Location, Location, Location: The Influence of Environmental Variables on Fish Species Composition in the Canadian Beaufort Sea

by

Brittany Lynn

Supervisor: Dr. James Reist

Committee Members: Dr. S. Forbes and N. Loadman

A thesis submitted in partial fulfillment

of the requirements of the

Biology Honours Thesis Course (05.4111/6)

Department of Biology

University of Winnipeg

Winnipeg, MB

2010

ABSTRACT

A multidisciplinary research cruise was conducted during each of the summers of 2003 to the present in an attempt to determine the composition of the ecosystem of the Beaufort Sea off the coast of Northern Canada. For the purposes of this study, sampling of fish and environmental variables at predetermined stations within transects extending offshore was undertaken. A total of 973 fish were examined in this study, collected in the Garry 2006, Kugmallit 2008, Garry 2009, and Dalhousie 2009 transects. This study sought to establish a baseline of environmental information and determine if there is a link between such information and fish species composition, specifically if differences in fish species composition among transects can be explained by the environmental variables considered. Environmental variables included in this study were depth of sampling, bottom salinity, temperature, oxygen concentration, and fluorescence. Fish found in the benthic zone of the Beaufort Sea were compared among stations to group those with similar species compositions. Non-parametric analyses of the relationship of species compositions and environmental variables for both, all stations as a whole, and within station groupings found to contain a similar fish species composition, illustrated similarity patterns in fish species composition and environmental variable data. However, a linkage analysis between the two similarity matrices determined that no one or subset of the environmental variables available and considered for this study explained the fish species composition at an acceptable and significant level. Before a conclusion can be made on the ability to predict fish species composition based on environmental data, more research needs to be done in the Beaufort Sea so that additional environmental variables can be analyzed to determine if they drive the species composition in the Beaufort Sea.

ACKNOWLEDGEMENTS

First of all, I would like to thank my supervisor, Dr. James Reist, for taking me on and assisting in setting up this project. His diligence in making sure I viewed the 'big picture' ensured this project was completed—and made sense! I would also like to thank Dr. Reist for introducing me to Andrew Majewski, whose knowledge and support were immensely appreciated throughout the past year or more. As well, the fact that they both gave me the opportunity to travel up north to the Beaufort Sea in September 2009 to take part in data collection—complete with a week at sea—is one adventure I will not soon forget!

I would also like to thank my committee members, Dr. Scott Forbes and Ms. Nancy Loadman, who provided valuable alternative viewpoints and support when it was most needed.

Finally, I would like to thank Dr. Wiegand for keeping me on track, being (or at least acting) interested, and having more faith in me and my work ethic than I sometimes had in myself.

TABLE OF CONTENTS

ABSTRACT……ii

ACKNOWLEDGEMENTS……iii

TABLE OF CONTENTS……iv

LIST OF TABLES……..vi

LIST OF FIGURES……vii

LIST OF APPENDICES……...…..……ix

LIST OF ACRONYMS……...xi

1.0 INTRODUCTION……..1

2.0 MATERIALS AND METHODS……...6

3.0 RESULTS……14

3.1 PATTERNS IN FISH SAMPLING DATA…….15

3.11 DOMINATING SPECIES…….15

3.12 ANALYSIS OF OVERALL PATTERNS OF SIMILARITY IN FISH SPECIES COMPOSITION AMONG STATIONS…...16

3.13 ORDINATION OF FISH SPECIES COMPOSITION…….....17

3.14 PROFILE OF SIMILAR SPECIES GROUPS…….....18

3.15 SPECIES CONTRIBUTIONS TO SIMILARITY AND DIFFERENCES WITHIN AND BETWEEN GROUPS…….20

3.2 THE ENVIRONMENT……...…22

3.21 RELATIONSHIPS BETWEEN ENVIRONMENTAL VARIABLES AND STATIONS…….22

3.3 RELATIONSHIP BETWEEN ENVIRONMENTAL VARIABLES AND FISH SPECIES COMPOSITION……25

4.0 DISCUSSION……..34

5.0 CONCLUSION…….……...…40

REFERENCES……...42

APPENDICES……....44

LIST OF TABLES

Table 1. List of scientific and common names corresponding to species codes of fish present in the catch for this study. Scientific and common names are sourced from Nelson, *et al.* (2004). Family classifications are sourced from Mecklenburg *et al.* (2002)……..…14

Table 2. Species contributions (%) to similarity within similar species composition groupings (Figures 4 and 5). For encoding of species, see Table 1.....23

Table 3. Species contributions (%) to dissimilarity between similar species composition groupings (Figures 4 and 5). For encoding of species, see Table 1…….……..23

Table 4. List of coefficients on environmental variables for the principal components analysis (PCA). Only two dimensions are necessary in this PCA, as they explain 77.5% of the variation in the environmental variables…….…….27

Table 5. List of the top 20 variable subsets resulting from the BIO-ENV analysis of all stations as a whole. A grey background indicates that the particular environmental variable is not included in the subset of environmental variables produced by the BIO-ENV analysis……..……...30

Table 6. List of the top 20 variable subsets resulting from the BIO-ENV analysis of Group A (Figure 5) in order of decreasing Spearman rank correlation coefficient level. A grey background indicates that the particular environmental variable is not included in the subset of environmental variables produced by the BIO-ENV analysis of this group.…….30

Table 7. List of the top 20 variable subsets resulting from the BIO-ENV analysis of Group B (Figure 5) in order of decreasing Spearman rank correlation coefficient level. A grey background indicates that the particular environmental variable is not included in the subset of environmental variables produced by the BIO-ENV analysis of this group. ……...….32

LIST OF FIGURES

Figure 1. Map of the Canadian Beaufort Sea……...1

Figure 2. Map of stations and transects sampled in the Beaufort Sea considered in this study…….8

Figure 3. Bar graph indicating the overall catch abundances of all species at all stations. For species encoding, see Table 1……..15

Figure 4. Multi-dimensional scaling (MDS) ordination of station species compositions. Stations are grouped according to their similarity levels, which are indicated by color (see legend at right). The groupings referred to in the analyses in this study are based upon a similarity level of 40%. ..……...18

Figure 5. Cluster analysis of station species composition. Stations are listed along the right. Similarity levels are indicated along the horizontal axis. Groupings of stations produced by this cluster analysis correspond with that of the multi-dimensional scaling ordination (MDS) (Figure 4). Red (i.e., lighter) lines indicate statistically significant groupings (SIMPROF) (PRIMER software, v. 6).…….....19

Figure 6. Correlation relationships among environmental variables based on the PCA of the average levels of the environmental variables at each station. The axes originating from the center of the plot correspond to an environmental variable……...…26

Figure 7. Similarity relationships among stations based on the PCA of the average levels of the environmental variables at all stations. The green star represents these stations: KUG 30m-08, KUG 50m-08, GRY 60m-06, GRY 65m-06, GRY 75m-06, and GRY 100m-06. The red star represents these stations: GRY 50m-09, GRY 100m-09, KUG 75m-08, KUG 100m-08, and DAL 100m-09. ……..……...27

Figure 8. Multi-dimensional scaling (MDS) ordination of the average levels of the environmental variables at all stations. The stations in the group signified by the red star are: GRY 50m-09, KUG 75m-08, KUG 100m-08, GRY 100m-09, and DAL 100m-09. The stations in the group signified by the green star are: GRY 65m-06, GRY 60m-06, KUG 50m-08, GRY 75m-06, GRY 45m-06, and GRY 100m-06. …….…...29

Figure 9. Multi-dimensional scaling (MDS) ordination of the subset of variables resulting from the BIO-ENV analysis of all the stations as a whole. The subset of variables includes salinity, oxygen concentration, fluorescence, and depth. The stations in the group signified by the red star are: GRY 45m-06, GRY 65m-06, and GRY 60m-06. The stations in the group signified by the green star are: KUG 50m-08 and GRY 75m-06……...…29

Figure 10. Average transformed levels of salinity (PSU) (Appendix 7) at a station illustrated by bubbles (directly proportional to those levels) overlaid on the initial MDS ordination of species composition (Figure 4). Note that salinity levels are reverse-logarithmically transformed (LOG(34-y), where y=observed salinity value). (Note: For example, 7E-2 = 35.175 PSU).....……..……31

Figure 11. Average transformed temperature levels (°C) (Appendix 7) at a station illustrated by bubbles (directly proportional to those levels) overlaid on the initial MDS ordination of species composition (Figure 4). Note that temperatures are logarithmically transformed (LOG(3+y), where y=observed temperature). (Note: For example, 7E-2 = -1.8251°C)……31

Figure 12. Average levels of oxygen concentration (mL/L) (Appendix 7) at a station illustrated by bubbles (directly proportional to those levels) overlaid on the initial MDS ordination of species composition (Figure 4)……...……32

Figure 13. Average levels of fluorescence (nm) (Appendix 7) at a station illustrated by bubbles (directly proportional to those levels) overlaid on the initial MDS ordination of species composition (Figure 4)……..…...33

Figure 14. Average depth (m) (Appendix 7) at a station illustrated by bubbles (directly proportional to those depths) overlaid on the initial MDS ordination of species composition (Figure 4)……...……33

LIST OF APPENDICES

Appendix 1. Photo of the CCGS *Nahidik*, the vessel used for the 2003-2009 NCMSP field seasons. (Photo courtesy of J. Jorgenson, DFO)……..…..44

Appendix 2(a). Pie charts depicting species abundances by station in the GRY 2006 transect, each colour representing a different fish species For species encoding, see Table 1…….…….....45

Appendix 2(b). Pie charts depicting species abundances by station in the KUG 2008 transect, each colour representing a different fish species. For species encoding, see Table 1……..……...46

Appendix 2(c). Pie charts depicting species abundances by station in the GRY 2009 transect, each colour representing a different fish species. For species encoding, see Table 1……..……...47

Appendix 2(d). Pie charts depicting species abundances by station in the DAL 2009 transect, each colour representing a different fish species. For species encoding, see Table 1…….48

Appendix 3. Fish catch abundances by station and species (continued on next page). Grey boxes indicate that none of that particular species were caught at that station. Total numbers for each station (along the bottom of this section of the table and the remaining section on the second page) and species (along the right side of the remainder of the table found on the second page) are also provided. For species encoding, see Table 1…….……...49/50

Appendix 4. The species proportions and their percentages of total catch numbers across all stations, transects, and years. For species encoding, see Table 1…….51

Appendix 5(a). Species composition of Group A (Figure 5). For species encoding, see Table 1…….....52

Appendix 5(b). Species composition of Group B (Figure 5). For species encoding, see Table 1……..….53

Appendix 5(c). Species composition of Group C (Figure 5). For species encoding, see Table 1……..……..54

Appendix 6(a). The contributions of each species to the dissimilarity in fish species compositions between Groups A and B (Figure 5). For species encoding, see Table 1……..……...……..55

Appendix 6(b). The contributions of each species to the dissimilarity in fish species composition between Groups A and C (Figure 5). For species encoding, see Table 1…….…….56

Appendix 6(c). The contributions of each species to the dissimilarity in fish species composition between Groups B and C (Figure 5). For species encoding, see Table 1……..….57

Appendix 7. List of the average levels of all of the environmental variables considered in this study, organized by station. Salinity values were reverse-logarithmically transformed (i.e., LOG(34-y), where y=observed value), while temperature values were logarithmically transformed (i.e., LOG(3+y)). (Mean ± SE)……..……..58

Appendix 8. Cluster analysis of species to illustrate those species which co-occur based on station catch. Stations are listed along the vertical axis, while similarity level is indicated along the horizontal axis. A lighter coloured line indicates a statistically significant grouping……59

Appendix 9. MDS ordination of the subset of environmental variables resulting from the BIO-ENV analysis of Group A (Figure 4)……60

Appendix 10. MDS ordination of the species compositions of the stations of Group A (Figure 4)……...61

Appendix 11. MDS ordination of the subset of environmental variables resulting from the BIO-ENV analysis of Group B (Figure 4)…….62

Appendix 12. MDS ordination of the species compositions of the stations of Group B (Figure 4)……...63

Appendix 13. Station benthic trawl (fish) sampling information. (Note: time is expressed in the 24-hour clock)……..64

Appendix 14. Station CTD logger (environmental) sampling information. (Note: time is expressed in the 24-hour clock)……..65

LIST OF ACRONYMS

BIO-ENV – Biota-Environmental Variable Rank Correlation

CCGS – Canadian Coast Guard Ship

CTD – Conductivity, Temperature, Depth

DAL 2009 – Dalhousie transect, sampled in 2009

DFO – Fisheries and Oceans Canada

GRY 2006 – Garry transect, sampled in 2006

GRY 2009 – Garry transect, sampled in 2009

KUG 2008 – Kugmallit transect, sampled in 2008

LOMA – Large Ocean Management Area

MDS – (non-metric) Multi-Dimensional Scaling

NCMSP – Northern Coastal Marine Studies Program

PCA – Principal Component Analysis

PSU – Practical Salinity Units

SIMPER – Similarity Percentages

1.0 INTRODUCTION

Interest in the Mackenzie Delta and nearshore Beaufort Sea (Figure 1) in the context of hydrocarbon development (e.g., oil and gas production) has resulted in increased industrial activity in the area (e.g., exploratory activities). Accordingly, there is an increased need to understand the environment and how it may be affected by such development. A specific aspect is how fishes in the Beaufort Sea might respond to fluctuations in temperature, salinity and other disturbances that may accompany this exploration. Temperature and salinity shifts may occur as a result of pollution of the water from oil spills (Oloruntegbe *et al.*, 2009). As well, the development of offshore drilling sites—which may include the creation of artificial islands—may

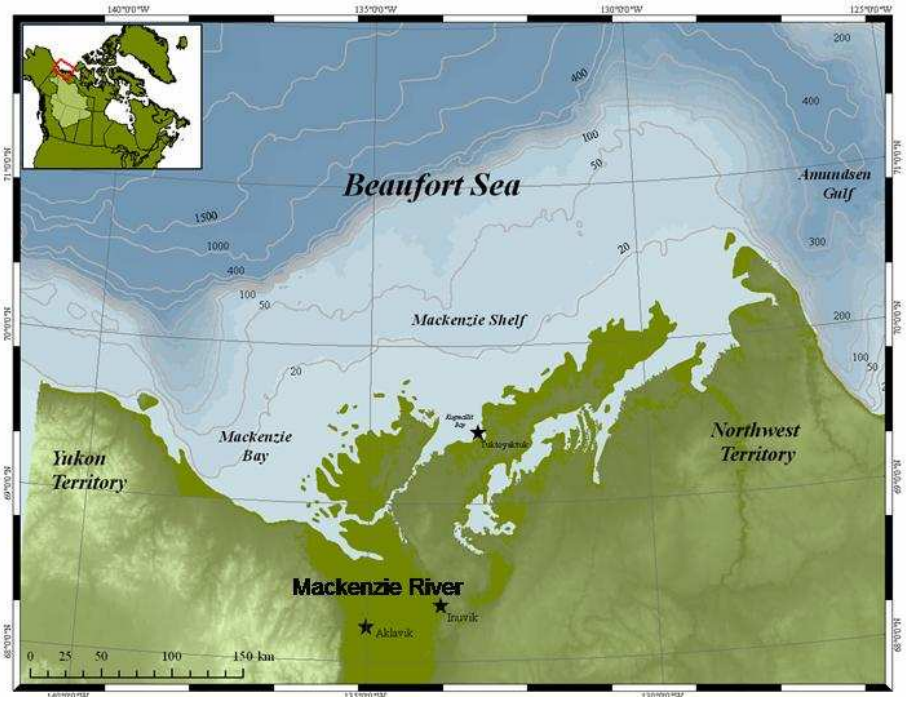


Figure 1. Map of the Canadian Beaufort Sea.

impact sediment, an environmental variable which has been found to influence fish species composition (Norcross *et al.*, 2009). Furthermore, the introduction of oil from oil spills into the

water has been known to reduce primary production in the immediate spill area (Percy *et al.* 1985). In terms of the impact on the food chain, fish are the least affected of all members. However, exposure to oil has been found to be toxic to many species and may cause shifts in the food chain (Percy *et al.*, 1985). The Beaufort Sea ecosystem (Figure 1) was studied by Fisheries and Oceans Canada (DFO) first during the late 1970s and early 1980s (Percy *et al.*, 1985), and recent effort has been conducted from 2003 to the present (Majewski *et al*. 2006, 2009a, 2009b). Note that the fish-related study within this thesis is only a subcomponent of a larger study on the Beaufort Sea ecosystem during the open water season.

Because the Beaufort Sea has largely remained undeveloped from both industrial/commercial and science perspectives, due in part to a short open water season and limited accessibility due to sea-ice, there is a poor understanding of ecosystem composition. To determine if the anthropogenic effects of oil exploration—which could hypothetically change the substrate and water column and thus lead to an impact in the ecosystem—documentation of the biodiversity of the Beaufort Sea is required to ensure a baseline of information is available. According to *The Beaufort Sea and the Search for Oil* series (1985), monitoring of this biodiversity will also help scientists associated with hydrocarbon development determine what areas are suitable for exploration, and allow them to track any changes that may occur with human activity through all levels of the ecosystem.

The Beaufort Sea ecosystem, as with any Arctic marine ecosystem, is influenced by environmental variables such as temperature, pH, dissolved oxygen, salinity, fluorescence, conductivity, turbidity, depth, sediment type, ice conditions, weather conditions (i.e., wind and wind-driven ocean currents), and many others. As with all living organisms, fish have differing

tolerance and preference levels for many of these variables. The Beaufort Sea is a dynamic environment, with different areas exhibiting different and highly varying levels of these environmental factors. Therefore, many fish that inhabit the Beaufort Sea either have extremely wide tolerances, or have the ability to choose an area that fulfills as many of their tolerance or preference levels as possible. Some of the species caught (for example: *Coregonus nasus* or Broad Whitefish) are anadromous, while some (i.e., *Boreogadus saida* or Arctic Cod, *Myoxocephalus quadricornis* or Fourhorn Sculpin, *Artediellus scaber* or Hamecon, etc.) will tolerate brackish waters. Still others, such as *Ulcina olrikii* (Arctic Alligatorfish), *Icelus spatula* (Spatulate Sculpin), *Liparis fabricii* (Gelatinous Seasnail), and *Lycodes polaris* (Canadian Eelpout) prefer high salinity marine waters (Mecklenburg *et al.*, 2002). Species encountered in the catch may also have depth preferences, some preferring shallower waters where, for example, temperatures are higher than further offshore. Others prefer the cool temperatures of the deep benthic zones. The purpose of this study is to determine if, because of the tolerance and preference levels fish species have for these environmental variables, these variables drive species composition.

The objective of this study was to determine if a relationship existed between the area's properties—both chemical and physical—and its fish species' composition, as well as to determine what relationships exist among sampling transects composed of stations. To explore this question, similarity relationships between stations based on fish species composition were established. Then, similarity relationships between the stations in regards to environmental variables were developed. Following that, a link between environmental variable and biotic data were formed by a rank correlation between their similarity matrices.

The general oceanography of the Beaufort Sea, as outlined by Carmack and Macdonald (2002), suggests that the Mackenzie River outflow influences the physical and chemical environment of the area surrounding the delta. The Mackenzie River and its freshwater plume may extend beyond the Mackenzie Delta into the offshore area of the Beaufort Sea dependent upon weather conditions such as wind. During the time when sampling occurred, inflows from the Mackenzie River dominate the surface waters of the plume region and thus there is a strong stratified surface layer at 5-10m. Also, at the time of sampling, the Mackenzie Shelf could still be mostly ice covered (Carmack and Macdonald, 2002).

Carmack and Macdonald (2002) describe the oceanography of the Mackenzie Shelf throughout the summer. At depths between 8 and 12 metres, the water column is well-mixed, with a range of salinities from 20 to 25 psu. Meanwhile, the outer boundary of the Mackenzie freshwater plume usually has a salinity range of 26-28 psu. Generally, the benthic area of the Mackenzie Shelf is described as being turbid, likely because of bottom re-suspension of sediment and associated nutrients. However, these patterns ignore any temporal variability in regards to wind, which can influence stratification and plume distribution. As well, complex patterns of nitrate and phosphate depletion across the shelf are apparent, and thus these nutrients usually govern the rate of primary production, along with ice cover. At low salinities within the plume, phosphate values are near zero (which is characteristic of nutrient-limited inland waters) and nitrate values are high, suggesting that either phosphate or light (or both) determine the rate of primary production in summer in this inland area of the Shelf. Meanwhile, farther offshore (at surface salinities of 26-30 psu), nitrate values are either near zero or relatively high (above 10 mmol m^{-3}). This suggests that in the middle and outer shelf regions, primary production is either

governed by light (when ice is present) or nitrate (when ice is absent) (Carmack and Macdonald, 2002).

