#60), a small incision was made from the base to the end of the stomach, at which point contents were emptied into the tray, and the stomach rinsed with 70% Isopropyl alcohol to clean out any remaining contents. Once rinsed, the contents of the stomach were placed in a 300 μm sieve and rinsed again to remove small sand and rock particles. Once fully rinsed, all contents were placed into a 90x15mm petri dish and viewed under a stereoscope (Leica, MZ12), where each prey item was identified to the lowest taxonomic level, counted and weighed (wet-weight with .01g precision), and recorded. Each species was separated and placed in 70% Isopropyl alcohol, labeled and placed in storage. Prey species identification was conducted in conjunction with the Natural History Museum of Bolungarvík Laboratory (Figure. 5).

Figure 5   (Left) Gammarus ssp & (Right) Prey species identification

3.4 Distribution & relative abundance

3.4.1   Distribution

The distributional range of *P. flesus* in the Westfjords region was mapped based on the fish distribution found in this study combined with historical and recent data collections from the Natural History Museum of Bolungarvík (Gudbrandsson, et al, 2005, Eiríksson et al, in press).

3.4.2   Relative abundance for gillnet sites (Vöð & Hafnarós estuaries)

The relative abundance of *P. flesus* and salmonids in the Vöð estuary was calculated on a catch per unit effort (CPUE) basis using the data from fish collected across all sample sites in the months of June, July, August and September. In Hafnarós estuary, the relative abundance (CPUE) of *P. flesus* and salmonids was calculated using data of fish collected from all sample sites in July 2011. Catch per unit effort was calculated three ways: (1) CPUE for all fish caught, (2) CPUE for flounder, and (3) CPUE for salmonids.

The following equation was used to calculate CPUE in Vöð sites:

$$CPUE = (total\ number\ of\ fish\ caught\ /\ 48\ hrs\ in\ minutes)\ x\ 60$$

The following equation was used to calculate CPUE for the Hafnarós sites:

$$CPUE = (total\ number\ of\ fish\ caught\ /\ 24\ hrs\ in\ minutes)\ x\ 60$$

3.4.3   Relative abundance for electroshock sites (Korpa, Hestá and Vatnið)

The relative abundance of *P. flesus* and salmonids was calculated on a fish caught per m^2 for electrofishing took place. Relative abundance for Korpa and Hestá was calculated for each month and each site using the data of fish collected during June, July, August and September. The relative abundance of *P. flesus* and salmonids was calculated for Vatnið sample site in July.

The following equation was used to calculate the density in Korpa, Hestá and Vatnið:

$$Density = (total\ number\ of\ fish\ caught\ /\ m^2)$$

3.5 Statistical analysis

All statistical analysis was performed using Microsoft Excel.

3.5.1 Relative importance of prey items

The relative importance of each prey item in the diet of *P. flesus* and salmonids was evaluated using three indices: the numeric index (NI), the percentage of the number of individuals of a prey over the total number of individuals of all prey types; the occurrence index (OI), the percentage of non-empty stomachs in which a prey occurred over the total number of occurrences; and the gravimetric index (GI), the percentage of weight of prey over the total weight of all prey items (Hyslop 1980; Vinagre et al, 2005).

3.5.2 Spatial niche overlap analysis

To measure the spatial overlap between *P. Flesus* and salmonids, Pianka's (1973) measurement of niche overlap was used.

$$O_{jk} = \frac{\sum p_{ij}p_{ik}}{\sqrt{\sum p_{ij}^2 p_{ik}^2}}$$

Where, O_{jk} is the overlap between species j and species k, p_{ij} is the proportion that resource i is of the total resources used by species j, and p_{ik} is the proportion that resource i is of the total resources used by species k. This measure ranges from 0, having no common resource; to 1 having complete overlap of resources, with accepted biologically significance value of 0.60 (Donovan & Welded, 2002; Vinagre et al, 2005).

3.5.3 Temporal niche overlap analysis

I used Schoener's (1970) index (T) to measure the temporal overlap in the diet between *P. flesus* and salmonids:

$$T = 1 - 0.5 \sum |px_{fi} - py_{fi}|$$

where, px_{fi} and py_{fi} are the proportions by weight in of the resource 'fi' (prey category) for species x and y respectively. The overlap index varies from 0, where the two species use completely different resources to 1 where the species use the same

prey categories in the same proportions, with accepted biologically significance value of 0.60 (Vinagre et al, 2005).

3.5.4 Prey-specific abundance analysis

Prey-specific abundance (P_i), is the percentage a prey taxon comprises of all prey items in only those predators in which the actual prey occurs. It is calculated as:

$$P_i = (\Sigma S_i / \Sigma S_t) \times 100$$

where P_i is the prey-specific abundance of prey i, S_i the stomach content (volume) comprised of prey *i*, and S_{ti} the total stomach content in only those predators with prey i in their stomach (Amundsen et al 1996). Prey-specific analysis was used to gain information on the importance of particular prey species and on the feeding strategies of *P. flesus* and salmonids in the Westfjords. This analysis provides information regarding the feeding strategy of a predator in terms of whether it can be classified as a specialist or generalist. Prey-specific abundance is also used to determine if a predator population will have a narrow or broad niche width (Amundsen et al 1996).

4 Results

4.1 Distribution and relative abundance

4.1.1 Distribution

Platichthys flesus were found in the estuary of Vöð, and both freshwater habitats of Korpa and Hestá in Önundarfjörður. In Hornvik, *P. flesus* were found in the estuary of Hafnarós and the freshwater habitat of Vatnið. Historical data collected by Gudbrandsson, et al, (2005) identified *P. flesus* in Norðurfjöður in the lower reaches of the freshwater habitat of Síki and recent findings by Eirkíksson et al (in press) identified *P. flesus* in Skálmarfjöður in the freshwater habitat of Skálmardalsá (Figure 6).

4.1.2 Catch and Relative abundance in Vöð & Hafnarós estuaries

I caught a total of 382 fish in the voð estuary, including 360 *P. flesus* and 22 salmonids (*Salvelinus alpinus and Salmo trutta)* (Table 2). The CPUE for all fish caught in the Voð estuary across all mesh sizes ranged from a low in June (0.0833 fish/hr) to a high in August (4.7500 fish/hr) (Table 3), while the CPUE for *P. flesus* ranged from 0 fish/hr in June to a high of 4.5833 fish/hr in August. The CPUE for salmonids was lowest in July (0.0208 fish/hr) and highest in September (0.4583/hr), but were an order of magnitude lower than peak CPUE for *P. flesus* (Table 3).

I caught a total of 82 fish in the Hafnarós estuary in (July sampling only), including 25 *P. flesus* and 53 salmonids (Table 5). The CPUE for all fish caught in all mesh sizes was 3.4167 fish/hr with a CPUE of 1.0417 fish/hr for *P. flesus* and 2.2083 fish/hr for salmonids (Table 4).

4.1.3 Relative abundance in Korpa, Hestá and Vatnið

I caught a total of 335 fish during electro-fishing in Korpa, including 63 *P. flesus* and 33 salmonids (*Salvelinus alpinus and Salmo salar)* (Table 5). This resulted in a density estimate for *P. flesus* of 0.03997 fish/m^2, and a density estimate of 0.02094 fish/m^2 for salmonids. I caught a total of 95 fish during electro-fishing in Hestá, including 46 *P. Flesus* and 6 salmonids (*Salvelinus alpinus, and Salmo trutta)* (Table 6). This resulted in a density estimate of 0.02788 fish/m^2 for *P. flesus*, and a density estimate of 0.00364 fish/m^2 for salmonids. I caught a total of 18 fish while sampling at Vatnið, all of which were *P. flesus*. This resulted in a density estimate of 0.0073 fish/m^2 (Table 5). No salmonids were sampled during electro-fishing at Vatnið.

Figure 6   Known distributional range of P. Flesus in Westfjords region of
                  Iceland (Map made in (Garmin: MapSource, 2012)).

Table 2   The total amount of fish caught per months, per mesh size; the total amount of P. flesus caught per month, per mesh size and the total amount of salmonids caught per month, per mesh size; in the Voð estuary.

Total amount of fish caught per month:

Mesh size (mm)	June	July	August	September	Total amount of fish caught in Voð
17.5	1	10	78	69	158
22.5	0	0	63	13	76
24.5	0	0	12	20	32
28.5	0	x	44	12	56
31.5	2	0	31	23	56
35	x	3	x	x	3
43	1	x	x	x	1
Total	4	13	228	137	382

Total amount of *P. flesus* caught per month:

Mesh size (mm)	June	July	August	September	Total amount of *P. Flesus* caught in Voð
17.5	0	9	77	66	152
22.5	0	0	62	11	73
24.5	0	0	9	16	25
28.5	0	x	43	12	55
31.5	0	0	29	23	52
35	x	3	x	x	3
43	0	x	x	x	0
Total	0	12	220	128	360

Total amount of salmonids caught per month:

Mesh size (mm)	June	July	August	September	Total amount of salmonids caught in Voð
17.5	1	1	1	3	6
22.5	0	0	1	2	3
24.5	0	0	3	4	7
28.5	0	x	1	0	1
31.5	2	0	2	0	4
35	x	0	x	x	0
43	1	x	x	x	1
Total	4	1	8	9	22

Table 3   The total CPUE of fish caught per month, per mesh size; the total CPUE of P. flesus caught per month, per mesh size; and the total CPUE of salmonids caught per month, per mesh size; over 48 hours or four tidal cycles in the Voð estuary.

