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Distribution of selected Munnopsidae (Crustacea, Isopoda, Asellota) species around Iceland linked to long-term oceanographic data

Master Thesis

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Sarah Maria Schnurr

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1st Examiner: Prof. Dr. Angelika Brandt
2nd Examiner: Prof. Dr. Detlef Quadfasel
Supervisor Biology: Dr. Saskia Brix
Supervisor Oceanography: Dr. Kerstin Jochumsen

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(Sarah   Maria   Schnurr)

Abbreviations

A/PW	Arctic/Polar Water
CTD	Conductivity Temperature Depth
EBS	Epibenthic sled
GSR	Greenland-Scotland Ridge
LSW	Labrador Sea Water
NADW	North Atlantic Deep Water
nMDS	non Metric Multidimensional Scaling
MEIW	Modified East Icelandic Water
MNAW	Modified North Atlantic Water
NSAIW	Norwegian Sea Arctic Intermediate Water
NSDW	Norwegian Sea Deep Water
RP sled	Rothlisberg Pearcy epibenthic sled
THC	Thermohaline circulation

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1 Abstract

Based on samples of the BIOICE (Benthic Invertebrates of Icelandic Waters; 1991-2004) and IceAGE (Icelandic marine Animals: Genetics and Ecology; since 2011) project, diversity, composition and distribution of selected isopod genera of the family Munnopsidae Lilljeborg, 1864 around Iceland were studied. The BIOICE project was initiated to gain more knowledge about the benthic fauna in the Icelandic Economic Zone. The IceAGE project which is based on the BIOICE project and aims to combine classic taxonomic methods with modern aspects of biodiversity research like phylogeography and ecological modelling.

The area around Iceland is climatically of great importance and thus located in a zoogeographic key position. The Greenland-Scotland Ridge (GSR), which extends from Greenland to Scotland, forms a barrier, which constrains the water exchange between the northern North Atlantic and the GIN seas. Therefore, water masses of the northern North Atlantic and the GIN seas feature substantial temperature differences. Water exchanges through the ridge are of major importance for the regional climate, the regional climate of northern Europe and the global thermohaline circulation.

In order to get a better foundation of the two abiotic factors temperature and salinity, data of the long-term NISE (Norwegian Icelandic Seas Experiment) dataset were used for modelling near-bottom long-term mean temperature and salinity values. Thus, layers with a high data resolution of 0.2° steps in longitudinal direction and 0.1° steps in latitudinal direction were created. Variation of temperature values especially across the GSR showed the variability of the overflows occurring in that region. In comparison, conditions of the deeper basins north and south of the GSR appeared to be rather stable.

Munnopsids are the most abundant and diverse isopod family in benthic deep-sea samples and even widespread in cold waters. Primitive asellotes usually cannot swim, while members of the family Munnopsidae Lilljeborg, 1864 possess the ability to swim quite efficiently. Within this study a total of 82 stations of the BIOICE project as well as subsamples of 26 IceAGE 1 samples were examined with focus on the munnopsid genera *Baeonectes* Wilson, 1982a, *Belonectes* Wilson and Hessler, 1981, *Disconectes* Wilson and Hessler, 1981, *Eurycope* Sars, 1864, *Munnopsurus* Richardson, 1912 and *Munnopsis* Sars, 1861, which are known to be very abundant and widespread in the research area. In all 10,787 individuals were found, belonging to 15 species of the selected six genera, whereas the major part of specimen belonged to the genus *Eurycope*. The majority of species (eight) was present north and south of the GSR, while three species were only found south of the ridge and four species were restricted to areas north of the ridge. Interestingly, most species were present in more

than one water mass. Species with quite extensive geographical distributions were even present in water masses with very different features. Depth seemed to be the most important factor in driving the distribution of the evaluated genera. Additionally, temperature and water mass also had an influence on shaping the distribution of the munnopsid species examined herein, but not to the same extent as depth. On the contrary, salinity and sediment type did not have much influence on the distribution patterns. Apparently, the isolation of the northern North Atlantic from the GIN seas (Greenland, Iceland and Norwegian Seas) through the GSR, does not affect the distribution of most of the evaluated species, which may be explained by the good swimming abilities of munnopsids.

2 Zusammenfassung

Die Diversität, die Artzusammensetzung und die Artverbreitung ausgewählter Gattungen der Familie Munnopsidae Lilljeborg, 1864 in der Region um Island wurde an Hand von Proben aus dem BIOICE (Benthic Invertebrates of Icelandic Waters; 1991-2004) und dem IceAGE (Icelandic marine Animals: Genetics and Ecology; seit 2011) Projekt untersucht. Initiiert wurde das BIOICE Projekt, um mehr Kenntnisse über die bentische Fauna der isländischen Wirtschaftszone zu erhalten. Das IceAGE Projekt kann als das Folgeprojet von BIOICE angesehen werden. Dabei steht bei IceAGE die Kombination klassischer taxonomischer Methoden und deren Verknüpfung mit modernen Aspekten der Biodiversitätsforschung und hier im besonderen mit der Phylogeographie und ökologischer Modellierung im Vordergrund.

Die Region um Island ist klimatisch von großer Bedeutung und stellt daher eine zoogeographische Schlüsselposition dar. Der Grönland-Schottland Rücken erstreckt sich von Grönland bis Schottland und beeinflusst den Wasseraustausch zwischen dem Nordatlantik und dem europäischen Nordmeer. Der Wasseraustausch durch die tiefen Passagen des Grönland-Schottland Rückens ist von großer Bedeutung für das regionale Klima einerseits und das regionale Klima im Norden Europas sowie für die globale thermohaline Zirkulation andererseits. Die Wassermassen des Nordatlantiks und des europäischen Nordmeers weisen große Temperaturdifferenzen auf.

Daten aus dem langjährigen NISE (Norwegian Icelandic Seas Experiment) Projekt bildeten die Grundlage zur Modellierung von gemittelten Bodentemperaturen und Salzgehalten mit einer hohen Datenauflösung. Gewählt wurde ein Raster von 0,2° in longitudinaler und 0,1° in latitudinaler Richtung. Variationen innerhalb der Temperaturwerte, besonders im Bereich des Grönland-Schottland Rückens verdeutlichen die Variabilität des „Overflows" in dieser Region. Die Bedingungen in den Tiefseebecken nördlich und südlich des Grönland-Schottland Rückens waren hingegen eher stabil.

