Spatial and Temporal Trends of Fifteen Noncommercial fin-fish species in Iceland between 1985 and 2009

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30 ECTS thesis submitted in partial fulfillment of a Master of Resource Management degree in Coastal and Marine Management at the University Centre of the Westfjords, Suðurgata 12, 400 Ísafjörður, Iceland

Degree accredited by the University of Akureyri, Faculty of Business and Science, Borgir, 600 Akureyri, Iceland

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Printing: University Centre of the Westfjords and H-Prent, Ísafjörður, June 2010
Declaration

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

__________________________________________
Jacob Matthew Cheatham Kasper
Master's thesis

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February 15, 2010

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ABSTRACT

A decline in the world fish stocks has been documented through scientific studies during the last 30 years. In recent years, fisheries managers have acknowledged that single-species management approaches ignore the greater ecosystem context. In response, a shift from a single-species management to ecosystem-based management is occurring. True ecosystem-based management approaches must consider all aspects of the ecosystem including non-commercial species. This study uses the data collected from 25 years of scientific trawl surveys to analyze the trends in non-commercial fin-fish species, which serve as an ecosystem indicator. In this dataset between 508 and 600 stations are surveyed each year (mean 558 stations per year) are sampled. At each station a 4.0 nautical mile trawl is conducted and fish are counted and identified to species level. Species were selected based on the following criteria: they must not have any commercial value in Iceland (therefore never kept), they must have been captured in more than 1% of the surveys, and they must always be identified to species level. Fifteen species fit the above criteria and were selected for analysis. Three species (*Leptagonus decagonus* [Bloch & Schneider], *Myxocephalus scorpius* [Linnaeus], and *Cottunculus microps* [Collett]) show a decreasing trend in population size while four species show increasing populations (*Trisopterus esmarkii* [Nilsson], *Rhinonemus cimbrius* [Linnaeus], *Gaidropsarus argentatus* [Reinhardt], and *Chelidinichthys gurnardus* [Linnaeus]). Additionally, the geographic center of eight species changed during time period studied. Three species shifted south (*Triglops murrayi* [Günther], *Artediellus atlanticus* [Jordan and Evermann], and *C. microps*), three species moved north (*T. esmarkii*, *R. cimbrius*, *Rajella fyllae* [Lütken]), three species migrated west (*T. esmarkii*, *Boreogadus saida* [Lepechin], and *C. gurardus*), and one species migrated east (*C. microps*). As would be expected with current warming water temperatures in Iceland, warm water species tended to increase in population (three out of four) and migrated north and west. None of the warm water species’ populations decreased. All species with decreasing populations were cold water species. Interestingly, two cold water species showed a positive trend in abundance and three cold water species had a southern component to their shift in distribution. These last results suggest that the role in changing ecosystem regimes and subtle temperature shifts can influence these species. The population and spatial trends of the species studied are of particular interest because the changes in these species are not confounded by the effects of harvest. The results can be used to better understand the effects of climate change on commercial fish species which occupy similar niches as the fish in the present study.
ACKNOWLEDGMENTS

First, I would like to thank the Marine Research Institute of Iceland (Hafrannsóknastofnunin) for sharing its tremendous database, which was the basis for the current investigation. Second, thanks to my advisor Mr. Höskuldur Björnsson from the Marine Research Institute in Iceland. Mr. Björnsson provided clear guidance and programming support. Third, Dr. Ólafur Arnar Ingólfsson helped with programming and data analysis. Finally, Mr. Hjalti Karlsson was instrumental in helping me understand the trawl survey process.
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INTRODUCTION

In response to overfishing and increased knowledge of ecosystem function, fisheries management is shifting from single-species management to ecosystem-based management. This is an important and essential step in order to ensure healthy oceans for the future. Unfortunately, largely due to lack of time, fisheries managers rarely monitor non-commercial species, yet these species often play important ecological roles. In order to better understand the health of the Icelandic large marine ecosystem, non-commercial fin-fish species will be analyzed in the region. Data collected by the Iceland annual spring over a 25 year period was used in this investigation. Non-commercial species can serve as an indicator for ecosystem health and to understand the impacts of climate change and other non-fishing anthropogenic forces. Fifteen species were selected for use in the current study. The abundance, populations’ geographic center, mean bottom temperature and mean depth were all analyzed.
THEORETICAL OVERVIEW

State of World’s Fish Stocks

Scientific studies have documented a decline in the world’s fish stocks during the last 30 years (Hilborn, 2003; Hutchings & Reynolds, 2004; Myers & Worm, 2003; Pauly, et al., 2003; Worm, et al., 2006; Worm, et al., 2009). These papers documented the rapid decline in the world’s fish since World War II and project a collapse in world fish stock unless current practices are curtailed. Myers found that industrialized fisheries reduce community biomass by 80% in a 15 year period (Myers & Worm, 2003). This study also estimated that the large predatory fish biomass has decreased by 90% since pre-industrialized fishing times. Hilborn, did not paint as bleak a picture, but still reported that many stocks are over fished and most others are heading towards depletion (Hilborn, 2003). One of the most widely cited studies claims that by 2048 all currently fished marine taxa will collapse (Worm, et al., 2006). Pauly et al. believe that present trends will lead to an expansion of deep water fisheries, declining global catches and impact biodiversity (2003).

Hutchings’ study of over 230 fish populations found a median reduction of 83% from known historic breeding population sizes (Hutchings & Reynolds, 2004). Fortunately, not all of the news from fisheries scientists is “gloom and doom” (Worm, et al., 2009). Five out of 10 well-studied ecosystems have shown that the average exploitation rate declined and is now at or below maximum sustainable yield, however, 63% of assessed fish stocks still require rebuilding (Worm, et al., 2009).

Fisheries management has been used in various forms world wide for hundreds of years. Since the end of World War II, fisheries management has drawn on scientific estimates of fish stocks to a set maximum sustainable yield (MSY) of a particular species. MSY is the largest catch, of a single species, that can be continuously taken over the long-term without causing the population to collapse under existing environmental conditions MSY is a single-species approach with a fundamental flaw: it ignores ecosystem interactions in which the target species live. Ecosystem
interactions are complicated, as shown in the simplified food web for the northwest Atlantic Ocean (Figure 1). Another problem with single-species management is that it ignores bycatch and discards, both issues in nearly all fisheries. Bycatch is the term used to describe non-target species which are retained; while discards are non-target species which are thrown away, usually dead. Discards occur because they are illegal to keep or have little or no commercial value.

**Ecosystem-Based Management**

In response to declining fish stocks, fisheries management is changing from managing single species to ecosystem-based approaches. As early as the 1992 United Nations Convention on Biological Diversity (UNCBD), ecosystem-based management goals were discussed and encouraged: “management… to meet human requirements to use natural resources, whilst maintaining the biological richness and ecological processes necessary to sustain the composition, structure and function of the…ecosystems.” Acknowledging that species are part of an ecosystem and that no fishery is free of bycatch is an essential step to successful fisheries management. Ecosystem-based approaches must consider basic aspects of ecosystem health, namely structure, function and resilience (Costanza & Mageau, 1999). Fisheries managers must join efforts with ecosystem managers to successfully meet the goals outlined above by the UNCB (Garcia, Zerbi, Aliaume, Do Chi, & Lasserre, 2003). An ecosystem is defined by the interaction of a number of parts, therefore all parts must be considered in the maintenance or reestablishment of a healthy ecosystem. While regional fisheries and even whole countries are adopting management schemes that attempt to consider the ecosystem as a whole, non-commercial fish species are usually ignored in management plans and ecosystem evaluations.

Ecosystem-based management goals take a broader approach than single-species management.

Ecosystem-based management is an integrated approach to management that considers the entire ecosystem, including humans. The goal of ecosystem-based management is to maintain an ecosystem in a healthy, productive and resilient condition so that it can
provide the services humans want and need. Ecosystem-based management differs from current approaches that usually focus on a single species, sector, activity or concern; it considers the cumulative impacts of different sectors. (McLeod, 2005)

The Reykjavík Conference on Responsible Fisheries in the Marine Ecosystem was signed in 2001. The conference, hosted by Iceland, Norway and the UN Food and Agriculture Organization (FAO), was attended by FAO and UN member states. Among other accomplishments, the conference recommended that countries advance scientific knowledge of ecosystem considerations. The 2002 World Summit on Sustainable Development (WSSD) implementation guidelines follow the Reykjavík Conference and require the implementation of ecosystem-based approach by 2012. This requirement includes the elimination of destructive fishing practices, the establishment of marine protected areas, the adoption of coastal land-use planning and the integration of economic factors into marine and coastal management. A major ecosystem considerations is how scientists will determine the key limits of a system (Frid, Paramor, & Scott, 2005).

One possible answer is to look at non-traditional ecosystem indicators. As previously stated, fisheries management has traditionally focused on single stock assessments of single species. Furthermore, this management has dealt with provisioning services (yield, revenues, and employment) and not with ecosystem services (Garcia & Cochrane, 2005). A more novel approach would be to investigate other species which could serve as proxies for ecosystem indicators. Ecosystems are influenced by fishing in several ways: (1) the effects of the removal of target species; (2) direct changes in the size and structure of target populations; (3) alterations in non-target populations of fish and benthos (Camphuysen, 1995; Garcia & Cochrane, 2005; Tuck, Hall, Robertson, Armstrong, & Basford, 1998); (4) alterations in the physical environment (Auster, 1995; Churchill, 1989); and (5) food chain effects such as tropic cascades and altering predation pressure (Frid, Hansson, Ragnarsson, Rijnsdorp, & Steingrimsson, 1999). Since killing non-target species is wasteful and ecosystem alterations should be avoided as per the ecosystem-based management philosophy, effects three to five must be minimized (Frid, et al., 2005).
There are numerous examples of fishing pressure on one species affecting the greater ecosystem balance. One example was the removal of baleen whales from the southern ocean which resulted in the release and reallocation of krill to seals, seabirds and squid (Dayton, Thrush, Agardy, & Hofman, 1995). Another was the removal of sea otters on the California coast resulting in the increase of the abalone population and the destruction of kelp forests (Reisewitz, Estes, & Simenstad, 2006). Finally, the establishment of a marine protected area in Chile resulted in the reintroduction of large predators and an alteration of the intertidal community (Moreno, 1986).