Total CPUE per month:

Mesh size (mm)	June	July	August	September	Total CPUE of fish caught in Voð
17.5	0.0208	0.2083	1.6250	1.4375	3.2917
22.5	0.0000	0.0000	1.3125	0.2708	1.5833
24.5	0.0000	0.0000	0.2500	0.4167	0.6667
28.5	0.0000	x	0.9167	0.2500	1.1667
31.5	0.0417	0.0000	0.6458	0.4792	1.1667
35	x	0.0625	x	x	0.0625
43	0.0208	x	x	x	0.0208
Total	0.0833	0.2708	4.7500	2.8542	7.9583

Total CPUE of *P. flesus* per month:

Mesh size (mm)	June	July	August	September	Total CPUE of *P. flesus* in Voð
17.5	0.0000	0.1875	1.6042	1.3750	3.1667
22.5	0.0000	0.0000	1.2917	0.2292	1.5208
24.5	0.0000	0.0000	0.1875	0.3333	0.5208
28.5	0.0000	x	0.8958	0.2500	1.1458
31.5	0.0000	0.0000	0.6042	0.4792	1.0833
35	x	0.0625	x	x	0.0625
43	0.0000	x	x	x	0.0000
Total	0.0000	0.2500	4.5833	2.6667	7.5000

Total CPUE of salmonids per month:

Mesh size (mm)	June	July	August	September	Total CPUE of Salmonids in Voð
17.5	0.0208	0.0208	0.0208	0.0625	0.1250
22.5	0.0000	0.0000	0.0208	0.0417	0.0625
24.5	0.0000	0.0000	0.0625	0.0833	0.1458
28.5	0.0000	x	0.0208	0.0000	0.0208
31.5	0.0417	0.0000	0.0417	0.0000	0.0833
35	x	0.0000	x	x	0.0000
43	0.0208	x	x	x	0.0208
Total	0.0833	0.0208	0.1667	0.1875	0.4583

Table 4   The total amount of fish caught per months, per mesh size; the total amount of P. flesus caught per month, per mesh size and the total amount of salmonids caught per month, per mesh size; in the Hafnarós estuary. The total CPUE of fish caught per month, per mesh size; the total CPUE of P. flesus caught per month, per mesh size; and the total CPUE of salmonids caught per month, per mesh size; over 24 hours or two tidal cycles in the Hafnarós estuary.

Total amount of fish caught per month:

Mesh size (mm)	July	Total amount of fish caught
17.5	4	4
22.5	24	24
24.5	7	7
28.5	30	30
31	17	17
Total	82	82

Total CPUE per month:

Mesh size (mm)	July	Total CPUE of fish caught in
17.5	0.1667	0.1667
22.5	1.0000	1.0000
24.5	0.2917	0.2917
28.5	1.2500	1.2500
31	0.7083	0.7083
Total	3.4167	3.4167

Total amount of *P. flesus* caught per month:

Mesh size (mm)	July	Total amount of P. flesus
17.5	2	2
22.5	1	1
24.5	4	4
28.5	13	13
31	5	5
Total	25	25

Total CPUE of *P. flesus*:

Mesh size (mm)	July	Total CPUE of P. flesus in Hafnarós
17.5	0.0833	0.0833
22.5	0.0417	0.0417
24.5	0.1667	0.1667
28.5	0.5417	0.5417
31	0.2083	0.2083
Total	1.0417	1.0417

Total amount of salmonids caught per month:

Mesh size (mm)	July	Total amount of salmonids
17.5	2	2
22.5	22	22
24.5	3	3
28.5	14	14
31	12	12
Total	53	53

Total CPUE of salmonids

Mesh size (mm)	July	Total CPUE of salmonids
17.5	0.0833	0.0833
22.5	0.9167	0.9167
24.5	0.1250	0.1250
28.5	0.5833	0.5833
31	0.5000	0.5000
Total	2.2083	2.2083

Table 5   The total number of P. flesus and salmonids sampled per month, total amount of P. flesus and salmonids caught and total density of each species per m^2 in Korpa, Hestá and Vatnið, electro-fishing sampling stations.

Number of *P. Flesus* sampled per month:

Site	June	July	August	September	Total amount of *P. flesus* caught	Density of (Fish/m^2)
Korpa	19	30	11	3	63	0.03997
Hestá	24	6	11	5	46	0.02788
Vatnið	x	18	x	x	18	0.00073

Number of salmonids sampled per month:

Site	June	July	August	September	Total amount salmonids caught	Density of (Fish/m^2)
Korpa	17	5	8	3	33	0.02094
Hestá	3	2	1	0	6	0.00364
Vatnið	x	0	x	x	0	0.00000

4.2 Relative importance of prey items

4.2.1 Vöð estuary

I collected a total of 332 *P. flesus* stomachs for content analysis in the Vöð estuary, of which 323 had at least one prey item. The *P. flesus* diet in the Vöð estuary was comprised mostly of *Gammarus* spp. The numerical, occurrence and gravimetrical indices indicate *Gammarus* spp., as the most important prey item (NI = 98.4, OI = 98.1, GI = 99.5) (Table 6). Chironomidea was the second highest most important prey item (NI = 1.3, OI = 34.6, GI = .06), *Mytilus edulis*, was overall third (NI = 0.1, OI = 15.7, GI = 0.3), although the gravimetrical index was higher in *Mytilus edulis*, than it was for Chironomidea. Actinopterygii, Mysidacea, Geometridae, *littorina obtusta* and *Gasterosteus aculeatus*, were also present but with low indices values.

I collected 21 salmonid (*Salvelinus alpinus, & Salmo trutta*) stomachs, all of which had at least one prey item. *Gammarus* spp., were also the most important prey item in salmonids according to the numerical, occurrence and gravimetrical indices (NI = 99.8, OI = 100, GI = 99.9) (Table 6). Chironomidea, was again second according to the numerical index (NI = 0.4), but Muscidae was second according to the occurrence index (OI = 19.0) and Mysidacea, was second most important prey item according to the gravimetrical index (0.02). *Silmulium* sp. and Brachycera were also present with low indices values.

Table 6   Numerical (NI – percentage of prey individuals over the total number of individuals of all prey), occurrence (OI – percentage of non-empty stomachs in which a prey occurred over total number of occurrences) and gravimetric (GI – percentage in weight of a prey over total weight of all prey) index values of prey found in stomachs of P. flesus and Salmonids (n.i. – not identified to lower systematic category).

Prey item	P. Flesus			Salmonids		
	NI	GI	OI	NI	GI	OI
Arthropoda						
Crustacea						
Mysidacea (n.i.)	0.00	0.00	0.31	0.01	0.03	4.76
Amphipoda						
Gammarus spp.	98.48	99.51	98.14	99.87	99.97	100.00
Isopoda						
Idotea emarginata	0.00	0.00	0.00	0.00	0.00	0.00
Decapoda						
Pagurus bernhardus	0.00	0.00	0.00	0.00	0.00	0.00
Insecta						
Diptera						
Brachycera (n.i)	0.00	0.00	0.00	0.02	0.00	4.76
Muscidae	0.01	0.00	0.62	0.04	0.00	19.05
Nematocera						
Chironomidae	1.32	0.07	34.67	0.05	0.00	9.52
Silmuliidae						
Silmulium sp.	0.00	0.00	0.00	0.01	0.00	4.76
Acalyptratae						
Coelopidea						
Coelopa frigida	0.00	0.00	0.00	0.00	0.00	0.00
Lepidoptera						
Geometridae (n.i)	0.01	0.04	0.31	0.00	0.00	0.00
Trichoptera						
Limnophilus griseus	0.00	0.00	0.00	0.00	0.00	0.00
Mollusca						
Gastropoda						
Littorina obtusata	0.01	0.00	0.93	0.00	0.00	0.00
Bivalvia						
Mytilus edulis	0.16	0.36	15.79	0.00	0.00	0.00
Chordata						
Actinopterygii						
Actinopterygii (n.i.)	0.02	0.00	2.17	0.00	0.00	0.00
Gasterosteidae						
Gasterosteus aculeatus	0.00	0.03	0.31	0.00	0.00	0.00
Percentage of empty stomachs		2.71			0.00	

4.2.2 Hafnarós estuary

I collected 21 *P. flesus* stomachs in the Hafnarós estuary, of which 12 contained at least one prey item. The *P. flesus* diet at Hafnarós was comprised mostly of Chironomidea and *Idotea emarginata*. Chironomidea, had the highest numerical index of (NI = 50.0, OI = 16.67, GI = <0.01) while *Idotea emarginata* had the highest occurrence and gravimetrical indices (NI = 32.35, OI = 41.67, GI = 58.86) (Table 7). The third and fourth most important food sitem were *Gammarus* spp. (NI = 8.82 OI = 16.67, GI = 24.57) and *Pagurus bernhardus* (NI = 4.41, OI = 25.00, GI = 16.57). *Mytilus edulis and* prey items in the famile Muscidae were also present with low indices values.

I collected 39 salmonid (*Salvelinus alpinus*) stomachs in the Hafnarós estuary of which 36 contained at least one prey item. *Gammarus* spp. was the most important prey item according to the numerical, occurrence and gravimetrical indices (NI = 92.92, OI = 72.22, GI = 94.04) (Table 7). *Coelopa frigida* (NI = 3.74, OI = 2.78, GI = 0.34), *Pagurus bernhardus* (NI = 1.38, OI = 3.63, GI = 8.33), *Idotea emarginata* (NI = 0.98, OI = 0.80, GI = 8.33), Actinoperygii, (NI = 0.20, OI = 5.56, GI = 1.07) and Muscidae, (NI = 0.20, OI = 5.56, GI = 0.08) all had high prey item importance value according to different indices. Chironomideae, *Limnophilus griseus,* and *Mytilus edulis* were also present but of low indices values.

Table 7   Numerical (NI – percentage of prey individuals over the total number of individuals of all prey), occurrence (OI – percentage of non-empty stomachs in which a prey occurred over total number of occurrences) and gravimetric (GI – percentage in weight of a prey over total weight of all prey) index values of prey found in stomachs of P. flesus and Salmonids (n.i. – not identified to lower systematic category).