As explained by both Carmack and Macdonald (2002) and the *Ecosystem Overview of the Beaufort Sea LOMA* (2006), this large river deposits millions of tonnes of silt and clay every year, and supplies the nearshore area with substantial amounts of freshwater and nutrients, producing a large brackish water area. The extent of the sediment deposition and freshwater flow, coupled with the largely pristine nature of the Beaufort Sea, make this ecosystem relatively unique in the world. Generally, the environment of the stations appears to be dependent upon depth and probably time of year; generally, a relationship between east-to-west orientation and benthic environment is not apparent. The Mackenzie River is a large contributor to the physical and chemical environment, but the Pacific, Atlantic and Arctic Ocean water masses also contribute to the environment of the Beaufort Sea. Thus, the fish composition of the Beaufort Sea possibly results from a mixture of fishes originating from any of these sources. Differences from east to west and nearshore to offshore could be due to the degree to which fish species from the Atlantic and Pacific oceans (east to west) were found in the area, the amount of turbidity (and associated low-salinity water) and benthic habitat differentiation associated with the Mackenzie outflow, and/or to upwelling events (nearshore to offshore).

Overall, this study sought to determine if differences in environmental variables and biota among transects located in the Beaufort Sea, and did so by analyzing the similarity relationships. Considering the influence of the Mackenzie freshwater plume, it is predicted that differences will exist from east to west for both variable types.

2.0 MATERIALS AND METHODS

Under DFO's Northern Coastal Marine Studies Program (NCMSP), fish were collected off the Canadian Coast Guard Ship (CCGS) *Nahidik* (Appendix 1) during the open water seasons (May to October) since 2003. A benthic beam trawl was used across all years and transects. The trawl was designed to sample—by use of a hydraulic boom and winch—from the Canadian Coast Guard Ship (CCGS) *Nahidik* (Appendix 1). The benthic trawl is three meters wide by an estimated two to three meters tall, dependent upon towing speed. Across all transects and years, a constant ship speed of around 1.03 m/s was maintained for the entire time length of sampling. Transects were chosen based on unique influences (e.g., sediment deposition) or topography (formed naturally or through anthropogenic activity). Fishing stations are located in the nearshore region of the Beaufort Sea, on the Mackenzie Shelf. The sampling transects were chosen by DFO based on unique influences (e.g., sediment deposition) or topography (formed naturally or through anthropogenic activity). The transects—composed of fishing stations—are organized to provide a depth gradient, extending from 10 to 100 meters depth. Again, recall that stations were named according to their transect location as well as depth and year of sampling.

The physical, chemical, and biological data analyzed in this study were collected in the Canadian Beaufort Sea during the months of July and August of the years 2006, 2008, and 2009. Though sampling has occurred every summer from 2003 to 2009, the transects analyzed herein were included based on their proximity to the Mackenzie River to determine if the freshwater and sediment that constitute the outflow of this river impact the fish diversity of the Mackenzie River Delta and Beaufort Sea, as well as because their sampling stations naturally supported contrast

because of their depth gradient, extending offshore. Sampling stations are labelled according to their transect, sampling depth, and sampling year (Figure 3).

Based on environmental information gathered from these transects, a description of these areas was formed. Once that profile was available, fish catch data were analyzed to construct species compositions of each of the defined areas.

The species compositions of all the 21 stations considered were analyzed to determine which stations are similar by statistical ordination. Once the stations were grouped according to species similarities, their environmental variables were statistically analyzed—again by statistical ordination methods—to determine if the stations with similar species compositions were also similar physically and chemically. Statistical analysis of which species contributed to the similarity within the similar species groupings and which species served to distinguish one grouping of similar species composition from another were also performed. A rank correlation between the ordinations was then calculated to explore which environmental variable (or subset of environmental variables) best explained the similarity patterns in fish species composition. Species compositions of stations were investigated to determine which species were present and dominated the catch, as well as which species whose presence or relative abundance allowed for discrimination between the groups formed by the ordination based on station species similarity.

In 2006, fishing efforts were conducted at nine sampling stations in the nearshore region of the Mackenzie Delta. Station depths ranged from 10 to 100 meters. The transect used in this study from 2006 was named the Garry Transect, based on its proximity to Garry Island, NT (Figure 3). This transect is located on the western edge of the major influence of the Mackenzie River.

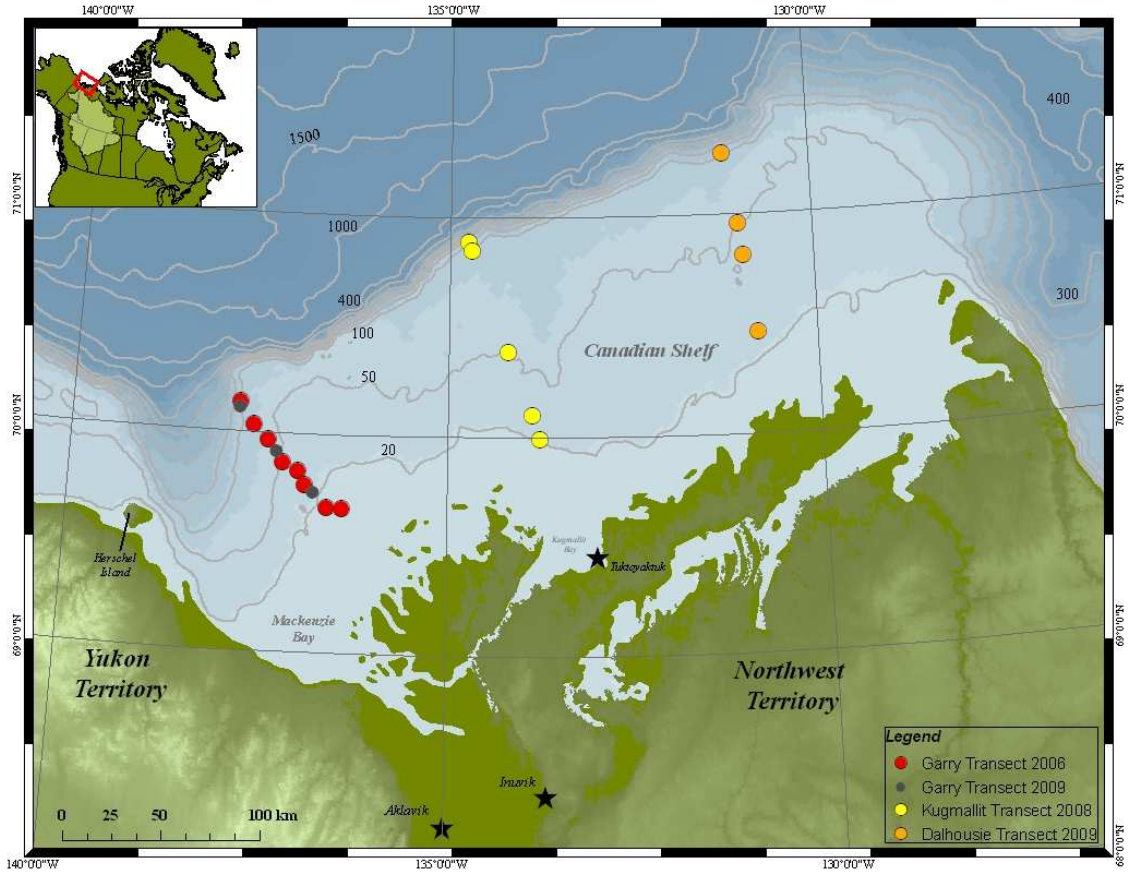


Figure 2. Map of stations and transects sampled in the Beaufort Sea considered in this study. Each colour corresponds to a different transect, while each circle represents a sampling station.

Note: the naming convention used herein for individual stations along transects for each year is as in the following example: GRY 20m-08; that is, Garry Transect, 20m depth station in 2008.

In 2008 stations were chosen extending offshore. The name of the transect sampled in this year and considered for this study, the Kugmallit Transect, was based on its proximity to Kugmallit Bay, which is close to where the most shallow (and nearshore) station is located. Sampling depths of the Kugmallit 2008 (KUG 2008) stations ranged from 20 to 100 meters (Figure 3). Five stations were analyzed in the KUG 2008 transect. This transect is located east of the Mackenzie River and is expected to experience significant influence from the Mackenzie

River. This is because, in absence of any strong winds from the east, the earth's rotation (the Coriolis Effect) will cause the outflow of the Mackenzie River to drift eastwards. As well, the Beaufort Undercurrent serves to move the waters of this area eastward along the shoreline (Carmack and Macdonald, 2002). Kugmallit Canyon has also been described as a potential site for nutrient upwelling events. Therefore, it was predicted that transects located east of the Mackenzie River (the Kugmallit transect and the Dalhousie transect to a lesser extent) would be the transects influenced the greatest by the Mackenzie River freshwater and sediment plume.

Two transects from 2009 were included in this study. These were the Garry Transect—located in the same area as in 2006—and the Dalhousie Transect. The four stations located in the Garry Transect of 2009 range from a depth of 20 to 100 meters. Similar to 2006, this transect was located west of the Mackenzie River, and is the closest transect to the mouth of the Mackenzie River. The Dalhousie Transect's three stations also ranged from 20 to 100 m depths. This transect is located east of the Mackenzie River, and is the most easterly transect considered in this study. The influence of the Mackenzie River plume on this transect is expected to be less than that experienced in the Kugmallit transect.

Differences in the length and number of tows at some stations analyzed were found, culminating in differences in sampling effort. Upon analysis of the fish abundances between trawl tows at a single station, it was found that there was no statistical pattern in fish catch related to tow number. Also, there was an inconsistency in the number of tows performed at a station, ranging from one to three. These differences were taken into account when analyzing the fish catch data by standardizing by total number of fishes captured to reduce the species abundances at a station to a proportion (expressed as a percentage) of its total catch. As well, to ensure that

species which are found at a lower abundance are still contributing to the biotic profile, a logarithmic transformation was performed on the standardized fish abundances. Following those pre-treatments, a cluster analysis and multi-dimensional scaling (MDS) ordination were performed on the data to illustrate the similarities between stations in regards to fish species composition based on Bray-Curtis similarity coefficients calculated for each contrast (PRIMER software, v. 6).

Since the MDS ordination of station species composition tell us that differences do exist, a SIMPER (similarity percentages; PRIMER software, v. 6) analysis among groups with similar species composition formed by the initial MDS investigates what species' presence and abundance contribute to the dissimilarity among the stations found in the MDS ordination.

Physical and chemical parameters used to describe the environment at each station were obtained using a Sea-Bird 19 Plus CTD profiler. This instrument was used to measure many variables in the Beaufort Sea, but only a subset were considered for analysis in this study based on conclusions from a previous study examining similar hypotheses and located in a similar geographic area (Norcross *et al.*, 2009), as well as hypotheses considered by this study itself. Use of this profiler usually occurred soon after trawling. The only exception is in the case of the KUG 30m-08 station, in which sampling of the environmental variables took place three days prior to fish sampling.

The physical and chemical environments of the stations were analyzed using data from the CTD logger (conductivity, temperature, and depth). The environmental variables included in the analyses were salinity (PSU or practical salinity units), temperature (°C), oxygen concentration (mL/L), and fluorescence (nm) assessed over depths. Salinity, temperature, depth

(which is related to the first two), and oxygen concentration were included in this study because fish have tolerance and/or preference levels for these which are expected to influence their distribution. Meanwhile, fluorescence was included in this study because it could act as a proxy for productivity as it may predict zooplankton, ichthyoplankton, and phytoplankton levels (which were unavailable for analysis in this study, but are expected to influence fish species composition in some way) because fluorescence measures light emission by plankton species. While the CTD logger sampled the entire water column every 0.5 meters, the analyses herein only consider the data from the bottom 2m sampled. This is to ensure environmental sampling parallel to the portion of water sampled by the benthic trawl with fishing swath of about 2m above the bottom. The data from the bottom 2m of the water column at an analyzed station were averaged (i.e., four samples separated by 0.5m vertical increments). This station average was compared with those for other stations/groups.

Draftsman plots of the environmental variables found that temperature values tended to be right-skewed, while salinity values were left-skewed. To allow for approximate normality in these data—which makes computation of variances and an approximate normal distribution possible, which is preferred before an ordination analysis is performed —transformations are required. To correct the left-skewness, a log transformation was performed on the temperature data, while a reverse-logarithmic (inverse-logarithmic) transformation of the salinity data was performed to correct the right-skewness (Clarke and Warwick, 2001). Consideration of these transformations should be given when analyzing the relationships between the variables.

To determine the similarity relationships in environmental variables between stations, a PCA analysis was performed on the data (PRIMER software, v. 6). A PCA, or principal

component analysis, illustrates the similarity relationships between the different stations based on the normalized matrix of environmental variable data. The environmental data were normalized in order to allow for comparison of data of different measurement scales. Each axis of the PCA is constructed from the set of the variables with the highest ability to explain the variance. This means that the components of principal component one (PC1) will explain most of the variation in environmental variables between the stations, while PC2 will explain less of the variation, PC3 (if necessary) will explain less of the variation, and so on. Thus PCA is used to determine which environmental variable, or subset of environmental variables, explain(s) the groupings of stations based on the similarity/dissimilarity of their environments.

Because examination of the groupings produced by both methods of ordination (PCA and MDS) based on their environmental data indicates that there is no apparent difference between the two methods, an MDS of the environmental variables was also performed, based on Euclidean distances. Confidence that an MDS of environmental variables paints an accurate picture of similarity between the stations is essential so as to allow for linkage of the environmental variables and fish species composition (BIO-ENV; discussed later). While the PCA provides insight into what environmental variables are contributing the most to the similarity in environment between the stations, an MDS of the environmental variables of the stations produces a clearer indication of the similarity between the stations because of its better distance preservation (Clarke and Warwick, 2001), with shorter MDS-distances being indicative of a higher similarity.

To determine if there is a link between fish species presence and environmental variables, a procedure known as BIO-ENV was performed (PRIMER software, v. 6). In this procedure,

rank correlations were calculated between similarity matrices of species composition (based on Bray-Curtis similarity indices) and environmental variables (based on Euclidean distances). By attempting to maximize the rank correlation between MDS ordinations of both the fish catch and environmental data, this procedure produced a subset of environmental variables that best explains the similarity in fish species diversity between stations. The resulting subset of environmental variables can be considered to predict fish species presence to a greater extent than any other of the variables. The confidence that this subset of environmental variables determines the similarity of fish species composition between the stations is proportional to the level of correlation between the subset of environmental variables and the fish composition of the stations.

Before the BIO-ENV can be performed, however, an analysis of the correlation among the environmental variables must first be considered. Because the environmental variable data has a normal distribution, a Pearson's product moment correlation analysis can be performed among the environmental variables. For any variables found to be directly correlated, all but one of them would be removed from the BIO-ENV analysis so as to simplify the investigation of the rank correlation.

An MDS based strictly on the subset of environmental variables determined by the BIO-ENV analysis was produced. This was contrasted with the initial MDS of species composition to visually determine if the same patterns are visible in both ordinations. BIO-ENV analyses were also performed within similar species groupings to determine if the subset of variables produced differed from that of the overall BIO-ENV analysis.

3.0 RESULTS

Fish catch at the stations in the Canadian Beaufort Sea analyzed by this study are dominated by one to three species. Interestingly, the only *Agonidae* species found in the fish catch, *Ulcina olrikii* (Arctic Alligatorfish), makes up a large proportion of the overall

Table 1. List of scientific and common names corresponding to species codes of fish present in the catch for this study. [a]Scientific and common names are sourced from Nelson, *et al.* (2004). [b]Family classifications are sourced from Mecklenburg, *et al.* (2002).

Species Code	[a]Scientific Name	[a]Common Name	[b]Family
ARAF	*Ulcina olrikii* (Lütken, 1876)	Arctic Alligatorfish	Agonidae
ARCD	*Boreogadus saida* (Lepechin, 1774)	Arctic Cod	Gadidae
AREP	*Lycodes reticulatus* (Reinhardt, 1835)	Arctic Eelpout	Zoarcidae
ARSS	*Gymnocanthus tricuspis* (Reinhardt, 1830)	Arctic Staghorn Sculpin	Cottidae
BDWF	*Coregonus nasus* (Pallas, 1776)	Broad Whitefish	Salmonidae
CAEP	*Lycodes polaris* (Sabine, 1824)	Canadian Eelpout	Zoarcidae
DBSH	*Leptoclinus maculatus* (Fries, 1838)	Daubed Shanny	Stichaeidae
FHSC	*Myoxocephalus quadricornis* (Linnaeus, 1758)	Fourhorn Sculpin	Cottidae
FSDR	*Gymnelus viridis* (Fabricius, 1780)	Fish Doctor	Zoarcidae
GLSS	*Liparis fabricii* (Krøyer, 1847)	Gelatinous Seasnail	Liparidae
HAME	*Artediellus scaber* (Knipowitsch, 1907)	Hamecon	Cottidae
KPSF	*Liparis tunicatus* (Reinhardt, 1837)	Kelp Snailfish	Liparidae
LFLS	*Eumicrotremus derjugini* (Popov, 1926)	Leatherfin Lumpsucker	Cyclopteridae
PAEP	*Lycodes pallidus* (Collett, 1879)	Pale Eelpout	Zoarcidae
PLEP	*Lycodes turneri* (Bean, 1879)	Polar Eelpout	Zoarcidae
RBSC	*Triglops pingelii* (Reinhardt, 1837)	Ribbed Sculpin	Cottidae
SPSC	*Icelus spatula* (Gilbert & Burke, 1912)	Spatulate Sculpin	Cottidae
SHSC	*Myoxocephalus scorpius* (Linnaeus, 1758)	Shorthorn Sculpin	Cottidae
SLEB	*Lumpenus fabricii* (Reinhardt, 1836)	Slender Eelblenny	Stichaeidae
STEB	*Anisarchus medius* (Reinhardt, 1837)	Stout Eelblenny	Stichaeidae
TSEP	*Lycodes rossi* (Malmgren, 1865)	Threespot Eelpout	Zoarcidae
THSC	*Icelus bicornis* (Reinhardt, 1840)	Twohorn Sculpin	Cottidae
Icelus sp.			Cottidae
Stichaeidae sp. (yoy)			Stichaeidae
Stichaeidae sp.			Stichaeidae
Liparidae sp. (yoy)			Liparidae
Liparidae sp.			Liparidae
Cottidae sp.			Cottidae
Cyclopteridae sp.			Cyclopteridae
Lamprey*	*Lampetra camtschatica* (Tilesius, 1811)	Arctic Lamprey	Petromyzontidae
Lycodes sp.			Zoarcidae

fish catch abundance (see section 3.11 and Figure 4). A full description of species as proportions of the total catch abundance can be found in Section 3.11, while species as proportions of the catch abundance of stations within a transect can be found in Appendix 2.