The term “non-commercial species” has traditionally been used by fisheries managers and scientists to refer to marine mammals, reptiles and birds that are caught as bycatch. While much research has been focused on methods to reduce the bycatch of these charismatic animals, little attention has focused on non-commercial fin-fish species. Non-commercial species fall into two categories: those which are caught and discarded and those which are never caught at all. There are many species of fish which are never caught in fisheries because their body shapes or sizes allow them to penetrate the nets of commercial trawls. The species which do not turn up in commercial trawls are often overlooked in scientific literature. Although these species are not commercial or bycatch species, they play an ecosystem role; the mortality of non-target species can have ecosystem-wide effects (Witherell, Pautzke, & Fluharty, 2000). Additionally these species can be used as indicators of ecosystem health and serve as proxies for understanding the non-fishing pressures on commercial species which occupy a similar environmental niche.

Studying non-commercial species which are not caught as bycatch is difficult, thus there are relatively few studies of these species (Bailey, Collins, Gordon, Zuur, & Priede, 2009). Yet, scientific trawl databases often contain a wealth of information on these species (Nye, Link, Hare, & Overholtz, 2009). Some scientific trawl surveys are carried out with smaller mesh sizes than those that are typically used in commercial fisheries. Small mesh sizes are used in surveys in order to
accurately sample juvenile fish from the main target species, thus the smaller or oddly shaped non-commercial species are also sampled in the surveys.

**Climate Change and Species Dynamics**

Anthropogenic pressures on fish ecology are not limited to population interactions. In recent years, the effects of warming ocean water temperature on fish populations has become the focus of an increasing amount of research. It is well documented that sea temperatures are rising globally (Knutson, et al., 2006; Levitus, Antonov, Boyer, & Stephens, 2000; Lozier, et al., 2008) and that this trend is likely to continue (Solomon, Plattner, Knutti, & Friedlingstein, 2009). In Iceland a 0.86°C increase in sea surface temperature of the Iceland large marine ecosystem was documented between the years 1982 and 2006 (Belkin, 2009). These changes are likely to impact the nature and value of commercial fisheries and species-specific responses will vary (Perry, Low, Ellis, & Reynolds, 2005). An organism’s initial response to climate change is characterized by redistribution (Frank, 1990; McCarty, 2001; Shuter, 1990). In the case of marine species this is characterized by a change in the center of biomass, an expansion or contraction of the range or a change in depth distribution (Nye, et al., 2009). These responses have been documented in the North Sea (Perry, et al., 2005) and the Bearing Sea (Mueter & Litzow, 2008). It is expected that marine fish populations will respond to warming water bodies with a poleward shift in the geographic center of the species and an increase in the mean depth of the species (Nye, et al., 2009; Parmesan & Yohe, 2003). Thus, in the case of the North Atlantic Ocean, a shift north is expected (Brander & H., 2003) and has been recently observed (Nye, et al., 2009; Perry, et al., 2005). In the case of island biogeography, such as Iceland, the expectation of a poleward shift needs to be modified to consider the unusual currents around the island. Scientific trawl surveys provide a unique data set to examine the effects of temperature shifts on species as these surveys record pertinent environmental information.

Since the start of the survey, mean bottom temperatures have increased in Iceland (Figure 2). This observation is based on survey data and is supported by other independent studies. The large
marine ecosystem (which essentially encompasses Iceland and its exclusive economic zone) increased in average sea surface temperature by 0.86°C between 1982 and 2006 (Belkin, 2009). Additionally, a 2°C increase in mean temperature was observed in the Flatey, Breiðafjörður area (Jonasson, Thorarinsdottir, Eiriksson, Solmundsson, & Marteinsdottir, 2007). A third report, shows that the sea temperatures are increasing much faster in the southwest than in the north or northeast (Sigurjónsson, 2008). One data set even shows a temperature decrease in the northeast (Figure 3). This might explain why two species in the northeast migrated south.

**Review of Scientific Trawl Studies**

Many regions of the world use scientific bottom trawls to monitor fish stocks. While there is a wealth of information stored in scientific trawls databases, few studies have used these databases to investigate non-commercial fish species. Many studies use scientific survey data to assess fish population health, and a few of these studies mention non-commercial species (Bailey, et al., 2009; Brind'Amour, Rouyer, & Martin, 2009; Casini, Cardinale, Hjelm, & Vitale, 2005; Gomes, 1995; Greenwood, Hill, & McLusky, 2002; Haedrich & Barnes, 1997; Heessen & Daan, 1996; Poulard & Blanchard, 2005; van Leeuwen, 1994).

Recently Brind'Amour et al. argued that in order for ecosystem-based management to succeed, the information from scientific trawls must be used to investigate the trends of non-commercial species (2009). This paper used data collected in the Bay of Biscay, between 2000 and 2005, in the International Beam Trawl Surveys. The authors found that when non-commercial species were included in the analysis of the ecosystem, a more accurate description of energy flux between the benthic and water column components of the ecosystem was obtained.

A second study, in the Bay of Biscay, used a different dataset to monitor the effects of climate change on community structure (Poulard & Blanchard, 2005). This paper used autumn groundfish surveys, conducted between 1987 and 2002. The authors’ required that species had to be present in at least 5% of the 1,279 hauls in order to be considered for subsequent analysis. Results
indicated that fish species with a wide distribution range in latitude increased in abundance, while species with a narrow latitude range decreased in abundance.

A third study used data collected between 1970 and 1993 by the International Bottom Trawl Survey (IBTS) in the North Sea (Heessen & Daan, 1996). This study investigated the changes in size composition, distribution and abundance of 10 non-commercial fish species. The majority of the species studied increased in abundance during the survey period, yet the authors were unable to attribute these trends to any specific factor.

A fourth study using the IBTS, investigated the trends in catch per unit effort (CPUE) of 32 demersal fish species in the Kattegat and Skagerrak areas of the North Sea (Casini, et al., 2005). Casini et al. used linear trends to model the fish populations, yet this is likely a flawed approach as fish populations tend to be cyclical in nature (Bailey, Ruhl, & Smith, 2006; Carson, Granger, Jackson, & Schlenker, 2009). The Casini et al. study observed no decrease in CPUE in non-commercial species. An interesting result was found by investigating the spatial distribution: the fish aggregated at low biomass while they dispersed at high biomass. This behavior has been observed in other species, including cod and haddock (Marshall & Frank, 1994; Rose, 1999).

In the lower Forth Estuary, Scotland, benthic and demersal fish were analyzed between 1982 and 2001 by measuring abundance at three stations each month during five months of the year (Greenwood, et al., 2002). This survey collected 30 demersal and benthic species. Of the 10 most abundant species, *Merlangius merlangus* (Linnaeus) and *Zoarces viviparous* (Linnaeus) declined significantly over the study period while *Myoxocephalus scorpius* (Linnaeus) increased in abundance. The linear model was weak and only 3.2% of the change in catch of *M. scorpius* was correlated with changes in time. The authors attributed the changes in abundance of *Z. viviparus* to an increase in water temperature in the estuary during the survey period. While the authors were unable to explain the changes in the other two species, they speculated that they were due to vacated niches as other species are lost.
The collapse of the Newfoundland cod fishery in the late 1980s and early 1990s is a famous example of fisheries mismanagement and the subject of numerous scientific studies. The decline of both commercial and non-commercial species has been attributed to multiple causes, including over-harvesting, stock mismanagement and environmental factors, yet few studies have looked at changes in community structure (Haedrich & Barnes, 1997). Haedrich investigated how commercial and non-commercial species changed with respect to mean size (grams/individual) and abundance. Of the non-commercial species subject to in-depth analysis, none were small enough to penetrate the cod ends of commercial vessels, but preliminary analysis of the small species found that most of them decreased in size over time.

These studies document trends in non-commercial fish species and have found varied results and are important as they identify trends in species which would have otherwise been ignored. In the current investigation, data from the Icelandic bentthic bottom trawl survey is used to study trends in non-commercial fish species.

**The Icelandic Scientific Trawls**

The Icelandic spring bottom trawl survey provides a dataset for investigating trends in non-commercial fin-fish species for several reasons: (1) the survey has been conducted for more than 25 years; (2) more than 500 stations are sampled each year; (3) the small mesh size designed to sample juveniles of commercial species also sample small fishes that are not caught in commercial fishing nets. Sampling has been conducted in Icelandic waters since the 1930s by the Marine Research Institute or its predecessor the Department of Fisheries of the University Research Institute (Pálsson, Jónsson, Schopka, Stefánsson, & Steinarsson, 1989). In the 1970s scientific surveys began. These surveys went through many iterations before the current system was developed. The survey, in its current form, has been carried out since 1985 and samples between 508 stations/year and 600 stations/year each March. There are several reasons so many stations are involved in this survey: (1) to cover a wide range of environments; (2) to sample all trawlable areas shallower than 500 meters
(m); (3) to decrease the standard error (standard error and square root of sample size are inversely proportional) (Grosslein, 1971). March was selected as the survey month for two reasons, diurnal vertical migration is considered less pronounced than in the autumn and the spawning stock of cod is aggregated in the waters south of Iceland. This latter point may increase the accuracy of sampling the main target species of Icelandic fisheries (Pálsson, et al., 1989).

In the current study, the data collected over the last 25 years in the Icelandic annual spring survey will be used to study the temperature preference, abundance and spatial trends of 15 non-commercial fish species on the Icelandic continental shelf. It is hypothesized that as sea temperatures have increased around Iceland the species have shifted north and that warm water species have increased in abundance. Furthermore, cold water species are expected to decrease in abundance and also move north to maintain their temperature preference.
MATERIAL

Data Collection

Data were obtained from the Icelandic annual groundfish surveys conducted between 1985 and 2009, by the Marine Research Institute, Iceland. The stations were located all around Iceland (Figure 4) and in a wide range of water depths (17m - 500m). The sampling stations are described as “semi-random;” half of the stations were chosen at random and the other half were selected by fishermen at known fishing grounds (Pálsson, et al., 1997). There are 595 official stations, but for various reasons (gear failure, obstructions, weather) the number of stations sampled each year varied between 508 stations per year and 600 stations per year (mean = 558 stations per year). Between 1996 and 2003 the stations in the southeast were not sampled (shaded area, Figure 4). In order to sample these stations within a few weeks, a commercial fishing fleet was employed by the government. Originally, five identical 462 Gross Registered Tonnage and 47.1m long stern-trawlers were used (Pálsson, et al., 1989) but this was changed to four vessels in 1996 to reduce the cost of the survey (Pálsson, et al., 1997). Four nautical miles (nm) trawls are conducted at each station at a tow speed of 3.8 knots (Sólmundsson, 2008). The mesh size of the cod end cover is 40 millimeters (mm) (Pálsson, et al., 1989), much smaller than the commercial standard size of 135mm (Fiskistofa, 2009).