Prey item	P. Flesus			Salmonids		
	NI	GI	OI	NI	GI	OI
Arthropoda						
Crustacea						
Mysidacea (n.i.)	0.00	0.00	0.00	0.00	0.00	0.00
Amphipoda						
Gammarus spp.	8.82	24.57	16.67	92.92	94.04	72.22
Isopoda						
Idotea emarginata	32.35	58.86	41.67	0.98	0.80	8.33
Decapoda						
Pagurus bernhardus	4.41	16.57	25.00	1.38	3.63	8.33
Insecta						
Diptera						
Brachycera (n.i)	0.00	0.00	0.00	0.00	0.00	0.00
Muscidae	2.94	0.00	8.33	0.20	0.08	5.56
Nematocera						
Chironomidae	50.00	0.00	16.67	0.29	0.00	2.78
Silmuliidae						
Silmulium sp.	0.00	0.00	0.00	0.00	0.00	0.00
Acalyptratae						
Coelopidea						
Coelopa frigida	0.00	0.00	0.00	3.74	0.34	2.78
Lepidoptera						
Geometridae (n.i)	0.00	0.00	0.00	0.00	0.00	0.00
Trichoptera						
Limnophilus griseus	0.00	0.00	0.00	0.10	0.00	2.78
Mollusca						
Gastropoda						
Littorina obtusata	0.00	0.00	0.00	0.00	0.00	0.00
Bivalvia						
Mytilus edulis	1.47	0.00	8.33	0.20	0.03	2.78
Chordata						
Actinopterygii						
Actinopterygii (n.i.)	0.00	0.00	0.00	0.20	1.07	5.56
Gasterosteidae						
Gasterosteus aculeatus	0.00	0.00	0.00	0.00	0.00	0.00
Percentage of empty stomachs		42.85			7.69	

4.3 Spatial niche overlap

The spatial niche overlap in the Vöð estuary between *P. flesus* and salmonids (*Salvelinus alpinus and Salmo trutta*) was a significant O = 0.94 using Pianka's index measurement of niche overlap, while the spatial niche overlap between *P. flesus* and salmonid (*Salvelinus alpinus*) in the Hafnarós estuary was insignificant at O = 0.45, as measured by Pianka's index.

4.4 Temporal niche overlap

The temporal niche overlap in the Vöð estuary between *P. Flesus* and salmonids (*Salvelinus alpinus* and *Salmo trutta*), as calculated using the Schoener index, indicates high overlap for the numeric index (T = 0.98), the occurrence index (T = 0.78) and a gravimetric index (T = 0.98). The temporal niche overlap of diets in the Hafnarós estuary of *P. Flesus* and salmonids (*Salvelinus alpinus)* showed significantly lower levels of temporal niche overlap for the numeric index (T = 0.11) and occurrence index (T = 0.30), but a higher level of overlap for the gravimetric index (T = 0.92).

4.5 Prey-specific abundance in diet

Prey-specific abundance calculations for *P. flesus* in the Vöð estuary showed *Gammarus spp.* at 90% (figure 7a). Indicating that *Gammarus spp.* is the dominant prey item in the diet, similar to the other metrics, and represents diet specialization by *P. flesus* and restricted in this estuary to a narrow niche width. In the Vöð estuary for salmonids, *Gammarus spp.* had a prey-specific abundance of 98% (figure 7b), indicating that *Gammarus spp.* is the dominant prey item for salmonids as well and that salmonids have a restricted narrow niche width to this estuary.

Prey-specific abundance calculations for *P. flesus* in the Hafnarós estuary showed *Pagurus bernhardus.* and *Mytilus edulis,* at 28% (figure 7c). This indicates that these prey items were consumed more than other species but are not dominant prey items, that diet overall in this location is more general and therefore *P. flesus* in the Hafnarós estuary has a broader niche width. Prey-specific abundance for salmonids *(Salvelinus alpinus)* in the Hafnarós estuary showed species from Actinopterygii and Muscidae, and *Limnophilus griseus* were at 90% (figure 7d), indicating that these three groups represent high specific abundance and

specialization for salmonids (*Salvelinus alpinus). Gammarus spp.* has a low specific abundance and high occurrence, and is occasionally eaten by the majority of the sampled population (figure 7d), indicating a broad niche width of salmonids in the Hafnarós estuary.

A combined analysis for both locations shows that prey-specific abundance for *P. flesus* overall is dominated by *Gammarus spp.* (86%) (figure 7e), and represents specialization of the entire *P. flesus* in both estuaries. Similarly, combined analysis for salmonids in the Vöð and Hafnarós estuaries show prey specific abundance for *Gammarus spp.* at 80% (figure 7f) and an overall narrow niche width.

4.6 Age structure of *P. flesus*

All *P. flesus* from Korpa and Hestá were one year old (Table 8a,b), while fish from Vöð and Önundarfjörðrður had fish that ranged from 1 to 6 years old (Table 8c,d). Similarly, all *P. flesus* from Vatnið one year old fish (Table 9a). While fish from Hafnarós estuary and Hornvik ranged from one to five years of age (Table 9b,c).
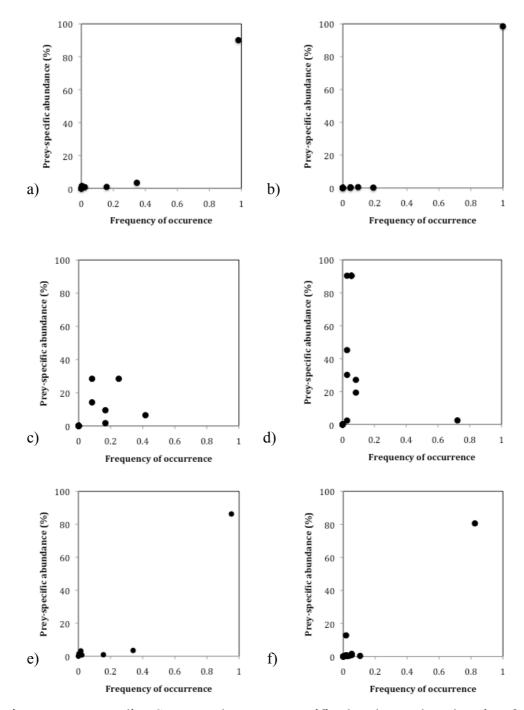
Figure 7   Feeding Strategy Plots: prey-specific abundance plotted against frequency
of occurrence of prey in diet of predator. (a) P.flesus from Vöð estuary;
(b) Salmonids from Vöð estuary; (c) P. flesus from Hafnarós estuary; (d)
Salmonids from Hafnarós estuary; (e) P. flesus from Vöð & Hafnarós
estuaries; (f) Salmonids from Vöð & Hafnarós estuaries combined.

Table 8   Aging structures of P. Flesus collected in a) Korpa, b) Hestá, c) Vöð,
               sampling stations and d) Önundarfjörður represent all sample stations
               combined (Korpa, Hestá & Vöð).

a)   Aging structures of *P. flesus* in Hestá

Age (years)	1	2	3	4	5	6
Total	46	0	0	0	0	0
%	100.0	0.0	0.0	0.0	0.0	0.0

b)   Aging structures of *P. flesus* in Korpa

Age (years)	1	2	3	4	5	6
Total	63	0	0	0	0	0
%	100.0	0.0	0.0	0.0	0.0	0.0

c)   Aging structures of *P. flesus* in Vöð Estuary

Age (years)	1	2	3	4	5	6
Total	28	76	138	101	16	1
%	7.8	21.1	38.3	28.1	4.4	0.3

d)   Aging structures of *P. Flesus* in Önundarfjöður:

Age (years)	1	2	3	4	5	6
Total	137	76	138	101	16	1
%	29.2	16.2	29.4	21.5	3.4	0.2

Table 9   Aging structures of P. Flesus collected in Hornvik from a) Vatnið,
               b) Hafnarós sampling locations and c) Hornvik, represent all
               sampling locations combined (Vatnið & Hafnarós).

a)   Aging structures of *P. flesus* in Vatnið

Age (years)	1	2	3	4	5
Total	18	0	0	0	0
%	100.0	0.0	0.0	0.0	0.0

b)   Aging structures of *P. flesus* in Hafnarós Estuary

Age (years)	1	2	3	4	5
Total	4	2	3	10	4
%	17.4	8.7	13.0	43.5	17.4

c)   Aging structures of *P. Flesus* in Hornvik:

Age (years)	1	2	3	4	5
Total	22	2	3	10	4
%	53.7	4.9	7.3	24.4	9.8

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5 Discussion

5.1 The Distribution of *P. flesus* in the Westfjords, Iceland

This work documents that *P. flesus* is now present in the Westfjords region of Iceland, and based on multiple age classes has established populations in both Önundarfjörður and Hornvik (Figure 6). In both Önundarfjörður and Hornvik, juvenile and adult populations were found inhabitating both estuarine and freshwater environments. It can be assumed that due to the occurrence of juvenile populations of *P. flesus* found in Skálmardalsa and Síki, in close proximity to estuarine environments of Skálmarfjöður and Norðurfjöður that both areas may potentially contain established populations of adult *P. flesus* (Gudbrandsson et al 2005; Eirkíksson et al, in press).

The distribution and settlement patterns of flatfish are based on larval transport and supply, but this can also be influenced by larval behavior and habitat selection during periods of settlement (Able et al; 2005, Bailey et al, 2005), by abiotic factors including sediment types, turbidity, salinity, depth and temperature, and biotic factors including prey distribution and abundance as significant factors driving the settlement patterns of flatfish species (Able et al 2005; Allen & Baltz 1997; Burke, 1995).

Many coastal areas surrounding the Westfjords region have habitat characteristics similar to those found in Önundarfjörður, Hornvik, Skálmarfjöður and Norðurfjöður (Ingólfsson, 2006; Bailey et al, 2005) . Therefore these places may potentially have established populations of *P. flesus* as well, although this has yet to be established. A changing climate in Icelandic waters has caused an increase in both ocean temperatures and salinity, which has likely changed the availability of suitable habitat conditons for *P.flesus* (Anon, 2006; Astthorson & Palsson, 2006; Astthorsson et al, 2007; Lassalle & Richard, 2009). With the influence of both the North Icelandic Irminger Current and the Icelandic Coastal Current traveling from southwest to northeast (clockwise) around Iceland, the potential for larval transport and supply to areas in the North and Northeast regions of Iceland can be hypothesized (Bailey et al, 2005).

5.2 Relative abundance

Following winter spawning, *P. flesus* begin the migration back to shallow coastal and estuarine environments during the summer. This might explain the pattern of seasonal abundance seen in Önundarfjörður and Hornvik areas during this study. There are no previous studies on the distribution and relative abundance of *P. flesus* in Icelandic waters, therefore there is no present information to compare to relative abundance trends over summer months in Icelandic waters. In Vöð estuary of Önundarfjörður, there was no *P. flesus* found during the month of June, within the estuarine environment (Table 2). A possible explanation to this result could be related to a late post spawning migration of adult *P. flesus* to estuarine environments. Abundance of *P. flesus* increased in July, peaked in August, which may be related to an increase of salinty and warmer surface temperatures found in the estuary and the migration of fish towards shallow waters and prey availability during this time of year (Henderson, 1988; Gibson, 1994; Vinagre et al 2005). There was a subsequent decline in September, which may be related to *P. flesus* more commonly found inhabitating mesohaline waters compared to oligohaline or fresh waters (Kerstan, 1991; Jager, 1998).