Sogar in Tiefseeproben kälterer Regionen bilden Munnopsiden meist die abundanteste und diverseste Familie innerhalb des Isopoden. Munnopsiden besitzen die Fähigkeit zum aktiven Schwimmen was sie von anderen aselloten Isopoden unterscheidet, die meist nur begrenzt schwimmfähig sind. Innerhalb dieser Abschlussarbeit wurden Munnopsiden ausgewählter Gattungen von 82 Stationen des BIOICE Projektes sowie 26 Unterproben aus Proben des IceAGE Projekts ausgewertet. Der Fokus lag dabei auf den Gattungen *Baeonectes* Wilson, 1982a, *Belonectes* Wilson und Hessler, 1981, *Disconectes* Wilson und Hessler, 1981, *Eurycope* Sars, 1864, *Munnopsurus* Richardson, 1912 und *Munnopsis* Sars, 1861, die innerhalb der Region rund um Island besonders abundant und weit verbreitet sind. Insgesamt

wurden 10787 Individuen bestimmt. Diese konnten 15 verschiedenen Arten innerhalb der sechs ausgewählten Gattungen zugeordnet werden. Ein Großteil der Individuen gehörte der Gattung *Eurycope* an. Die Mehrheit von acht Arten kam in Regionen nördlich und südlich von Island vor. Drei Arten fanden sich ausschließlich südlich und vier weitere Arten nur nördlich von Island. Die meisten Arten kamen in mehr als nur einer Wassermasse vor; einige davon fanden sich sogar in Wassermassen mit stark unterschiedlichen Eigenschaften. Am meisten ausschlaggebend für das Vorkommen einer Art erscheint der Faktor Tiefe. Außerdem schienen Temperatur und Wassermassen ebenfalls die Verbreitung zu beeinflussen, jedoch bei weitem nicht so stark wie der Faktor Tiefe. Die Sedimentzusammensetzung und der Salzgehalt haben wohl keinen Einfluss auf die Verbreitung der hier untersuchten Munnopsiden. Die Trennung des Nordatlantiks vom Europäischen Nordmeer durch den Grönland-Schottland Rücken hat vermutlich keinen Einfluss auf die Verbreitung der meisten hier evaluierten Arten, was auf die außerordentlich guten Schwimmfähigkeiten der Munnopsiden zurückgeführt werden kann.

3 Introduction

Climate change is currently a widely discussed topic. The number of publications on possible climate change impacts has been rising since 1993 almost exponentially (Harley et al. 2006). Most publications dealing with climate change in the marine environment focus on impacts connected to changes in temperature (Harley et al. 2006). Ecological consequences such as the alteration of species distribution and species composition of benthic communities may occur as a consequence of changes in climatic conditions (Macdonald et al. 2005; Walther et al. 2002; Harley et al. 2006; Barber et al. 2008).

The area around Iceland is of great importance to observe climate change. The northern North Atlantic is separated from the Greenland, Iceland and Norwegian Seas (GIN seas) by the Greenland-Scotland Ridge (GSR), which ranges from Greenland to Scotland. This natural border constrains, but does not block the water exchange of water from the North Atlantic and the ocean regions north of the ridge (figure 4). In addition, water exchange across the ridge is of great importance for the global thermohaline circulation and the ocean regions north of the GSR, as well as for the regional climate of the northern part of Europe (Hansen and Østerhus 2000). The water masses of the northern North Atlantic and the GIN seas hold major temperature differences. Hence, they may be eminently affected by climate alterations (Hansen and Østerhus 2000; Malmberg and Valdimarsson 2003). There is already some evidence for increasing temperatures in Arctic and subarctic waters as well as in the shallower regions around Iceland within the last 10 years (Astthorsson et al. 2007).

This leads to the question in which ways changes in the marine ecosystem will affect species distributions. Thus, it is important to know the current situation. For this reason it is necessary to distinguish possible factors that influence and shape the distribution of certain species. Dayton and Oliver (1977) detected that benthic community structures are highly affected by food supply. Additionally, sediment type is also regarded to eminently influence the distribution of epibenthic organisms (Hecker 1990; Stransky and Svavarsson 2010). In comparison, Mayer & Piepenburg (1996) and Weisshappel & Svavarsson (1998) discovered that temperature and salinity greatly influence communities, whereas Graf (1992) postulated that benthic-pelagic coupling plays a key role in structuring of benthic communities, which is mainly relevant in high latitude oceans. In addition, those regions are characterized by a strongly pulsed primary production (Piepenburg et al. 1997; Brandt 1995, 1993). Hence, the diversity of epibenthic animals such as peracarid crustaceans (e.g. munnopsid isopods) can be limited and influenced by the interaction of numerous factors.

Therefore, in the context of climate change, variations and disturbances within special habitats become more and more important. Changes of oceanographic conditions may affect organisms such as the munnopsid crustaceans that were examined within this study. It is of great importance to compile information of the current situation in order to create a solid benchmark against which future changes can be measured or detected.

3.1 Background & Motivation

Several studies have indicated that the GSR or conditions connected to this ridge influence and shape the species distribution and composition of particular benthic groups (Stephensen 1940, 1944; Svavarsson et al. 1990; Svavarsson et al. 1993b; Negoescu and Svavarsson 1997; Svavarsson 1997; Gudmundsson 1998; Weisshappel 2000, 2001; Dijkstra et al. 2009; Brix and Svavarsson 2010). The region around Iceland is eminently important when considering that the North Atlantic and the Arctic Mediterranean are connected with each other only through shallow passages in the GSR. Within this context species distributional patterns and latitudinal changes of species composition become interesting. Especially, when taking into account benthic species with different lifestyles.