At each station, all fish were identified to species level (although prior to 1995 some species were only identified to genus level). In addition, geographic location (always), depth (always) and bottom temperature (> 93% of the time) were recorded. Temperature was recorded on the headline of the net with a Scanmar thermometer (Pálsson, et al., 1989). Depth was recorded by sonar; position was recorded by Loran or GPS. Other environmental statistics were recorded, but are irrelevant for the present study.
While tows are supposed to be 4nm at each station, issues arise during trawls that require tows to be lengthened or shortened. The average tow length is 3.88nm. The distribution, on a y-axis log scale, of tow lengths is shown (Figure 5).
METHODS

Species Selection

The criteria used to select species for this study were: (1) species must have no commercial value in Iceland; (2) species must be present in at least 1% of all stations. All data analysis was performed in the statistical package R-statistics (R Development Core Team, 2009). Species selection procedures were used to narrow down the complete species list to 24 species and two genera; this list needed to be refined for further analysis. Prior to 1995, the identification of the species in the Lycodes genus was inconsistent. Some observers were insufficiently trained and when they could not identify to the species level, the fish were pooled into one “Lycodes sp.” category. Since the six Lycodes species in Iceland occupy a wide range of habitats (minimum depth range 25m to 357m and a maximum depth range 365m to 1808m) (Coad, 2004; McAllister, 1981) the species are not included in the subsequent analysis. Prior to 1995, the species Leptoclinus maculatus (Fries, 1838) and Lumpenus lampretaeformis (Walbaum, 1792) were combined into the classification Lumenidae. L. maculates’ mean length is 14.5 centimeter (cm) (based on 90 observations) and L. lampretaeformis’ mean length is 30.9cm (based on 859 observations). While these two species occupy similar depth ranges (minimum 2m to 30m and maximum 373m to 607m) (Coad, 2004; Mecklenburg, 2004) they were eliminated from subsequent analysis because they are different species thus they occupy different ecological niches and are under different selection pressures. The 15 species which remained for subsequent analysis are described, with their scientific, English and Icelandic names (Table 1). Artistic illustrations of the species as well as their catch size and location are shown (Figure 6A-21A). Three species (Triglops murrayi [Günther], Rajella fyllae [Lütken], and Gaidropsarus argentatus [Reinhardt]) had two distinct population clusters in the east and west of Iceland. To address this, data analysis was performed separately for these species on either side of 19°W longitude (Figure 8, 9, 10, 20, and 21). Since stations on the Iceland-Faroe ridge were not
sampled between 1996 and 2003, and because this ridge is the location of one of the populations of
*R. fyllae*, the eastern population of *R. fyllae* was not analyzed. Cold and warm water species were
defined as species which are found at mean bottom temperature of < 4°C (cold) or > 4°C (warm).

Whether a species is above or below the 50% retention level was qualitatively estimated
using a paper which measured retention in 40mm cod end trawls (Tosunoglu, et al., 2003). Species
in the current study which are larger than the maximum 50% retention size found in the Tosunoglu
paper are assumed to be above the 50% retention level. The retention of species which are in the
range of the 50% retention found the Tosunoglu paper is unknown. Species which are well below the
minimum size of 50% retention in the Tosunoglu paper are assumed to be below the 50% retention.
There are two important caveats to this qualitative estimation. 1) Shape is also a determining factor
in retention. Thus species which are long and slender are considered differently that species which
are round (please see discussion for species specific examples). 2) The lengths of fish in the current
study is based on fish which were retained in a 40mm trawl: this is likely going to skew the results,
particularly for the smaller fish, and the measurement are likely bigger than the actual fish size.

**Data Trimming**

Data were trimmed to eliminate obvious outliers resulting from data entry errors. Outliers
were identified by Cook’s distance values > 0.25 and removed from the dataset. Subsequent analysis
was performed with basic R package and the Geo package (Björnsson, 2007). Eight data points,
from seven different species, had Cooks values greater than 0.25 and were removed from the dataset.

The depth data were scrutinized for obvious errors. Erroneous depth measurements (i.e. 0m
or 900m) were replaced with the mean depth measurements for the same station in the other survey
years. Temperature measurements were missing from 941 stations. While the missing temperature
data could be interpolated from surrounding stations, this method was not chosen due to potential
inaccuracies arising in data interpolation. Instead of interpolating data, missing temperature data
points were ignored in subsequent temperature calculations. Six temperature measurements were obviously erroneous (< -2.0°C), and were set to average neighboring values.

Calculations

CPUE was calculated by dividing the number of individuals in a given species caught at a station by the length of tow at that station:

$$CPUE = \frac{I}{L}$$

where $I$ is the number of individuals caught at a particular station and $L$ is the length of the tow at that station. To standardize the variance, CPUE was log transformed:

$$\ln(CPUE) = \ln(CPUE + 1)$$

All subsequent calculations were based on the lnCPUE. Error bars in abundance graphs represent standard error of mean (SEM). SEM was calculated using the standard deviation (SD) with these formulas:

$$SD = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \mu)^2}{n}}$$

$$SEM = \frac{SD(x)}{\sqrt{n}}$$

where $x$ is the number of individuals caught in a given year, $n$ is the number of stations and $\mu$ is the mean. Mean latitude, longitude, temperature and depth were calculated (and plotted) all using the weighted mean function in R with the following equation:

$$X_j = \frac{\sum_{i=1}^{n} W_i X_{ij}}{\sum W_i}$$
where $X$ is the value of interest (latitude, longitude, temperature or depth), $j$ is the survey year and $W_i$ is the number of individuals caught at each station $i$. Species which had obvious east or west population concentrations were split along the 19°W longitude line for all analyses.

Abundance trends were calculated in two different manners. Calculations were based on lnCPUE for abundance trends. First, a simple linear model was used to calculate changes in abundance over time. Acknowledging that a linear model is problematic for evaluating natural populations which are cyclical, Spearman’s rank correlation coefficient ($\rho$) was calculated:

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2 - 1)}$$

where $n$ is the number of ranks and $d$ is the difference between each ranked value. Positive trends indicated increasing abundance and negative trends indicated decreasing abundance over time. Spearman’s rank does not assume a linear relationship and is a more powerful tool than the linear model. Additionally, Spearman’s rank is distribution independent. In order to determine if the relationship between abundance and time is random or describes a trend, the mean catch for each year was bootstrapped 1,000 times and Spearman’s rank was calculated for each iteration. The number of times the bootstrapped output was greater than (for decreasing populations) or less than (for increasing populations) the $\rho$ value was divided by 10. Ten is the number of iterations (1,000) multiplied by 100 (for percent) and here after referred to as the “bootstrapped value.” The resulting value indicated the percent chance that the $\rho$ was due to random variation. In some cases, the above calculation was performed over a 15 year period from 1995 to 2009, when the abundance graph indicated that a recent trend was masked by the first 10 years. For the weighted mean temperature, depth, latitude and longitude calculations, linear models were used to calculate trend lines. P values and $r^2$ values were extracted from the linear models. P-values < 0.05 are considered statistically significant and $r^2$ indicate how much variation is correlated with time.
Spearman’s rank cannot calculate correlation coefficients when there are tied values in the data set. Since some species had zero landings in more than one year, the Pearson’s rank correlation coefficient was used instead of the Spearman’s rank:

\[
r = \frac{N \sum xy - (\sum x)(\sum y)}{\sqrt{N \sum x^2 - (\sum x)^2} \sqrt{N \sum y^2 - (\sum y)^2}}
\]

where \( r \) is the Pearson correlation coefficient, \( N \) is the number of value in each data set, \( x \) is the value of one of the parameters (number of individuals) and \( y \) is the value of the other parameter (year). Pearson’s coefficient was computed for species which had the same CPUE in more than one year. Bootstrapping was performed as above.
RESULTS

Data description

A general description of the data shows that the species included in this study are diverse (Table 2). Some species are common, found at nearly 25% of the total stations, while some occur at just 1% of the stations. There is a broad range in the maximum and minimum number of stations that any given species was found in a particular year (in some years some species were not found at all). Similarly, the maximum number of individuals caught in a given year had a wide range of values. The highest maximum was Trisopterus esmarkii (Nilsson), 200,954, while the highest minimum, Gymnelus retrodorsalis (Le Danois), was 30 individuals. The minimum yearly totals had a wide range of values as well, six species were found in numbers of less than five individuals while the minimum number of T. esmarkii was 1,965.

Specific Species

T. esmarkii (Norway Pout)

T. esmarkii is a short lived, benthopelagic gadoid species found throughout the northeast Atlantic Ocean (ICES, 2009). T. esmarkii’s average size 18cm, thus it is likely that more then 50% of this species is retained. As would be expected with short lived, schooling species, its abundance is cyclical. T. esmarkii is an important prey species for commercial species such as: cod, Gadus morhua (Linnaeus); whiting, Merlangius merlangus (Linnaeus); saithe, Pollachius virens (Linnaeus); haddock, Melanogrammus aeglefinus (Linnaeus); mackerel, Scomber scombrus (Linnaeus) (ICES, 2009). While there is no directed fishery for T. esmarkii in Iceland, it is likely that it turns up in bycatch in the shrimp, herring and mackerel fisheries because of the small mesh sizes used in these fisheries. The ln(CPUE+1) trend for T. esmarkii has increased over the course of this study (Figure 6C), as confirmed by both the abundance linear model (P = .001, r^2 = .375) and the Spearman’s rank correlation (P = .003, \( \rho = .585 \), bootstrapped value = 0.1%). This is not in
agreement with other published data that shows stable spawning stock biomass in the North Sea between 1983 and 2007 (Lambert, Nielsen, Larsen, & Sparholt, 2009). It is clear that this species’ range has shifted and its population has expanded. The $r^2$ values for the latitude and longitudinal changes indicate that 28% of the change in latitude and 18% of the change in longitude are correlated with time. The geographic center has shifted north ($P = .006, r^2 = .282$) and west ($P = .034, r^2 = .18$) (Figure 6E and 6F). Additionally, the mean temperature at which *T. esmarkii* was caught has increased over the course of the study ($P = .02, r^2 = .214$) (Figure 6H).

The increasing population size is possibly due to several interacting variables. In recent years the capelin, *Mallotus villosus* (Cuvier) stock has migrated north (Vilhjalmsson, 2002). This northern distribution shift could allow *T. esmarkii* to expand its population and range due to reduced competition. In support of this hypothesis, a negative correlation between *T. esmarkii* population and Atlantic herring, *Clupea harengus* (Linnaeus) has previously been shown (Huse, Salthaug, & Skogen, 2008). Thus, it is possible to speculate a similar relationship between *T. esmarkii* and *M. villosus*.