The amount of salmonids caught in the estuary of Vöð was relatively low, compared to the number of *P. flesus* caught. This could be related to a variety of factors, as populations of anadromous brown trout and arctic char often travel between near shore and offshore areas, exploiting both fresh and salt waters for feeding and spawning (Klemetsen et al, 2003). Both species are known to be partially migratory. Arctic char can spend up to 40 days or more at sea, but the migration patterns often vary between populations (Klemetsen et al, 2003). The relative abundance of salmonids found in the Vöð estuary could be related to timing of migration and habitat use during the summer. During the period covered by this study there was a greater number of *P. flesus* than salmonids captured, but no further conclusions can be made regarding the differences between species.

It is difficult to make any definitive conclusions about the relative abundance of both species of salmonids found, as very little previous research has been done.

The Hafnarós estuary in Hornvik was only sampled once in the month of July, but it had a relative abundance of *P. flesus* similar that of Vöð estuary. Salmonids (*Salvelinus alpinus*) were found in higher abundance than *P. flesus* in Hafnarós

estuary. Due to the limited of data collected, very few conclusions can be made on the relative abundance of salmonids in the Hafnarós estruary, but it could be driven by environmental factors, differential susceptibility to the gear, inter-annual variability in abundance.

The relative abundance of *P. Flesus* in the freshwater environments of Korpa, Hestá and Vatnið is facilitiated by its broad osmoregulatory ability (Bos, 1999; Andersen et al, 2005; Larsen et al, 2007). The use of freshwater environments is often associated with the juvenile stages of life, which offer feeding opportunities and and sanctuary from predation (Nash & Geffen, 2005). The density of *P. flesus* found in Korpa and Hestá was higher in early than late summer. This likely indicates freshwater use by new recruits (van der Veer et al, 2001) followed by dispersal into coastal waters in autumn (Berghahm, 1984; Morais et al 2011).

The relative abundance or density of salmonids found in Korpa and Hestá were higher June through August than in September. This pattern is likely associated with smolt migration from freshwater to saltwater environments, although since each species of salmonids sampled (*Salmo salar, Salmo trutta* and *Salvelinus alpinus*) has a different size and age at smoltification (Klemetsen et al, 2003; Jonsson & Antonsson, 2005) few other conclusions can be made.

The results of sampling in Vatnið, Hornvik confirms that there is an established population of juvenile *P. flesus* inhabiting the freshwater environment. Due to the limited amount of sampling conducted, no trends or conclusions can be discussed on the overall trend in density of *P. flesus* in Vatnið. I found no salmonids in Vatnið, but did not investigate the smaller tributaries and other areas surrounding Vatnið. No previous research has been conducted on salmonds in the Vatnið area so no comparisons to previous research can be made.

5.3 Relative importance of prey items

I found Crustacea, specifically *Gammarus spp.* to be the predominant prey type of *P. flesus* in the Vöð estuary, with no Polychaeta prey items found. *P. flesus* caught in the Vöð estuary also had *Gammarus* spp represented at greater than 90% for all diet indices calculated. Ingólfsson (2006) identified *Gammarus spp.* to be the only macrofauna found in the upper reaches of the Langárös estuary in western Iceland and Polychaeta were found inhabitating the outer most regions (Ingólfsson, 2006). My sampling area in Vöð was located in the upper reaches of the estuary. Link et al

(2005) identify two primary prey types in the flatfish diet: polychaetes and small benthic crustaceans. Other studies (de Groot, 1971; Summers, 1980; Piet et al, 1998; Andersen et al., 2005; Vinagre et al, 2005) have come to similar conclusions. Vinagre et al (2005) compared the diets of *P. flesus* in two different estuaries separated by 300 km and found Polychaeta to be predominant prey type in one and and Crustacea in the other. Summers (1980) indicates that the diet of *P. flesus* is flexible and often changes with prey availability. Given the apparent flexibility in diet, it should not be surprising that in estuarine locations dominated by a particular crustacean or polychaete, that *P. flesus* diet reflects that dominance.

The salmonids (*Salvelinus alpinus and Salmo trutta*) in the Vöd estuary have diets similar to that of *P. flesus*, as the main prey item of salmonids in this location was *Gammarus* spp. Some studies have shown anadromous arctic char to be opportunistic feeders that feed on a diversity of prey items (Adams et al 1989), while other studies show arctic char feeding primarily on invertebrates and amphipods (Johnson, 1980; Dempson et al, 2002), and Gronvik and Klemetsen (1987) found that anadromous arctic char feed primarily on fish. My results for the Vöð estuary are in line with Johnson, (1980) and Dempson et al, (2002).

While anadromous brown trout often feed on marine crustaceans, they are also known as opportunistic feed and diets tend to vary depending on season (Klemetsen et al, 2003). Some individual populations apparently specialize when prey items become abundant or prominent in the ecosystem (Gronvik & Klemetsen, 1987; Klemetsen et al, 2003).

In the Hafnarós estuary, depending the index used, Chironomidae and *Idotea emarginata*, were the predominant prey item found in the diet of *P. flesus*. Link et al, (2005) indicate common but less dominant prey types can include harpacticoid copepods, bivalves, echinoderms, oligochaetes, insect larva (chironomids), decapods, mysids, euphausids and similar shrimps. Gronkjær et al (2007) found isopods to be a rare prey item in the diet of *P. flesus*. Overall, in Hafnarós *P. flesus* had a broader diet than the fish from Vöð.

Gammarus spp. was the main prey item found in Arctic char from the Hafnarós estuary, the only salmonid species found in this location. This is similar to what was observed in Vöð, and is in line with the results from Johnson (1980) and Dempson et al (2002).

5.4 Spatial Niche Overlap & Trophic Niche Overlap

There was both spatial and temporal overlap between *P. flesus* and salmonids (*Salvelinus alpinus and Salmo trutta*) in the Vöð estuary. The spatial overlap, according to Pianka´s index, was almost complete, with a strong trophic overlap (Schoener's index) as well. Overall, flatfish have been shown to have spatial, temporal and dietary overlaps with a number of species and the potential for flatfish to compete with other species does occur (Link et al 2005). According to Link et al (2005), the four requirements that must be met to demonstrate competition include these features, plus limiting resources and notable population impacts from interaction. Species that consume benthic invertebrates or forage fishes have the greatest potential for competition with flatfish; arctic char and brown trout have this potential (Johnson, 1980; Adams et al, 1989; Dempson et al, 2002; Klemetsen et al, 2003; Link et al, 2005). Members of similar feeding guilds by definition have the potential to exhibit competition among species. Some populations of flatfish have had significant impacts on their prey populations, which can induce dramatic shifts in ecosystem dynamics (Link, et al, 2005). The relatively recent presence of *P. flesus* in Westfjords environments creates the potential for competition with salmonid populations that share similar habitats and prey items, resulting in increased competition and resultant declines in salmonid populations.

In the Hafnarós estuary, there was no significant spatial or temporal overlap between *P.flesus* and *Salvelinus alpinus*, the only salmonid species caught in this location, as indicated by the Pianka index. The temporal overlap in diet between species was largely insignificant (Schoener's index), with the exception of a potential for competition based on gravimetric measurements of prey overlap. This exception could be related to an overemphasis of single heavy items found in the diet of both species (George & Hadley, 1979; Hellawell & Abel, 1971), making the gravimetric index of lower importance than the numeric and occurrence indices (Hyslop, 1980). The lack of spatial and temporal overlap found in Hafnarós could be a result of short-term changes in diet, seasonal differences that have been observed in many flatfish species, or the opportunistic feeding types of both species combined with a wider variety of prey items available (Link, et al, 2005; Vinagre et al, 2005; Johnson, 1980; Adams et al, 1989; Dempson et al, 2002). Due to the limited sampling effort in

Hafnarós, specific conclusions regarding competition among species are difficult to make.

5.5 Prey specific abundance in diets

The relative abundance of prey found in the diet based on the Amundesen et al (1996) approach to feeding strategies showed that in the Vöð estuary, *Gammarus* spp. was the most abundant of any diet item in both *P. flesus*, and salmonids. In other words, both species exhibit a narrow niche width, as the remaining prey items were found only occasionally and in low abundance and frequency. This could be related to the feeding strategies of generalist predators, which consume prey in proportion to their abundance (Summers 1980; Klemetsen et al 2003), or it could reflect specialization on particular prey items. Link et al (2005) due discuss that some populations of flatfish can become specialist feeders depending on the seasonality and abundance of given prey type. It is noted that during periods of low prey diversity diets will be dominated by a specific species that is abundant, usually amphipods species supplemented by small portions of other prey (Summers, 1980; Andersen et al, 2005; Link et al, 2005).

Diet for salmonids in the Vöð estuary results is in line with that seen by Johnson (1980) and Dempson et al (2002), where anadromous arctic char were observed to feed primarily on invertebrate species. Anadromous brown trout populations often feed on marine crustaceans, and some individual populations will become specialized when prey items become abundant or prominent in the ecosystem (Gronvik & Klemetsen, 1987; Klemetsen et al, 2003). *Gammarus spp.* was the only macrofaunal taxon found in the upper reaches of an estuarine environment in western regions of Iceland (Ingólfsson, 2006). Although no studies of this type have been carried out on the Vöð estuary, it may be assumed that there is a similar invertebrate fauna to Ingolfsson (2006), indicating that overall the limited diet may be a function of limited prey diversity and not specialization by the predators in the system. Depending on the abundance of *Gammarus* spp. in estuarine environments, there is a potential for competition between *P. flesus* and salmonids. The feeding patterns of both *P. flesus* and salmonids means there is high spatial and temporal overlap in resource use.

The relative abundance of prey found in the diet of P. flesus from Hafnarós estuary, based on the Amundesen et al (1996) approach, showed different

characteristics compared to those found in Vöð as there was no single dominant prey item for *P. flesus* or the salmonids. This indicates the potential for a generalist feeding strategy with a broad niche width (Aarnio et al, 1996; Beaumont & Mann, 1984; Link et al 2005; Andersen et al, 2005).