Brix and Svavarsson (2010) examined the distribution of desmosomatid and nannoniscid isopods in Icelandic waters. They detected that most species were restricted to certain water masses of a particular temperature and salinity. Moreover, they stated that the presence of the GSR itself did not affect the distribution of the examined species to the same extent as temperature and salinity. Interestingly, sediment type and depth did not seem to be limiting factors for the distribution of desmosomatid and nannoniscid isopods. For this purpose samples collected during the BIOICE (Benthic Invertebrates of Icelandic Waters) project and the IceAGE (Icelandic marine Animals: Genetics and Ecology) project were evaluated in order to obtain information about Munnopsidae Lilljeborg, 1864, which unlike desmosomatid and nannoniscid isopods, have good swimming abilities. Also, data of the NISE (Norwegian Iceland Seas Experiment) project were evaluated for the development of maps of long-term near-bottom mean temperature and salinity values. Thus, a better foundation of these two abiotic factors can be provided to characterize the habitat of the determined munnopsids.
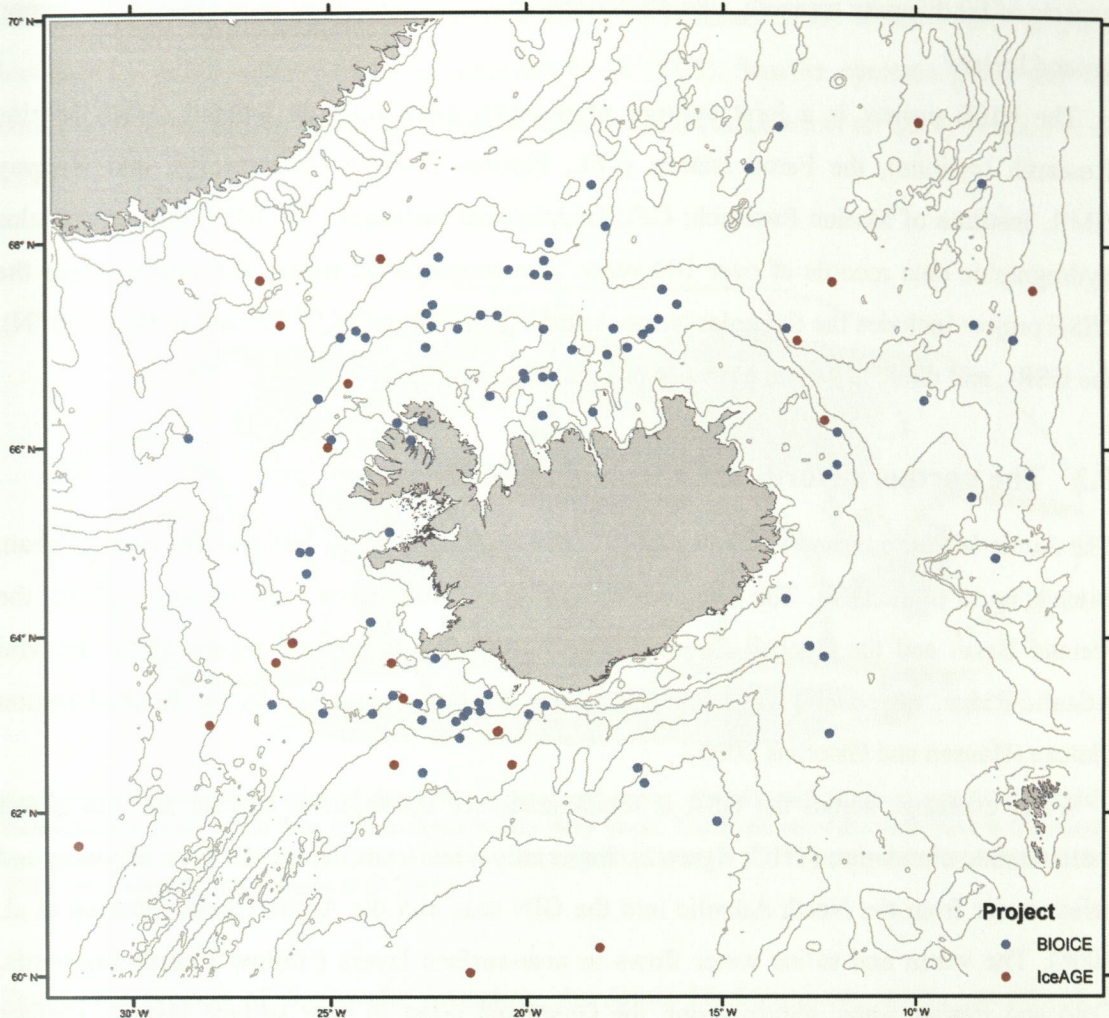
Figure 1: Location of the evaluated stations used in this study. **Blue circles** BIOICE stations, **red circles** IceAGE 1 stations. The bottom depth is taken from ETOPO2 bathymetry and contours give the [3000 2000 1500 1000 300 100] m depth levels.

The international BIOICE expeditions took place between 1991 – 2004 and the project was designed to gather comprehensive knowledge of the marine benthic biodiversity of the 200 mile exclusive economic zone of Iceland. The sampled area covered a region of 758,000 km^2 and samples were taken in depths from 17 m to 2400 m. Because the samples of the BIOICE project were taken on both sides of the GSR over such a large time span, this dataset forms an extraordinary source of information (figure 1). In addition, such an incredibly large dataset provides the opportunity to analyse present day distributions and also serves as an important basis for future studies in providing evidence for climate change trough monitoring responses of the marine fauna (Gudmundsson 1998; Tendal 1998; Schuchert 2000).

The IceAGE project is based on the BIOICE project and can be regarded as a follow-up project. The general aims of IceAGE are to combine classic taxonomic methods with modern

aspects of biodiversity research, like phylogeography and ecological modelling in the region around Iceland.

The NISE project is a joint venture of research institutions in Iceland (MRI, Marine Research Institute), the Faroe Islands (FFL, Faroese Fisheries Laboratory), and Norway (IMR, Institute of Marine Research; GFI, Geophysical Institute). The NISE dataset contains hydrographic data records of over 100 years. The geographical region that encompasses the NISE project includes the Subpolar North Atlantic Ocean (east of 55 °W and north of 50 °N), the GSR-, and the Iceland and Norwegian Seas (Nilsen et al. 2008).

3.2   The northern North Atlantic and the GIN seas

The Arctic Mediterranean, which covers the GIN seas, the Barents Sea and the Arctic Ocean, extends north of the GSR. The area southwest of the GSR consists of the Irminger Basin, the Iceland Basin and the Rockall Channel. The former two basins are separated by the Mid Atlantic Ridge, whereat the latter and the Iceland Basin are separated by the Rockall-Hatton Plateau (Hansen and Østerhus 2000).

Water exchange across the GSR is fundamental for the regional climate and the global thermohaline circulation (THC; figure 2). Especially when considering the flow of warm and saline water from the North Atlantic into the GIN seas and the Arctic Ocean (Hansen et al. 2008). The warm and saline water flows in near-surface layers ('inflow') north-eastwards. Cold and fresher water returns along the Greenland coast in near surface layers ('surface outflow'). The deep overflows of cold and dense waters pass the GSR at different locations of the ridge ('overflow'; Hansen and Østerhus 2000). The North Atlantic Current feeds the Arctic Mediterranean with three branches that affect different regions within the GIN seas (figure 4). The Iceland branch (the North Icelandic Irminger Current) affects the southern parts of the Iceland Sea (Hansen et al. 2008; Hansen and Østerhus 2000; Swift and Aagaard 1981; Jónsson 1992). The Faroe branch (the Faroe Current) recirculates in the southern Norwegian Sea. The Shetland branch is joined by part of the Faroe branch, which is considered to be the main water contributor to the North Sea and presumably the Barents Sea (Hansen et al. 2008; Hansen and Østerhus 2000). In addition to these three branches there is the Continental Slope Current of North Atlantic Water that flows north-eastwards over the European continental slope (figure 4; Hansen and Østerhus 2000).