3.1 PATTERNS IN FISH SAMPLING DATA

3.11 DOMINANT SPECIES

When considering all stations, Arctic Cod had the highest catch abundance with 247 specimens, or approximately 25% of the total catch (Figure 3, Appendix 4). The second highest catch abundance was shared by both Stout Eelblenny and Arctic Alligatorfish with 104 specimens each, or approximately 11% of the total catch. On the opposite end of the spectrum, only one specimen of each of *Lycodes reticulatus* (Arctic Eelpout), *Coregonus nasus* (Broad Whitefish), *Leptoclinus maculatus* (Daubed Shanny), *Myoxocephalus quadricornis* (Fourhorn

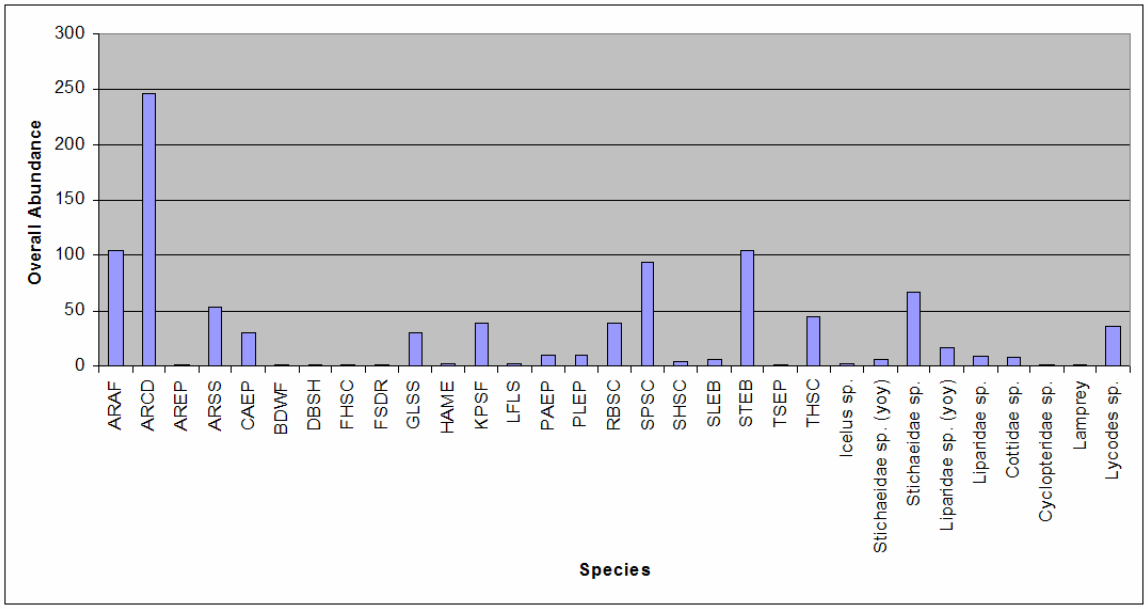


Figure 3. Bar graph indicating the overall catch abundance of each species at all stations. A total of 973 fish were caught across all stations, transects, and years. For species encoding, see Table 1.

Sculpin), *Gymnelus viridis* (Fish Doctor), *Lycodes rossi* (Threespot Eelpout), *Cyclopteridae* sp., and *Lampetra camtschatica* (Arctic Lamprey) were caught across all stations and all years. More in-depth analyses of species differences between stations and similar station groups are discussed

below in SIMPER analyses, a secondary analysis to the MDS of fish species composition discussed in section 3.13.

Transects differed with respect to the species compositions with the highest relative abundances. The two species with the highest catch abundance across the GRY 2006 transect are Arctic Cod at a proportion of ~38% of the total catch and Stout Eelblenny at ~20% (total catch number for GRY 2006 is 484). The two species with the highest catch abundance across the KUG 2008 transect are *Icelus spatula* (Spatulate Sculpin) at a proportion of ~23% of the total catch, followed by *Stichaeidae* sp. at ~22% of the total catch (total catch number for KUG 2008 is 307). For GRY 2009, the two species with the highest catch abundance are the Arctic Alligatorfish and *Liparidae* sp. (yoy), which both comprise ~20% of the total catch (total catch number for GRY 2009 is 87). Finally, the two species with the highest catch abundance across the DAL 2009 transect are the Arctic Alligatorfish at a proportion of ~32% of the total catch within this transect, followed by *Icelus bicornis* (Twohorn Sculpin) at ~16% of the total catch (total catch number for DAL 2009 is 95).

3.12 ANALYSIS OF OVERALL PATTERNS OF SIMILARITY IN FISH SPECIES COMPOSITION AMONG STATIONS

Fish species compositions (based on abundance) by station are presented visually in Appendix 2 and numerically in Appendix 3. Differences in species composition among stations are depicted in the MDS ordination of species compositions (Figure 5).

The species composition of the GRY 2006 stations appears to be dominated by *Boreogadus saida* (Arctic Cod) and *Anisarchus medius* (Stout Eelblenny) (Appendices 2(a) and 3).

Of all transects, KUG 2008 appears to contain the most variation in its catch among its stations (Figure 5 and Appendices 2(b) and 3).

The GRY 2009 transect (Appendix 2(c) and Appendix 2) station catch numbers were low in comparison to the catches of the earlier years, especially that of GRY 2006. Arctic Cod and Arctic Alligatorfish were found at all stations in varying abundances. Finally, focusing on the DAL 2009 transect, Arctic Cod and *Lycodes* sp. were the only species and family level classification found in the catch of all stations. As was the case in GRY 2009, sampling of this transect in this year produced lower catch numbers than the earlier years. Similar to KUG 2008, the stations of this transect also had a lot of variability in their fish species composition. Again, for a list as well as a visual representation of the species proportions (%) of catch by station in the DAL 2009 transect, see Appendices 2(d) and 3.

3.13 ORDINATION OF FISH SPECIES COMPOSITION

Analysis of the similarity of species' compositions for all stations at a 40% similarity level produced three groups (Figure 4). One group (Group A) contains the shallower GRY 2006 stations (i.e., < 45m). A second group (Group B) is composed of the entire KUG 2008 and DAL 2009 stations, along with the deeper (i.e., > 60m) GRY 2006 stations and GRY 50m-09. Meanwhile, a third group (Group C) contains the remainder of the GRY 2009

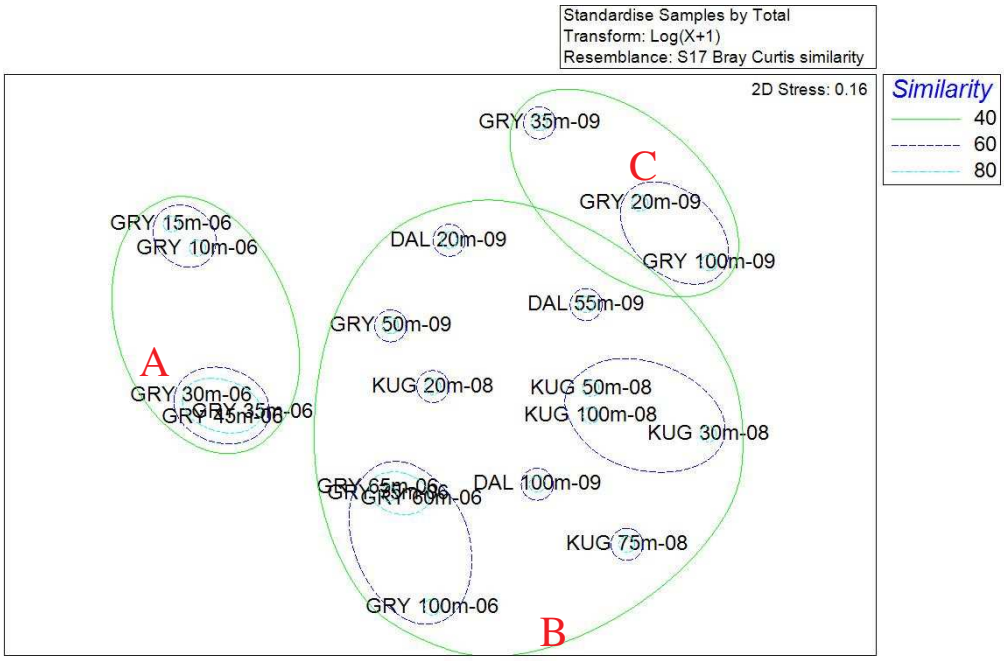


Figure 4. Multi-dimensional scaling (MDS) ordination of station species compositions. Stations are grouped according to their similarity levels, which are indicated by color (see legend at right). The groupings referred to in the analyses in this study are based upon a similarity level of 40%.

stations: GRY 20m-09, GRY 35m-09, and GRY 100m-09. The information obtained from the MDS was reinforced by a cluster analysis (Figure 5), where the species abundances were given the same logarithmic transformation pre-treatment as the MDS. The same clustering of stations based on Bray-Curtis similarity indices was illustrated in the cluster analysis as in the MDS ordination (Figures 4 and 5).

3.14 PROFILE OF SIMILAR SPECIES GROUPS

A total of 973 fish were caught representing at least 23 species from eight families (as well as a single Arctic Lamprey specimen) (Table 1). The uncertainty in the number of species—thus forcing classification to only the family level—was due to either juvenile specimens being

too young to properly identify to species level, or specimens were damaged beyond identification in the trawl net. In Group A (Figure 4), three species constituted approximately 73% of the total catch by number. The catch of this group was dominated by (measured in proportion of total catch) Stout Eelblenny at approximately (~)30% of the total catch, followed by Arctic Cod (~29%), and *Gymnocanthus tricuspis* (Arctic Staghorn Sculpin) (~14%). For a list of the species composition of Group A, see Appendix 5(a).

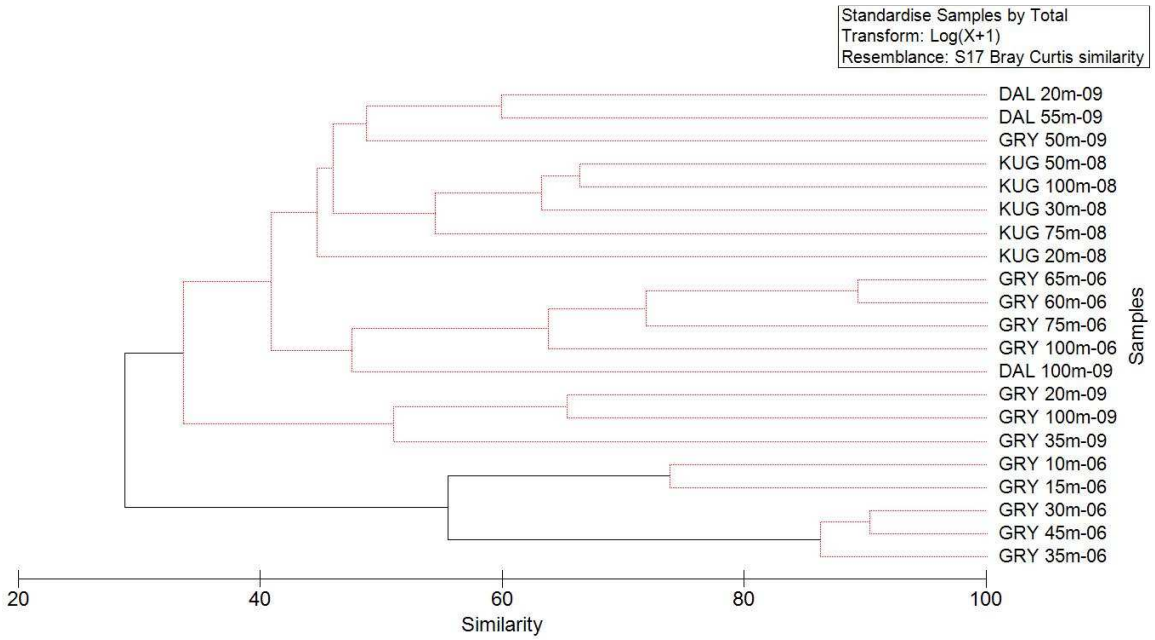


Figure 5. Cluster analysis of station species composition. Stations are listed along the right. Similarity levels are indicated along the horizontal axis. Groupings of stations produced by this cluster analysis correspond with that of the multi-dimensional scaling ordination (MDS) (Figure 4). Red (i.e., lighter) lines indicate statistically significant groupings (SIMPROF) (PRIMER software, v. 6).

In Group B (Figure 4), five species constitute approximately 70% of the total catch by number. This proportion of the catch of this group was composed of Arctic Cod (~26%), followed by Spatulate Sculpin (~14%), Arctic Alligatorfish (~14%), *Stichaeidae* sp. (~10%), and

Liparis tunicatus (Kelp Snailfish) (~6%). For a list of the species composition of Group B, see Appendix 5(b).

In Group C (Figure 4), two species and two family level classifications make up approximately 70% of the total catch abundance. This proportion of the catch of this third group was composed of *Liparidae* sp. (young-of-the-year or yoy) (~25%), followed by Arctic Alligatorfish (~22%), *Liparidae* sp. (~13%), and *Lycodes turneri* (Polar Eelpout) (~10%). For a list of the species composition of Group C, see Appendix 5(c).

3.15 SPECIES CONTRIBUTIONS TO SIMILARITY AND DIFFERENCES WITHIN AND BETWEEN GROUPS

A SIMPER analysis of species composition within a group illustrated in Figure 4 identifies which species contribute to the similarity within the station groups (i.e., which species presence/abundance determined whether the stations would group together). The species contributing to approximately 80% of the similarity within these groups (by use of a dummy variable) are listed in Table 2. Because Arctic Cod are present at all stations, its contribution to similarity is based on its abundance at the stations.

Within Group A, four species contribute to approximately 84% of the similarity. Arctic Cod contribute the most to the similarity between the stations found in this first grouping at a level of ~30% contribution. The Arctic Staghorn Sculpin follows at a contribution of ~23%, *Lycodes polaris* (Canadian Eelpout) at ~21%, then the Stout Eelblenny at ~10%. For a complete list of species contributions to similarity within Group A, see Table 2.

Within Group B, five species account for approximately 77% of the similarity among the stations. Again, Arctic Cod contribute the most to the similarity between the stations within the similar species composition grouping, at a level of ~23% contribution. Spatulate Sculpin follow at a contribution of ~20%, Arctic Alligatorfish at ~19%, *Lycodes* sp. at ~9%, and Twohorn Sculpin at ~6%. For a complete list of species contributions to similarity within Group B, see Table 2.

Within the final group, Group C, two species and two family-level classifications account for approximately 79% of the similarity among the stations. *Lycodes* sp. contributes the most to the similarity between the stations found in this similar species grouping, at a contribution level of ~24%. *Ulcina olrikii* follows at ~22% contribution, Arctic Cod at ~22% as well, then *Liparidae* sp. at ~11%. For a complete list of the species contributions to similarity within Group C, see Table 2.

While the species listed above contributed to the similarity between the station groups formed by the Bray-Curtis similarity indices, it is interesting to note which species' presence or (absence) and abundance distinguished one group from another. A SIMPER analysis provides this information. When comparing the species compositions of groups A and B, five species account for approximately 64% of the dissimilarity between the station groupings. The difference in abundance of Arctic Cod contribute approximately 19% to the dissimilarity between groups A and B. Stout Eelblenny also contribute ~19%, Arctic Alligatorfish ~9%, Arctic Staghorn Sculpin ~9% as well, and Canadian Eelpout to ~8% of the dissimilarity between the groups. The species that account for the remaining dissimilarity between groups A and B can be found in Table 3.

When comparing the species compositions of groups A and C, four species account for approximately 59% of the dissimilarity. Differences in Arctic Cod contribute to about 20% of the dissimilarity between the groups. Stout Eelblenny contribute to ~19%, Arctic Staghorn Sculpin ~11%, and Canadian Eelpout to ~9% of the dissimilarity between groups A and C. The remaining 19 species and 8 family-level classifications account for the rest of the dissimilarity between groups A and C (Table 3).

Finally, when comparing the species compositions of groups B and C, three species and three family level classifications contribute to approximately 62% of the dissimilarity between them. Again, differences in Arctic Cod contribute the most to the dissimilarity, at a level of ~17%. Arctic Alligatorfish contribute to ~12%, Spatulate Sculpin ~11%, *Liparidae* sp. (yoy) ~10%, *Liparidae* sp. ~6%, and *Stichaeidae* sp. also to ~6% of the dissimilarity between groups B and C. The remaining 20 species and 5 family-level classifications account for the rest of the dissimilarity between groups B and C (Table 3).

3.2 THE ENVIRONMENT

3.21 RELATIONSHIPS BETWEEN ENVIRONMENTAL VARIABLES AND STATIONS

As is expected of oceans, stratification did occur. Surface waters were less saline than the benthic zone. Salinities in the area studied ranged from 29-33 psu, while surface salinities ranged from 5-28 psu. Temperature stratification was also present, with the surface waters being more

Table 2. Species contributions (%) to similarity within similar species composition groupings (Figures 4 and 5). For encoding of species, see Table 1.

	Species Codes																				
Group	ARAF	ARCD	AREP	ARSS	BDWF	CAEP	DBSH	FHSC	FSDR	GLSS	HAME	KPSF	LFLS	PAEP	PLEP	RBSC	SPSC	SHSC	SLEB	STEB	TSEP	THSC
A	0.02	30.44	0.02	23.18	0.02	20.84	0.02	0.02	0.02	2.84	0.02	0.02	0.02	6.83	0.02	0.02	0.71	0.02	0.02	9.76	0.02	5.00
B	19.27	23.21	0.02	2.01	0.02	0.2	0.02	0.02	0.03	4.84	0.03	4.52	0.03	0.02	0.58	6.18	19.84	0.02	0.02	1.33	0.02	6.42
C	22.16	21.75	0.04	0.06	0.04	0.04	0.04	0.05	0.04	0.04	0.04	0.04	0.04	0.04	8.26	0.04	0.04	0.04	5.97	0.04	0.04	0.04

	Family Level Classifications & Non-Fish Species								
Group	*Icelus* sp.	*Stichaeidae* sp. (yoy)	*Stichaeidae* sp.	*Liparidae* sp. (yoy)	*Liparidae* sp.	*Cottidae* sp.	*Cyclopteridae* sp.	*Lampetra camtschatica*	*Lycodes* sp.
A	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
B	0.13	0.12	2.37	0.02	0.02	0.03	0.03	0.03	8.60
C	0.04	0.04	0.04	0.06	11.08	5.82	0.04	0.04	23.89

Table 3. Species contributions (%) to dissimilarity between similar species composition groupings (Figures 4 and 5). For encoding of species, see Table 1.

	Species Codes																				
Group Contrast	ARAF	ARCD	AREP	ARSS	BDWF	CAEP	DBSH	FHSC	FSDR	GLSS	HAME	KPSF	LFLS	PAEP	PLEP	RBSC	SPSC	SHSC	SLEB	STEB	TSEP	THSC
A vs. B	10.05	5.41	0.50	9.85	1.00	10.48	0.50	0.01	0.37	4.64	1.22	4.75	0.60	5.46	1.52	5.15	8.17	1.02	1.50	9.06	0.50	5.49
A vs. C	11.41	4.81	0.01	8.87	0.88	9.83	0.01	2.16	0.01	2.54	0.88	0.01	0.01	4.79	6.76	0.01	1.92	0.01	4.53	8.30	0.01	4.93
B vs. C	6.17	5.44	0.51	4.04	0.01	0.73	0.51	2.48	0.38	4.81	0.38	4.79	0.60	0.01	7.34	5.18	9.93	1.03	5.35	3.08	0.51	4.87

	Family Level Classifications & Non-Fish Species								
Group Contrast	*Icelus* sp.	*Stichaeidae* sp. (yoy)	*Stichaeidae* sp.	*Liparidae* sp. (yoy)	*Liparidae* sp.	*Cottidae* sp.	*Cyclopteridae* sp.	*Lampetra camtschatica*	*Lycodes* sp.
A vs. B	0.89	0.77	3.88	0.01	0.01	0.55	0.41	0.22	6.01
A vs. C	0.01	0.01	0.01	5.17	8.34	4.63	0.01	0.01	9.14
B vs. C	0.89	0.77	3.9	5.93	9.54	5.16	0.42	0.22	5.04

dynamic and ranging from as low as -1°C to as high as +14°C, and benthic waters being more steady and ranging from approximately -2°C to +1°C. Oxygen concentration levels stayed within a range from 6-8 mL/L throughout the water column, while fluorescence values varied greatly according to the transect; GRY 2006 fluorescence values gradually got lower with increasing depth; KUG 2008 and GRY 2009values increased into the mid-water (pelagic) zone then decreased closer to the bottom; DAL 2009 fluorescence values overall gradually got higher with increasing depth.

The similarity in environmental variable levels between stations was depicted in a principal components analysis (PCA) with two principal component axes (Figure 6). The first principal component axis (PC1) explains 53.9% of the variation in the samples, and the second principal component axis (PC2) explains 23.9% of the variation in the samples (Table 4). The cumulative level of "% variance explained"—at 77.5%--is an acceptable level to conclude that the relationship between the stations based on their environmental variables can be explained by two axes of the PCA (Clarke and Warwick, 2001). The coefficients in the linear combination of the first axis (PC1) indicate that the variation in environment between the stations was found to be influenced by all environmental variables measured: salinity coefficient = (-0.522), temperature coefficient = (-0.334), oxygen concentration coefficient = (-0.462), fluorescence coefficient = (-0.343), and depth coefficient = (0.535). This means that a large proportion of the variation in environmental variable data is explained by the five environmental variables considered in this study, further proving that no correlations exist between the variables. The second axis (PC2), which explains slightly less of the variation than the components of PC1, is associated with fluorescence (coefficient = -0.747). This suggests that slightly less of the

variation in environmental variable data explained by the components of PC1 is explained by the fluorescence data.