The salmonid population also had a diverse diet, with Actinopterygii, Muscidea and *Limnophilus griseus,* equally represented in the stomachs of individual salmonids sampled. These results show the opportunistic feeding behavior of arctic char within estuarine environments (Johnson 1980; Adams et al 1989; Dempson et al 2002; Klemetsen et al 2003), where arctic char were found to be primarily consumers of invertebrates, but are also known to feed specifically on fish (Gronvik and Klemetsen 1987). Further research is needed to identify the seasonal variation in prey abundance. It can be assumed though, that due the more diverse diets observed here that there should be less resource competition between species in Hafnaros than in Vöð.

The relative abundance of prey found in the diet, when both estuaries are combined, based on the Amundesen et al (1996) approach show that *Gammarus* spp. had the highest abundance of any diet item for both *P. flesus* and salmonids. This is not surprising given the dominance of gammarid amphipods in the diet of all fish from Vöð. The competition for similar prey resources potentially increases the chance of decline of salmonid populations, depending the adaptive feeding ecology of a given population.

The diet of *P. flesus* and salmonids indicates both high spatial and temporal overlap in resource use within certain environments within the Westfjords region.

5.6 Aging structures of *P. flesus*

Only juvenile populations of *P. flesus* were found in freshwater areas sampled near Vöð. Similar to Vöð, only age one fish were found in the freshwater environment of Vatnið. Nash and Geffen, (2005), found that freshwater environments are often associated with juvenile stages of flounder, and offer sanctuary from predation and productive areas for growth.

Vöð estuary populations of *P. flesus* ranged from one to six years of age, with a peak in numbers between age 3 and 4, while fish ranged from age one to five in the Hafnarós estuary with the highest proportion at age four. This overall pattern in age structure is likely caused by a couple of different features. The low number of age one

individuals is likely due to that life stage occurring in freshwater. The low numbers of two year olds could be related to the 2010 weather patterns in Iceland. The weather in the south and western parts of Iceland were the warmest and driest months on record, and snow accumulation during the winter month was described as unusually light (Icelandic Meteorological Office, 2011). These conditions may have influenced the juvenile populations of 2010, contributing to a lower abundance of age 2 fish in 2011. The general lack of larger and older individuals is caused by long-term declines in numbers at age related to fishing or natural mortality (Jenning et al, 2001). Kleinkauf et al (2004) described a similar age structure for *P. flesus* in the United Kingdom, where male P. flesus were found as old six years of age and females up to age nine.

Due to the limited sample size and sampling events in Hafnarós estuary compared to those which took place in the Vöð estuary, caution should be used in making conclusions regarding the otoliths of *P. flesus* sampled from that location but these results do provide insight into the potential age range of *P. flesus* found in Hafnarós in relation to the recent distibution to Icelandic waters. Hornvik had a high proportion of age one individuals, but also had limited sampling. Therefore few conclusions can be made regarding the aging structures of *P. flesus* sampled from this location.

5.7 Future Research

5.7.1 Distribution

Future research regarding the distribution patterns of *P. flesus* in Icelandic coastal waters should examine areas of the north, northwest and east areas of Iceland. Many areas along the coastline of Iceland hold large areas of shallow estuarine and lagoon environments, often associated with freshwater tributaries, which offer optimal habitat for both juvenile and adult flounder life stages (Ingólfsson, 2006). Research on distribution should also examine and identify the off shore winter migration patterns of *P. flesus* to potential spawning areas around Iceland.

5.7.2 Relative Abundance

The need for future research on relative abundance is needed to identify the timing of migration and general ecology of both species of salmonids found in both marine and fresh water habitats of Önundarfjöður; to understand the potential risks associated to

climate changes on Icelandic salmonids populations, helping to fill research gaps on the ecology of salmonids population in Westfjords region of Iceland. This type of research will gain vital information on the status of the overall populations of salmonids in fresh and marine water environments throughout the Westfjords. Highlighting the need for further research on arctic char populations, which have been suggested to be decline in the southern areas Iceland to do climatic change (Gudbergsson, 2011), to provide long-term conservation measures for the species across Iceland.

Future research on relative abundance of *P. Flesus* is needed to estimate population denisty within specific areas and identify the seasonal trends of *P. flesus* in freshwater environments within Iceland; including identifying the months of first migration of new recruits into freshwater, habitat preferences and use by juvenile *P. flesus* in freshwater environments.

5.7.3   Relative importance of prey items

Future research on the diet of *P. flesus* in Icelandic waters should focus on seasonal variability in diet to understand the feeding ecology in both estuarine and coastal waters and the potential for competitive impacts of *P. flesus* on native estuarine fish species in Iceland. Specifically research is needed to understand both anadromous arctic char and brown trout diets found in the Westfjords region due its unique habitats of estuarine and coastal lagoons.

5.7.4   Spatial Niche Overlap & Trophic Niche Overlap

Future research should examine the competition between and population-level impacts of *P.flesus* on Icelandic salmonids, to provide potential mangement and conservation measures to protect Icelandic salmonid populations across the country. This is research is of highest concern and immediate action should be taken in regards to this area of research. Such work would provide valuable information regarding the adaptive strategies of both species to potentially coexist and adapt within a given habitat, and/or provide vital information on the potential long-term impacts of *P. flesus* on salmonid populations within fresh and marine environments across Iceland.

5.7.5 Prey specific abundance in diets

Future research should characterize the prey field available and seasonal variation in the Westfjords region of Iceland and the potential for competition between the *P. flesus* and salmonids within similar estuarine environments to those found in the Vöð estuary. Depending on the abundance of *Gammarus* spp. in estuarine environments, there is a potential for competition between *P. flesus* and salmonids. The feeding patterns of both *P. flesus* and salmonids means there is high spatial and temporal overlap in resource use.

5.7.6 Aging Structure of *P. flesus*

Further research is needed to identify and compare the age distribution of *P. flesus* across Icelandic waters. Helping to provide answers regarding life expectancy in Icelandic waters compared to others areas where *P. flesus* are present.

5.7.7 General Consideration in Research

In general future research is needed to examine the life history traits of *P. flesus*, including growth, maturity, fecundity, and mortality to understand the population dynamics of the species in Icelandic waters and the potential impacts on anadromous populations of salmonids in Iceland. This research will help to provide information to develop potential management stategies that act in favour in the conservation of Icelandic salmonids from the potential threats of *P. flesus* in Icelandic waters.

6 Conclusion

The aim of this study was to determine if *P. flesus* was present in the Westfjords region of Iceland, and if so, characterize the distribution, relative abundance, and spatial and temporal niche overlap with local salmonid populations within the estuarine and freshwater ecosystems of Önundarfjörður and Hornvik, in the Westfjords region of Iceland. With this study I hoped to gain new information regarding the emergence of *P. flesus* in Icelandic waters and its potential impacts to ecosystem dynamics, specifically affecting Icelandic salmonids; contributing to future management considerations regarding the conservation of Icelandic salmonids and the long term effects of *P. flesus* in Icelandic waters

This study identified the presence and described the distribution of *P. flesus* in the Westfjords region of Iceland confirming its presence in four areas of Önundarfjörður, Hornvik areas, Skálmardalsa in Skálmarfjöður and Síki, located in Norðurfjöður. Characterizing the relative abundance of *P. flesus* in both estuarne and freshwater environments in all sampling locations in Önundarfjörður and Hornvik. Further research in highly recommended to understand the overall distributution and relative abundance of *P. flesus* throughout both the coastal waters of Iceland. There was significant spatial and temporal niche overlap between *P. flesus* and Icelandic salmonids in Önundarfjörður, indicatating that the potential for competition among species. Based on the results of this study I recommend further research be done on the spatial and temporal overlap between *P. flesus* and salmonids throughout Iceland's coastal waters, where both species potentially overlap. Further studies should also identify seasonal variations in spatial and temporal overlap between *P. flesus* and salmonids.

Climate change within marine environments is affecting species richness within fish and invertebrates communities and influencing a variety of environmental factors from ocean temperatures, salinity, depth bathymetry and ocean currents (Rose, 2005). The emergence, present distribution and relative abundance of *P. flesus* in Icelandic waters (Cheung et al, 2009; Portner & Peck, 2010; Perry et al, 2005) may be related to these changes. Potential shifts in latitudinal range of species caused by climate change may also cause local extinctions and range expansion of new species which influence the changes in distribution, abundance, survival, reproduction,

population and changes in community-ecosystems, or responses trophic levels within fisheries (Portner & Peck, 2010; Rose, 2005; Perry et al, 2005).

The results of this study suggest that within certain local ecosystems there is present change in community-ecosystem structures and changes within trophic levels as a result of niche overlap and competition between *P. flesus* and local salmonids with the potential to influence changes in the distribution, abundance, reproduction and survival of Icelandic salmonids.

Wrona et al, (2006) suggest that within sub-arctic and arctic estuarine ecosystem there will be a shift in species composition to more euryhaline and anadromous species, potentially causing significant effects to local ecosystems, resulting in competition for food resources with marine species that currently inhabit estuarine ecosystems. This may disrupt the balance of fish populations across the sub-arctic and arctic environments (see also Reist, et al 2006a). Specifically anadromous arctic char species, which occupy and use a variety of habitats including freshwater, estuarine, near shore and marine habitats, have the greatest potential for alterations to local tropic structures (Reist, et al 2006a, Wrona, et al, 2006). Based on the results regarding spatial and temporal niche overlap between *P. flesus* and Icelandic salmonids, conclusions that competition for food and habitat resources on sub-arctic and arctic marine fish populations by other species expanding into their range can be confirmed.

7 Future Management Considerations

Gudbergsson, (2011) saw a decline in arctic char populations in Iceland, between 2001-2007, but notes that populations are currently on the rise except in the rivers of the southwest regions of Iceland. Gudbergsson, (2011) relates these declines in arctic char catch rates to the effects of climate change in Iceland. Gudbergsson, (2011), does not acknowledge that there is still open net fishing by land owners throughout Iceland in both marine and freshwaters environments for arctic char, which may also be a factor effecting local populations, but does suggest land owners should take precautionary steps to avoid depletions of stocks.

Reist et al, (2006b) and Reist & Sawatzky, (2010) suggest that arctic char represent an essential component of the aquatic ecosystems in the arctic, acting as an important indicator species on the general health of ecosystems from a local and global perspective. This study helps to frame the need to monitor and conduct future research on the potential impacts of range expansion of new species into arctic char habitats in Iceland.