**C. monstrosa (Rabbit fish)**

*Chimaera monstrosa* (Linnaeus) is a relatively warm water, cartilaginous fish that is found almost exclusively in the southwest of Iceland (Figure 7A). *C. monstrosa’s* average size 36cm, thus it is likely that more then 50% of this species is retained. There are no significant trends either by linear model or by Spearman’s rank in the abundance of *C. monstrosa* over the entire study period (Figure 7C). A significant positive increase since 1995 using Spearman’s rank is observed ($P = .011$, $\rho = .646$, bootstrapped value = 0.3%), indicating that the recent population trend is not due to random chance. This does not necessarily mean, however, that this trend is due to anthropogenic activity. It is quite possible that *C. monstrosa* has exhibited natural increase in population size for the past 15 years, independent of anthropogenic effect.
The diet of *C. monstrosa* has not been studied in Icelandic waters, but a report out of the western Mediterranean indicates that its diet is composed almost entirely of ophiuroids (brittle stars), benthic crustaceans, and polychaetes (MacPherson, 1980). Since all three of these organisms are commonly found in Icelandic waters, a similar diet is expected. As the *C. monstrosa* diet is not heavily dependant on any commercially fished species, *C. monstrosa* may not be affected directly by the removal of fish.

Unexpectedly, while *C. monstrosa*’s position (by latitude and longitude) has not changed significantly, it has moved to deeper water (*P* = .047, *r*^2^ = .161) (Figure 7G). Although the *P*-value is weak, it is significant. By the linear model, *C. monstrosa*’s mean depth increased by 42m over the course of the study. Since *C. monstrosa*’s population is centered on the steep Reykjanes ridge, it is likely that a non-significant change in latitude or longitude resulted in a significant shift in depth. In addition to the depth shift, the bottom temperature where *C. monstrosa* is found increased by 1.3°C (*P* = .003, *r*^2^ = .317) over the course of the study. As sea temperatures are increasing rapidly in the southwest region (Sigurjónsson, 2008) this observation is not unexpected. The shift to deeper waters and the increase in mean bottom temperature describe a situation where the species is trying to maintain homeostasis as sea temperatures rise.

*T. murrayi* (Moustache sculpin)

This small sculpin (mean size 11cm) is commonly found in colder waters off the east and northwest of Iceland (Figure 8A). The small average size of *T. murrayi* implies suggests that less than 50% of the fish are retained in the survey. The population abundance of this species is clearly cyclical and no trends have been observed over the course of this study (Figure 8C). A longer study period would be helpful in sorting out the population cycle as the population “highs” and “lows” could be compared. When the population is split along the 19°W line of longitude there is a positive correlation for abundance in the western population, as discovered both by the linear model (*P* = .034, *r*^2^ = .181) and the Spearman’s rank correlation coefficient (*P* = .034, $\rho = .425$, bootstrapped
value = 1.9%) (Figure 9C). The western concentration had no change in latitude, longitude, temperature and depth. While the eastern concentration did not change in abundance, it migrated south (P < .000, $r^2 = .762$), mean bottom temperature increased (P = .004, $r^2 = .313$), and mean depth decreased (P = .003, $r^2 = .32$) (Figure 10). While the change in depth is significant it is not large. The change in latitude has a strong correlation and corresponds to a southern shift in the geographic center of this species by 0.712° latitude.

**L. decagonus (Atlantic Poacher)**

*Leptagonus decagonus* (Bloch & Schneider) was present in 11.93% of trawls, which is surprising considering small amount of scientific information for the species. *L. decagonus*’ average length is 17cm, yet this is a long slender fish, thus it is unclear what percent of this species is retained in trawl surveys. The species is exclusively found in the north and west in the scientific surveys (Figure 11A). The linear model (P = .024, $r^2 = .204$) and Spearman’s correlation (P = .009, $\rho = -.517$, bootstrapped value = 0.4%) show that the species is decreasing in abundance (Figure 11C). There is no significant change in the geographical distribution, mean depth or bottom temperature (Figure 11E, 11F, 11G and 11H). Guijarro (2006) studied bycatch in the scallop dredge in Breiðafjörður and found that the *L. decagonus* population increased between 1993 and 2001 (Guijarro, Ragnarsson, & Eiriksson, 2006). While this result disagrees with the conclusion drawn from the current data analysis there are explanatory factors. First, the gear used in the two surveys was different. Second, in the current study there is only one station with a single specimen of *L. decagonus* from Breiðafjörður, which indicates that the survey does not accurately sample *L. decagonus* in Breiðafjörður. Thirdly, the Guijarro study only found *L. decagonus* in 0.3% of their trawls, so they may not have had a large enough sample size to accurately assess population dynamics.
**R. cimbrius** (Four-bearded rockling)

*Rhinonemus cimbrius* (Linnaeus) is a warmer water species (mean bottom temperature 4.4°C) that is widely distributed all around Iceland, with the highest concentrations of this species found in the southwest (Figure 12A). *R. cimbrius*’s average length is 26cm, thus more than 50% of this species is most likely retained in the surveys. Total abundance increased significantly over the course of the study, as shown by both the linear model (P < 0.000, \( r^2 = .635 \)) and Spearman’s correlation (P < .000, \( \rho = .732 \), bootstrapped value = 0.0%) (Figure 12C). Corresponding to the increase in abundance, there is a northern shift in the geographic center (P = .037, \( r^2 = .176 \)) (Figure 11E). As would be expected with a species concentrated in the southwest there is an increase in the mean bottom temperature (P = .012, \( r^2 = .246 \)) (Figure 11H). The increase in abundance of this species correlates with an increase in abundance of the same species in the North Sea from 1980-1990 (Heessen & Daan, 1996).

**I. bicornis** (Twohorn sculpin)

*Icelus bicornis* (Reinhardt) is found around the northwest and northeast of Iceland (Figure 13A). The highest ln(CPUE+1) for *I. bicornis* is 0.012; thus this species is quite rare and was found in only 1.25% of trawls. *I. bicornis*’ average length is 6cm, likely well below the 50% retention size. The Spearman’s test for this species was not valid because there were three years where no specimens were caught. To this end, a Pearson’s correlation was performed, but no significant correlation was found (Table 3). There are no significant trends in this species for geographical location, mean bottom temperature or mean depth (Figure 13C-13H). As it appears that there are two population clusters, one in the east and one in the west, the west and east clusters were analyzed separately. The only significant trend in this analysis is that the west population exhibited an increase in mean bottom temperature (P = .028, \( r^2 = .267 \), data not shown). However, as this is based on so few individuals (max CPUE = 0.025) the data is not considered robust and does not warrant
further analysis. Since the average size of this species in the trawls is 6cm, it is possible that the species is more abundant, but not effectively sampled in the trawls.

**Gymnelus retrodorsalis (Aurora pout)**

*Gymnelus retrodorsalis* (Le Danois) is a rare, coldwater species (1.0°C) distributed in the north and east of Iceland (Figure 14A). While *G. retrodorsalis*’ average length is 13cm, it is a long slender fish, so less than 50% of this species is retained in the survey. Statistically, this species is similar to *I. bicornis*. *G. retrodorsalis* was found at 1.29% of stations and there was no clear trend in abundance, geographic center or depth (Figure 14C-14H). Similar to *I. bicornis* there is a significant increase in mean bottom temperature ($P = .012, r^2 = .246$).

**Careproctus reinhardtii (Sea tadpole)**

*Careproctus reinhardtii* (Krøyer) was found in nearly 8.97% of trawls, exclusively in the north and the east of Iceland (Figure 15A). While the average size of *C. reinhardtii* is on 14cm the odd shape of this fish likely means that more than 50% are retained in the hauls. *C. reinhardtii* clearly has a temperature preference for near 0°C water (Figure 15H) which did not change in the survey. No significant trends in latitude or longitude were detected, but the depth preference increased ($P = .006, r^2 = .287$) (Figure 15G). As with *C. monstrosa*, there was a significant change in depth without a change in geographic center. In this case the species moved into deeper water, by 46m. In order for this to happen the population must be centered on a steep drop-off so that a small (not significant) change in latitude or longitude results in significant change in depth. This species has a narrow temperature range, so it is likely that it moved to deeper water as sea temperatures rose to maintain its preferred temperature.

**B. saida (Polar cod)**

*Boreogadus saida* [Lepechin] is a small, circumpolar, cold water codfish found mostly in the north of Iceland (Figure 16A). No significant trends in population abundance, bottom temperature or mean depth were detected (Figure 16G). *B. saida’s* average length is 16cm so it is likely that more
than 50% of the species is retained. A significant westward population shift was detected \((P = .03, r^2 = .1)\), but the data points are scattered, which is reflected in the weak P-value and the weak \(r^2\) value (Figure 16E). It is clear that Iceland is just on the southern edge of this species boundary, so it is likely that more effective sampling (further north) is required to gain significant insight into its population trends.

**A. atlanticus (Atlantic hookear sculpin)**

*Arctediellus atlanticus* [Jordan and Evermann] is found in cold water, normally below 0°C in the Arctic regions of North America, Scalbard, Iceland, Scotland and Norway (Vanguelpen, 1986; vonDorrien, 1996). *A. atlanticus’s* average length is 11cm so less than 50% of this species is retained in the trawls. Little else is known about this species, except that it is prey of the Greenland shark *Somniosus microcephalus* (Bloch & Schneider) (Yano, Stevens, & Compagno, 2007). *A. atlanticus* is found primarily in the east, but its distribution extends slightly to the north (Figure 17A). This coldwater species was found in nearly 14% of the trawls. No trends in abundance, mean temperature or mean depth were detected (Figure 17). The species did have a southern trend in latitude \((P = .014, r^2 = .236)\) (Figure 17E).

**M. scorpius (Bull Rout)**

*M. scorpius* is commonly found in shallow waters in Icelandic harbors (Figure 18A). *M. scorpius’* average length is 23cm so more than 50% of this species is retained. This species is considered a nuisance in Iceland because it is a carrier of *Pseudoterranova decipiens*, the “seal worm” parasite which infects cod (Midtgaard, Andersen, & Halvorsen, 2003). Surprisingly, the species has nearly disappeared from the scientific trawls (Figure 18C); 88.5% of the total catch occurred between 1985 and 1995. Both the linear model \((P < .000, r^2 = .786,)\) and the Pearson’s rank (zero fish in two years so Spearman’s does not work) \((P < 0.000, r = -.89, bootstrapped value = 0.0\%\) indicated a negative trend in abundance (Figure 18C).
In the North Sea, a 13-year study from 1980-1993 found that *M. scorpius* populations were stable in coastal waters and declined in estuary environments (van Leeuwen, 1994). As there are only a few shallow water stations a more detailed survey of the fjords and harbors in Iceland should be conducted to understand the population trends. While such a study has not occurred, there is data from the MRI shrimp trawl surveys which show a steep decline in abundance after 1995 (Björnsson, personal communication, 2009). There is a significant southern trend in this species (Figure 18E) (particularly after 1995), but this is an artifact due to the low number of individuals caught in later years (only 484 specimens after 1995) rather than an indication of change in species distribution.