In the PCA of the environmental variables (Figure 6), two groups are apparent. The first group includes the stations KUG 50m-08, GRY 100m-06, GRY 75m-06, GRY 65m-06, and GRY 60m-06. The other group resulting from their similarity in environmental variables included stations GRY 50m-09, KUG 75m-08, GRY 100m-09, DAL 100m-09, and KUG 100m-08.

Because inspection of an MDS ordination—based on Euclidean distances to depict similarity relationships—of the environmental variables found that the stations are grouping in the same way as they did in the PCA of environmental variables, we can be confident that this is the true similarity relationship of the environmental variables of the stations (Figures 6 & 8). This concordance is important because the analysis used to explore the linkage of environmental data to biotic data (as discussed below) requires an MDS of the environmental variables. An MDS depicts the similarity relationships between the stations more clearly, as its distance preservation is much greater than that of PCA.

3.3 RELATIONSHIP BETWEEN ENVIRONMENTAL VARIABLES AND FISH SPECIES COMPOSITION

The rank correlation analysis between the similarity matrices of the environmental variable data and fish catch data (BIO-ENV; PRIMER software, v. 6) revealed that the subset of variables including salinity, oxygen concentration, fluorescence, and depth best group the sites in a manner consistent with the fish species composition similarity patterns at a correlation level of 0.409 (Table 5). The MDS ordinations of fish species

compositions (Figure 4) and environmental variables (Figure 8) were visually quite different; therefore the inclusion of all environmental variables which were considered in this study indicated little visual similarity between the two ordinations. The next most prominent subset of environmental variables to explain the similarity patterns in fish species composition is the subset of salinity, fluorescence, and depth at a correlation level of 0.408. The subset of only salinity, oxygen concentration, and fluorescence predict slightly less of the pattern, with a correlation level of 0.395. Because there is no direct correlation between the variables, these results can be accepted. However, in Table 5,

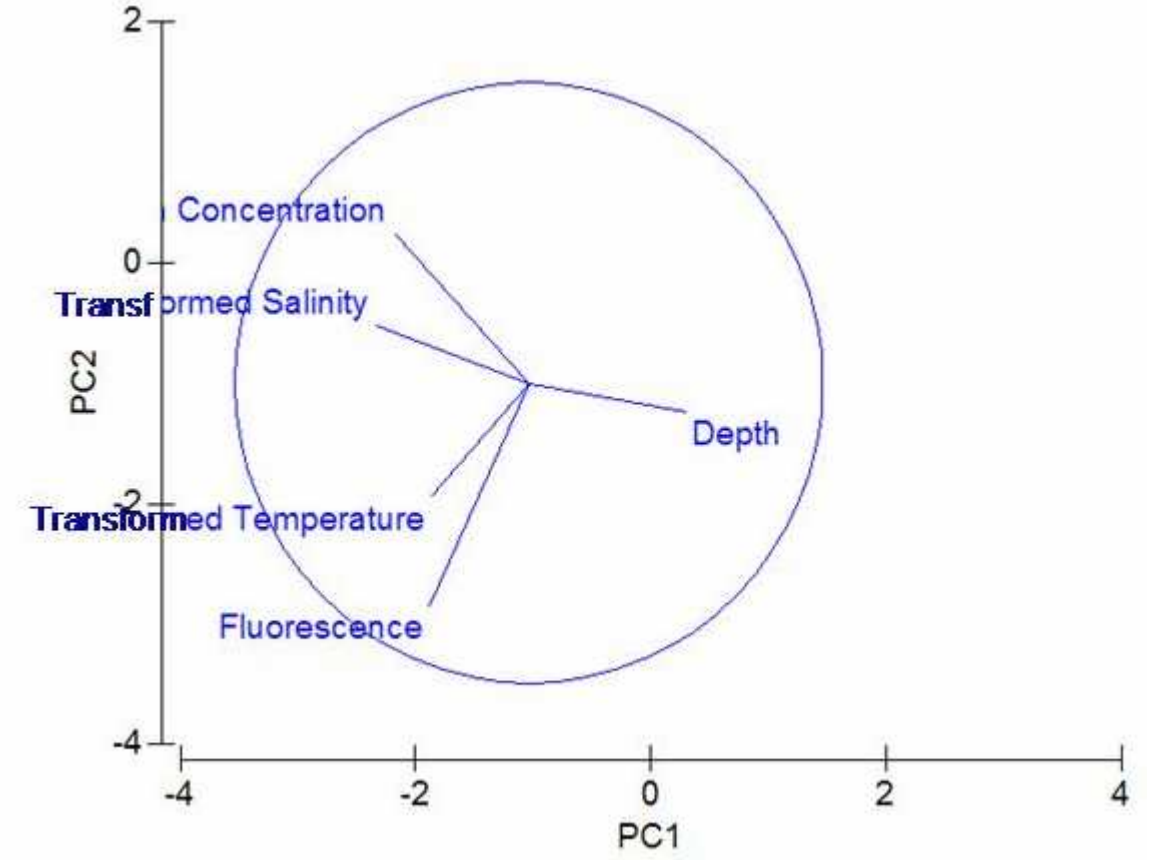


Figure 6. Correlation relationships among environmental variables based on the PCA of the average levels of the environmental variables at all stations. The axes originating from the center of the plot correspond to an environmental variable.

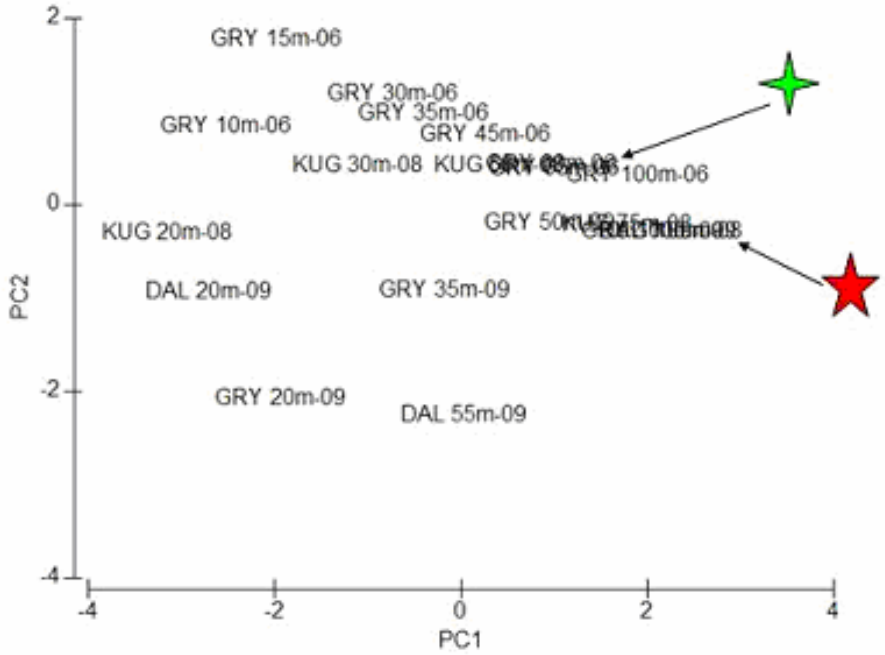


Figure 7. Similarity relationships among stations based on the PCA of the average levels of the environmental variables at all stations. The green star represents these stations: KUG 30m-08, KUG 50m-08, GRY 60m-06, GRY 65m-06, GRY 75m-06, and GRY 100m-06. The red star represents these stations: GRY 50m-09, GRY 100m-09, KUG 75m-08, KUG 100m-08, and DAL 100m-09.

Table 4. List of coefficients on environmental variables for the principal components analysis (PCA). Only two dimensions are necessary in this PCA, as they explain 77.5% of the variation in the environmental variables.

	Principal Component			
Variable	**PC1**	**PC2**	**PC3**	**PC4**
Transformed Salinity	-0.522	0.194	-0.276	-0.136
Transformed Temperature	-0.334	-0.384	0.810	0.216
Oxygen Concentration	-0.462	0.498	0.290	-0.523
Fluorescence	-0.343	-0.747	-0.331	-0.401
Depth	0.535	-0.099	0.274	-0.707

note that the subsets of variables which best explain the patterns in similarity of fish species composition, signified by the eight highest Spearman rank correlation values, all include salinity. Rank correlation of the environmental variables and species composition were also performed within similar species groups formed from the initial MDS of

species composition. The subsets of variables found to best explain the patterns in similarity of species composition within Group A were salinity and oxygen concentration (0.806) as well as oxygen concentration, fluorescence, and depth (0.806) (Table 6). The MDS of stations in Group A based on these subsets of variables alone can be found in Appendix 9.

For Group B, the subset of variables found to best explain the similarity patterns of species composition of these stations was temperature and fluorescence (0.399) (Table 7). An MDS ordination of stations in Group B based on this subset of environmental variables alone can be found in Appendix 10. The set of variables that next best explains the similarity patterns is fluorescence alone at a correlation of 0.387. A rank correlation for Group C is impossible because of the small number of stations in the group.

To further examine both the fish catch and environmental data visually to determine if the similar species groupings are indeed produced because of some direct relationship between one of the variables, bubbles corresponding to the level of the environmental variable at that station are overlaid on the initial MDS of species composition (Figures 10-14). The similar station groupings produced by the MDS ordination of environment did not appear to be explained by any single environmental variable overlaid as bubbles related to their level at the station.

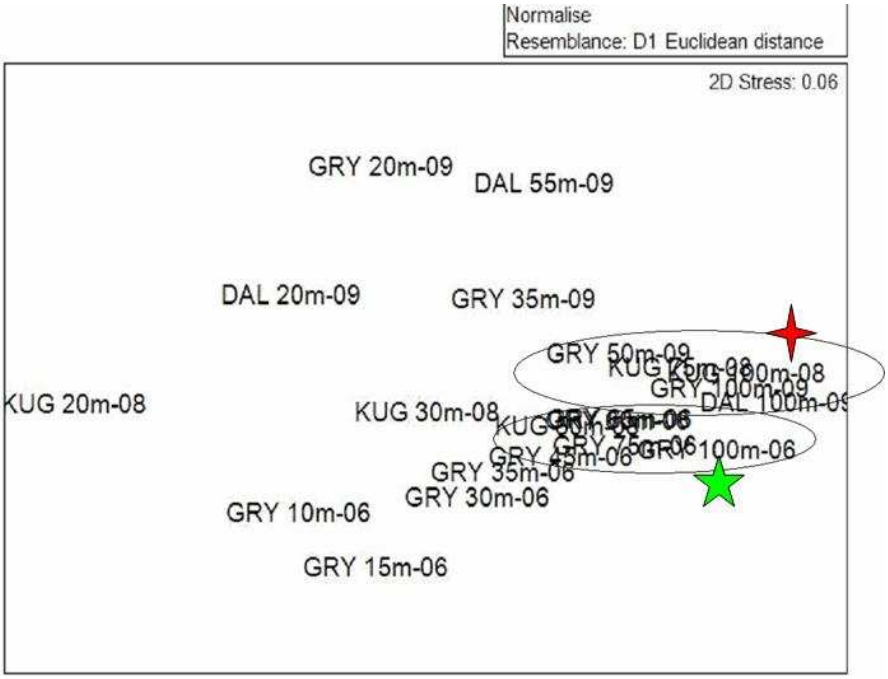


Figure 8. Multi-dimensional scaling (MDS) ordination of the average levels of the environmental variables at all stations. The stations in the group signified by the red star are: GRY 50m-09, KUG 75m-08, KUG 100m-08, GRY 100m-09, and DAL 100m-09. The stations in the group signified by the green star are: GRY 65m-06, GRY 60m-06, KUG 50m-08, GRY 75m-06, GRY 45m-06, and GRY 100m-06.

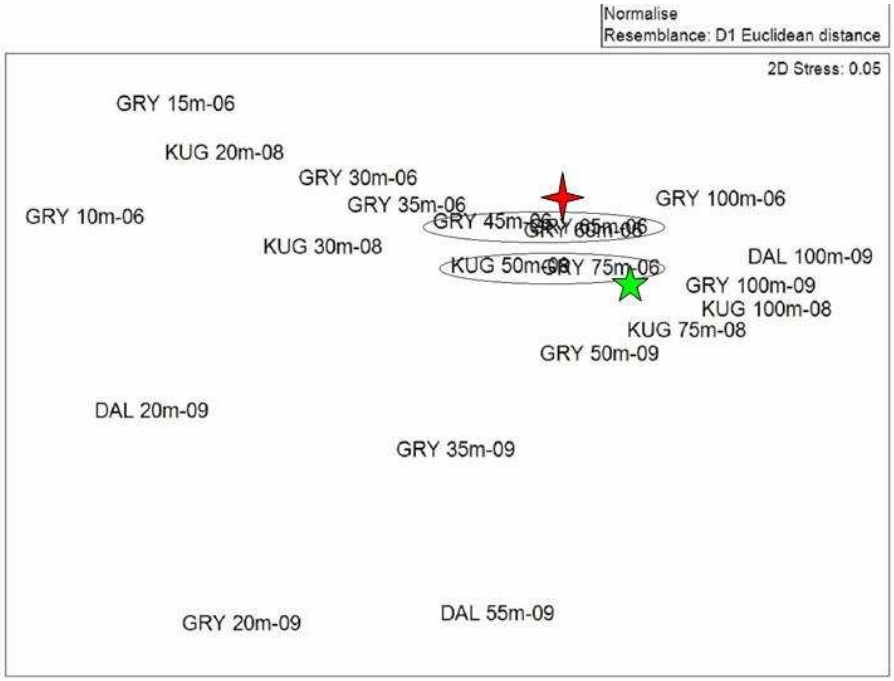


Figure 9. Multi-dimensional scaling (MDS) ordination of the subset of variables resulting from the BIO-ENV analysis of all the stations as a whole. The subset of variables includes salinity, oxygen concentration, fluorescence, and depth. The stations in the group signified by the red star are: GRY 45m-06, GRY 65m-06, and GRY 60m-06. The stations in the group signified by the green star are: KUG 50m-08 and GRY 75m-06.

Table 5. List of the top 20 variable subsets resulting from the BIO-ENV analysis of all stations as a whole. A grey background indicates that the particular environmental variable is not included in the subset of environmental variables produced by the BIO-ENV analysis.

Subset	# of Variables	Spearman Correlation Coefficient	Variables in Subset				
			Salinity	Temperature	Oxygen Concentration	Fluorescence	Depth
1	4	0.409	Yes	No	Yes	Yes	Yes
2	3	0.408	Yes	No	No	Yes	Yes
3	3	0.395	Yes	No	Yes	Yes	No
4	2	0.39	Yes	No	No	Yes	No
5	2	0.375	Yes	No	Yes	No	No
6	3	0.363	Yes	No	Yes	No	Yes
7	3	0.362	No	No	Yes	Yes	Yes
8	5	0.361	Yes	Yes	Yes	Yes	Yes
9	2	0.35	No	No	No	Yes	Yes
10	4	0.346	Yes	Yes	No	Yes	Yes
11	4	0.341	Yes	Yes	Yes	No	Yes
12	3	0.341	Yes	Yes	Yes	No	No
13	3	0.337	Yes	Yes	Yes	Yes	No
14	4	0.324	No	No	Yes	No	Yes
15	2	0.321	Yes	Yes	No	No	No
16	2	0.318	Yes	Yes	No	Yes	No
17	1	0.315	Yes	No	No	No	No
18	3	0.315	No	Yes	Yes	No	Yes
19	4	0.315	No	Yes	Yes	Yes	Yes
20	2	0.314	No	No	Yes	Yes	No

Table 6. List of the top 20 variable subsets resulting from the BIO-ENV analysis of Group A (Figure 4) in order of decreasing Spearman correlation level. A grey background indicates that the particular environmental variable is not included in the subset of environmental variables produced by the BIO-ENV analysis of this group.

Subset	# of Variables	Spearman Correlation Coefficient	Variables in Subset				
			Salinity	Temperature	Oxygen Concentration	Fluorescence	Depth
1	2	0.806	Yes	No	Yes	No	No
2	3	0.806	No	No	Yes	Yes	Yes
3	3	0.794	Yes	No	Yes	No	Yes
4	1	0.77	Yes	No	No	No	No
5	4	0.77	Yes	Yes	Yes	No	Yes
6	2	0.758	No	No	Yes	No	Yes
7	3	0.758	Yes	No	Yes	Yes	No
8	4	0.758	Yes	No	Yes	Yes	Yes
9	2	0.721	Yes	No	No	No	Yes
10	2	0.697	No	No	Yes	Yes	No
11	3	0.697	Yes	Yes	Yes	No	No
12	5	0.697	Yes	Yes	Yes	Yes	Yes
13	3	0.685	Yes	No	No	Yes	Yes
14	3	0.685	No	Yes	Yes	No	Yes
15	4	0.685	Yes	Yes	Yes	Yes	No
16	3	0.661	Yes	Yes	No	No	Yes
17	1	0.648	No	No	No	No	Yes
18	2	0.648	Yes	Yes	No	No	No
19	2	0.636	Yes	No	No	Yes	No
20	3	0.636	Yes	Yes	No	Yes	No

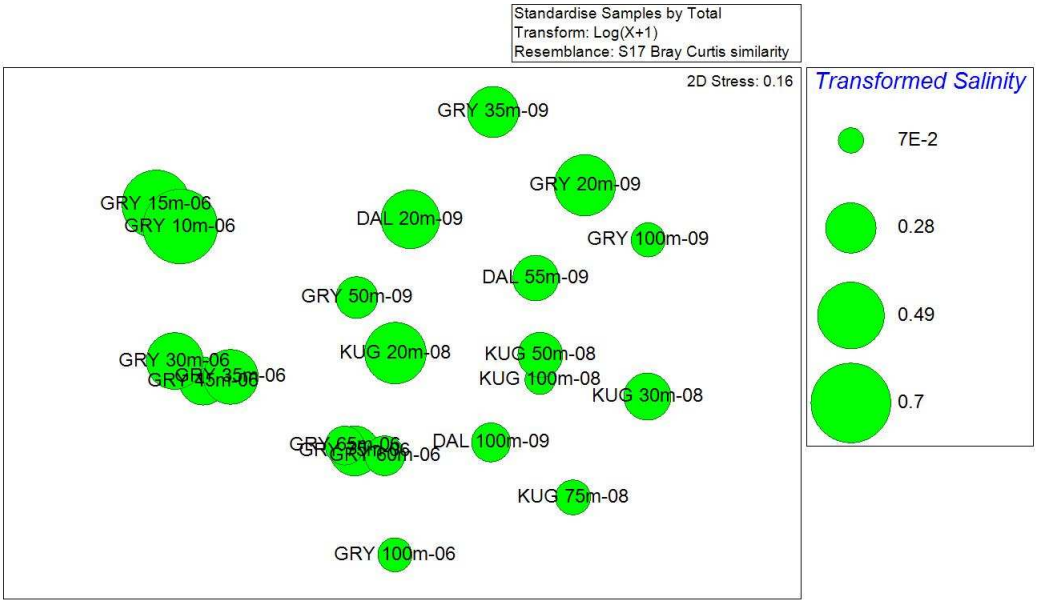


Figure 10. Average transformed levels of salinity (PSU) (Appendix 7) at a station illustrated by bubbles (directly proportional to those levels) overlaid on the initial MDS ordination of species composition (Figure 5). Note that salinity levels are reverse-logarithmically transformed (LOG(34-y), where y=observed salinity value). (Note: For example, 7E-2 = 35.175 PSU)

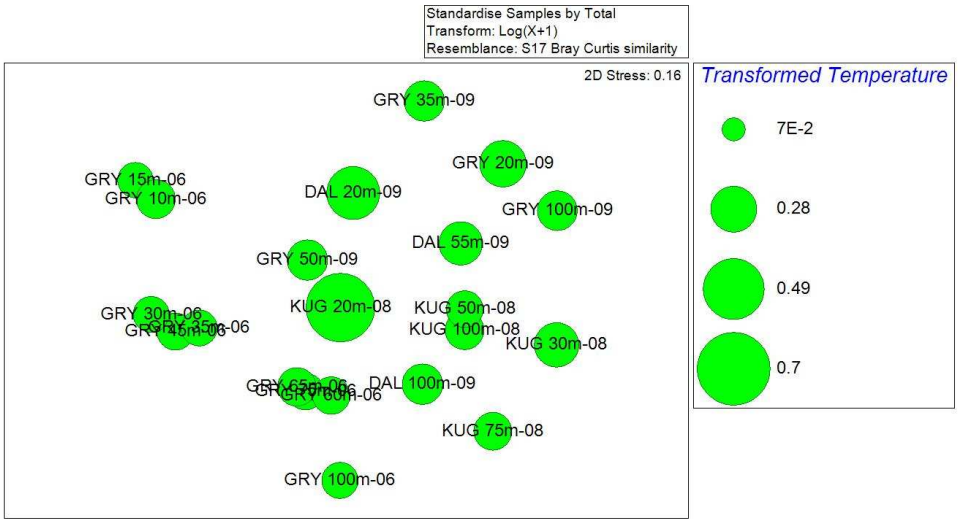


Figure 11. Average transformed temperature levels (°C) (Appendix 7) at a station illustrated by bubbles (directly proportional to those levels) overlaid on the initial MDS ordination of species composition (Figure 5). Note that temperatures are logarithmically transformed (LOG(3+y), where y=observed temperature). (Note: For example, 7E-2 = -1.8251°C)

Table 7. List of the top 20 variable subsets resulting from the BIO-ENV analysis of Group B (Figure 4) in order of decreasing Spearman correlation level. A grey background indicates that the particular environmental variable is not included in the subset of environmental variables produced by the BIO-ENV analysis of this group.