In Iceland there has been a general ban on ocean Atlantic salmon fishing since 1932, with an exception of a few areas with coastal fisheries on the west coast of Iceland (Gudbersson 2011). The economic value of recreational salmon fishing in Iceland, generates over 30 million USD both in direct and indirect annual revenue from salmon angling and is a important tourist sector attracting foreign anglers from around the world (FAO 2010). With increasing numbers of recreational fishermen targeting both arctic char and brown trout populations in Iceland (FAO 2010), possibly because of a lower priced fishing license when compared to that required for Atlantic salmon.

The results of this study conclude established populations of *P. flesus* are competing both spatially and temporally with Icelandic salmonids, with many unknown long-term affects of its presence and with the growing concern of climate change in Icelandic waters with the decline of arctic char catch rates in various locations throughout Iceland. Future management considerations should consider the overall ban of net fishing on all salmonids species, specifically arctic char populations that have seen increasing pressure from climate change which are more susceptible than other Icelandic salmonids both brown trout and Atlantic salmon; providing a

precautionary approach to the affects of climate change and steps toward further conservation of salmonids species. This approach may also help to provide long-term benefits by enhancing salmonid populations, diversifying recreational fishing opportunities and provide economic growth in the tourism sector of the economy.

In conclusion climate change will continue to affect the distribution and abundance of Icelandic flora and fauna, therefore future management considerations should take the precautionary approaches needed to limit these effects and help provide conservation and protection for both terrestrial and aquatic species most threatened in Iceland.

References

Aarnio, K., Bonsdorff, E. & Rosenback, N. (1996). Food and feeding habits of juvenile flounder Platichthys flesus (L.), and turbot Scophthalmus maximus L. in the Aaland Archipelago, northern Baltic Sea. *Journal of Sea Research* 36, 311–320.

Able, K.W., Neuman, M.J. & Wennhage, H. (2005). Chapter 8: Ecology of juvenile and adult stages of flatfish: distribution and dynamics of habitat associations. In Gibson, R. N., (Eds.). (2005). *Flatfishes, Biology and Exploration.* Oxford, UK: Blackwell Science Ltd.

Adalsteinsson, H., Gislason, G.M., Gislason, S.R. & Snorrason (2000). Physical and chemical characteristics of glacial rivers in Iceland, with particular reference to the River W-Jokulsa, North Iceland. *Verh. int. Verein. Limnol.* 27: pp. 735-739

Adams, N.J., G. Power & D.R. Barton (1989). Diet and daily ration of anadromous arctic charr in Ungava Bay. *Physiology & Ecology, Japan. Special Issue* 1, 253–264.

Allen, R.L. & Baltz, D.N. (1997). Distribution and microhabitat use by flatfishes in a Louisiana estury. *Environmental Biology of Fishes, 50, 85-103*

Amundesen, P.-A., Gabler, H.-M. & Staldvik, F.J. (1996). A new approach to graphical analysis of feeding strategy from stomach contents data-modification of the Costello (1990) method. *Journal of Fish Biology, 48, 607-614*

Anderson, A.K., Schou, J., & Sparrevohn, C.R., (2005). The quality of release habitat for reared juvenile flounder, Platichthys flesus, with respect to salinity and depth. *Fisheries Management and Ecology 12. 211-219*

Anon., (2004). Hydrographic status report (2003). Report of the working group of oceanic hydrography. *International Council for the Exploration of the Sea*, CM 2004/C:06, 182 p.

Anon, (2006). Environmental conditions in Icelandic waters in 2005. *Hafrannsoknastofnunin Fjolrit*, 125, 34 (In Icelandic, English summary)

Antonsson, Th., Gudbergsson, G. and Gudjonsson, S. (1996). Environmental continuity in fluctuation of fish stocks in the North Atlantic Ocean, with particular reference to Atlantic salmon. *North American Journal of Fisheries Management 16, 540-547*

Astthorson, O.S., Gislason, A., & Jonsson, S. (2007). Climate variability and the Icelandic marine ecosystem. *Deep Sea Research Part II* 54, 2456-2477

Asttorsson, O.S. & Palsson, J. (2006). New fish records and records of rare southern species in Icelandic waters in the warm period 1996-2005. ICES C.M. 2006/C:20, 22.

Bailey, K.M. Nakata, H, and van der Veer, H.W. (2005) Chapter 5. The plankton stages of flatfishes: physical and biological interactions in transport. In Gibson, R. N., (Eds.). (2005). *Flatfishes, Biology and Exploration.* Oxford, UK: Blackwell Science Ltd.

Beaumont, W.R.C & Mann, R.H.K. (1984). The age, growth and diet of freshwater populations of the flounder *Platichthys flesus* (L), in southern England. *Journal of fish Biology 25, 607-616*

Berghahn, R. (1984). *Zeitliche und raumliche Koexistenz ausgewahlter Fisch- und Krebsarten irn Wattenmeer und Berucksichtigung von Rauber-Beute-Beziehungen und Nahrungskonkurrenz*. Thesis, UNV. of Hamburg.

Bjornsson, H., Palsson, O.K. (2004). *Distribution patterns and dynamics of fish stocks under recent climate change in Icelandic waters.* Marine Research Institute, Reykjavik. Retrieved September 14. 2011. From: http://www.ices.dk/products/CMdocs/2004/K/K3004.pdf

Bos, A.R. (1999) Tidal transport of flouder larvae (*Platichthys flesus*) in the Elbe River, Germany. *Archive of Fishery and Marine Research* 47, 47-60

Bos, A.R. (2006). Influence of salinity on the migration of postlarval and juvenile flounder *Pleuronectes flesus L.* in a gradient experiment. *Journal of Fish Biology 68, 1411-1420*

Bos, A. R. (2000). *Aspects of the life history of the European flounder (Pleuronectes flesus L. 1758) in the tidal River Elbe*. PhD Thesis, University of Hamburg. Berlin: Dissertation.de – Verlag im Internet GmbH.

Burke, J.S. (1995). Role of feeding and prey distribution of summer flounder and southern flounder in selection of estuarine nursery habitats. *Journal of Fish Biology 47, 355-366.*

Byers, J. E. (2002). Impact of non-indigenous species on natives enhanced by anthropogenic alteration of selection regimes. *Oikos* 97, 449– 458.

Cargenelli, L.M., Griesbach, S.J., Packer, D.B., Berrien, P.L., Morse W.W. & Johnson, D.L. (1999). Essential fish habitat source document: Witch flounder, *Glyptocephalus cynoglossus,* Life history and habitat characteristics. *United States Department of Commerce, NOAA Technical Memorandum, NMFS-NE-139*

Chapleau, F. (1993). Pleuronectiform relationships: a cladistic reassessment. *Bulletin of Marine Science 52, 516-540*

Cheung, W.W.L., Lam, V.W.Y., Sarmieto, J.L., Kearney, K., Watson, R., & Pauly, D., (2009). Projecting global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries 10. pp. 235-251*

Colwell, R.K., & Futuyma, D.J. (1971). On the measurement of Niche Breadth and Overlap. *Ecology 52, 567-576*

Conway, S.J., Decaulne, A., Balme, M.R., Murray, J.B., & Towner, M.C. (2010) A new approach to estimating hazard posed by debris flows in the Westfjords of Iceland. *Geomorphology* 114. 556-572

Cooney, S. J., Covich, A.P., Lukacs, P.M., Harig, A.L., and Fausch. K.D., (2005). Modeling global warming scenarios in greenback cutthroat trout (*Oncorhynchus clarkii stomias*) streams: implications for species recovery. *Western North American Naturalist 65***,** 371–381

Cooper, J.A., & Chapleau, F. (1998). Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fishery Bulletin 96, 686-726*

Costello, M.J. (1990). Predator feeding strategy and prey importance: a new geographical analysis. *Journal of Fish Biology, 36, 261-263*

Crooks, J. A., and M. E. Soule ́. (1999). Lag times in population explo- sions of invasive species: causes and implications. In O. T. Sandlund et al., editors. *Invasive species and biodiversity management*. Kluwer, New York.

de Groot (1971). On the interrelationships between morphology of the alimentary tract, food and feeding behavior in flatfish (Pisces: Pleuronectiformes). Netherlands Journal of Sea Research 5, 121-196.

de Vlas, J.(1979). The annual food intake by plaice and flounder in a tidal flat area in the Dutch Wadden Sea, with special reference to consumption of regenerating parts of macrobenthic prey. *Netherlands Journal of Sea Research 13, 117-153*

Dres, T., Kadakas, V., Lang, T. & Mellergaard, S. (1999). Geographical variation in the age/length relation in Baltic flounder (*Platichthys flesus). ICES Jounral of Marine Science 56, 134-137*

Donovan, T. M., & Welden. C. (2002). *Spreadsheet exercises in ecology and evolution*. Sinauer Associates, Inc. Sunderland, MA, USA.

Dukes, J.S., & Mooney, H.A. (1999). Does global change increase the success of biological invaders? *Trends in Ecology & Evolution* 14, 135-139

Elliott, S.R.., Coe, T.A., Helfield, J.M. & Naiman, R.J. (1998). Spatial variation in environmental characteristics of Atlantic salmon (*Salmo salar*) rivers. *Canadian Journal of Fisheries and Aquatic Sciences* 55, 267–280.

Eloranta, A.P., Siwertsson, A., Knudsen, R., Amundsen P-A. (2011). Dietary plasticity of Arctic charr (*Salvelinus alpinus*) facilitates coexistence with competitively superior European whitefish (*Coregonus lavaretus).* Ecology of Freshwater Fish 20, 558-568

Eiríksson, Þ., Gallo, C., O´Farrell, D., & Þórisson, B. (2012). Samanburður á dýralífi í Fjarðarhornsá og Skálmardalsá, fyrir og eftir efnistöku. Styrkt af Rannsóknasjóði Vegagerðarinnar. Náttúrustofa Vestfjarða, NV nr. 2-12. in press

Food and Agriculture Organization of the United Nations (FAO) (2010). *National Fishery Sector Overview, The Republic of Iceland. Retrieved*: April 27, 2011. From: ftp://ftp.fao.org/FI/DOCUMENT/fcp/en/FI_CP_IS.pdf

Freitas, V., Costa-Dias, S., Campos, J., Bio, A., Santos, P., & Antunes C. (2009). Patterns in abundace and distribution of juvenile flounder, *Platichthys flesus,* In Minho estuary (NW Iberian Peninsula). *Aquatic Ecology 43, 1143-1153*

Gardarsson, A. 1979: Vistfraedileg flokkun íslenskra vatna [An ecological classification on Icelandic freshwaters]. *Týli* **9**:1-10. [in Icelandic, with an English summary].