*C. microps* (polar sculpin)

*Cottunculus microps* (Collett), is a cold water species found predominantly in the north and east, although a few individuals specimens have been caught in the west of Iceland (Figure 19A). While *C. microps'* average length is 15cm it is likely above the 50% retention because of this specie’s odd body shape. The abundance of *C. microps* has decreased, based on the linear model (P < 0.021, $r^2 = .212$) and the Spearman’s rank (P = .011, $\rho = -.501$, bootstrapped value = 0.6%) (Figure 19C). There is a strong trend for a southern (P < 0.000, $r^2 = .521$) and eastern (P < 0.000, $r^2 = .423$) shift in the geographic center of the population (Figures 19E, 19F). Upon examination of the distributions before 1995 and after 1995 (when the population decline began) it is clear that the population is not “migrating south and east” but that the geographic center shifts as this species’ abundance declines in the northern and western stations (Figure 22). This is an important observation which shows that there are flaws in using geographic center analysis. The change in location of geographic center is correlated with an increase in mean depth (Figure 19G).

*R. fyllae* (Round ray)

*R. fyllae* has two distinct population clusters, one in the east on Þórsbanki and one in the west (Figure 20A). *R. fyllae* average length is 40cm and it is a wide ray, so more than 50% of this species
is retained. Because the populations are disparate, all analyses were carried out separately for the two populations, on either side of 19°W longitude. East of this longitude there were no significant P values in the abundance for either the linear model or the Pearson’s test (data not shown). Even if there was a significant trend for the population in this area, the result would need to be considered cautiously as the area where this species is found in the east was not sampled between 1996 and 2004. West of 19°W longitude, however, there is a significant trend in the linear model (P = .017, $r^2 = .225$) and for the Spearman’s correlation (P = .022, $\rho = .458$, bootstrapped value = 0.5%) (Figure 20C). These results indicate that the population of *R. fyllae* is increasing on the banks in the west. The temperature analysis describes a significant increase in mean bottom temperature of the western cluster (P = .039, $r^2 = .188$), but there is clearly one outlying data point which is likely an error in species identification because the 1988 0.3°C measurement only describes one individual (Figure 20H). When this data point is removed the trend is no longer significant (P = .107, data not shown). There is a significant, increasing westward trend for *R. fyllae* (P = .025, $r^2 = .2$) and corresponds to a shift of 0.691 degrees longitude at the given latitude.

**G. argentatus** (Arctic rockling)

While *G. argentatus* is found all around Iceland, it has a preference for the west and the north east (Figure 21A). *G. argentatus’* average length is 18cm, so more than 50% of this species is retained. There are two distinct population clusters which have been analyzed separately, on either side of 19°W longitude. While there is no trend in the abundance for the eastern cluster, there is a positive population increase in the west, as shown by both the linear model (P < .000, $r^2 = .521$) and Spearman’s rank (P < 0.000, $\rho = .732$, bootstrapped = 0.0%) (Figure 21C). In addition to the increase in abundance in the west, the western concentration also shifted south (P = .022, $r^2 = .209$), west (P = .034, $r^2 = .181$), increased in mean bottom temperature (P = .002, $r^2 = .343$) and moved into shallower waters (P = .012, $r^2 = .246$) (Figure 21G). *G. argentatus* is the only species that an
increased population in the west corresponded to a southern change in distribution. Since the mean bottom temperature for this species has increased, it is possible that the increased temperature has allowed the organism to exploit a new niche, explaining the increase in abundance.

*C. gurnardus* (Grey Gurnard)

While *Chelidonichthys gurnardus* (Linnaeus) is widespread in the eastern Atlantic Ocean (ICES, 2009), it is predominantly found in the south of Iceland, with a few specimens taken in the west (Figure 22A). *C. gurnardus*’ average length is 33cm so more than 50% of this species is retained in the trawl surveys. *C. gurnardus*’ abundance has increased significantly over the survey period, as shown both by the linear model analysis ($P < 0.000$, $r^2 = .826$) and Spearman’s rank correlation ($P < .000$, $\rho = .943$, bootstrap value = 0.0%) (Figure 22C). This strong population increase in *C. gurnardus* corresponds to the catch trends in the IBTS of the North Sea, where catches have at least doubled since the late 1980s (ICES, 2009). The increase in abundance corresponds with a strong shift westward shift in the geographic center ($P < .000$, $r^2 = .696$), which is a 4.4°W shift in longitude at the latitude center (Figure 22F). For Iceland, this is a warm water species, mean bottom temperature 6.7°C. The mean bottom temperature graph suggests that *C. gurnardus* tolerates a narrow range of temperatures (Figure 22H). As sea temperatures in the southwest rise *C. gurnardus* is able to expand in abundance and migrate further west, into these warmer waters. The waters to the west that *C. gurnardus* is expanding into are slightly deeper (Figure 22G).
DISCUSSION

The research indicates that the abundance and location of some of the non-commercial species studied has changed in Iceland since 1985. Five species increased in abundance over the whole period studied and one species increased in abundance since 1995. Three species decreased in abundance since 1985. The changes in population abundance of these species are likely due to a combination of factors including changing ecosystem structure and changing sea temperature.

Geographic Centers

The geographic center of each species in each year, was calculated by a weighted mean (latitude: Figures 6E – 22E; and longitude: Figure 6F – 22F). The linear model used to identify trends in the position of each fish species indicated that the geographic centers of eight species changed significantly during the survey period. Two species (A. atlanticus and C. microps) and the eastern population of (T. murrayi) shifted south. Two species shifted north (T. esmarkii, and R. cimbrius), four species moved west (T. esmarkii, B. saida, R. fyllae [West], and C. gurnardus) and two species migrate east (C. microps and G. argentatus) (Table 4).

The use of latitude and longitude to study spatial changes only provides limited information. It is important to note that a change of 1° longitude at 65°N latitude is different than a change of 1° longitude at 60°N latitude. A better approach to this would be to use a polar coordinate system to measure the changes in the geographic centers of the species.

Temperature

The weighted mean bottom temperature was calculated for each species. For six of 15 species (T. esmarkii, C. monstrosa, T. murrayi [East], R. cimbrius, G. retrodorsalis, R. fyllae and G. argentatus [West]) the mean bottom temperature changed according to the linear model. The mean bottom sea temperature increased for all seven of these species (Figures 6H, 7H, 10H, 12H, 14H, and 21H, respectively, and Table 4). Cold and warm water species were defined as species which are
found at mean bottom temperature of $< 4^\circ C$ (cold) or $> 4^\circ C$ (warm) (Table 2). Ten species were classified as cold water species and five species were classified as warm water species. Both of the species with northern shifts in their geographic centers were warm water species (Table 4). All of the warm water species’ centers are in the south of Iceland and all the cold water species are in the north (Figure 23). Three of the warm water species ($T. esmarkii$, $R. cimbrius$, and $C. gurnardus$) increased in abundance (Table 4). $C. monstrosa$, the other warm water species, has increased in abundance since 1995 (Table 3). The only species with decreasing population trends were cold waters species ($L. decagonus$, $M. scorpius$, and $C. microps$). Two of the cold water species ($T. murrayi$ [West] and $G. argentatus$ [West]) increased in abundance. None of the cold water species migrated north while four ($T. murrayi$ [East], $A. atlanticus$, $C. microps$, $G. argentatus$ [West and East]) migrated south.

Abundance

The abundance analyses were performed by fitting the CPUE to a linear model and performing correlation coefficient analysis. Both of these methods are simple tools for investigating complex phenomenon. The results of the analysis provide insight into the abundance trends for the species investigated, but some of the weaker correlations may describe natural population cycles as opposed to anthropogenic influenced trends. Another problem with the abundance trends is that the stations may not accurately sample an individual species’ habitat. An example of this is $L. decagonus$, which was landed at only one station in Breiðafjörður in the spring survey data set, has been shown to be abundant in this fjord according to other studies (Jonasson, et al., 2007). Additionally, many of the species in the north of the Iceland appear to be most common on the outside edge of the trawl survey area. It is likely that these species’ populations extend well north of Iceland and they were not accurately sampled by the survey.

The CPUE abundance graphs follow, almost precisely, the number of stations at which the species were found. The number of stations at which a species is landed can serve as a proxy for the abundance of nearly all these species. This is of particular interest for rare species which scientist do
not often have the time to count. The number of stations at which species are found can be used to estimate abundance trends and should be considered for use in other datasets when the number of individuals is not available. The mean catch per year of each species is offered in each species figure as an alternative to the CPUE measurement.

For the 15 species investigated mean fish/haul was plotted against time (Figures 6C – 22C). The mean ln(CPUE+1) is plotted on the left y-axis and the number of stations where the species were found is plotted on the right y-axis. It is important to note the different scales on the two y-axes. The mean number of fish caught each year is also plotted (Figure 6D-22D). Nine species had significant P values for the linear model; *T. esmarkii, T. murrayi* (West), *L. decagonus* (Bloch & Schneider), *Rhinonemus cimbrius* (Linnaeus), *M. scorpius, C. microps, R. fyllae* (West), *G. argentatus* and *C. gurnardus* (Table 3). The $r^2$ value for these species describes goodness of fit of the linear model and the data. Since natural populations often have cyclical population cycles, the Spearman’s rank correlation coefficient was used to calculate the correlation between the number of species caught per year and time. Seven species had significant P values for the Spearman rank, *T. esmarkii, T. murrayi* (West), *L. decagonus, R. cimbrius, C. microps, G. argentatus* (West), *C. gurnardus*, all of which had significant linear model P values (Table 3). Pearson’s rank correlation coefficient was computed for *M. scorpius* and *I. bicornis* because there was more than one year in which no fish were caught. The Pearson’s rank was significant for *M. scorpius* but not for *I. bicornis* (Table 3).

Over the survey period, and according to the Spearman’s rank correlation coefficient, *L. decagonus, M. scorpius, and C. microps* decreased in abundance while *T. esmarkii, R. cimbrius, G. argentatus, and C. gurnardus* increased in abundance. To calculate the percent chance that the variation observed was random, the data were bootstrapped 1,000 times. The number of times the bootstrapped $\rho$ value was greater than (for positive correlations) or less than (for negative correlations) the measured value was recorded (Table 3). The significant Spearman’s P-values for
the correlation between abundance and time is unlikely to be attained through random variation (Table 3). Visual analysis of the abundance trends of the species suggested that *C. monstrosa* which did not have significant trends over the whole survey period, increased in abundance between 1995 and 2009. To this end, the Spearman’s rank correlation coefficient was calculated over this shorter period of time. The resulting low P-values and high $\rho$ indicated that *C. monstrosa* has recently increased in abundance. Additionally, the percent chance that the $\rho$ value was random, as obtained from bootstrapping, was quite low. The Spearman rank was not significant for the other species, but this is not an indicator that the populations were homogenous. For most of these other species, there are obvious, observable, cyclical population trends during the survey period. Cyclical population trends are complicated to model and beyond the scope of this study.