The surface circulation of the GIN seas is mainly cyclonic (e.g. (Latarius and Quadfasel 2010), with cross-gyre exchanges at the GSR and Fram Strait. The Norwegian Atlantic Current is responsible for the transport of warm and saline Atlantic water northwards in the

eastern part of the GIN seas, while the East Greenland Current in the western part transports low-salinity polar waters (figure 4; Jakobsen et al. 2003). Smaller cyclonic gyres that are connected to the bottom topography appear in each basin (Jakobsen et al. 2003; Poulain et al. 1996).
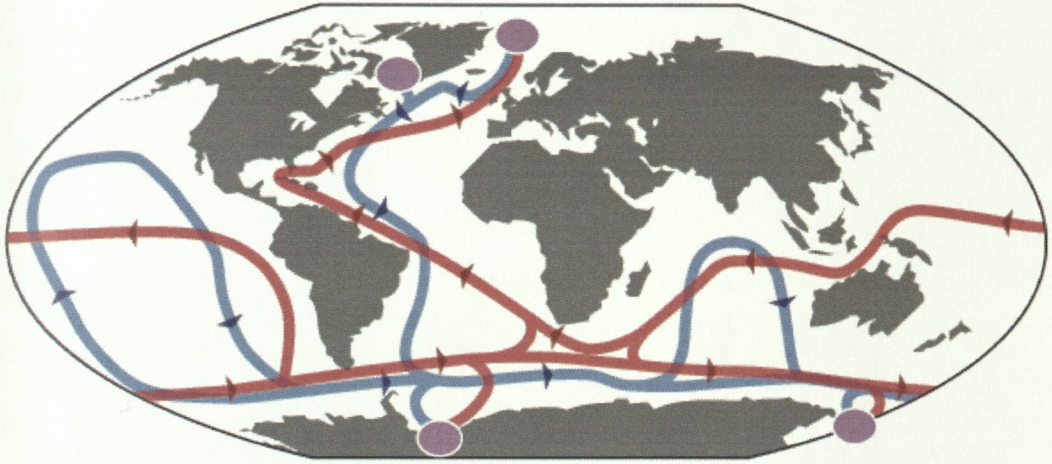
Figure 2: Schematic illustration of the THC of the world ocean. *Purple ovals* illustrate ventilation, which functions as a driver of the flow of deep dense waters (*blue lines*). The direction of the water flow is illustrated by *arrows*. The warm currents (*red lines*) return as compensation currents in the upper ocean layers to the areas where ventilation occurs (Hansen et al. 2004).

Due to the process of deep-water formation, the Arctic Mediterranean can be considered as the 'kitchen for deep water mass transformation' (Quadfasel and Käse 2007; Jakobsen et al. 2003). Cooling of surface waters and loss of heat to the atmosphere in the GIN seas and the Arctic Ocean leads to higher densities and subsequent sinking of the water. This process, named convection, occurs on a spatial scale of approximately 1 km. Water from deeper layers ascents in between those plumes, which causes an upward transport of heat and warming to the atmosphere. This combination of ascending and descending water leads to a homogenisation of the water column, which can reach down to 2000 m depth. The upper layer of the water column gets enriched with oxygen and carbon dioxide by the motion of the sea. Convection leads to ventilation of deeper water layers and formation of a cold-water reservoir. Part of this deep water flows through the GSR as overflow and sinks due to its high density to the bottom of the North Atlantic (Quadfasel and Käse 2007; Quadfasel 2011). The volume transport across the ridge of around 6 Sverdrup doubles while sinking due to entrainment with surrounding Atlantic water and the water becomes a component of the North Atlantic Deep Water (figure 3; Hansen et al. 2004). Local convection in the Labrador Sea adds another 4-6 Sverdrup of volume transport to the deep water (Quadfasel and Käse 2007;

Quadfasel 2011). Strong overflow of about 80 % of the southward transport through the GSR appears in the deepest depressions of the Denmark Strait (3 Sv) and the Faroe Bank Channel (2 Sv). These overflows are rather stable on time scales above seasonal. In comparison, overflows through the shallower Iceland-Faroe Ridge (1 Sv) and the Wyville Thomson Ridge (< 0.3 Sv) are intermittent and account for about 20 % of the whole water export (Quadfasel and Käse 2007; Hansen and Østerhus 2000; Dickson and Brown 1994; Østerhus et al. 2008; Meincke 1983; Voet 2010). The deep overflow and the surface outflow are compensated by the northwards directed flow of warm water that influences the European climate (figure 3 and figure 4; Quadfasel and Käse 2007; Quadfasel 2011).
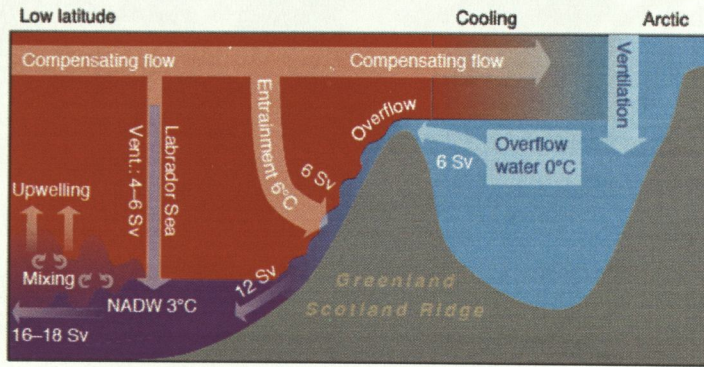
Figure 3: Schematic illustration of the water exchange across the GSR. The temperature values are given in °C and the volume transports are given in Sverdrup [10^6 m³/s]. Part of the cold and dense deep-water (*blue*) flows as overflow across the GSR, which gets entrained and becomes part of the NADW (*purple*). *Red* indicates the northwards directed compensating inflow (Hansen et al. 2004).
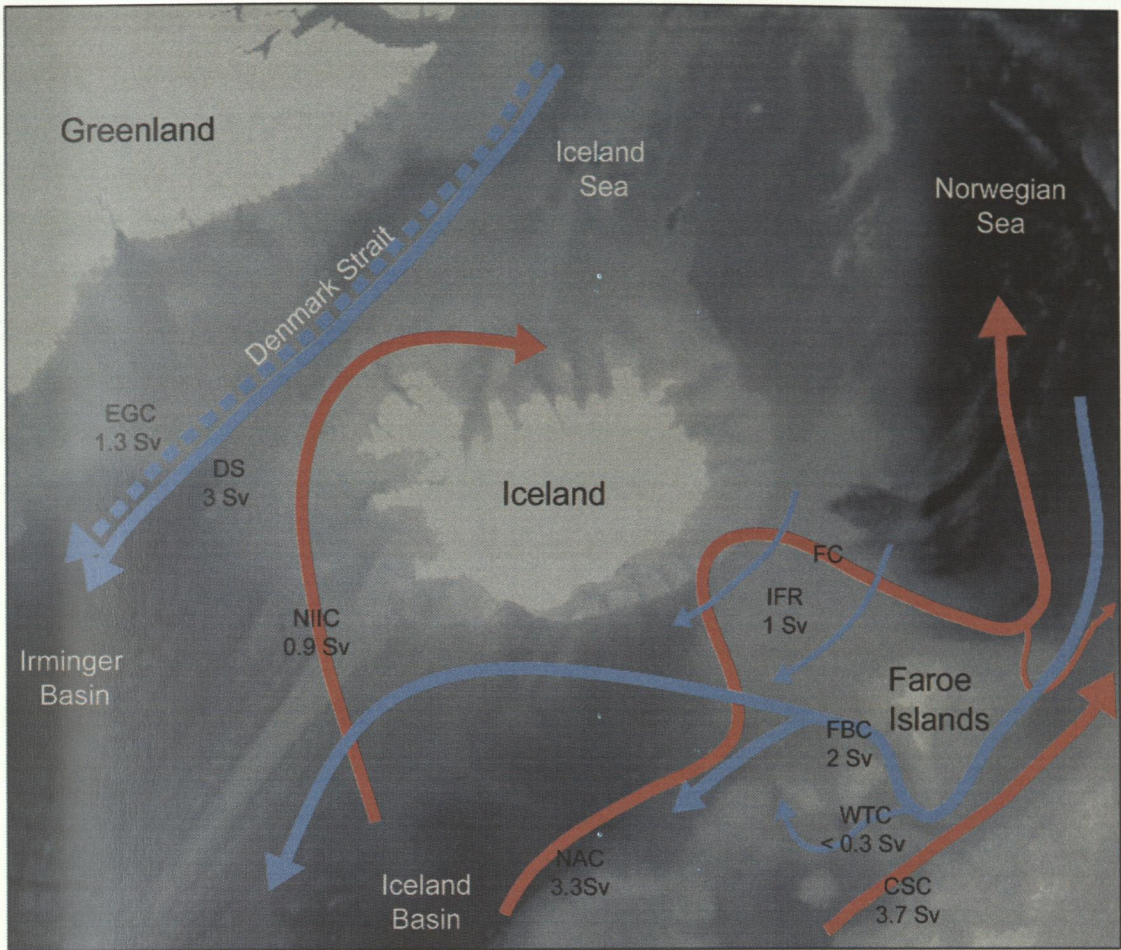
Figure 4: Overview of the main near-surface and near-bottom currents in the northern North Atlantic and the GIN seas. *Red arrows* indicate the directions of Atlantic water, while *blue arrows* show the flow of cold and dense water masses across the GSR (*continuous blue arrows* = overflows, *dashed blue arrow* = surface outflow). The volume transports are given in Sverdrup [10^6 m^3/s]. Continental Slope Current, *CSC*; Denmark Strait, *DS*; East Greenland Current, *EGC*; Faroe Current, *FC*; Faroe Bank Channel, *FBC*; Iceland Faroe Ridge, *IFR*; North Atlantic Current, *NAC*; North Icelandic Irminger Current, *NIIC*; Wyville Thomson Channel, *WTC* (modified after: Hansen and Østerhus 2000; Østerhus et al. 2008; Hansen et al. 2008).