Garmin: MapSource (2012). Map of Iceland. 1986-2012 Garmin Ltd.

Garrisson, L.P. & Link, J.S. (2000a). Dietary guild structure of fish community in the northeast United States continental shelf ecosystem. *Marine Ecology Progress Series,* 202, 231-240

Garrisson, L.P. & Link, J.S. (2000b). Fishing effects on spatial distribution and trophic guild structure in the Georges Bank fish community. *ICES Jounral of Marine Sciences, 57, 723-730*

George, E.L. & Hadley, W.F. (1979). Food and habitat partitioning between rock bass (*Ambloplites rupestris)* and smallmouth bass (*Micropterus dolomieui*) young of the year. *Trans American Fish Society 108, 253-261.*

Gibson, R.N. (2005). Chapter 1:The fascination of flatfishes. In Gibson, R. N., (Eds.). (2005). *Flatfishes, Biology and Exploration.* Oxford, UK: Blackwell Science Ltd.

Gibson, R.N. (1994). Impact of habitat quality and quantity on the reqruitment of juvenile flatfishes. *Netherlands Journal of Sea Research 32, 191-206.*

Gibson, R. N., (Eds.). (2005). *Flatfishes, Biology and Exploration.* Oxford, UK: Blackwell Science Ltd.

Graham, C.T. & Harrod, C. (2009). Implications of climate change for the fishes of the British Isles. *Journal of Fish Biology* 74, 1143–1205

Gronkjær, P, Carl, J.D., Rasmussen, T.H., Hansen, K.W. (2007). Effect o habitat

shifts on the feeding behaviour and growth of 0 year-group flounder *Platichthys flesus* (L.) transferred between macroalgea and bare sand habitat. *Journal of Fish Biology* 70, 1587-1605.

Gronvik, S., & Klemetsen, A. (1987). Marine and diet overlap of co-occurring arctic charr *Salvelinus alpinus* (L.), brown trout *Salmo trutta L.* and atlantic salmon *S. salar* L. off Senja, N. Norway. *Polar Biology 7, 173-177.*

Gudbrandsson, G.I., Jonsson, B, Elfarsdottir, E., & Bjarnason, K. (2005) *Áhrif brúa- og ræsagerðar á ferðir ferskvatnsfiska og búsvæði þeirra.* Veiðimálastofnun Norðurlandsdeild [in Icelandic, with an English Summary].

Gudbergsson, G. (2011). *Catch statistics for Iceland rivers and lakes 2010.* Institute of Freshwater, Keldnaholt, 112 Reykjavik.

Hermmer-Hanson, J. Nielsen E.E., Gronkjaer, P & Loeschcke, V. (2007). Evolutionary mechanisms shaping the genetic population structure of marine fishes; lesions from the European flounder (*Platichthys flesus L.*)

Hellawell, J.M. & Abel, R. (1971). A rapid volumetric method for the analysis of the food of fishes. *Journal of Fish Biology 3, 29-37.*

Hofstede, R.T., Hiddink, J.G. & Dijnsdorp, A.D. (2010). Regional warming changes fish species richness in the eastern North Atlantic Ocean. *Marine Ecology Progress Series 414, 1-9*

Hylland, K., Sandvik, M., Utne Skare, J., Beyer, J., Egaas, E., & Goksoyr, A. (1996). Biomarkers in flounder (*platichthys flesus*): an evaluation of their use in pollution monitoring.

Hyslop, E.J. (1980). Stomach content analysis-a review of methods and their application. *Journal of Fish Biology 19, 36-58*

Icelandic Fisheries (2011). Diadromous Fish. Retreived: April 28, 2011. From: http://www.fisheries.is/main-species/diadromous-fish/

Icelandic Meteorological Office (2011). The weather of 2010 in Iceland, climate summary. Retrieved: September 25, 2011. From: http://en.vedur.is/about-imo/news/2011/nr/2112

Ingólfsson, A. (2006). The intertidal seashore of Iceland and its animal communities. Volume I, Part 7. In Jónasson P.M., Ottósson, J.G., & Gíslason G.M., (Eds). (2006). The zoology of Iceland. Steenstrupia, Zoological Museum, University of Copenhagen.

Jager, Z., (1998). Accumulation of flounder larvae (*Platichthys flesus* L.) in the Dollard (Emms estuary, Wadden Sea). *Journal of Sea Research* 40, 43–58.

Ja.is (2011). Map of Iceland. Retrieved December 29, 2011. From: http://en.ja.is/kort/#x=312675&y=612977&z=2

Jennings, S., Kaiser, M.J. & Reynolds, J.D. (2001) *Marine Fisheries Ecology.* Blackwell Publishing. 350 Main street, Malden, MA. USA

Jonsson, G., Palsson, J., & Johannsson, M. 2001. First record of flounder, *Platichthys flesus*, (Linnaeus, 1758) at Iceland (In Icelandic, English summary). Natturufraedingurinn, 70, 83-89.

Jonsson, I.R. Antonsson T. (2005). Emigration of age-1 Arctic charr, *Salvelinus alpinus* into a brackish lagoon. *Environmental Biology of Fishes* 74, 195-200.

Jonsson, S. (2011). Waves and Tides. Icelandic Fisheries. Retrieved July 23, 2011. From: http://www.fisheries.is/ecosystem/oceanography/waves-and-tides/

Jóhannsson, M., & Jónsson, B., (2008). Flundra í íslenskum vatnakerfum. *Unpublished Document, Institute of Freshwater Fisheries, Iceland.*

Kerstan, M., (1991). The importance of rivers as nursery grounds for 0- and 1-group flounder (*Platichthys flesus* L.) in comparison to the Wadden Sea. *Netherlands Journal of Sea Research* 27, 353–366

Kleinkauf, A., Conner, L., Swarbreck, D., Levene, C., Walker, P., Johnson, P.J. and Leah, R.T., (2004). General condition biomarkers in relation to contaminant burden in European flounder (*Platichthus flesus). Ecotoxicology and Environmental Safety* 58, 335-355

Klemetsen, A., Amundsen, P.A., Dempson, J.B., Josson, B., Jonsson, N., O'Connell, M.F., & Mortensen, E. (2003). Atlantic salmon *Salmo salar* L., brown trout *Salmo trutta* L. and Arctic charr *Salvelinus alpinus* (L.): a review of aspects of their life histories. *Ecology of Freshwater Fish 12, 1-59*

Krebs, C.J. (1999). *Ecological Methodology*, 2nd Edition. Addison-Wesley, New York

Larsen, P.F., Nielsen, E.E., Williams, T.D., Hemmer-Hanson, J., Chipman, J.K., Kruhoffer, M., Gronkjaer, P., George, G.S., Dyrskjots, L., & Loeschcke, V. (2007). Adaptive differences in gene expression in European flounder (*Platichys flesus).* Molecular Ecology 16, 4674-4683

Lassalle, G., & Rochard, E. (2009). Impact of twenty-first century climate change on diadromous fish spread over Europe, North Africa and the Middle East. *Global Chane Biology 15, 1072-1089.*

Lehtonen, H. (1996). Potential effects of global warming on northern European freshwater fish and fisheries. *Fisheries Management and Ecology* 3, 59–71.

Levings, C.D. Hvidsten N.A., & Johnsen, B.O. (1994). Feeding of Atlantic salmon (*Salmo salar* L.) postsmolts in a fjord in central Norway. Canadian Journal of Zoology 72, 834-839

Link, J.S., Bolles, K., & Milliken, C.G. (2002). Feeding ecology of flatfish in the Northwest Atlantic. *Journal of Northwest Atlantic Fishery Science 30, 1-17*

Link, J.S., Fogarty, M.J., & Langton, R.W. (2005). Chapter 9: The trophic ecology of flatfishes. In Gibson, R. N., (Eds.). (2005). *Flatfishes, Biology and Exploration.* Oxford, UK: Blackwell Science Ltd.

Litzow, M.A., (2006). Climate regime shifts and community reorganization in the Gulf of Alaska: how do recent shifts compare with 1976/1977. *ICES Journal of Marine Science* 63, 1386-1396

MacArthur, R. and R. Levins. (1967). The limiting similarity, convergence, and divergence of coexisting species. *American Naturalist 101. 377-385.*

MacArthur R.H., Levins R (1964) Competition, habitat selection, and character displacement in a patchy environment. *National Academy of Science of the United States of America* 51, 1207–1210

MacCrimmon, H.R. & Gots, B.L. (1979). World distribution of Atlantic salmon, *Salmo salar. Journal of the Fisheries Research Board of Canada* 36, 422–457.

Magnuson, J. J., Webster, K.E., Assel, R.A., Bowser, C.J. Dillon, P.J., Eaton, J.G., Evans, H.E., Fee, E.J., Hall, R.I., Mortsch, L.R., Schindler, D.W., & Guinn, F.H. (1997). Potential effects of climate changes on aquatic ecosystems: Laurentian Great Lakes and Precambrian Shield region. *Hydrological Processes* 11, 825–871.

McConnaughey, R.A. & Smith, K.R. (2000). Associations between flatfish abundance and surficial sediments in the eastern Bering Sea. *Candian Journal of Fisheries and Aquatic Services 57, 2410-2419*

Mills, M.D., Rader, R.B., & Belk, M.C. (2004). Complex interactions between native and invasive fish: the simultaneous effects of multiple negative interactions. *Oecologia* 141, 713-721

Morgan, G.E. & Snucins, E. (2005). *Manual of Instuctions and Provincial Biodiversity*
    Benchmark Values, NORIC Index Netting. Ontario Ministry of Natural Resources. Queens Printer for Ontario.

Munroe, T.A. (2005a). Chapter 3: Distributions and biogeography. In Gibson, R. N., (Eds.). (2005). *Flatfishes, Biology and Exploration.* Oxford, UK: Blackwell Science Ltd.

Munroe, T.A. (2005b). Chapter 2: Systematic diversity of pleuronectiformes. In Gibson, R. N., (Eds.). (2005). *Flatfishes, Biology and Exploration.* Oxford, UK: Blackwell Science Ltd.