**Data Quality**

Data quality is an important consideration when analyzing such a large data set, collected by many different people, over a long period of time. As previously mentioned, there was an effort made in 1995 to increase the training of scientists to identify rare species more accurately. Thus it is important to note that some specimens have been misidentified. Another issue is that sometimes there is as little as two hours between stations, limiting the time to process and identify all the species correctly. In such cases it is likely that the non-commercial species are going to be overlooked so that the species driving the sampling are correctly recorded. When just a few specimens per station are caught the fish are counted correctly, but when a large haul of one species is taken, the number of individuals is estimated by weight. While this is efficient it may not be as accurate. Other sources of errors arise from data entry and data processing.

Some trimming of the data were performed to eliminate outliers as previously discussed. One of these outlying data points (500,038 *T. esmarkii* in one haul) was removed the abundance trend for
the species changed. The other seven data points which were removed probably did not affect the
data set, but were removed to maintain consistent data preparation techniques.

There were few stations at which the depth measurements were wrong or missing, as was
previously discussed. The temperature measurements, however, pose a problem. The equipment
used to measure the temperature is not particularly accurate and can vary by as much as 1°C between
ships (Ingolfsson, personal communication, 2009). Additionally, temperature measurements were
missing from 7% of the stations. In the last ten years, the nets have been fitted with more accurate
temperature-depth sensors. It is interesting to note that over time the percent of stations with
temperature measurements has increased (Figure 24).

Another potential problem is that Iceland is on the edge of many species’ boundaries,
particularly those species in the north. The species which are found well north of Iceland, and
beyond the sampling area are not sampled effectively. It is possible that the southern shift in the
geographical center of western *G. argentatus* represents an expansion of the species’ range. The
southern shift in the geographic center of *C. microps* is not due to an expansion of the range, but
rather a contraction, as previously discussed. The distribution maps show that it is most abundant at
the outer edge of the sampling stations, thus to effectively sample this species a survey which
samples the whole geographical range or the species is necessary. This same issue was previously
discussed when fish surveys sample the edge of a populations (Nye, et al., 2009). The Nye study
attributed the southern shift in the geographical center of some species to the fact that the species’
true population center was beyond the boarders of the survey. As the population expanded, it
expanded in all directions, thus appearing to migrate south. *L. decagonus*, centered in the north of
Iceland (Figure 23) decreased in population, possibly due to the geographic center shifting north, and
out of the survey area.

Another issue with the data collection that must be addressed is the sampling efficacy of the
small mesh size of the cod end. The ability of a cod end mesh to sample fish depends greatly on the
shape of the species (Tosunoglu, et al., 2003). Since the species in the current study have different body shapes they are sampled with varying accuracy. The shape and size of two species suggests that they were not sampled effectively, *I. bicornis* which has a mean size of 6cm and *G. retrodorsalis*, while longer (mean length 13cm) is long and slender. These two species are also among the rarest species in the current investigation.

Throughout the results, estimates as to whether a given species is likely to be above or below the 50% retention level in the survey mesh. These are estimates based on the size and shape of the fish and compared to previously published estimates of retention in 40 mm trawl nets (Tosunoglu, et al., 2003). It is important to note that the sizes of the fish are based on fish caught in the survey, skewing the results. Of particular concern is the fish with average sizes right around the 50% retention size as their average size is skewed by the survey more than fish which are much larger than the 50% retention size.
SUMMARY

The current study provides insight into the abundance, location and temperature trends of 15 non-commercial fin-fish species between 1985 and 2009. Data collected from the Icelandic spring trawl surveys was used. While the species in this study have no commercial value in Iceland, this does not necessarily mean that they are rare. Some species were quite common, found at nearly 25% of all stations, while other species were found at just 1% of stations. The abundance trends for all species were calculated by both a linear model and a Spearman’s rank correlation. Some species have increased in abundance, others decreased in abundance while some showed no significant trends. The absence of a trend does not mean the population was static, often the number of these species’ fluctuated from year to year, but this fluctuation did not result in a general trend over the whole study period. Four out of five warm water species, centered in the south, increased in abundance while three out of 10 cold water species, centered in the north, decreased in abundance. Two cold water species, centered in the north, increased in abundance.

The geographic center of nine species changed during the survey period. There is an interesting division in the geographic center trends of the warm and cold water species. Only warm water species’ geographic centers shifted north and only cold water species’ geographic centers shifted south. While the mean sea temperatures all around Iceland are warming (Figure 2) there is no uniform pattern for the entire water mass. In fact, the temperatures in the southwest are warming much faster than the temperatures in the northeast (Sigurjónsson, 2008). One data set even shows temperatures in the northeast cooling over the survey period (Figure 3).

The original hypothesis, that both warm water and cold water species’ geographic center would shift north, that warm water species would increase in abundance and cold water species would decrease in abundance is partially true. In reality, these changes are species-dependant, however, larger trends were discussed above. These trends should be applied to commercial species
which occupy similar niches and behaviors in order to understand how the species might change were there no fishing pressures.

The insights into the spatial temporal trends of the 15 species in this study are interesting and important. More research is needed, however, to fully understand the causes of these trends. Clearly, there is a lack of data regarding the species on the edge of the survey. To better understand these species, the survey area must be expanded north beyond the current range. Additionally, research should be conducted to better understand the interactions of the species in the current study with the more common commercial species. Finally, the fall survey data should be used to complement the existing dataset and confirm the current findings.
Figure 1: The simplified food web for the Northwest Atlantic Ocean. The figure is nearly directly applicable to the Northeast Atlantic. Adopted from (Lavigne, 1996).
Figure 2: Mean Temperature for all stations. The linear trend indicates that the mean temperature has risen during the survey period.
Figure 3: The mean temperature between 300m and 700m of depth from stations LN3 (67°15′N, 13°34′W) and LN4 (67°30′N, 13°16′W) in the northeast of Iceland shows that the mean temperature in this region decreased over the survey period. Thanks to Héðinn Valdimarsson for providing this graph.
Figure 4: The locations of the 595 survey stations conducted in March of 2009. At each station, a 4 nm long bottom trawl, with a cod end mesh size of 40mm, was executed to sample fish. Stations are distributed all around Iceland and were selected on a “semi-random” basis, please see text for more detailed information. The grey shaded region indicates an area which was not sampled in between 1996 and 2003. Solid grey line is the 200m depth line and the dasked line is the 400 m depth line.
Figure 5: The tow length (x-axis) plotted against frequency (y-axis) on a log scale.
Figure 6: (A) Catch distribution at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of *Trisopterus esmarkii* (top). Painting reprinted with permission Jón Hlímberg www.fauna.is. Catch summary (C), thin black line, ln(CPUE+1) for *T. esmarkii*, left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model (P = .001, $r^2 = .375$) and Spearman’s rank correlation coefficient (P = .003, rho = .298, bootstrapped value = 0.1%) indicate that the population has increased over the study period. (D) The mean number of individuals caught in each year. The geographic center of the catch shifted north (E) and west (F); linear model results indicated in figure. Mean depth (G) of catch did not change, as linear model indicates. Mean bottom temperature increased over the study period (H); as linear model indicates.
Figure 7: (A) Map indicates catch size at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of *C. monstrosa* (top). Painting reprinted with permission Jón Hliðberg www.fauna.is. Catch summary (C), thin black line, in ln(CPUE+1) for *C. monstrosa* left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model and Spearman's rank correlation coefficient indicate no significant trend in the population over the study period. (D) The mean number of individuals caught in each year. The geographic center of the catch did not move; linear model results indicated (E) latitude and (F) longitude. Mean depth (G) of catch increased as linear model indicates. Mean bottom temperature increased over the study period (H); the statistical results from the linear model are in the figure.
**Figure 8:** (A) Map indicates catch size at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of *Triglops murrayi*. Painting reprinted with permission Jón Hliöberg www.fauna.is. Catch summary (C), thin black line, in ln(CPUE+1) for *T. murrayi* left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model and Spearman's rank correlation coefficient indicate no significant trend in the population over the study period. (D) The mean number of individuals caught in each year. The geographic center of the catch shifted south (E) and there was no longitudinal change (F); linear model results are indicated in figure. Mean depth (G) of catch decreased as linear model indicates. Mean bottom temperature increased over the study period (H); the statistical results from the linear model are in the figure.
Figure 9: (A) map indicates catch size at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of *T. murrayi*. Painting reprinted with permission Jón Hlíðberg www.fauna.is. Catch summary (C), thin black line, ln(CPUE+1) for *T. murrayi*, west of 19°W latitude. Left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model (P = .034, $r^2 = .181$) and Spearman's rank correlation coefficient (P = .034, rho = .425, bootstrapped value = 1.9%) indicate that the western population has increased over the study period. (D) The mean number of individuals caught in each year. Mean latitude (E), mean longitude (F), mean depth (G), and mean bottom temperature (H) did not change; as linear model indicates.
Figure 10: (A) Map indicates catch size at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of *Triglops murrayi*. Painting reprinted with permission Jón Hliöberg www.fauna.is. Catch summary (C), thin black line, ln(CPUE+1) for *T. murrayi*, east of 19°W latitude, left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model and Spearman's rank correlation coefficient do not indicate any abundance trends. (D) The mean number of individuals caught in each year. The mean latitude of the catch (E) moved south; as described by the linear model. There were no trends in the mean longitude (F). The mean depth preference of the species decreased (G) and mean bottom temperature (H) increased; see linear model results.
Figure 11: (A) map indicates catch size at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of *Leptagonus decagonus*. Painting reprinted with permission Jón Hilđberg www.fauna.is. Catch summary (C), thin black line, ln(CPUE+1) for *Leptagonus decagonus* left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model (P = .024, \( r^2 = .204 \)) and Spearman's rank correlation coefficient (P = .009, rho = -.517, bootstrapped value = 0.4%) indicate that the population has increased over the study period. (D) The mean number of individuals caught in each year. Mean latitude (E), mean longitude (F), mean depth (G) and Mean bottom temperature (H), did not change; as linear model indicates.
Figure 12: (A) map indicates catch size at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of *R. cimbrius*. Painting reprinted with permission Jón Hlióberg www.fauna.is. Catch summary (C), thin black line, in ln(CPUE+1) for *R. cimbrius* left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model (P = .000, $r^2 = .635$) and Spearman’s rank correlation coefficient (P = .000, rho = .732, bootstrapped value = 0.0%) indicate that the population has increased over the study period. (D) The mean number of individuals caught in each year. The geographic center of the species shifted north (E); the statistical results from linear model are in the figure. The geographic center of the catch did not have a significant longitudinal trend (F); linear model results indicated in figure. Mean depth (G) of catch did not change, as linear model indicates. Mean bottom temperature (H) increased over the study period and
A) Catch Distribution