3.3 Deep-sea Isopoda

Crustaceans are especially regarded to be ubiquitous and very diverse, in terms of both species numbers and in their range of morphologies (Hessler 1981). Asellote isopods are regarded as the most frequent crustacean taxon present in most abyssal benthic samples. Often asellote isopods represent a notable large fraction of all species present in the area (Sanders et al. 1965; Sanders and Hessler 1969; Brandt et al. 2007b). Asellota Latreille, 1803 are considered to be distinguishing constituents of deep-sea fauna (Brandt et al. 2004; Brandt et al. 2005a; Gage and Tyler 1991; Hessler et al. 1979). Approximately one-third of all presently known aquatic isopods belong to this taxon. The group currently globally consists of 29 known families and over 1800 species. Their habitats extend from freshwater to marine and from tropical to polar waters (Merrin 2004). Deep-sea isopods differ from shallow marine,

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freshwater and terrestrial species (Wilson 1989). Specifically, deep-sea Asellota appear in multifaced forms, e.g. extended stick-like animals (Ischnomesidae Hansen, 1916), acanthous species (e.g. Acanthaspidiidae Menzies, 1962; Mesosignidae, Menzies and George 1972), burrowing dozer-like animals (e.g. Desmosomatidae Sars, 1897; Nannoniscidae Hansen, 1916; Janirellidae Menzies, 1956) as well secondarily highly modified swimmers within the Munnopsidae (Wilson 1989; Hessler and Strömberg 1989; Hessler 1993; Marshall and Diebel 1995; Raupach et al. 2009). Identification to the species level of these generally very small and usually blind isopods can be very challenging. Like other peracarids, isopods are brooders and do not have planktonic larvae. The development from larvae to juvenile takes place in the marsupium. Thus the distribution and gene flow of peracarid crustaceans is dependent on the active and passive (e.g. currents) migration of adults (Brandt 1992).

3.3.1 Munnopsidae Lilljeborg, 1864

Munnopsidae are one of the largest isopod families and are often the most abundant and diverse isopod family in benthic deep-sea samples and widespread even in cold waters (Brandt et al. 2004; Brandt et al. 2005b; Brenke et al. 2005; Wilson and Hessler 1981, 1980; Svavarsson 1987). The family has a bathymetric range from 4 m (Svavarsson et al. 1993b) to up to 8430 m depth (Merrin 2004). In general, primitive asellote isopods cannot swim. Hence, one of the reasons for the success of munnopsids may be their ability to swim (Wilson 1989). This deep-sea family features four different modes of swimming: forward striding, slow backward paddling, fast backward paddling and escape (Marshall and Diebel 1995). Also, Marshall & Diebel (1995) depicted that munnopsids can be observed while swimming slowly through the water. Also, they can be seen with their legs spread radially outwards in order to create drag and avoid rapid sinking (Marshall and Diebel 1995).

Wolff (1962) stated that most deep-sea asellotes are assumed to be deposit feeders. Studying their gut contents revealed that they contain mineral particles and foraminiferans and other items, which can be usually connected to detritivory. Though, it has to be noted that some species feature mouthparts that might be usable for crushing hard objects (Svavarsson et al. 1993a). Hence, Svavarsson et al. (1993a) and Gudmundsson et al. (2000) studied the diet of selected Munnopsidae and demonstrated that foraminiferans are an important food source for some species. In addition, fatty acid analysis by Würzberg et al. (2011) also confirmed that munnopsids feed on foraminiferans.

Presently around 300 species of Munnopsidae are known to science (Merrin 2007). The first member of the family Munnopsidae, *Munnopsis typica*, was described by Sars in 1861.