Subset	# of Variables	Spearman Correlation Coefficient	Variables in Subset				
			Salinity	Temperature	Oxygen Concentration	Fluorescence	Depth
1	2	0.399	No	Yes	No	Yes	No
2	1	0.387	No	No	No	Yes	No
3	1	0.372	No	Yes	No	No	No
4	4	0.359	Yes	No	Yes	Yes	Yes
5	3	0.358	Yes	No	No	Yes	Yes
6	3	0.353	No	No	Yes	Yes	Yes
7	3	0.349	No	Yes	No	Yes	Yes
8	2	0.346	No	No	No	Yes	Yes
9	4	0.341	No	Yes	Yes	Yes	Yes
10	2	0.336	Yes	No	No	No	Yes
11	5	0.336	Yes	Yes	Yes	Yes	Yes
12	4	0.335	Yes	Yes	No	Yes	Yes
13	3	0.324	Yes	No	Yes	No	Yes
14	2	0.323	No	Yes	No	No	Yes
15	3	0.322	No	Yes	Yes	Yes	No
16	2	0.319	Yes	No	No	Yes	No
17	3	0.317	Yes	No	Yes	Yes	No
18	2	0.315	No	No	Yes	Yes	No
19	3	0.315	Yes	Yes	No	No	Yes
20	4	0.314	Yes	Yes	Yes	No	Yes

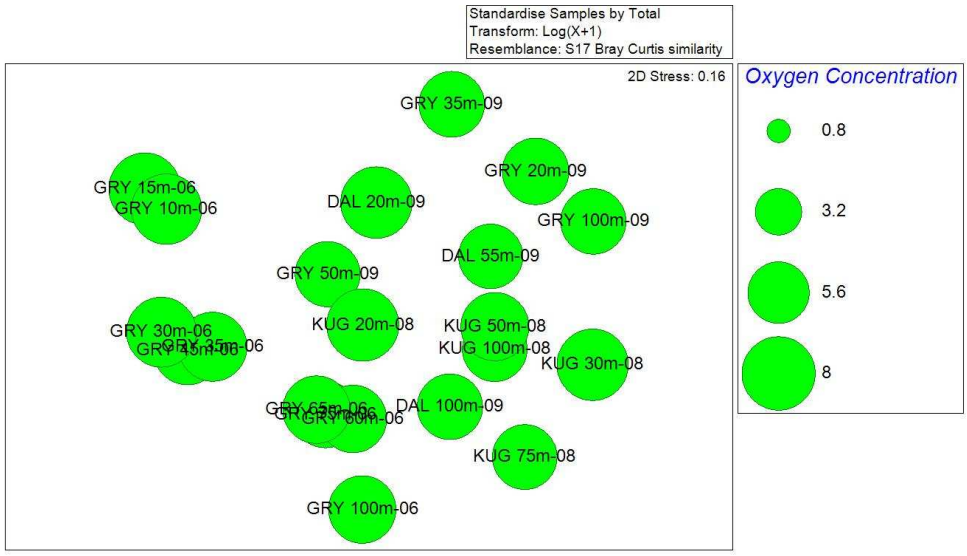


Figure 12. Average levels of oxygen concentration (mL/L) (Appendix 7) at a station illustrated by bubbles (directly proportional to those levels) overlaid on the initial MDS ordination of species composition (Figure 4).

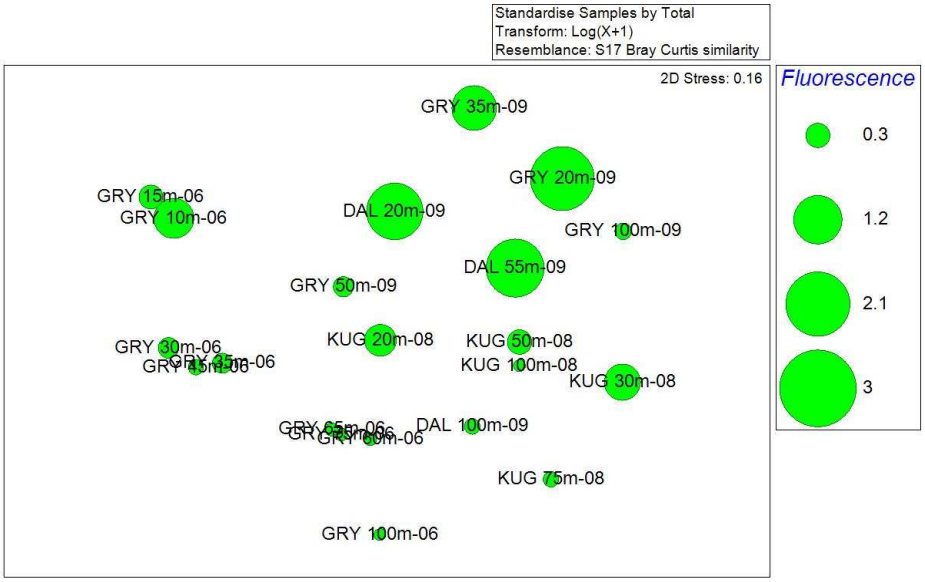


Figure 13. Average levels of fluorescence (nm) (Appendix 7) at a station illustrated by bubbles (directly proportional to those levels) overlaid on the initial MDS of species composition (Figure 4).

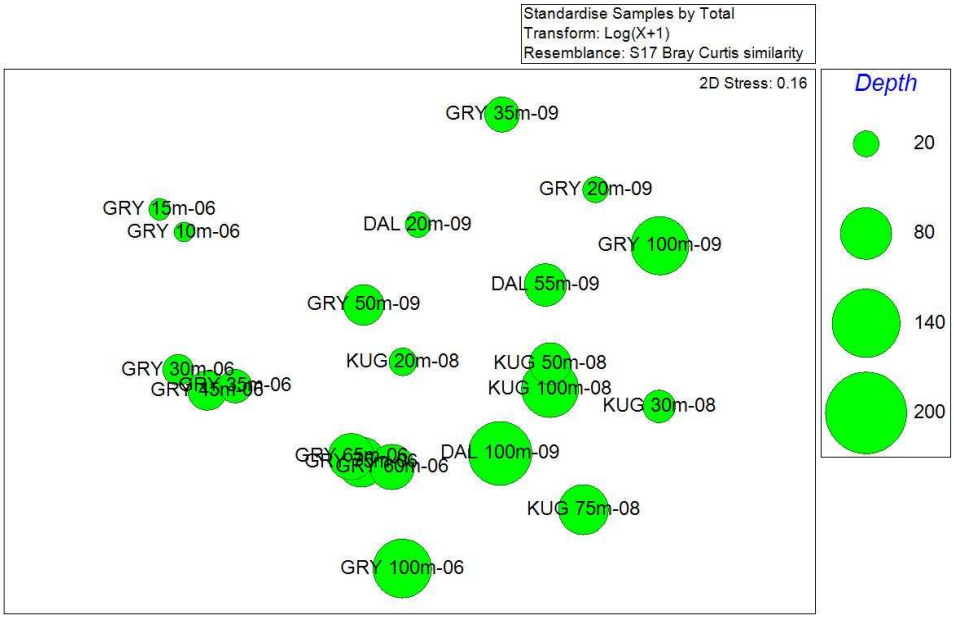


Figure 14. Average depth (m) (Appendix 7) at a station illustrated by bubbles (directly proportional to those depths) overlaid on the initial MDS of species composition (Figure 5).

4.0 DISCUSSION

The Arctic marine ecosystem is complex and largely unexplored due to the severity of weather conditions, presence of ice and high costs of research. This study establishes a baseline of information on fish species diversity and composition in the area of the Beaufort Sea studied. Additionally, this work attempts to develop an initial understanding of linkages between oceanographic factors which might determine the composition of fishes in particular areas, thus providing a predictive tool. As the Beaufort Sea has the potential for oil and gas development, an understanding of how such development might affect habitat conditions (i.e., oceanographic conditions) and thus the fish populations is important in order for habitat managers to effectively conserve the delicate ecosystem. Also, because productivity is affected by oceanographic conditions, the linkage between environment and fish species composition is an important avenue of investigation of anthropogenic impacts. Also, as explained by Percy *et al.* (1985), the dynamic nature of major influences on this environment such as the freshwater output of the Mackenzie River, its estuary, and the Arctic Ocean all produce fluctuations in salinity, temperature, ice, the availability of prey, and the presence of predators. These factors require that the fish species inhabiting these waters be flexible in terms of their "life-style"; in other words they must exhibit wide tolerances and preferences for specific niche and environmental variable levels.

The MDS ordination of the fish species composition suggests that depth may have some influence on the pattern of similarity. Specifically, the separation of the shallower stations of the GRY 2006 transect—from 10 to 45 meters depth—and nearly the entire DAL 2009 transect—the 100 meter, 35 meter, and 20 meter stations—from the remainder

of the stations, all suggest that depth may explain some of the differences in species composition between the stations.

Overlaying the levels of each of the environmental variables on the initial MDS of species composition does not suggest that the stations are grouping according to a single variable. The environmental variables considered for this study were based on conclusions from a previous study examining similar hypotheses and located in similar geographical areas (Norcross *et al.*, 2009) as well as hypotheses considered by this study alone. The investigation of which, if any, of the environmental variables influence fish species composition is important as this could allow for predictions of how changes in the environment, in particular due to oil and gas development, will impact the fish biota. The BIO-ENV procedure, which calculates a rank correlation between the MDS ordinations of fish species composition and environmental variables, found that salinity, oxygen concentration, fluorescence, and depth best explain the patterns of similarity in fish species composition among the stations. The confidence that this subset of environmental variables drive/determine the similarity of fish species compositions among the stations is proportional to the level of correlation between the subset of environmental variables and the fish species composition of the stations. Reducing the environmental variable MDS ordinations to include only those environmental variables selected by the BIO-ENV procedure to "best" explain the similarity in fish species composition did not result in a better visual correlation with the MDS of the fish species compositions (Figure 9). This conclusion is further supported by the low 0.409 Spearman rank correlation between the ordinations, which is far from a perfect correlation. This suggests that the environmental variables included in this study are not the only ones that drive (or can drive) the fish species composition. Rather, as found by Norcross *et al.* (2009), sediment type could

explain much of the similarity of fish species composition. This is because some fish will associate with a certain type of sediment. This may be to take advantage of the prey types associated with it, or to bury themselves within the substrate for protection or predation. Another possible explanation for the inconclusive result in linking environmental variables to fish species composition is that environment alone does not fully explain the patterns of fish species composition. That is, ichthyoplankton, zooplankton, and phytoplankton distributions may play a significant role. Patterns of ichthyoplankton which respond to additional environmental variables than those examined here may also influence survival and, thus, the species composition of older fishes. Additionally, the distribution of older fish captured in this study may also result from patterns in their sources of food (e.g., zooplankton and phytoplankton). The contribution of the environmental components to the ecosystem should be considered in the analysis of similarity patterns in fish species composition. Given the result of the rank correlation analysis, which found that fluorescence was one of the environmental variables to best explain the similarity patterns in the MDS of fish species composition, further investigation of the influence of this parameter (which may indirectly measure zooplankton and phytoplankton abundances) on fish species composition is worth considering.

In the MDS of fish species composition (Figure 4), it was apparent that the stations were grouping according to similarity which resulted in separation nearly by transect. The MDS ordination of environmental variables, however, did not exhibit grouping by transect. Therefore, while differences in species composition did exist among transects, those differences can not be explained by the environmental variables in this

study since the stations did not group by transect when analyzing the stations based on environmental variables alone.

When rank correlations were performed within similar species composition groups formed from the initial MDS of all stations, the pattern in the subsets of environmental variables found to best explain the *overall* patterns of similarity in the initial MDS did not align with the results of the BIO-ENV analysis *within* the groups. While salinity, oxygen concentration, fluorescence, and depth were found to best explain the overall similarity patterns of species composition (0.409), salinity and oxygen concentration alone were found to best explain the similarity in species composition within Group A (0.806). Also, the Spearman rank correlation for the subset of variables best explaining the similarity relationships between the stations was much higher within Group A based on its BIO-ENV analyses (0.806 when considering only salinity and temperature, and again 0.806 when considering oxygen concentration, fluorescence, and depth) than the highest Spearman rank correlation for the subset of environmental variables best explaining the similarity patterns in species composition over all stations (0.409 when considering salinity, oxygen concentration, fluorescence, and depth). This difference may be explained by the fact that the initial BIO-ENV analysis considers the overall similarity patterns, while the BIO-ENV analyses performed at the similar species composition groupings level considers only the similarity patterns within those groups. The subset of variables produced by the BIO-ENV analysis for Group A explains why these stations group together, but not why they separate from the stations of Groups B and C, while the initial BIO-ENV procedure considering all stations and the overall similarity patterns does just that. Visually, the MDS on the environmental variables of Group A based on the subset of variables (salinity and temperature) produced by its BIO-ENV

analysis resembles more closely the MDS of the species composition of Group A's stations than does the MDS based on the environmental variable subset (salinity, oxygen concentration, fluorescence, and depth) produced by BIO-ENV analysis of the species compositions of all stations as a whole. This difference may be explained by the respective Spearman rank correlation coefficients of these variable subsets, with 0.806 for the subset resulting from the BIO-ENV analysis of Group A, and 0.409 for the same analysis of all stations as a whole.

Differences in weather conditions over the season and among years, especially wind, contribute to differences in circulation of the Beaufort Sea and to the influence of the Mackenzie River plume fresh waters. Thus, the marine environment of the Beaufort Sea is highly variable both spatially and temporally. This was confirmed by analysis of the MDS ordination of environmental variables, in particular the comparison of environmental variables of GRY 2006 and GRY 2009, the only transect for which data were available for multiple years. This allowed the comparison of environmental variation across years for the locations along this transect. This variability in environment—from year-to-year and even day-to-day—due to weather conditions makes it very difficult to definitively say that an assemblage of species will occur in an area, given a certain set of environmental variables. Information on weather conditions at the time of sampling was not considered in this study. However, seawater circulation should be considered in future studies as it could potentially influence the similarity patterns of fish species composition.

While a difference in environmental variables according to their east-west orientation (especially in salinity) was expected, there were no apparent differences found when comparing environmental data from west of the Mackenzie River to those from east

of the Mackenzie River. This suggests that any influence from the Mackenzie River in terms of salinity due to freshwater outflow may be restricted to the upper areas of the water column and does not extend to the benthic area studied here. Indeed, circulation of freshwater is dependent upon wind and weather conditions (Carmack and Macdonald, 2001). Another possibility is that the spatial extent of analysis in this study is insufficient to determine if the Mackenzie plume affects the environmental variables and perhaps eventually fish species composition. Further analysis of the influence of the Mackenzie River on the marine environment of the shelf should take weather conditions into consideration.

A lack of information makes interpretation of the results difficult, as there is very little consistency in information—in time or location—against which to contrast both the biotic and abiotic variables. A lack of past research also makes it difficult to analyze changes through time. Generally, when performing statistical tests such as those which have been included in this study, the larger the sample size, the more confident one can be that the results are not produced by chance. In particular, data on additional environmental variables would allow for a more complete analysis of the influence of the environment on fish species composition. The necessity of further research can not be over-stressed.

5.0 CONCLUSION

Statistical ordination within this study found that while differences clearly exist among transects based on fish species composition, distinct differences in environmental variables among transects are not apparent. Therefore, similarity relationships among stations based on fish species composition are not predicted by strictly the environmental variables considered by this study. However, the BIO-ENV linkage analysis did find that the subset of environmental variables containing salinity, oxygen concentration, fluorescence, and depth explain a great deal of the variation in fish species composition (r_S=0.409).

Establishment of a baseline of information on environmental conditions at sampling stations and analysis of the possibility that these variables could drive fish species composition is important to allow for further research into the effects of resource development on the Canadian Beaufort Sea and the Mackenzie Delta. Understanding this baseline of information and the resulting institution of future guidelines for oil and gas companies which they will be required to adhere to will ensure the maintenance of this ecosystem. This study specifically investigates the ability of environmental variables to drive fish species composition.

Due to the short open water season and harsh weather conditions which make research difficult, there was limited data available for this study. Because oil and gas development will occur year-round, future studies on the impact of such development should be performed under the ice during the winter months, along with an increase in sampling during the open water season. This would make habitat management strategies much more complete and easier to construct.

The environmental data available for this thesis is likely insufficient to fully determine whether or not any one or subset of environmental variables drives fish species composition. If further research is to be done on the effects of environmental variables on species composition, consideration should be given to other variables. In particular, sediment, the distance from ice, and non-fish biological data such as ichthyoplankton, phytoplankton, and zooplankton populations should be analyzed for their influence.

The rank correlation between the similarity matrices based on station species composition and environmental data respectively found that the subset of variables including salinity, oxygen concentration, fluorescence, and depth best explain the similarity patterns of fish species composition. However, because this subset of variables only results in a Spearman correlation level of 0.409, the similarity patterns of fish species composition are not fully explained. This suggests that additional environmental variables need to be considered in future studies of the ability of the environment to drive fish species composition in the Canadian Beaufort Sea.

REFERENCES

Carmack, E. C. and R.W. Macdonald. 2001. Oceanography of the Canadian Shelf of the Beaufort Sea: A setting for marine life. Arctic 55: 29-45.

Clarke, K.R., and R.M. Warwick. 2001. Change in marine communities: An approach to statistical analysis and interpretation second ed. PRIMER-E, Plymouth.

Clarke, K.R., Gorley, R.N., 2006. In: PRIMER v6: User manual/tutorial. PRIMER-E Ltd., Plymouth.

Department of Fisheries and Oceans Canada, 2006. In: Ecosystem overview of the Beaufort Sea large ocean management area. Department of Fisheries and Oceans Canada, Winnipeg.

Field, J.G., Clarke, K.R., and R.M. Warwick. 1982. A practical strategy for analysing multispecies distribution patterns. Marine Ecology Progress Series 8: 39.

Froese, R., Pauly, D., FishBase, version (01/2010), www.fishbase.org, 2010

Majewski, A.R., Reist, J.D., and J.E. Sareault. 2006. Fish catch data from offshore sites in the Mackenzie River estuary and Beaufort Sea during the open water season, August 2004 aboard the CCGS *Nahidik*. Can. Manuscr. Rep. Fish. Aquat. Sci. 2771: vi +37 p.

Majewski, A.R., Reist, J.D., Park, B.J., Sareault, J.E., and M.K. Lowdon. 2009a. Fish catch data from offshore sites in the Mackenzie River estuary and Beaufort Sea during the open water season, July and August, 2005, aboard the CCGS *Nahidik*. Can. Data Rep. Fish. Aquat. Sci. 1204: vii + 53 p.

Majewski, A.R., Reist, J.D., Park, B.J., and M.K. Lowdon. 2009b. Fish catch data from offshore sites in the Mackenzie River estuary and Beaufort Sea during the open water season, August 2006, aboard the CCGS *Nahidik*. Can. Data Rep. Fish. Aquat. Sci. 1218: vi + 37p.

Mecklenburg, C.W., Mecklenburg, T.A., and L.K. Thorsteinson. 2002. Fishes of Alaska. American Fisheries Society, Bethesda, Maryland.

Milne, A.. In: Oil, ice and climate change: The Beaufort Sea and the search for oil. Ed. Childerhose, R.J.. Department of Fisheries and Oceans Canada, Ottawa.