![Catch Distribution Map](image)

B) *Icelus bicornis*

![Illustration of Icelus bicornis](image)

C) Catch Summary

![Graph showing catch summary](image)

D) Mean Individuals

![Graph showing mean individuals](image)

E) Latitude Center of Catch

![Graph showing latitude center of catch](image)

F) Longitude Center of Catch

![Graph showing longitude center of catch](image)

G) Mean Depth (m)

![Graph showing mean depth](image)

H) Mean Bottom Temperature (°C)

![Graph showing mean bottom temperature](image)

Figure 13: (A) map indicates catch size at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of *I. bicornis*. Painting reprinted with permission Jón Hliöberg www.fauna.is. Catch summary (C), thin black line, in ln(CPUE+1) for *I. bicornis* left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model (P = .847, r² = .002) and Pearson's rank correlation coefficient (P = .847, rho = .040, bootstrapped value = 43.2%) indicates no significant trend in the population over the study period. Pearson's rank was used instead of Spearman's rank because there were three years in which no fish of this species were landed and Spearman's rank cannot calculate with tied values. (D) The mean number of individuals caught in each year. There were no trends, as detected by linear models for mean latitude (E), mean longitude (F), mean bottom temperature (G), and mean depth (H) of catch.
Figure 14: (A) map indicates catch size at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of *G. retrodorsalis*. Painting reprinted with permission Jón Hliöberg www.fauna.is. Catch summary (C), thin black line, in ln(CPUE+1) for *G. retrodorsalis* left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model (P = .782, r² = .003) and Spearman's rank correlation coefficient (P = .952, rho = .013, bootstrapped value = 47.8%) does not indicate any significant population trend over the study period. (D) The mean number of individuals caught in each year. There were no trends, as detected by linear models for mean latitude (E), mean longitude (F), and mean depth (G) of catch. Mean bottom temperature increased over the study period (H); the statistical results from linear model are indicated.
Figure 15: (A) map indicates catch size at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of Careproctus reinhardtii. Painting reprinted with permission Jón Hilöberg www.fauna.is. Catch summary (C), thin black line, ln(CPUE+1) for C. reinhardtii left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model (P = .521, r² = .018) and Spearman’s rank correlation coefficient (P = .679, rho = -.087, bootstrapped value = 34.4%) does not indicate any significant population trend over the study period. (D) The mean number of individuals caught in each year. Mean latitudinal center of the catch (E), and longitudinal center of the catch (F) did not change during the study period. The mean depth of the catch (G) increased during the study period. Mean bottom temperature (H) did not change.
Figure 16: (A) map indicates catch size at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of *B. saida*. Painting reprinted with permission Jón Hliðberg www.fauna.is. Catch summary (C), thin black line, in ln(CPUE+1) for *B. saida* left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model (P = .243, $r^2 = .059$) and Spearman’s rank correlation coefficient (P = .147, rho = .298, bootstrapped value = 5.7%) does not indicate any significant population trend over the study period. (D) The mean number of individuals caught in each year. Mean latitudinal center of the catch (E) did not change during the study period. The longitudinal center of the catch (F) shifted to the west. There was no trend in the mean depth of the catch (G) or mean bottom temperature (H).
Figure 17: (A) map indicates catch size at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of A. atlanticus. Painting reprinted with permission Jón Hliðberg www.fauna.is. Catch summary (C), thin black line, ln(CPUE+1) for A. atlanticus left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model (P = .343, r² = .039) and Spearman's rank correlation coefficient (P = .332, rho = -.202, bootstrapped value = 16.9%) does not indicate any significant population trend over the study period. (D) The mean number of individuals caught in each year. The geographic center shifted south (E) but did not change in longitude (F). There was no trend in the mean depth of the catch (G) or mean bottom temperature (H).
Figure 18: (A) map indicates catch size at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of *A. atlanticus*. Painting reprinted with permission Jón Hliðberg www.fauna.is. Catch summary (C), thin black line, in ln(CPUE +1) for *M. scorpius* left left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model (P < .000, \( r^2 = .786 \)) and Pearson’s rank correlation coefficient (P < 0.000, rho = -.886, bootstrapped value = 0.0%) indicate that the abundance decreased over the study period. Pearson’s rank was used instead of Spearman’s rank because there were two years in which no fish of this species were landed and Spearman’s rank cannot calculate with tied values. (D) The mean number of individuals caught in each year. The geographic center shifted south (E) but this is an artifact of the decreased population and so few fish in the most recent years of sampling. There was no change in the longitude (F) or the mean depth of the catch (G). Mean bottom temperature (H) did not change during the study period.
Figure 19: (A) map indicates catch size at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of C. microps. Painting reprinted with permission Jón Hliðberg www.fauna.is. Catch summary (C), thin black line, in ln(CPUE+1) for C. microps left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model (P = .021, r² = .212) and Spearman's rank correlation coefficient (P = .012, rho = -.501, bootstrapped value = 0.6%) indicate that the abundance decreased over the study period. (D) The mean number of individuals caught in each year. The geographic center shifted south (E) and east (F). The mean depth increased (G). Mean bottom temperature (H) did not change during the study period.
Figure 20: (A) map indicates catch size at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of *C. microps*. Painting reprinted with permission Jón Hliöberg www.fauna.is. Trends of the population of *R. fyllae* west of 19°W longitude. Catch summary (C), thin black line, in ln(CPUE+1) for *R. fyllae* left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model (\( P = .017, r^2 = .225 \)) and Spearman’s rank correlation coefficient (\( P = .3002 \text{ rho = .458, bootstrapped value = .5%} \)) indicates that the population increased over the study period. (D) The mean number of individuals caught in each year. The geographic center did not change in latitude (E) but moved west longitudinally (F). There was no trend in the mean depth (G). Mean bottom temperature (H) increased, although this is due to one erroneous measurement.
Figure 21: (A) map indicates catch size at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of *C. microps*. Painting reprinted with permission Jón Hliöberg www.fauna.is. Catch summary (C), thin black line, in ln(CPUE+1) for *G. argentatus* left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model (P < .000, r² = .521) and Spearman's rank correlation coefficient (P < .000, rho = .722, bootstrapped value = 0.0%) indicates that the population increased over the study period. (D) The mean number of individuals caught in each year. There were no trends in the geographic center of the species measure either by latitude (E) or longitude (F). The mean depth deceased (G) indicating that the population must be located in a steep area. Mean bottom temperature (H) increased.
Figure 22: (A) map indicates catch size at stations where the species was landed around Iceland between 1985 and 2009. Circle size corresponds to catch size, please see legend for circle size. (B) Illustration of *Chelidonichthys gurnardus*. Painting reprinted with permission Jón Hlóberg www.fauna.is. Catch summary (C), thin black line, ln(CPUE+1) for *C. gurnardus* left y-axis, time on x-axis. Blue vertical error bars indicate the standard error of mean. Right y-axis (wide gray line) indicates the number of stations the given species was caught in any year. Please note, scales on y-axes differ. Results for linear model (P < .000, r² = .826) and Spearman's rank correlation coefficient (P < .000, rho = .943, bootstrapped value = 0.0%) indicates that the population increased over the study period. (D) The mean number of individuals caught in each year. No significant trend was found in the mean latitude (E) center of the catch. The longitude center shifted west (F) and the mean depth increased (G). Mean bottom temperature (B) did not change.
Figure 22: Maps showing the catch size and distribution of *C. microps* from 1985-1995 (top) and 1995-2009 (bottom). By comparing the top and bottom it is apparent that the population in the North is decreasing while the population in the west is constant.
Figure 23: The geographic center of each species in the current study. Species in blue are cold water species (mean < 4°C) and species in red are warm water species (mean > 4°C). Cold water species: *T. murrayi* (C), *L. decagonus* (D); *L. bicornis* (F); *G. retrodorsalis* (G); *C. reinhardtii* (H); *B. saida* (I); *A. atlanticus* (J); *M. scorpius* (K); *C. microps* (L); *G. argentatus* (N). Warm water species: *T. esmarkii* (A); *C. monstrosa* (B); *R. cimbrius* (E); *R. fyllae* (M); *G. argentatus* (N).
Figure 24: The percent of stations with bottom temperature has increased over the course of the study.
### Species Names: Scientific, Icelandic and English

<table>
<thead>
<tr>
<th>Latin Name</th>
<th>Icelandic Name</th>
<th>English Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trisopterus esmarkii</td>
<td>Spærlingur</td>
<td>Norway pout</td>
</tr>
<tr>
<td>Chimaera monstrosa</td>
<td>Geirnyt</td>
<td>Rabbit fish</td>
</tr>
<tr>
<td>Triglops murrayi</td>
<td>Prömmungur</td>
<td>Moustache sculpin</td>
</tr>
<tr>
<td>Leptagonus decagonus</td>
<td>Attstrendingur</td>
<td>Atlantic poacher</td>
</tr>
<tr>
<td>Rhinonemus cimbrius</td>
<td>Blákjafta</td>
<td>Four-bearded rockling</td>
</tr>
<tr>
<td>Icelus bicornis</td>
<td>Fuðriskill</td>
<td>Twohorn sculpin</td>
</tr>
<tr>
<td>Gymnelus retrodorsalis</td>
<td>Guli brandáll</td>
<td>Aurora pout</td>
</tr>
<tr>
<td>Careproctus reinhardtii</td>
<td>Hveljusogfiskur</td>
<td>Sea tadpole</td>
</tr>
<tr>
<td>Boreogadus saida</td>
<td>Iskóð</td>
<td>Polar cod</td>
</tr>
<tr>
<td>Artediellus atlanticus</td>
<td>Krækill</td>
<td>Atlantic hookear sculpin</td>
</tr>
<tr>
<td>Myxocephalus scorpius</td>
<td>Marhnútur</td>
<td>Bull Rout</td>
</tr>
<tr>
<td>Cottunculus microps</td>
<td>Marhnýtill</td>
<td>Polar sculpin</td>
</tr>
<tr>
<td>Rajella fyllae</td>
<td>Pólskata</td>
<td>Round Ray</td>
</tr>
<tr>
<td>Gaidropsarus argentatus</td>
<td>Rauða sævesla</td>
<td>Arctic rockling</td>
</tr>
<tr>
<td>Chelidonichthys gurnardus</td>
<td>Urrari</td>
<td>Grey gurnard</td>
</tr>
</tbody>
</table>