Since then the family Munnopsidae was frequently revised during several phylogenetic studies. For instance, Wilson (1989) combined in his phylogenetic study the existing three families Munnopsidae, Eurycopidae Hansen, 1916 and Ilyarachnidae Hansen, 1916 to Munnopsidae. The until that time existing two families Eurycopidae and Ilyarachnidae, were placed by Wilson (1989) within the family Munnopsidae as subfamilies. The reorganisation by Wilson (1989) is based on the following synapomorphies: enlarged pereonites 5-7; pereopods V-VII with many fully plumose setae with broadened and paddle-like carpi and propodi; unguis that encloses distal sensillae; rami of pleopod III with several distal pulmose setae; and the broadened first article of the antennulae (Wilson 1989). (See Appendix B for an illustration of the general munnopsid external morphology and some additional morphological explanations.) Furthermore, Wilson (1989) placed the following seven subfamilies within the family Munnopsidae: Munnopsinae; Acanthocopinae Wolff, 1962; Bathyopsurinae Wolff, 1962; Eurycopinae; Ilyarachninae; Lipomerinae Tattersall, 1905; Syneurycopinae Wolff, 1962. Those subfamilies contained all but seven genera *(incertae sedis)*, which could not clearly be placed within these subfamilies. Kussakin (2003) also revised the family Munnopsidae and introduced two new subfamilies: Betamorphinae Kussakin, 2003 and Storthyngurinae Kussakin, 2003. As a result, only the three genera *Munneurycope* Stephensen, 1913, *Munnicope* Menzies and George, 1972 and *Munnopsurus* Richardson, 1912 remained *incertae sedis*.

Currently many taxonomical problems within the family Munnopsidae are still not solved. The subfamily Eurycopinae Hansen, 1916 presently comprises for example six genera: *Eurycope* Sars, 1864, *Disconectes* Wilson and Hessler, 1981, *Tytthocope* Wilson and Hessler, 1981, *Belonectes* Wilson and Hessler, 1981, *Baeonectes* Wilson, 1982a and *Dubinectes* Malyutina and Brandt, 2006. A remarkable example for the taxonomical need of revision of certain genera within Eurycopinae is the genus *Eurycope* Sars, 1864, which is regarded to be the most complex and species rich genus within this subfamily (Kussakin 2003; Wilson 1983a). The heterogeneity of this genus has already been discussed by different authors (Wolff 1962; Wilson and Hessler 1981; Kussakin 2003; Wilson 1989; Malyutina and Brandt 2006). However, the genus has not yet been completely revised. In addition, the genus includes subgroups of species that are closely related with each other. Wilson 1985 stated that according to literature exceedingly widespread species tend to feature variations which are not yet explained. Elucidation of those variations in species characters will lead recognition of previously unknown species and their distributions could improve our knowledge of deep-sea biogeography (Wilson 1985).

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3.4 Aims & Questions

The research area of the BIOICE and IceAGE project is very much influenced by the GSR. Thus, Iceland inhabits a zoogeographic key position at the transition between the northern North Atlantic and the GIN seas. Within this region major temperature differences occur and the highly variable hydrographic conditions shape the environment. Former studies showed that benthic species composition varies between areas north and south of this natural border. Therefore, it will be interesting to investigate whether the distributional patterns of members of the family Munnopsidae, which have the ability to swim quite efficiently, differ from others. Thus the aim of this thesis is to evaluate species distribution, faunal composition and diversity of selected Munnopsidae in Icelandic waters obtained in the BIOICE and IceAGE project. Also, temperature and salinity data of the NISE project will be used in order to create circum Icelandic layers of long-term mean values, which will be connected to the species sample data.

To this end, the scientific aims and questions are as follows:

- To provide an overview on long-term near-bottom mean temperature and salinity conditions on the basis of the NISE dataset of the northern North Atlantic and the GIN seas.
- To briefly discuss the variation in temperature and salinity values by examining the standard deviation of the dataset.
- To document patterns of the current composition of the munnopsid genera *Baeonectes*, *Belonectes*, *Disconectes*, *Eurycope*, *Munnopsurus*, *Munnopsis* in Icelandic waters.
- To analyse and compare the biodiversity and faunal similarity of the selected genera in Icelandic waters.
- To analyse whether the selected Munnopsidae species occur within wide or narrow temperature and/or salinity ranges and if they are restricted to certain water masses.
- To investigate which of the abiotic factors, like temperature, salinity, sediment or depth is more likely to limit or influence the species distribution in the area.
- To examine if there is a difference in species composition between the areas north and south of the GSR. Does the ridge itself act as a barrier for species distribution of Munnopsidae, especially when considering their swimming ability?

4 Material & Methods

4.1 Study area

The geographic area [70°N -32°W 60°N -6°W] of the current study is presented in figure 1. This area of the BIOICE project includes the northernmost part of the North Atlantic and the south-western part of the GIN seas. The GSR is a continuous barrier with three sills and has a maximum depth of 840 m in the Faroe Bank Channel between the Faroe Islands and Scotland. Hence, the GSR with a mean depth of less than 500 m separates the deep-sea basins of the North Atlantic from the deep-sea basins north of the ridge. The deepest part of the Denmark Strait between Greenland and Iceland has a sill depth of 620 m, whereas the Iceland-Faroe Ridge between Iceland and the Faroe Islands features a maximum depth of about 480 m (Hansen and Østerhus 2000). The maximum depth of the whole study area is roughly 3000 m. The hydrographic conditions of the research area are complex with numerous primary water masses overlaying each other (Hansen and Østerhus 2000; Malmberg and Valdimarsson 2003; Stefánsson 1962). Those different water masses that can be observed in the study area of the BIOICE project also occur at the bottom. Intersections with the bottom boundary layer are illustrated in figure 5 (Brix and Svavarsson 2010).

At all BIOICE stations used in the present study temperature and salinity values just off the sea bottom were measured. Thus, stations could be allocated to the water masses using Hansen and Østerhus (2000), Malmberg and Valdimarsson (2003) and Stefánsson (1962). The following water masses could be assigned to BIOICE stations as already published by Brix and Svavarsson (2010): Modified North Atlantic Water (MNAW; 7-8.5°C; salinity 35.1-35.3), North Atlantic Water (NAW; 9.5-10.5°C; salinity 35.35-35.45), Modified East Icelandic Water (MEIW; 1-3°C; salinity 34.7-34.9), Norwegian Sea Arctic Intermediate Water (NSAIW; -0.5 to 0.5°C; salinity 34.87-> 34.9), Norwegian Sea Deep Water (NSDW; <-0.5°C; salinity 34.91), Labrador Sea Water (LSW; 3-4°C; salinity 34.9-34.95), Iceland Sea Overflow Water (ISOW; 2-3°C; salinity 34.85-35), Arctic/Polar Water (A/PW; 0-2°C; 34.3-34.9) and Coastal Water (CW; 5-12°C; salinity < 34.5). The salinity of the research area varied between 34.3 and 35.45 (excluding sites with extensive river inflow), while temperatures ranged between -1°C and 12°C. In addition, coastal areas are also very much influenced by seasonal variations of temperature.

The area south of the GSR is dominated by warmer water masses (e.g. MNAW, LSW), while the region north of the GSR is mostly influenced by colder water masses (e.g. NSDW). The deepest sills of the GSR either possess constantly or intermittently cold waters (e.g.