Nelson J.S., Crossman, E.J., Espinosa-Pérez, H., Findley, L.T., Gilbert, C.R., Lea, R.N., and J.D. Williams. 2004. Common and scientific names of fishes from the United States, Canada, and Mexico. American Fisheries Society, Special Publication 29, Bethesda, Maryland.

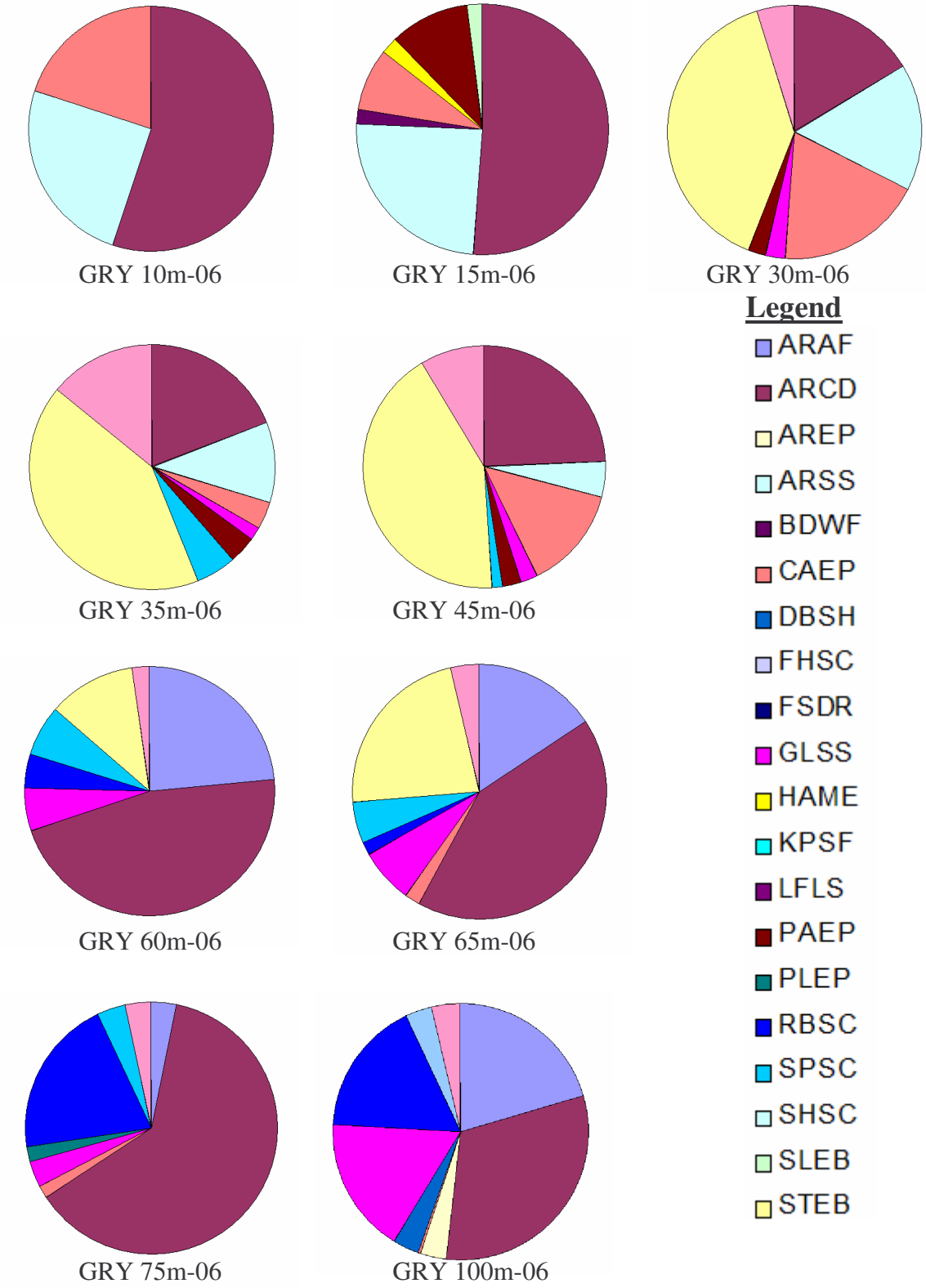
Norcross, B.L., Holladay, B.A, Busby, M.S., and K.L. Mier. 2009. Demersal and larval fish assemblages in the Chukchi Sea. Deep-Sea Research II, doi:10.1016/j.dsr2.2009.08.006

Oloruntegbe, K.O., Akinsete, M.A. and M.O. Odutuyi. 2009. Fifty years of oil exploration in Nigeria: Physico-chemical impacts and implication for environmental accounting and development. Journal of Applied Sciences Research 5, 2131.

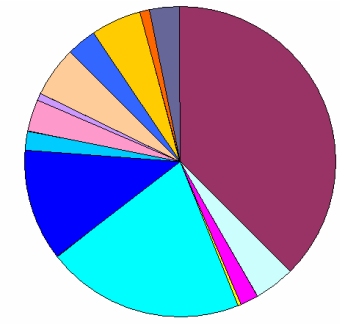
Percy, R., Smiley, B., and T. Mullen. 1985. In; Fishes, invertebrates and marine plants: The Beaufort Sea and the search for oil. Ed. Childerhose, R.J.. Department of Fisheries and Oceans Canada, Ottawa.

Appendix 1. Photo of the CCGS *Nahidik*, the vessel used for the 2003-2009 NCMSP field seasons. (Photo courtesy of J. Jorgenson, DFO)

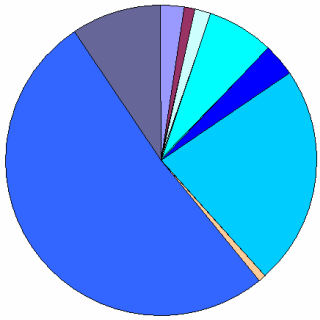
Appendix 2(a). Pie charts depicting species abundances by station in the GRY 2006 transect, each colour representing a different fish species. For species encoding, see Table 1.



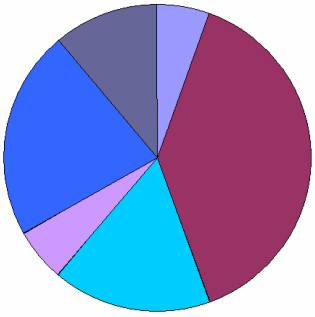
Appendix 2(b). Pie charts depicting species abundances by station in the KUG 2008 transect, each colour representing a different fish species. For species encoding, see Table 1.



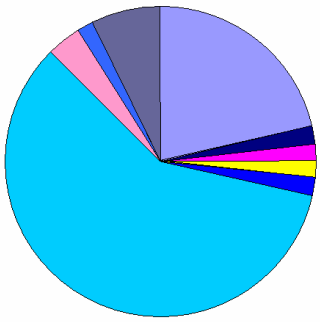
KUG 20m-08



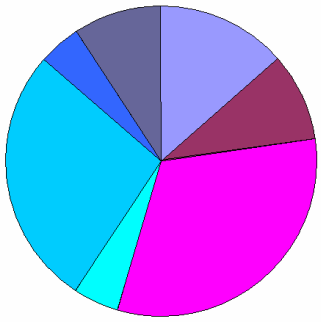
KUG 30m-08



KUG 50m-08



KUG 75m-08

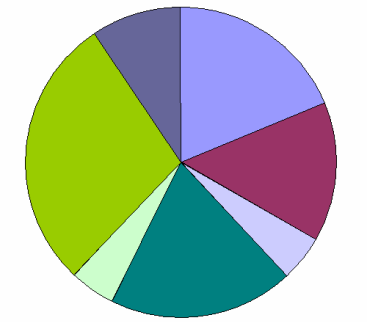


KUG 100m-08

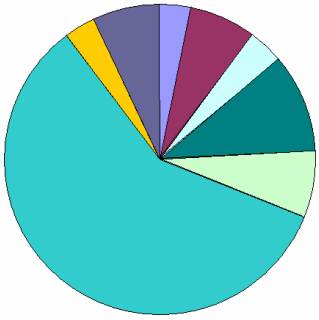
Legend

- ARAF
- ARCD
- AREP
- ARSS
- BDWF
- CAEP
- DBSH
- FHSC
- FSDR
- GLSS
- HAME
- KPSF
- LFLS
- PAEP
- PLEP
- RBSC
- SPSC
- SHSC
- SLEB
- STEB

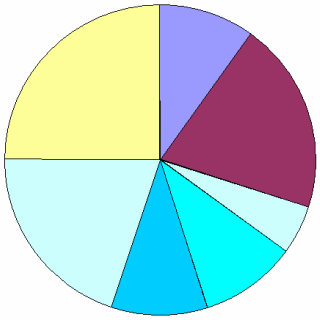
Appendix 2(c). Pie charts depicting species abundances by station in the GRY 2009 transect, each colour representing a different fish species. For species encoding, see Table 1.



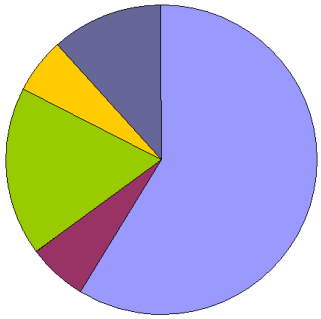
GRY 20m-09



GRY 35m-09



GRY 50m-09

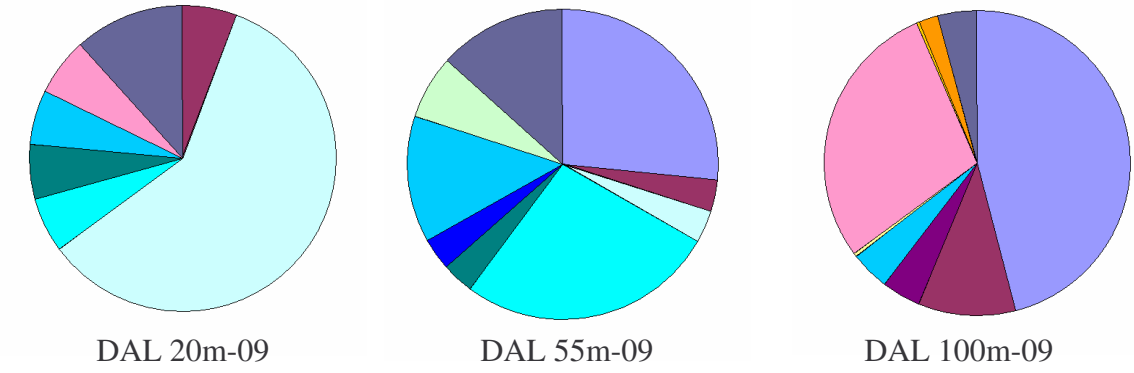


GRY 100m-09

Legend

- ARAF
- ARCD
- AREP
- ARSS
- BDWF
- CAEP
- DBSH
- FHSC
- FSDR
- GLSS
- HAME
- KPSF
- LFLS
- PAEP
- PLEP
- RBSC
- SPSC
- SHSC
- SLEB
- STEB

Appendix 2(d). Pie charts depicting species abundances by station in the DAL 2009 transect, each colour representing a different fish species. For species encoding, see Table 1.



DAL 20m-09 DAL 55m-09 DAL 100m-09

Legend

- ARAF
- ARCD
- AREP
- ARSS
- BDWF
- CAEP
- DBSH
- FHSC
- FSDR
- GLSS
- HAME
- KPSF
- LFLS
- PAEP
- PLEP
- RBSC
- SPSC
- SHSC
- SLEB
- STEB

Appendix 3. Fish catch abundances by station and species (continued on next page). Grey boxes indicate that none of that particular species were caught at that station. Total numbers for each station (along the bottom of this section of the table and the remaining section on the next page) and species (along the right side of the remainder of the table found on the following page) are also provided. For species encoding, see Table 1.

Species Code	GRY 100m-09	GRY 20m-09	GRY 35m-09	GRY 50m-09	GRY 100m-06	GRY 75m-06	GRY 60m-06	GRY 65m-06	GRY 45m-06	GRY 35m-06	GRY 30m-06	GRY 15m-06	GRY 10m-06
ARAF	10	4	1	2	6	2	21	9	0	0	0	0	0
ARCD	1	3	2	4	9	36	41	24	20	11	7	25	11
AREP	0	0	0	0	1	0	0	0	0	0	0	0	0
ARSS	0	0	1	1	0	0	0	0	4	6	7	12	5
BDWF	0	0	0	0	0	0	0	0	0	0	0	1	0
CAEP	0	0	0	0	0	1	0	1	11	2	8	4	4
DBSH	0	0	0	0	1	0	0	0	0	0	0	0	0
FHSC	0	1	0	0	0	0	0	0	0	0	0	0	0
FSDR	0	0	0	0	0	0	0	0	0	0	0	0	0
GLSS	0	0	0	0	5	2	5	4	2	1	1	0	0
HAME	0	0	0	0	0	0	0	0	0	0	0	1	0
KPSF	0	0	0	2	0	0	0	0	0	0	0	0	0
LFLS	0	0	0	0	0	0	0	0	0	0	0	0	0
PAEP	0	0	0	0	0	0	0	0	2	2	1	5	0
PLEP	0	4	3	0	0	1	0	0	0	0	0	0	0
RBSC	0	0	0	0	5	12	4	1	0	0	0	0	0
SPSC	0	0	0	2	0	2	6	3	1	3	0	0	0
SHSC	0	0	0	4	0	0	0	0	0	0	0	0	0
SLEB	0	1	2	0	0	0	0	0	0	0	0	1	0
STEB	0	0	0	5	0	0	10	13	35	24	17	0	0
TSEP	0	0	0	0	1	0	0	0	0	0	0	0	0
THSC	0	0	0	0	1	2	2	2	7	8	2	0	0
Icelus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Stichaeidae sp. (yoy)	0	0	0	0	0	0	0	0	0	0	0	0	0
Stichaeidae sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Liparidae sp. (yoy)	0	0	17	0	0	0	0	0	0	0	0	0	0
Liparidae sp.	3	6	0	0	0	0	0	0	0	0	0	0	0
Cottidae sp.	1	0	1	0	0	0	0	0	0	0	0	0	0
Cyclopteridae sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Lamprey	0	0	0	0	0	0	0	0	0	0	0	0	0
Lycodes sp.	2	2	2	0	0	0	0	0	0	0	0	0	0
Station Catch Abundance	17	21	29	20	29	58	89	57	82	57	43	49	20

Appendix 3. (continued) Fish catch abundances by station and species (continued from the previous page). Grey boxes indicate that none of that particular species were caught at that station. Total numbers for each station (along the bottom of this

section of the table) and species (along the right side of this section of the table) are also provided. For species encoding, see the species key on page x. Note that total species abundances are calculated across all stations (illustrated in this and the table on the preceding page). For species encoding, see Table 1.

Species Code	KUG 30m-08	KUG 100m-08	KUG 75m-08	KUG 50m-08	KUG 20m-08	DAL 100m-09	DAL 55m-09	DAL 20m-09	Total Species Abundance
ARAF	3	3	12	1	0	22	8	0	104
ARCD	1	2	0	7	36	5	1	1	247
AREP	0	0	0	0	0	0	0	0	1
ARSS	2	0	0	0	4	0	1	10	53
BDWF	0	0	0	0	0	0	0	0	1
CAEP	0	0	0	0	0	0	0	0	31
DBSH	0	0	0	0	0	0	0	0	1
FHSC	0	0	0	0	0	0	0	0	1
FSDR	0	0	1	0	0	0	0	0	1
GLSS	0	7	1	0	2	0	0	0	30
HAME	0	0	1	0	0	0	0	0	2
KPSF	8	1	0	0	20	0	8	1	40
LFLS	0	0	0	0	0	2	0	0	2
PAEP	0	0	0	0	0	0	0	0	10
PLEP	0	0	0	0	0	0	1	1	10
RBSC	4	0	1	0	11	0	1	0	39
SPSC	26	6	33	3	2	2	4	1	94
SHSC	0	0	0	0	0	0	0	0	4
SLEB	0	0	0	0	0	0	2	0	6
STEB	0	0	0	0	0	0	0	0	104
TSEP	0	0	0	0	0	0	0	0	1
THSC	0	0	2	0	3	14	0	1	44
Icelus sp.	0	0	0	1	1	0	0	0	2
Stichaeidae sp. (yoy)	1	0	0	0	5	0	0	0	6
Stichaeidae sp.	59	1	1	4	3	0	0	0	68
Liparidae sp. (yoy)	0	0	0	0	0	0	0	0	17
Liparidae sp.	0	0	0	0	0	0	0	0	9
Cottidae sp.	0	0	0	0	5	0	0	0	7
Cyclopteridae sp.	0	0	0	0	0	1	0	0	1
Lamprey	0	0	0	0	1	0	0	0	1
Lycodes sp.	11	2	4	2	3	2	4	2	36
Station Catch Abundance	115	22	56	18	96	48	30	17	973

Appendix 4. The species proportions and their percentages of total catch numbers across all stations, transects, and years. For species encoding, see Table 1.

Species	Overall Abundance	Proportion of Total Catch	Percentage of Total Catch
ARAF	104	0.10689	10.69
ARCD	247	0.25385	25.39
AREP	1	0.00103	0.10
ARSS	53	0.05447	5.45
CAEP	31	0.03186	3.19
BDWF	1	0.00103	0.10
DBSH	1	0.00103	0.10
FHSC	1	0.00103	0.10
FSDR	1	0.00103	0.10
GLSS	30	0.03083	3.08
HAME	2	0.00206	0.21
KPSF	40	0.04111	4.11
LFLS	2	0.00206	0.21
PAEP	10	0.01028	1.03
PLEP	10	0.01028	1.03
RBSC	39	0.04008	4.01
SPSC	94	0.09661	9.66
SHSC	4	0.00411	0.41
SLEB	6	0.00617	0.62
STEB	104	0.10689	10.69
TSEP	1	0.00103	0.10
THSC	44	0.04522	4.52
Icelus sp.	2	0.00206	0.21
Stichaeidae sp. (yoy)	6	0.00617	0.62
Stichaeidae sp.	68	0.06989	6.99
Liparidae sp. (yoy)	17	0.01747	1.75
Liparidae sp.	9	0.00925	0.92
Cottidae sp.	7	0.00719	0.72
Cyclopteridae sp.	1	0.00103	0.10
Lamprey	1	0.00103	0.10
Lycodes sp.	36	0.03700	3.70

Appendix 5(a). Species composition of Group A (Figure 4). For species encoding, see Table 1.

		Station						
Species Code	Scientific Name	GRY 45m-06	GRY 35m-06	GRY 30m-06	GRY 15m-06	GRY 10m-06	Species Total Abundance	Proportion (%)
ARAF	*U. olrikii*	0	0	0	0	0	0	0.00
ARCD	*B. saida*	20	11	7	25	11	74	29.48
AREP	*L. reticulatus*	0	0	0	0	0	0	0.00
ARSS	*G.tricuspis*	4	6	7	12	5	34	13.55
BDWF	*C. nasus*	0	0	0	1	0	1	0.40
CAEP	*L. polaris*	11	2	8	4	4	29	11.55
DBSH	*L. maculatus*	0	0	0	0	0	0	0.00
FHSC	**M. quadricornis*	0	0	0	0	0	0	0.00
FSDR	*G. viridis*	0	0	0	0	0	0	0.00
GLSS	*L. fabricii*	2	1	1	0	0	4	1.59
HAME	*A. scaber*	0	0	0	1	0	1	0.40
KPSF	**L. tunicatus*	0	0	0	0	0	0	0.00
LFLS	**E. derjugini*	0	0	0	0	0	0	0.00
PAEP	**L. pallidus*	2	2	1	5	0	10	3.98
PLEP	**L. turneri*	0	0	0	0	0	0	0.00
RBSC	*T. pingelii*	0	0	0	0	0	0	0.00
SPSC	*I. spatula*	1	3	0	0	0	4	1.59
SHSC	**M. scorpius*	0	0	0	0	0	0	0.00
SLEB	*L. fabricii*	0	0	0	1	0	1	0.00
STEB	*A. medius*	35	24	17	0	0	76	30.28
TSEP	*L. rossi*	0	0	0	0	0	0	0.00
THSC	*I. bicornis*	7	8	2	0	0	17	6.77
Icelus sp.		0	0	0	0	0	0	0.00
Stichaeidae sp. (yoy)		0	0	0	0	0	0	0.00
Stichaeidae sp.		0	0	0	0	0	0	0.00
Liparidae sp. (yoy)		0	0	0	0	0	0	0.00
Liparidae sp.		0	0	0	0	0	0	0.00
Cottidae sp.		0	0	0	0	0	0	0.00
Cyclopteridae sp.		0	0	0	0	0	0	0.00
Lamprey	*L. camtschatica*	0	0	0	0	0	0	0.00
Lycodes sp.		0	0	0	0	0	0	0.00
							251	

Appendix 5(b). Species composition of Group B (Figure 4). For species encoding, see Table 1.