Table 1: The scientific, Icelandic and English names of the 15 non-commercial fin fish species in the current study.
### General Data Description

<table>
<thead>
<tr>
<th>Species</th>
<th>Max Sta/Yr</th>
<th>Min Sta/Yr</th>
<th>% Stations</th>
<th>Max/Yr</th>
<th>Min/Yr</th>
<th>Temp (°C)</th>
<th>Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. esmarkii</td>
<td>246</td>
<td>45</td>
<td>23.15</td>
<td>200954</td>
<td>1965</td>
<td>5.9</td>
<td>18 (2681)</td>
</tr>
<tr>
<td>C. monstrosa</td>
<td>17</td>
<td>5</td>
<td>1.75</td>
<td>547</td>
<td>69</td>
<td>6.1</td>
<td>36 (170)</td>
</tr>
<tr>
<td>T. murrayi</td>
<td>179</td>
<td>91</td>
<td>23.73</td>
<td>2632</td>
<td>743</td>
<td>2.2</td>
<td>11 (935)</td>
</tr>
<tr>
<td>L. decagonus</td>
<td>123</td>
<td>24</td>
<td>11.93</td>
<td>2106</td>
<td>334</td>
<td>0.6</td>
<td>17 (469)</td>
</tr>
<tr>
<td>R. cimbrius</td>
<td>112</td>
<td>35</td>
<td>13.64</td>
<td>781</td>
<td>127</td>
<td>4.4</td>
<td>26 (699)</td>
</tr>
<tr>
<td>I. bicorini</td>
<td>18</td>
<td>0</td>
<td>1.25</td>
<td>44</td>
<td>0</td>
<td>2.4</td>
<td>6 (16)</td>
</tr>
<tr>
<td>G. retrodorsalis</td>
<td>16</td>
<td>2</td>
<td>1.29</td>
<td>30</td>
<td>2</td>
<td>1.0</td>
<td>13 (30)</td>
</tr>
<tr>
<td>C. reinhardtii</td>
<td>75</td>
<td>27</td>
<td>8.97</td>
<td>550</td>
<td>64</td>
<td>0.5</td>
<td>14 (324)</td>
</tr>
<tr>
<td>B. saida</td>
<td>75</td>
<td>4</td>
<td>5.53</td>
<td>363</td>
<td>4</td>
<td>1.0</td>
<td>16 (140)</td>
</tr>
<tr>
<td>A. atlanticus</td>
<td>101</td>
<td>51</td>
<td>13.86</td>
<td>5289</td>
<td>968</td>
<td>0.7</td>
<td>11 (574)</td>
</tr>
<tr>
<td>M. scorpius</td>
<td>15</td>
<td>0</td>
<td>1.10</td>
<td>773</td>
<td>0</td>
<td>2.1</td>
<td>23 (26)</td>
</tr>
<tr>
<td>C. microps</td>
<td>81</td>
<td>40</td>
<td>10.14</td>
<td>251</td>
<td>71</td>
<td>1.3</td>
<td>15 (1250)</td>
</tr>
<tr>
<td>R. fyllae</td>
<td>25</td>
<td>1</td>
<td>1.92</td>
<td>108</td>
<td>1</td>
<td>3.9</td>
<td>40 (102)</td>
</tr>
<tr>
<td>G. argentatus</td>
<td>86</td>
<td>27</td>
<td>11.01</td>
<td>416</td>
<td>101</td>
<td>1.3</td>
<td>18 (388)</td>
</tr>
<tr>
<td>C. gurnardus</td>
<td>58</td>
<td>2</td>
<td>3.35</td>
<td>1054</td>
<td>5</td>
<td>6.7</td>
<td>33 (289)</td>
</tr>
</tbody>
</table>

Table 2: General data description of the species and stations. The maximum number of stations that an individual species was caught in any year (Max Sta/Yr) and the minimum number of stations that a species was caught in any given year (Min Sta/Yr) are in the second and third column. Some of these species are more widely distributed than others. The percent of the total stations (% Stations) shows the frequency that these species were caught at the 13,948 stations sampled. The maximum number of fish caught in any year (Max/Yr) and the minimum number of fish caught in any year (Min/Yr) shows the variation in species abundance. The weighted mean bottom temperature (Temp [°C]) provides information on the temperature preference for the different species. The mean length in cm (Length [cm]) is in the last column. The number of specimens that this measurement is based on is shown parenthetically.
Table 3: Trends in catch abundance of non-commercial fin-fish species in Iceland between 1985 and 2009. Significance (P < 0.05) by linear model or by Spearman’s rank correlation coefficient is indicated with bold font. To determine if the relationship between abundance and time is random or describes a trend, the mean catch for each year was bootstrapped 1,000 times and Spearman’s rank was calculated for each of these iterations (bootstrapped). Since Spearman’s rank cannot be calculated with tie values, Pearson’s rank was used for \textit{I. bicornis} and \textit{M. scorpius}. Pearson’s rank values are indicated with italics and parentheses. Spearman’s rank was calculated separately for \textit{C. monstrosa} for the years 1995-2009, both were significant, (P = .011, rho = 0.646, bootstrapped value = 0.3%). Abundance trends were calculated separately for the \textit{R. fyllae}, \textit{T. murrayi} and \textit{G. argentatus} east and west populations. Only the east or west divisions with a significant trend are shown.

<table>
<thead>
<tr>
<th>Species</th>
<th>Linear Model</th>
<th>Spearman’s (1985-2009)</th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>P-value</td>
<td>r²</td>
<td>P-value</td>
<td>rho</td>
<td>bootstrapped</td>
</tr>
<tr>
<td>\textit{T. esmarkii}</td>
<td>0.001</td>
<td>0.375</td>
<td>0.003</td>
<td>0.585</td>
<td>0.1%</td>
</tr>
<tr>
<td>\textit{C. monstrosa}</td>
<td>0.941</td>
<td>0</td>
<td>0.736</td>
<td>0.071</td>
<td>35.8%</td>
</tr>
<tr>
<td>\textit{T. murrayi} (WEST)</td>
<td>0.034</td>
<td>0.181</td>
<td>0.034</td>
<td>0.425</td>
<td>1.7%</td>
</tr>
<tr>
<td>\textit{L. decagonus}</td>
<td>0.024</td>
<td>0.204</td>
<td>0.009</td>
<td>-0.517</td>
<td>0.4%</td>
</tr>
<tr>
<td>\textit{R. cimbrius}</td>
<td>0</td>
<td>0.635</td>
<td>0.000</td>
<td>0.732</td>
<td>0.0%</td>
</tr>
<tr>
<td>\textit{I. bicornis}</td>
<td>0.847</td>
<td>0.002</td>
<td>(-0.847)</td>
<td>(-0.040)</td>
<td>(43.2%)</td>
</tr>
<tr>
<td>\textit{G. retrodorsalis}</td>
<td>0.782</td>
<td>0.003</td>
<td>0.952</td>
<td>0.013</td>
<td>47.8%</td>
</tr>
<tr>
<td>\textit{C. reinhardtii}</td>
<td>0.521</td>
<td>0.018</td>
<td>0.679</td>
<td>-0.087</td>
<td>34.4%</td>
</tr>
<tr>
<td>\textit{B.saida}</td>
<td>0.243</td>
<td>0.059</td>
<td>0.147</td>
<td>0.298</td>
<td>5.7%</td>
</tr>
<tr>
<td>\textit{A. atlanticus}</td>
<td>0.343</td>
<td>0.039</td>
<td>0.332</td>
<td>-0.202</td>
<td>16.9%</td>
</tr>
<tr>
<td>\textit{M. scorpius}</td>
<td>0</td>
<td>0.786</td>
<td>(0.000)</td>
<td>(-0.886)</td>
<td>(0%)</td>
</tr>
<tr>
<td>\textit{C. microps}</td>
<td>0.021</td>
<td>0.212</td>
<td>0.012</td>
<td>-0.501</td>
<td>0.6%</td>
</tr>
<tr>
<td>\textit{R. fyllae} (WEST)</td>
<td>0.017</td>
<td>0.225</td>
<td>0.002</td>
<td>0.458</td>
<td>0.5%</td>
</tr>
<tr>
<td>\textit{G. argentatus} (WEST)</td>
<td>0</td>
<td>0.521</td>
<td>0.000</td>
<td>0.722</td>
<td>0.0%</td>
</tr>
<tr>
<td>\textit{C. gurnardus}</td>
<td>0</td>
<td>0.826</td>
<td>0.000</td>
<td>0.943</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Catch Abundance Trends
<table>
<thead>
<tr>
<th>Species</th>
<th>Mean Temp (°C)</th>
<th>Abundance Trend</th>
<th>Latitude Trend</th>
<th>Longitude Trend</th>
<th>Temp Trend</th>
<th>Depth Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. esmarkii</td>
<td>5.9</td>
<td>+</td>
<td>N</td>
<td>W</td>
<td>+</td>
<td>+</td>
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<tr>
<td>C. monstrosa</td>
<td>6.1</td>
<td>+</td>
<td></td>
<td>+</td>
<td></td>
<td>+</td>
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<tr>
<td>T. murrayi (EAST)</td>
<td>1.5</td>
<td>+</td>
<td>S</td>
<td></td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>T. murrayi (WEST)</td>
<td>3.4</td>
<td>+</td>
<td></td>
<td>+</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>L. decagonus</td>
<td>0.6</td>
<td>-</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>R. cimbrius</td>
<td>4.4</td>
<td>+</td>
<td>N</td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>I. bicornis</td>
<td>2.4</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>G. retrodorsalis</td>
<td>1.0</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>C. reinhardtii</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. saida</td>
<td>1.0</td>
<td></td>
<td></td>
<td>W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. atlanticus</td>
<td>0.7</td>
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<td>S</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>M. scorpius</td>
<td>2.1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. microps</td>
<td>1.3</td>
<td></td>
<td>S</td>
<td>E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R. fyllae (WEST)</td>
<td>5.3</td>
<td>+</td>
<td></td>
<td>W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G. argentatus (EAST)</td>
<td>0.7</td>
<td></td>
<td>S</td>
<td>E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G. argentatus (WEST)</td>
<td>2.3</td>
<td>+</td>
<td>S</td>
<td>W</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>C. gurnardus</td>
<td>6.7</td>
<td>+</td>
<td></td>
<td>W</td>
<td>+</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Summary of major trends found in this study. Mean bottom temperature (Mean Temp (°C)) was used to classify species as colder (< 4°C) or warmer (> 4°C) water species. General trends in abundance, geographic centers, mean bottom temperatures and depth at which fish were found are indicated. Refer to text, figures and other tables for more detailed information.
Literature Cited