NSAIW, NSDW). In contrast, shallower parts of the GSR are influenced by warmer waters (e.g. MNAW, MEIW, CW; figure 5; Hansen and Østerhus 2000).
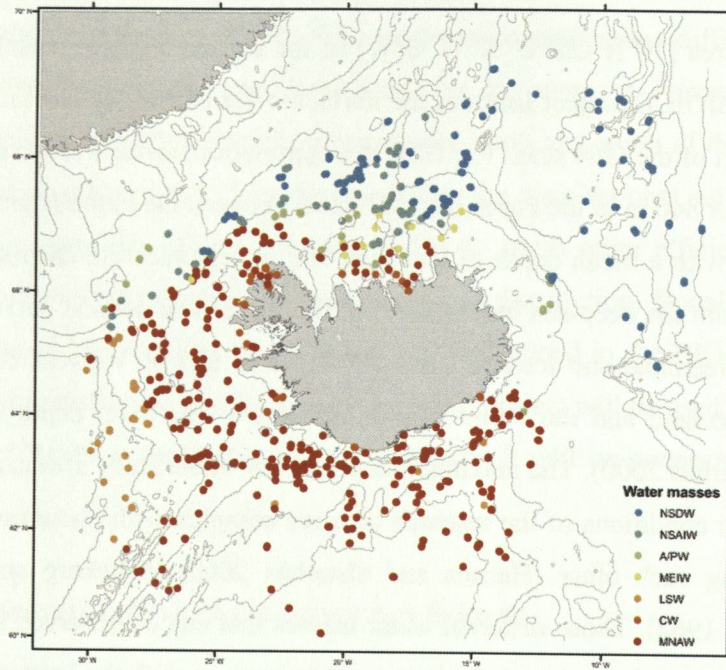
Figure 5: Distribution of water masses occurring at the bottom on the basis of data sampled during the BIOICE project. Arctic/Polar Water, *A/PW*; Coastal Water, *CW*; Labrador Sea Water, *LSW*; Modified East Icelandic Water, *MEIW*; Modified North Atlantic Water, *MNAW*; Norwegian Sea Arctic Intermediate Water, *NSAIW* and Norwegian Sea Deep Water, *NSDW*. The bottom depth is taken from ETOPO2 bathymetry and contours give the [3000 2000 1500 1000 300 100] m depth levels.
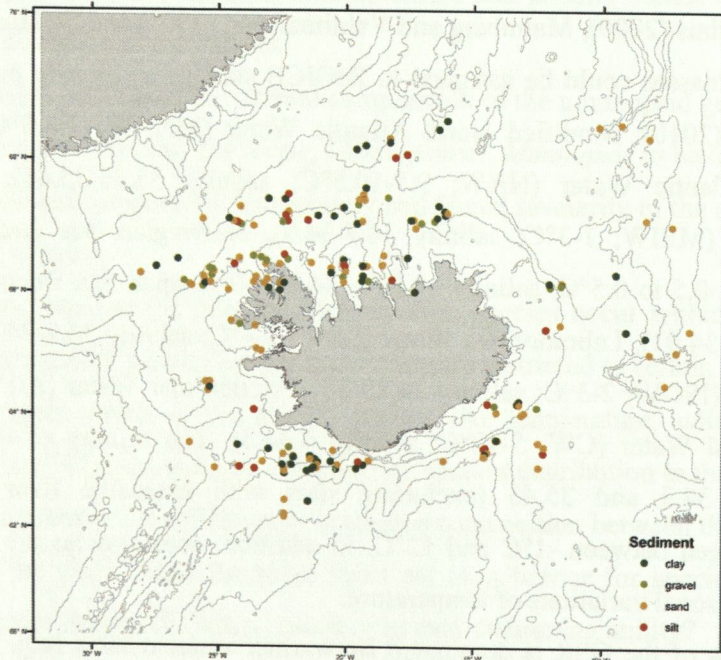
Figure 6: Distribution of sediment types based on Shipek grab samples around Iceland on the basis of data sampled during the BIOICE project. The bottom depth is taken from ETOPO2 bathymetry and contours give the [3000 2000 1500 1000 300 100] m depth levels.

4.2 Evaluation of NISE data

The whole NISE dataset compromises a total of 509,625 stations and contains hydrographic measurements of over one hundred years of the northern North Atlantic and the GIN seas. The version (V3) of the NISE dataset used in this study includes many variables, but only the hydrographic properties temperature and salinity are discussed here. Measurement of these variables was either achieved by collecting water samples in (Nansen/Niskin) bottles or electronically by using a CTD (Conductivity Temperature Depth; Nilsen et al. 2008).

For this thesis only the part of the NISE dataset with temperature and/or salinity data corresponding to the polygon [70°N -32°W 60°N -6°W] were imported into MATLAB 7.11.0 (R2010b). Thus, the dataset included for the chosen polygon from 1900 until 2008 more than 80,000 stations. Then stations were selected for further analysis by the following criteria: First of all, a maximum bottom depth was allocated to all stations with no given maximum bottom depth indicated in the dataset. Therefore, ETOPO2 (ETOPO2v2), a dataset generated using digital databases in order to provide data on a 2-minute latitude/longitude grid of seafloor and land elevations, was used. The ETOPO2 dataset for the region of the GIN seas south of 64°N consists of the Smith and Sandwell bathymetry (Smith and Sandwell 1997) and north of 64°N of the International Bathymetric Chart of the Arctic Ocean (Jakobsson et al. 2000). For assigning bottom depths to stations, the closest ETOPO2 latitude and longitude position was used to define the possible bottom depth at the given stations. Also, the maximum bottom depth indicated in the dataset was checked with ETOPO2. All stations, where the maximum bottom depth differed from the maximum bottom depth determined with ETOPO2 by a value larger than 200 m, were excluded from further analysis. Subsequently, only stations with a maximum distance of up to 80 m between employed gear (CTD or Bottle) and bottom depth (indicated in the dataset or allocated with ETOPO2) were used for further analysis. Also, the time distribution of the data was evaluated, in order to have an idea of the temporal distribution of the dataset. Thus, the annual occurrence of all stations was calculated and illustrated as a bar graph (figure 7). It has to be noted that the number of stations varied with the years. Most data were derived from the beginning of the 1950's to 2008. Also, more stations with temperature data (48,833 stations) than salinity data (45,019 stations) were present in the dataset. Merging data of all years and looking at monthly frequency distributions showed that sampling effort was least in wintertime. The majority of the samples were taken between April and September (not shown).

After the station selection, all the remaining stations were plotted into the chosen geographic area [70°N -32°W 60°N -6°W], in order to examine the spatial distribution of the

available NISE data. Afterwards, the whole research area was gridded, whereat the area was divided in longitudinal direction into 0.2° steps and in latitudinal direction into 0.1° steps.