		Station														
Species Code	Scientific Name	GRY 100m-06	GRY 75m-06	GRY 60m-06	GRY 65m-06	GRY 50m-09	KUG 30m-08	KUG 100m-08	KUG 75m-08	KUG 50m-08	KUG 20m-08	DAL 100m-09	DAL 55m-09	DAL 20m-09	Species Total Abundance	Proportion (%)
ARAF	*U. olnikii*	6	2	21	9	2	3	3	12	1	0	22	8	0	89	13.59
ARCD	*B. saida*	9	36	41	24	4	1	2	0	7	36	5	1	1	167	25.50
AREP	*L. reticulatus*	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0.15
ARSS	*G.tricuspis*	0	0	0	0	1	2	0	0	0	4	0	1	10	18	2.75
BDWF	*C. nasus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
CAEP	*L. polaris*	0	1	0	1	0	0	0	0	0	0	0	0	0	2	0.31
DBSH	*L. maculatus*	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0.15
FHSC	**M. quadricornis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
FSDR	*G. viridis*	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0.15
GLSS	*L. fabricii*	5	2	5	4	0	0	7	1	0	2	0	0	0	26	3.97
HAME	*A. scaber*	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0.15
KPSF	**L. tunicatus*	0	0	0	0	2	8	1	0	0	20	0	8	1	40	6.11
LFLS	**E. derjugini*	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0.31
PAEP	**L. pallidus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
PLEP	**L. tumeri*	0	1	0	0	0	0	0	0	0	0	0	1	1	3	0.46
RBSC	*T. pingelii*	5	12	4	1	0	4	0	1	0	11	0	1	0	39	5.95
SPSC	*I. spatula*	0	2	6	3	2	26	6	33	3	2	2	4	1	90	13.74
SHSC	**M. scorpius*	0	0	0	0	4	0	0	0	0	0	0	0	0	4	0.61
SLEB	*L. fabricii*	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0.31
STEB	*A. medius*	0	0	10	13	5	0	0	0	0	0	0	0	0	28	4.27
TSEP	*L. rossi*	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0.15
THSC	*I. bicornis*	1	2	2	2	0	0	0	2	0	3	14	0	1	27	4.12
Icelus sp.		0	0	0	0	0	0	0	0	1	1	0	0	0	2	0.31
Stichaeidae sp. (yoy)		0	0	0	0	0	1	0	0	0	5	0	0	0	6	0.92
Stichaeidae sp.		0	0	0	0	0	59	1	1	4	3	0	0	0	68	10.38
Liparidae sp. (yoy)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Liparidae sp.		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Cottidae sp.		0	0	0	0	0	0	0	0	0	5	0	0	0	5	0.76
Cyclopteridae sp.		0	0	0	0	0	0	0	0	0	0	1	0	0	1	0.15
Lamprey	*L. camtschatica*	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0.15
Lycodes sp.		0	0	0	0	0	11	2	4	2	3	2	4	2	30	4.58
															655	

Appendix 5(c). Species composition of Group C (Figure 4). For species encoding, see Table 1.

		Station				
Species Code	Scientific Name	GRY 100m-09	GRY 20m-09	GRY 35m-09	Specites Total Abundance	Proportion (%)
ARAF	*U. olrikii*	10	4	1	15	22.39
ARCD	*B. saida*	1	3	2	6	8.96
AREP	*L. reticulatus*	0	0	0	0	0.00
ARSS	*G.tricuspis*	0	0	1	1	1.49
BDWF	*C. nasus*	0	0	0	0	0.00
CAEP	*L. polaris*	0	0	0	0	0.00
DBSH	*L. maculatus*	0	0	0	0	0.00
FHSC	**M. quadricornis*	0	1	0	1	1.49
FSDR	*G. viridis*	0	0	0	0	0.00
GLSS	*L. fabricii*	0	0	0	0	0.00
HAME	*A. scaber*	0	0	0	0	0.00
KPSF	**L. tunicatus*	0	0	0	0	0.00
LFLS	**E. derjugini*	0	0	0	0	0.00
PAEP	**L. pallidus*	0	0	0	0	0.00
PLEP	**L. tumeri*	0	4	3	7	10.45
RBSC	*T. pingelii*	0	0	0	0	0.00
SPSC	*I. spatula*	0	0	0	0	0.00
SHSC	**M. scorpius*	0	0	0	0	0.00
SLEB	*L. fabricii*	0	1	2	3	4.48
STEB	*A. medius*	0	0	0	0	0.00
TSEP	*L. rossi*	0	0	0	0	0.00
THSC	*I. bicornis*	0	0	0	0	0.00
Icelus sp.		0	0	0	0	0.00
Stichaeidae sp. (yoy)		0	0	0	0	0.00
Stichaeidae sp.		0	0	0	0	0.00
Liparidae sp. (yoy)		0	0	17	17	25.37
Liparidae sp.		3	6	0	9	13.43
Cottidae sp.		1	0	1	2	2.99
Cyclopteridae sp.		0	0	0	0	0.00
Lamprey	*L. camtschatica*	0	0	0	0	0.00
Lycodes sp.		2	2	2	6	8.96
					67	

Appendix 6(a). The contributions of each species to the dissimilarity in fish species compositions between Groups A and B (Figure 4). For species encoding, see Table 1.

Species	Group A Average Abundance	Group B Average Abundance	Average Dissimilarity	Contribution (%)	Cumulative %
ARCD	14.8	12.85	14.5	18.67	18.67
STEB	15.2	2.15	14.29	18.4	37.08
ARAF	0	6.85	7.01	9.03	46.11
ARSS	6.8	1.38	6.96	8.97	55.08
CAEP	5.8	0.15	6.14	7.91	62.98
SPSC	0.8	6.92	6.11	7.87	70.86
THSC	3.4	2.08	3.83	4.94	75.79
Stichaeidae sp.	0	5.23	3.64	4.69	80.48
KPSF	0	3.08	2.76	3.55	84.03
RBSC	0	3	2.66	3.43	87.46
Lycodes sp.	0	2.31	2.29	2.95	90.41
GLSS	0.8	2	2.28	2.94	93.35
PAEP	2	0	2.06	2.65	96
SHSC	0	0.31	0.48	0.62	96.62
SLEB	0.2	0.15	0.39	0.5	97.12
Stichaeidae sp. (yoy)	0	0.46	0.32	0.41	97.52
PLEP	0	0.23	0.3	0.39	97.91
Cottidae sp.	0	0.38	0.27	0.35	98.26
HAME	0.2	0.08	0.27	0.34	98.6
BDWF	0.2	0	0.22	0.28	98.89
Icelus sp.	0	0.15	0.18	0.23	99.11
LFLS	0	0.15	0.16	0.21	99.33
AREP	0	0.08	0.1	0.13	99.46
DBSH	0	0.08	0.1	0.13	99.59
TSEP	0	0.08	0.1	0.13	99.73
Cyclopteridae sp.	0	0.08	0.08	0.11	99.83
FSDR	0	0.08	0.08	0.1	99.93
Lamprey	0	0.08	0.05	0.07	100
FHSC	0	0	0	0	100
Liparidae sp. (yoy)	0	0	0	0	100
Liparidae sp.	0	0	0	0	100

Appendix 6(b). The contributions of each species to the dissimilarity in fish species composition between Groups A and C (Figure 4). For species encoding, see Table 1.

Species	Group A Average Abundance	Group C Average Abundance	Average Dissimilarity	Contribution (%)	Cumulative %
ARCD	14.8	2	18.1	19.52	19.52
STEB	15.2	0	18.03	19.44	38.96
ARSS	6.8	0.33	9.77	10.53	49.48
CAEP	5.8	0	8.12	8.76	58.24
ARAF	0	5	8	8.62	66.87
Liparidae sp. (yoy)	0	5.67	7.68	8.28	75.14
Liparidae sp.	0	3	4.72	5.09	80.24
THSC	3.4	0	3.99	4.3	84.53
PLEP	0	2.33	3.4	3.67	88.2
Lycodes sp.	0	2	3.03	3.26	91.47
PAEP	2	0	2.61	2.81	94.28
SLEB	0.2	1	1.34	1.44	95.72
Cottidae sp.	0	0.67	1	1.08	96.8
SPSC	0.8	0	0.95	1.03	97.82
GLSS	0.8	0	0.95	1.02	98.84
FHSC	0	0.33	0.51	0.55	99.39
BDWF	0.2	0	0.28	0.3	99.7
HAME	0.2	0	0.28	0.3	100
AREP	0	0	0	0	100
DBSH	0	0	0	0	100
FSDR	0	0	0	0	100
KPSF	0	0	0	0	100
LFLS	0	0	0	0	100
RBSC	0	0	0	0	100
SHSC	0	0	0	0	100
TSEP	0	0	0	0	100
Icelus sp.	0	0	0	0	100
Stichaeidae sp. (yoy)	0	0	0	0	100
Stichaeidae sp.	0	0	0	0	100
Cyclopteridae sp.	0	0	0	0	100
Lamprey	0	0	0	0	100

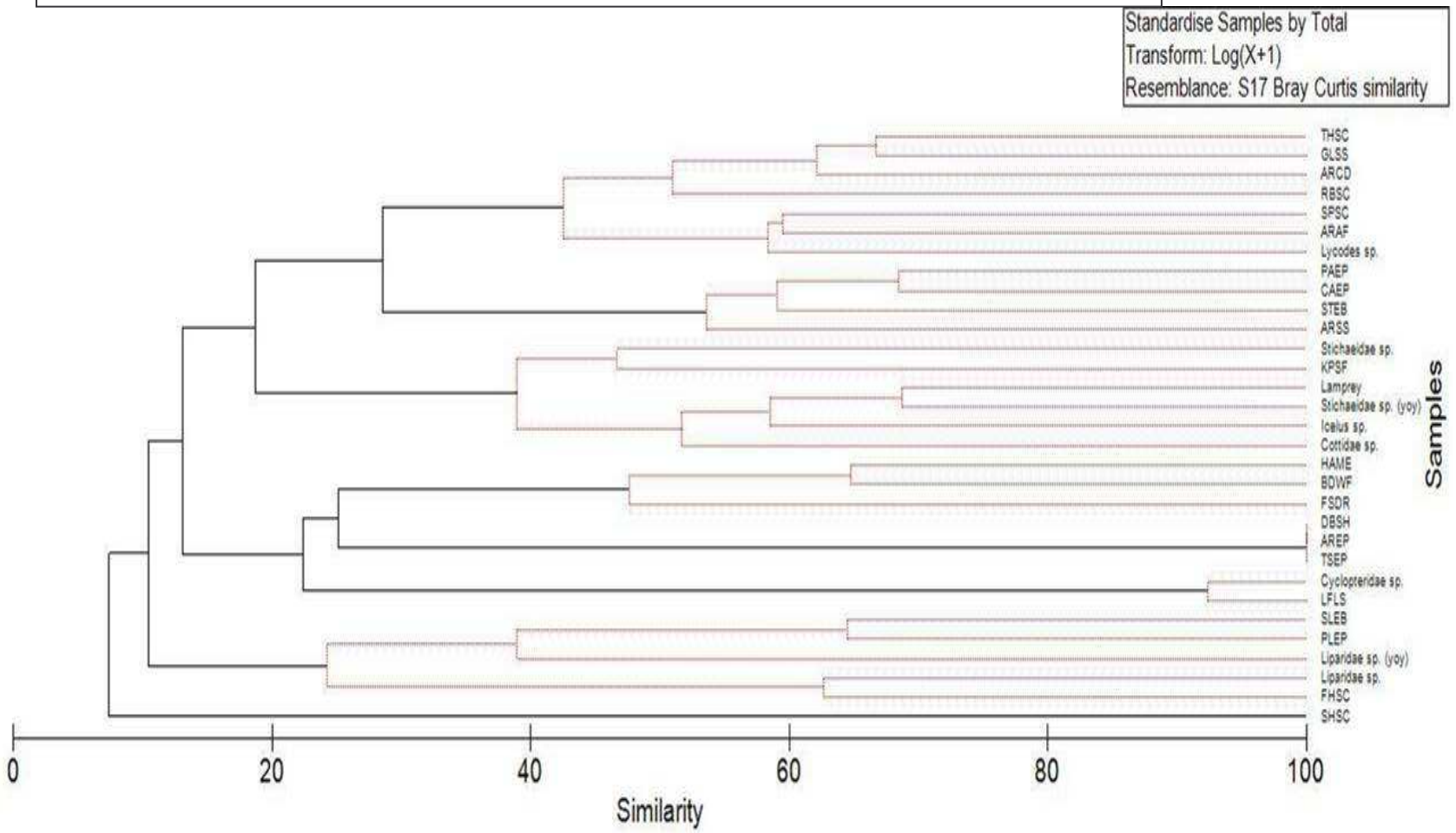
Appendix 6(c). The contributions of each species to the dissimilarity in fish species composition between Groups B and C (Figure 4). For species encoding, see Table 1.

Species	Group B Average Abundance	Group C Average Abundance	Average Dissimilarity	Contribution (%)	Cumulative %
SPSC	2.2	0	6.6	9.93	9.93
Liparidae sp.	0	2.1	6.34	9.54	19.47
PLEP	0.34	1.81	4.88	7.34	26.82
ARAF	2.24	2.86	4.09	6.17	32.98
Liparidae sp. (yoy)	0	1.37	3.94	5.93	38.92
ARCD	2.64	2.24	3.61	5.44	44.35
SLEB	0.16	1.27	3.55	5.35	49.7
RBSC	1.17	0	3.44	5.18	54.88
Cottidae sp.	0.14	1.14	3.42	5.16	60.03
Lycodes sp.	1.35	2.32	3.35	5.04	65.07
THSC	1.07	0	3.23	4.87	69.94
GLSS	1.08	0	3.19	4.81	74.75
KPSF	1.12	0	3.18	4.79	79.54
ARSS	0.77	0.5	2.68	4.04	83.58
Stichaeidae sp.	0.87	0	2.59	3.9	87.48
STEB	0.69	0	2.05	3.08	90.56
FHSC	0	0.59	1.65	2.48	93.05
SHSC	0.24	0	0.68	1.03	94.07
Icelus sp.	0.2	0	0.59	0.89	94.97
Stichaeidae sp. (yoy)	0.19	0	0.51	0.77	95.74
CAEP	0.16	0	0.48	0.73	96.46
LFLS	0.13	0	0.4	0.6	97.07
AREP	0.12	0	0.34	0.51	97.57
DBSH	0.12	0	0.34	0.51	98.08
TSEP	0.12	0	0.34	0.51	98.59
Cyclopteridae sp.	0.09	0	0.28	0.42	99.01
FSDR	0.08	0	0.25	0.38	99.38
HAME	0.08	0	0.25	0.38	99.76
Lamprey	0.06	0	0.15	0.22	99.98
BDWF	0	0	0.01	0.01	99.99
PAEP	0	0	0.01	0.01	100

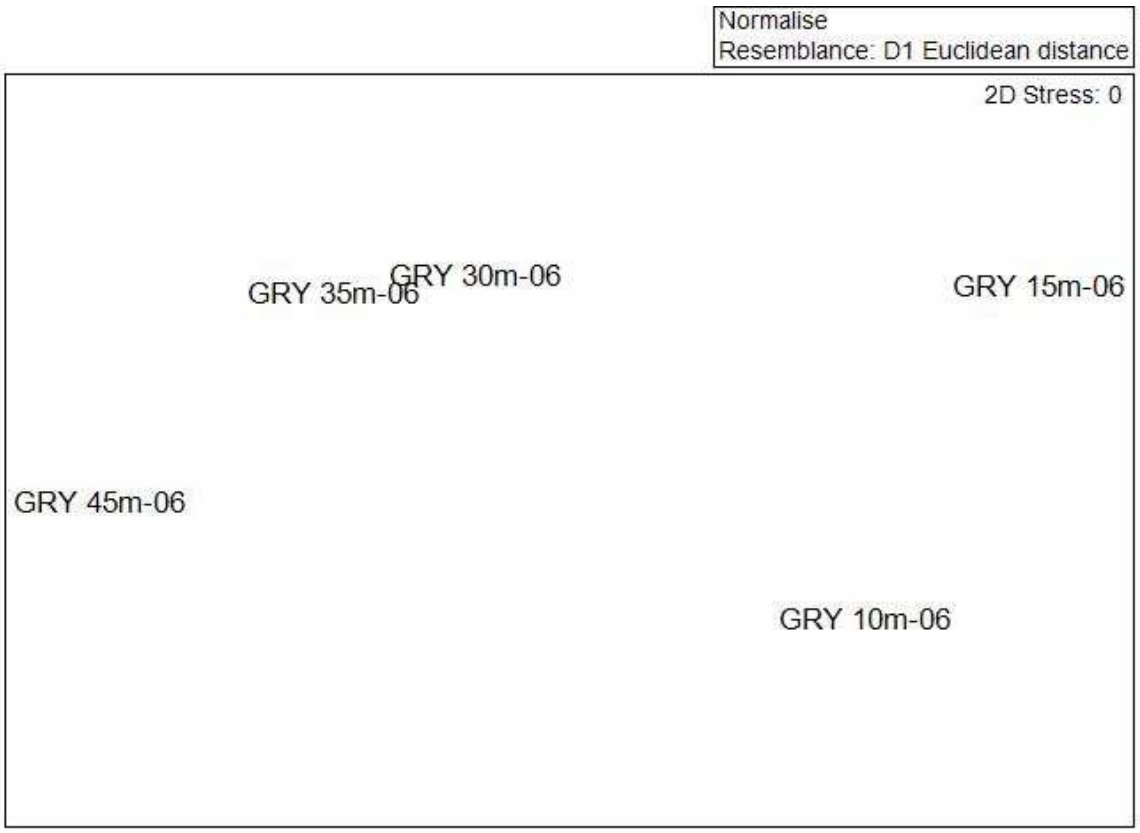
Appendix 7. List of the average levels of all of the environmental variables considered in this study, organized by station. Salinity values were reverse-logarithmically transformed (i.e., LOG(34-y), where y=observed value), while temperature values were logarithmically transformed (i.e., LOG(3+y)). (Mean ± SE)