Nash, R.D.M & Geffen, A.J. (2005). Chapter 7: Age and growth. In Gibson, R. N., (Eds.). (2005). *Flatfishes, Biology and Exploration.* Oxford, UK: Blackwell Science Ltd.

Nilsson, N.A. 1965. Food segregation between salmonid species in North Sweden. *Report of the Institute of Fresh- water Research, Drottningholm* 2: 58–78.

Nissling, A., Westin, L., & Hjerne, O. (2002). Reproductive success in relation to salinity for three flatfish species, dab (*Limanda limanda*), plaice (*Pleuronectus platessa*), and flounder (*Pleuronectes flesus*), in the brackish water Baltic sea. *ICES Journal of Marine Science 59, 93-108.*

Occhipinti-Ambrogi, A. (2007). Global change and marine communities: Alien species and climate change. *Marine Pollution Bulletin 55, 342-352*

Ólafsson, J., Gíslason, G.M., & Aðalsteinsson, H. (2002). Icelandic running waters; anthropological impact and their ecological status. *TemaNord 2002: 566: pp.86-88.*

Parmesan, C., & Yohe, G., (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421, 37-42

Pemberton, R. (1976). Sea trout in North Argyll sea lochs: II. diet. *Journal of Fish Biology* 9, 195–208.

Percy, W.G. & Handcock, D. (1978). Feeding habitats of Dover sole, *Microstomus pacificus;* rex sole *Glyptocephalus zachirus;* slender sole*, Lyopsetta exilis;* and Pacific sanddab, *Citharichthys sordidus,* in a region of diverse sediment and bathymetry off Oregon. *Fishery Bulletin 76, 641-651*

Periera, J.J., Goldberg, R., Zikowski, J.J., Berrien, P.L., Morese, W.W. & Johnson, D.L. (1999). Essential fish habitat source document: Winter flounder, *Pseudopleuronectes americanus*, life history and habitat characteristics. *United States Department of Commerce NOAA Technical Memorandum, NMFS-NE-138*

Perry, A.L., Low, P.J. & Reynolds, J.D. (2005). Climate Change and Distribution Shifts in Marine Fishes. *Science 308.* pp. 1912-1915.

Pianka, E. R. (1973) The structure of lizard communities. Annual. Review of . Ecology and Systematics 4, 53–74.

Pianka, E.R. (1974). Niche Overlap and Diffuse Competition. *Proceeding of the National Academy of Science of the United States of America* 71, 2141-2145

Piet, G.J., Pfisterer, A.B. & Rijnsdop, A.D. (1998). On factors structuring the flatfish assemblage in the southern North Sea. *Journal of Sea Research 40, 143-152.*

Phelan, B.A., Manderson, J.P., Stoner, A.W. & Bejda, A.J. (2001). Size-related shifts in the habitat associations of young –of-the-year winter flounder (*Pseudopleuronectes americanus);* field observations and laboratory experiments with sediments and prey. *Journal of Experimental Marine Biology and Ecology, 257, 297-315*

Portner, H.O., & Peck, M.A. (2010). Climate change effect on fishes and fisheries: towards a cause-and-effect understanding. *Journal of Fish Biology 77, 1745-1779*

Philippart, C.J.M., Anadon, R., Danovaro, R., Dippner, J.W., Drinkwater, K.F., Oguz, T., O'Sullivan, G., & Reid, P.C. (2011). Impacts of climate change on European marine ecosystems: Observations, expectations and indicators. *Journal of Experimental Marine Biology and Scology 400, 52-69*

Rahel, F.J., & Olden, J.D. (2008). Assesing the effects of climate change on aquatic invasive species. *Conservation Biology 22, 521-533*

Reeves, G.H., Everest, F.H. & Hall, J.D. (1987). Interactions between the Redside Shiner (*Richardsonius balteatus)* and the Steelhead Trout (*Salmo gairdneri)* in Western Oregon: The Influence of Water Temperatures. *Canadian Journal of Fisheries and Aquatic Sciences 44, 1603-1613*

Rijnsdorp, A.D. & Witthames P.R. (2005). Chapter 4: Ecology of Reproduction. In Gibson, R. N., (Eds.). (2005). *Flatfishes, Biology and Exploration.* Oxford, UK: Blackwell Science Ltd.

Rikardsen, A. H., Haugland, M., Bjørn, P. A., Finstad, B., Knudsen, R., Dempson, B., Holst, J. C., Hvidsten, N. A. & Holm, M. (2004). Geographical differences in marine feeding of Atlantic salmon post-smolts in Norwegian fjords. *Journal of Fish Biology* 64, 1655–1679

Rikardsen A.H., & Amundsen, P.-A (2005). Pelagic marine feeding of Arctic charr and sea trout. *Journal of Fish Biology* 66, 1163-1166

Robitaille, J.A., Cote, Y., Shooner, G., and Hayeur, G. (1984). Croissance estuarienne du saumon atlantique (Salmo salar) dans le fleuve Koksoak, en Ungava. [Estuarine growth of Atlantic Salmon (Salmo salar) in the Koksoak River, in Ungava. *Canadian Technical Report of Fisheries and Aquatic Science* 1314

Robitaille, J.A., Cote, Y., Shooner, G., and Hayeur, G. 1986. Growth and maturation patterns of Atlantic salmon (Salmo salar) in the Koksoak River, Ungava, Quebec. *Canadian Special Publication of Fisheries and Aquatic Science* 89. pp. 62-69

Roessig, J.M., Woodley, C.M., Cech, Jr., J.J., & Hansen, L.J. (2004). Effects of global climate change on marine and estuarine fishes and fisheries. *Reviews in Fish Biology and Fisheries* 14, 251

Rose, G.A. (2005). On distributional responses of north Atlantic fish to climate change. *ICES, Journal of Marine Science 62, 1360-1374*

Reist, J.D., Wrona, F.J., Prowse, T.D., Power, M., Dempson, J.B., Beamish, R.J., King, J.R., Carmichael, T.J., & (2006a). General Effects of Climate Change on Arctic Fishes and Fish Populations. *Ambio 35 (7).* pp. 370-380

Reist, J.D., Wrona, F.J., Prowse, T.D., Power, M., Dempson, J.B., King, J.R. & Beamish, R.J.,(2006b). An overview of effects of climate change on selected Arctic freshwater and anadromous fishes *Ambio 35 (7).* pp. 381-387.

Reist J.D., & Sawatzky C.D. (2010). Arctic Char. *Arctic Biodiversity Trends 2010.* Retrieved: May 10, 2011.From: http://www.arcticbiodiversity.is/index.php/en/species/arctic-char

Sarafanov, A. (2009). On the effect of the North Atlantic Oscillation on temperature and salinity of the subpolar North Atlantic intermediate and deep water. *ICES Journal of Marine Sciences, 66. 1448-1454*

Scabell, J. (1988) *Der Ruegensche Frühjahrshering. das Laichgeschehen. Inaugural*, Dissertation, Universität Rostock, August 1988:1-177.

Scarnecchia, D.L. 1984. Climatic and oceanic variations affecting yield of Icelandic stocks of Atlantic salmon. *Canadian Journal of Fisheries and Aquatic Science 41, 917-935*

Sims, D.W., Wearmouth, V.J., Genner, M.J., Southward, A.J., & Hawkins S.J. (2004). Low-temperature-driven early spawning migration of temperate marine fish. *Journal of Animal Ecology 73*, 333-341

Skerritt, D.J. (2010). A review of he European flounder *Platichthys flesus* – biology, life history and trends in population. NewCastle University. Retrieved from http://www.esfjc.co.uk/Flounder%20literature%20review.pdf

Strathmann, R. (1974). The spread of sibling larvae of sedentary marine invertrates. *American Naturalist* 108, 29-44.

Schoener, T.W. (1974). Nonsynchronous spatial overlap of lizards in patchy habitats. *Ecology* 51, 408-418

Schoener, T.W. (1974). Resource partitioning in ecological communities. *Science, New series* 185. 27-39

Stefansdottir, L., Solmundsson, J., Marteinsdottir, G., Kristinsson, K., & Jonasson, J.P. (2010). Groundfish species diversity and assemblage structure in Icelandic waters during recent years of warming. Fisheries Oceanography 19 (1). 42-62

Summers, R.W., (1979) Life cycle and population ecology of the flounder *Platichthys flesus* (L) in the Ythan estuary, Scotland. *Journal of Natural History 13*, 703-723

Summers, R.W. (1980). The diet and feeding behaviour of the flounder Platichthys flesus (L.) in the Ythan estuary, Aberdeenshire, Scotland. *Estuarine and Coastal Shelf Science 11, 217-232*

Valdimarsson, H., Malmberg, S.A., 1999. Near-surface circula- tion in Icelandic waters derived from satellite tracked drifters. *Rit Fiskideildar* 16, 23–39.

Vilhjalmsson, H., 2002. Capelin (*Mallotus villosus*) in the Iceland–East Greenland–Jan Mayen ecosystem. *ICES Journal of Marine Science* 59, 870–883.

van der Veer, H.W., Bergman, M.J.N., Dapper, R., & Witte, J.IJ. (1991). Population dynamics of an intertidal 0-group flounder *Platichthys flesus* population in the western Dutch Wadden Sea. *Marine Ecology Progress Series 73*, 141-148

Vinagre, C., Franca, S., Costa, M.J., Cabral, H.N. (2005). Niche overlap between juvenile flatfish*, Platichthys flesus* and *Solea solea*, in a southern European estuary and adjacent coastal waters. *Journal of Applied Ichthyology 21, 114-120*

Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, G., Beebee, T.J.C., Fromentin, J.M., Hoegh-Guldberg, O., & Bairlein, F. (2002). Ecological r esponses to recent climate change. *Nature 416, 389-395*

Winfield, I.J., Fletcher, J.M. & James, J.B. (2010). An overview of fish species introductions to the English Lake District, UK, an area of outstanding conservation and fisheries importance. *Journal of Applied Ichthyology* 26, 60–65.

Wheeler, A.W. (1969). *The fishes of British Isles and North West Europe*. Macmillan, London.

Wrona, F.J., Prowse, T.D., Reist, J.D., Hobbie, J.E., Levesque, L.M.J., & Vicent W.F. (2006). Climate change effects on aquatic biota, ecosystem structure and function. *Ambio 35 (7). 359-369*