	Environmental Variables						
Station	***Salinity (PSU)***	**Transformed Salinity**	***Temperature (°C)***	**Transformed Temperature**	**Oxygen Concentration (mL/L)**	**Fluorescence (nm)**	**Depth (m)**
DAL 100m-09	*32.5296 ± 0.01653*	0.1674 ± 0.004808	*-1.3509 ± 0.00048*	0.2173 ± 0.000126	6.35899 ± 0.00677	0.12537 ± 0.00132	122.4 ± 0.36052
DAL 55m-09	*32.3019* ± 0.03937	0.2300 ± 0.009739	*-1.2224 ± 0.00009*	0.2498 ± 0.000021	6.15634 ± 0.01589	1.71646 ± 0.08321	54.0 ± 0.36052
DAL 20m-09	*31.6103 ± 0.01062*	0.3783 ± 0.00192	*-0.6447 ± 0.00276*	0.3721 ± 0.00051	7.57685 ± 0.03157	1.62769 ± 0.41400	19.4 ± 0.36052
GRY100m-09	*32.657 ± 0.01698*	0.1281 ± 0.00548	*-1.3797 ± 0.00258*	0.2096 ± 0.00069	6.34657 ± 0.01869	0.14036 ± 0.00685	102.0 ± 0.36052
GRY 50m-09	*32.4434 ± 0.00352*	0.1922 ± 0.000982	*-1.3533 ± 0.00541*	0.2166 ± 0.001423	6.28002 ± 0.01127	0.20664 ± 0.00559	49.5 ± 0.36052
GRY 35m-09	*32.0604 ± 0.02598*	0.2877 ± 0.005812	*-1.3524 ± 0.00430*	0.2169 ± 0.001134	6.38137 ± 0.00207	1.01738 ± 0.07999	36.7 ± 0.36052
GRY 20m-09	*31.4029 ± 0.02949*	0.4145 ± 0.004957	*-1.0660 ± 0.03134*	0.2865 ± 0.007066	6.57661 ± 0.03161	2.07788 ± 0.17993	19.9 ± 0.36052
KUG 100m-08	*32.7376 ± 0.00016*	0.1012 ± 0.000054	*-1.4139 ± 0.00005*	0.2003 ± 0.000013	6.25246 ± 0.00161	0.07444 ± 0.00109	98.9 ± 0.36052
KUG 75m-08	*32.6361 ± 0.00020*	0.1348 ± 0.000063	*-1.4516 ± 0.00009*	0.1899 ± 0.000024	6.22998 ± 0.00430	0.12151 ± 0.01187	75.5 ± 0.36052
KUG 50m-08	*32.3303 ± 0.02129*	0.2226 ± 0.005435	*1.4855 ± 0.00020*	0.1803 ± 0.000056	6.87521 ± 0.00990	0.30464 ± 0.01632	52.5 ± 0.36052
KUG 30m-08	*32.2464 ± 0.00157*	0.2439 ± -0.000389	*-1.1814 ± 0.00293*	0.2597 ± 0.000695	7.57257 ± 0.00912	0.67144 ± 0.01709	31.6 ± 0.29437
KUG 20m-08	*31.3905 ± 0.01556*	0.4166 ± 0.002572	*1.1808 ± 0.03868*	0.6213 ± 0.003978	7.75013 ± 0.01559	0.51335 ± 0.02277	22.9 ± 0.36052
GRY 100m-06	*32.6586 ± 0.00012*	0.1276 ± 0.000041	*-1.5105 ± 0.00076*	0.1730 ± 0.000222	6.75243 ± 0.00131	0.07341 ± 0.00141	104.0 ± 0.36052
GRY 75m-06	*32.6308 ± 0.00066*	0.1365 ± 0.00021	*-1.4868 ± 0.00163*	0.1799 ± 0.000467	6.54911 ± 0.00380	0.08446 ± 0.00188	74.9 ± 0.29437
GRY 65m-06	*32.5294 ± 0.00059*	0.1675 ± 0.000176	*-1.4249 ± 0.01635*	0.1973 ± 0.004509	6.73815 ± 0.00659	0.08418 ± 0.00171	64.8 ± 0.29437
GRY 60m-06	*32.5037 ± 0.00073*	0.1750 ± 0.000212	*-1.4655 ± 0.00130*	0.1860 ± 0.000367	6.76321 ± 0.03313	0.09049 ± 0.00412	61.4 ± 0.35037
GRY 45m-06	*32.2052 ± 0.00600*	0.2540 ± 0.001462	*-1.4796 ± 0.00136*	0.1820 ± 0.000387	6.92787 ± 0.00757	0.11859 ± 0.00403	46.9 ± 0.29437
GRY 35m-06	*31.8528 ± 0.01268*	0.3319 ± 0.002544	*-1.5171 ± 0.00200*	0.1711 ± 0.000586	7.06620 ± 0.00954	0.20440 ± 0.00718	33.4 ± 0.25493
GRY 30m-06	*31.7291 ± 0.03791*	0.3562 ± 0.002294	*-1.5205 ± 0.01291*	0.1701 ± 0.001194	7.25225 ± 0.02215	0.21489 ± 0.07196	28.6 ± 0.93087
GRY 15m-06	*30.7101 ± 0.00891*	0.5172 ± 0.001174	*-1.5357 ± 0.00322*	0.1656 ± 0.000950	7.65474 ± 0.00916	0.28930 ± 0.02656	13.8 ± 0.24035
GRY 10m-06	*29.8781 ± 0.03470*	0.6151 ± 0.003641	*-1.4145 ± 0.01378*	0.2002 ± 0.002477	7.34114 ± 0.01378	0.82172 ± 0.15279	11.5 ± 0.25493

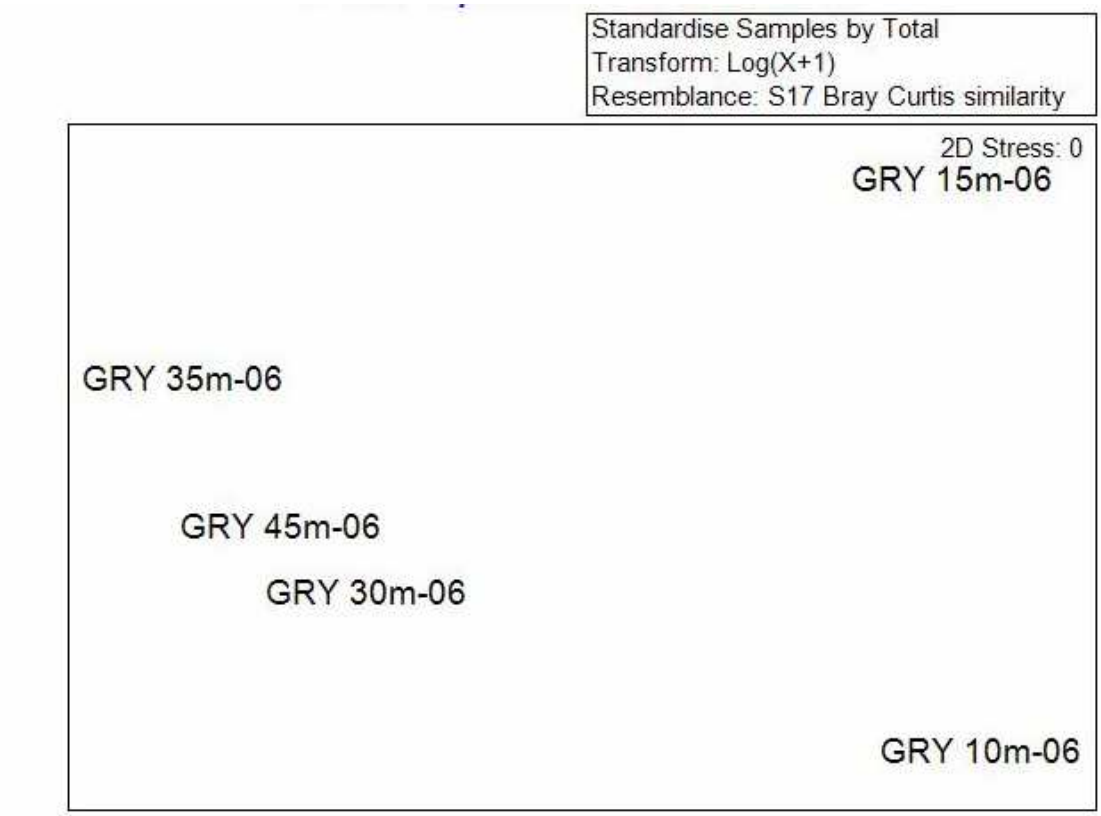
Appendix 8. Cluster analysis of species to illustrate those species which co-occur based on station catch. Species are listed along the vertical axis, while percent similarity level is indicated along the horizontal axis. A lighter coloured line indicates a statistically significant grouping. For species encoding, see Table 1.



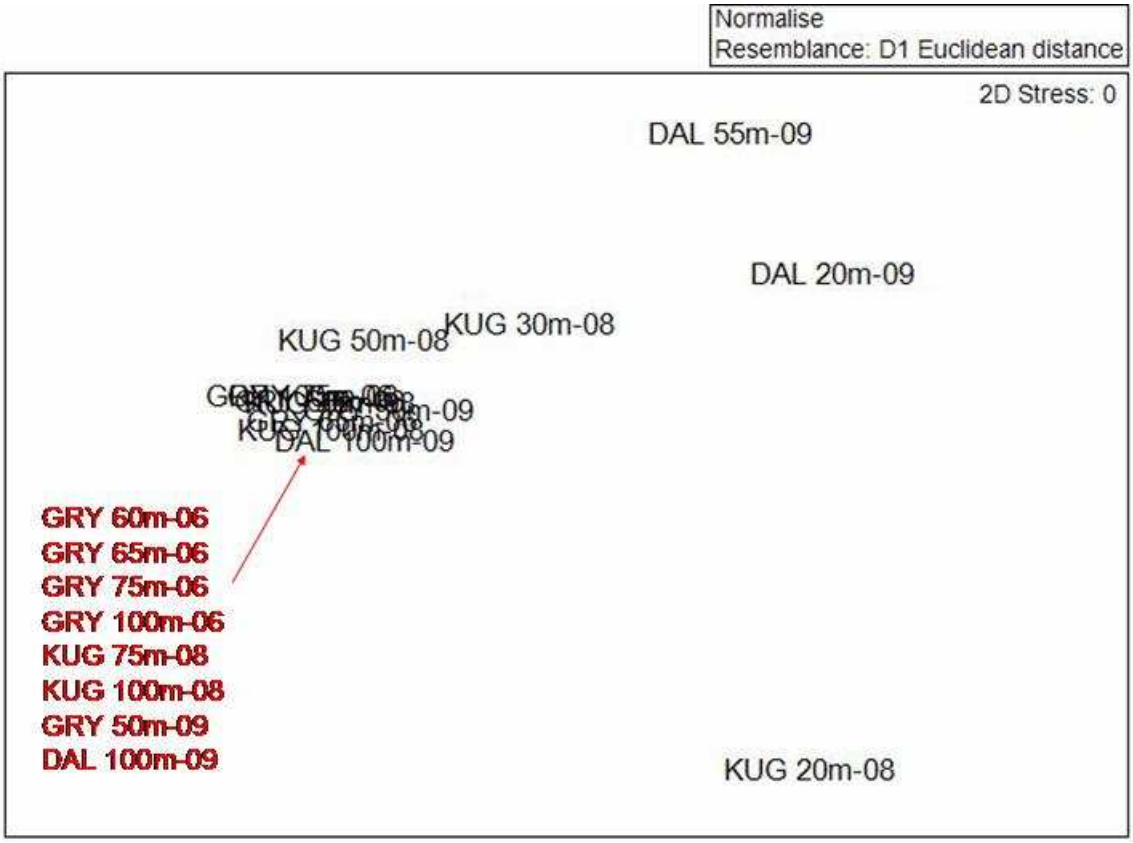
Appendix 9. MDS ordination of the subset of environmental variables resulting from the BIO-ENV analysis of Group A (Figure 4).



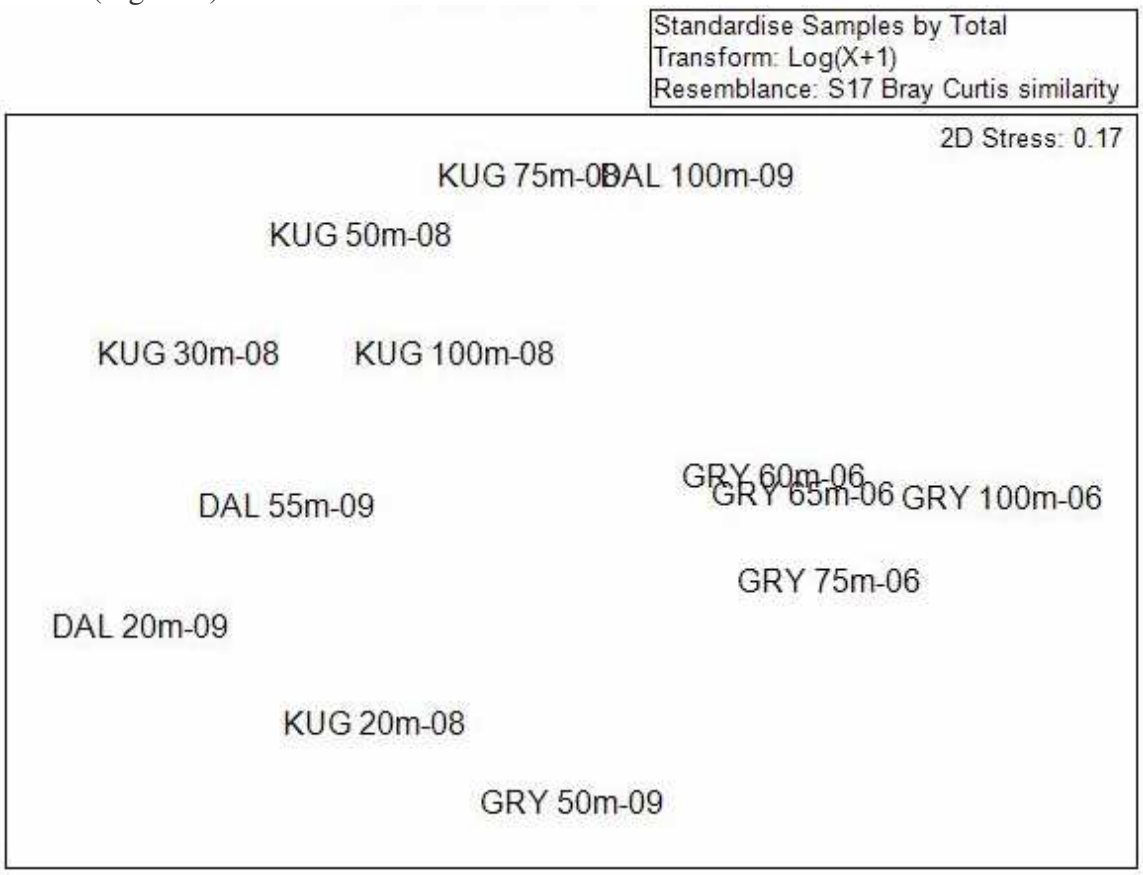
Appendix 10. MDS ordination of the species compositions of the stations of Group A (Figure 4).



Appendix 11. MDS ordination of the subset of environmental variables resulting from the BIO-ENV analysis of Group B (Figure 5).



Appendix 12. MDS ordination of the species compositions of the stations of Group B (Figure 5)



Appendix 13. Station benthic trawl (fish) sampling information. (Note: time is expressed in the 24-hour clock)

			Time		Trawl Fish Sampling	Station Fish Sampling
Station	Trawl #	Date (dd/mm/yyyy)	Net on bottom	Net off bottom	Time (mins)	Time (mins)
GRY 100m-06	BT-06-01	02/08/2006	01:35:00	1:45:00	10	50
	BT-06-02	03/08/2006	14:50:00	15:10:00	20	
	BT-06-03	03/08/2006	15:32:00	15:52:00	20	
GRY 75m-06	BT-06-04	03/08/2006	22:48:00	23:48:00	60	60
GRY 65m-06	BT-06-10	04/08/2006	00:50:00	1:10:00	20	60
	BT-06-09	04/08/2006	00:19:00	0:39:00	20	
	BT-06-08	04/08/2006	23:41:00	0:01:00	20	
GRY 60m-06	BT-06-06	04/08/2006	17:40:00	18:00:00	20	60
	BT-06-05	04/08/2006	16:58:00	17:18:00	20	
	BT-06-07	04/08/2006	18:22:00	18:42:00	20	
GRY 45m-06	BT-06-11	05/08/2006	18:45:00	19:05:00	20	60
	BT-06-12	05/08/2006	19:20:00	19:40:00	20	
	BT-06-13	05/08/2006	20:00:00	20:20:00	20	
GRY 35m-06	BT-06-14	06/08/2006	16:23:00	16:43:00	20	60
	BT-06-15	06/08/2006	17:30:00	17:50:00	20	
	BT-06-16	06/08/2006	18:35:00	18:55:00	20	
GRY 30m-06	BT-06-17	06/08/2006	21:47:00	22:07:00	20	60
	BT-06-18	06/08/2006	22:23:00	22:43:00	20	
	BT-06-19	06/08/2006	23:02:00	23:22:00	20	
GRY 15m-06	BT-06-20	07/08/2006	15:36:00	15:56:00	20	60
	BT-06-21	07/08/2006	16:12:00	16:32:00	20	
	BT-06-22	07/08/2006	16:56:00	17:16:00	20	
GRY 10m-06	BT-06-23	07/08/2006	21:47:00	22:07:00	20	60
	BT-06-24	07/08/2006	22:44:00	23:04:00	20	
	BT-06-25	07/08/2006	23:18:00	23:38:00	20	
KUG 100m-08	BT-08-33	01/08/2008	15:50:00	16:10:00	20	40
	BT-08-34	01/08/2008	16:48:00	17:08:00	20	
KUG 75m-08	BT-08-35	02/08/2008	16:56:00	17:16:00	20	60
	BT-08-36	02/08/2008	17:41:00	18:01:00	20	
	BT-08-37	02/08/2008	19:20:00	19:40:00	20	
KUG 50m-08	BT-08-38	03/08/2008	16:13:00	16:33:00	20	40
	BT-08-39	03/08/2008	16:58:00	17:18:00	20	
KUG 30m-08	BT-08-30	31/07/2008	11:26:00	11:46:00	20	60
	BT-08-31	31/07/2008	12:07:00	12:27:00	20	
	BT-08-32	31/07/2008	12:50:00	13:10:00	20	
KUG 20m-08	BT-08-40	05/08/2008	11:58:00	12:18:00	20	60
	BT-08-41	05/08/2008	12:40:00	13:00:00	20	
	BT-08-42	05/08/2008	13:37:00	13:57:00	20	
GRY 100m-09	BT-09-10	08/08/2009	14:00:00	14:26:00	20	60
	BT-09-11	08/08/2009	15:14:00	15:40:00	26*	
	BT-09-12	08/08/2009	16:10:00	16:37:00	27*	
GRY 50m-09	BT-09-19	13/08/2009	10:16:00	10:36:00	20	60
	BT-09-20	13/08/2009	10:59:00	11:19:00	20	
	BT-09-21	13/08/2009	12:17:00	12:37:00	20	
GRY 35m-09	BT-09-16	13/08/2009	14:49:00	15:09:00	20	60
	BT-09-17	13/08/2009	16:36:00	16:56:00	20	
	BT-09-18	13/08/2009	18:00:00	18:20:00	20	
GRY 20m-09	BT-09-13	12/08/2009	10:42:00	11:02:00	20	60
	BT-09-14	12/08/2009	11:22:00	11:42:00	20	
	BT-09-15	12/08/2009	12:44:00	13:04:00	20	
DAL 100m-09	BT-09-22	15/08/2009	10:37:00	10:57:00	20	60
	BT-09-23	15/08/2009	12:16:00	12:36:00	20	
	BT-09-24	15/08/2009	13:19:00	13:39:00	20	
DAL 55m-09	BT-09-25	15/08/2009	17:51:00	18:11:00	20	60
	BT-09-26	15/08/2009	18:32:00	18:52:00	20	
	BT-09-27	15/08/2009	19:14:00	19:34:00	20	
DAL 20m-09	BT-09-30	16/08/2009	16:39:00	16:59:00	20	60
	BT-09-31	16/08/2009	17:43:00	18:03:00	20	
	BT-09-32	16/08/2009	18:23:00	18:43:00	20	

* effort still described at 20 mins.

Appendix 14. Station CTD logger (environmental) sampling information. (Note: time is expressed in the 24-hour clock)

Station	Sample #	Date (dd/mm/yyyy)	Station CTD Logger Start Time
GRY 100m-06	1	03/08/2006	13:04:26
	2	03/08/2006	18:18:25
GRY 75m-06	1	03/08/2006	19:26:16
	2	03/08/2006	20:53:25
GRY 65m-06	1	04/08/2006	20:23:22
	2	04/08/2006	21:28:31
GRY 60m-06	1	04/08/2006	13:07:31
	2	04/08/2006	14:33:13
GRY 45m-06	1	05/08/2006	14:54:05
	2	05/08/2006	16:19:24
GRY 35m-06	1	06/08/2006	13:13:51
	2	06/08/2006	14:45:47
GRY 30m-06	1	06/08/2006	19:40:17
	2	06/08/2006	20:30:02
GRY 15m-06	1	07/08/2006	13:10:45
	2	07/08/2006	14:16:47
GRY 10m-06	1	07/08/2006	19:26:41
	2	07/08/2006	20:10:51
KUG 100m-08	1	01/08/2008	22:41:36
KUG 75m-08	1	02/08/2008	18:08:08
KUG 50m-08	1	03/08/2008	16:45:22
KUG 30m-08	1	31/07/2008	12:13:17
	2	31/07/2008	13:39:30
KUG 20m-08	1	05/08/2008	13:06:36
GRY 100m-09	1	08/08/2009	14:07:08
GRY 50m-09	1	13/08/2009	10:05:27
GRY 35m-09	1	13/08/2009	8:36:02
GRY 20m-09	1	12/08/2009	11:42:17
DAL 100m-09	1	15/08/2009	11:51:35
DAL 55m-09	1	16/08/2009	10:43:45
DAL 20m-09	1	17/08/2009	1:17:09