After this, mean values of temperature and salinity of each grid cell as well as the number of stations per grid cell were calculated and illustrated. The standard deviation of the obtained mean values of each grid cell was again calculated and illustrated. Subsequently, gridded mean values of temperature and salinity data were interpolated along topography. This method after Davis (1998) assumes a barotropic flow and thereby a drift along lines of constant f/H, while f is the Coriolis parameter and H the water depth. This kind of assumption can be made in an ocean like the North Atlantic where stratification is weak. Averaging is achieved in elongated areas that stretch along lines of constant water depth (Davis 1998; Jakobsen et al. 2003).
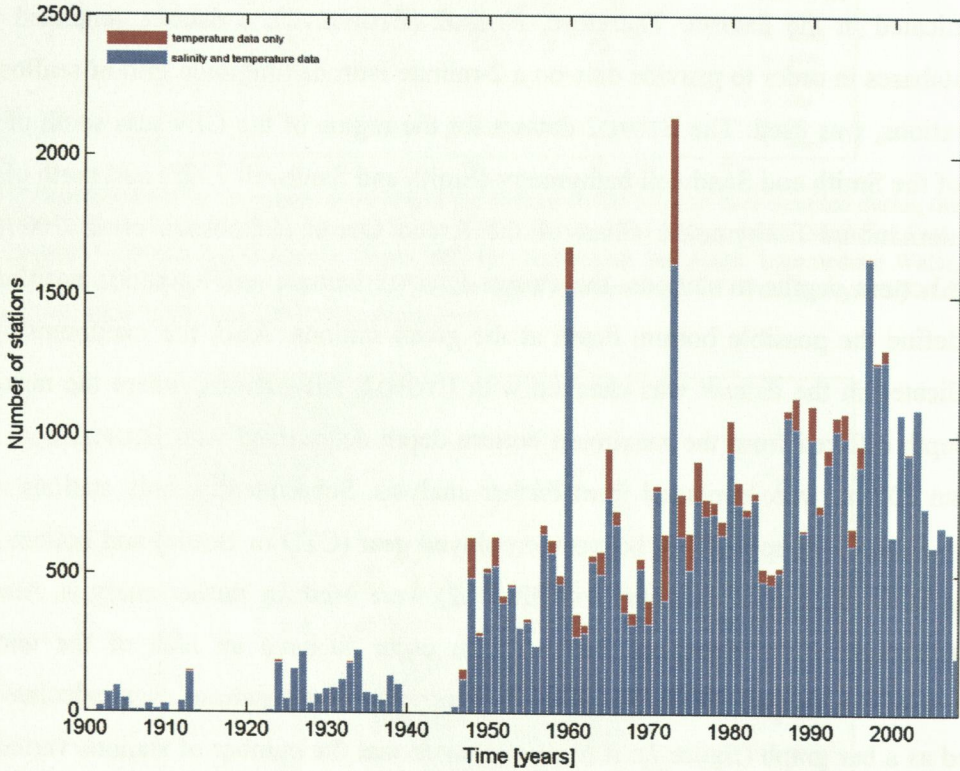
Figure 7: Total number of NISE stations present per year. *Blue bars* = salinity and temperature data; *red bars* = temperature data only.

4.3 Evaluation of BIOICE & IceAGE data

The major part of the evaluated Munnopsidae of this thesis was provided through the BIOICE project. During this project a total of 1,411 samples were collected at several stations by the research vessels *Bjarni Sæmundsson*, *Håkon Mosby* and *Magnus Heinason*, using different instruments. This study is based on samples taken with a modified Rothlisberg Pearcy epibenthic sled (RP sled; Brattegard and Fosså 1991; Rothlisberg and Pearcy 1977) with a sled net 0.5 mm mesh in the cod-end. The RP sled was towed along the sea floor and the animals, which were lifted in front of the sled due to turbulence, were collected. The closing mechanism of the sled guarantees that samples are only collected at the sea floor. RP sled samples are not quantitative. The term abundance will therefore be used in a semi-quantitative way and will accordingly refer to the number of individuals caught per successful RP sled deployment. The same gear was used at all stations and it was employed in the same manner at all times. Hence, comparisons between stations should be reliable. On deck, samples were decanted over 0.5 mm sieve, whereat the remaining sediment and animals were sieved over a series of sieves (8, 4, 2, 1, 0.5 mm). Subsequently, samples were preserved in 10 % buffered formalin and later transferred into 80 % ethanol (Brix and Svavarsson 2010; Svavarsson et al. 2001; Svavarsson 1997; Negoescu and Svavarsson 1997).

All samples of the BIOICE project were sorted to family level at the Sandgerði Marine Centre, Sandgerði, Iceland. During the BIOICE project a total of 223 RP sled samples were taken. For this thesis a total of 10,055 specimen of Munnopsidae from 82 selected RP sled stations were determined to species level. The positions of the evaluated BIOICE stations are presented in figure 1.

In addition, Shipek grab samples were taken at most of the evaluated RP sled stations. Thus sediment composition could be analysed and determined through the percentage of grain sizes. Sediment types were classified depending on the percentage of gravel, mud, sand and silt (figure 6; Brix and Svavarsson 2010).

A smaller fraction of munnopsids which were included in the dataset (732 specimen) were derived from sorting of 26 subsamples during the "IceAGE expedition 1" on board of *RV METEOR* (M85/3) in September 2011. The samples were taken with different types of epibenthic sledges, the RP sled and a modified epibenthic sled (EBS; Brenke 2005). Once on deck, these samples were immediately transferred into pre-cooled 96 % undenatured ethanol and kept cool for 48 h at 0°C. In order to guarantee a good fixation of the whole sample, samples were gently shaken every two hours within the first 24 hours after they had been collected. After 24 hours ethanol was renewed. Samples were kept cool throughout the whole

time in order to prevent tissue digestion, a standard procedure developed for deep-sea samples and proven during several CeDAMar expeditions (e.g. Schnurr and Brix 2012; Brix et al. 2011). The individuals of the subsamples that were determined to species level were included in the species distribution maps of this thesis. It has to be noted that the data of the subsamples were not used for any statistical analysis, due to the lack of abundances.

Temperature and salinity values for each BIOICE an IceAGE station were extracted from the modelled NISE data results (figure 10 and figure 13), using the ArcGIS 10.0 software. In order to illustrate the distribution of the selected Munnopsidae species distribution maps were generated using the ArcGIS. All species that occurred in at least three samples of the BIOICE dataset were included for further analysis. The relative abundance data were transformed by fourth root to reduce the impact of very dominant species (Field et al. 1982). The Primer version 6.0 package (Clarke and Warwick 2001) was applied for community analysis. The Bray-Curtis coefficient (Bray and Curtis 1957) was used to calculate similarities in species composition between the different stations of the BIOICE project. In contrast, the Euclidean distance (Clifford and Stephenson 1975) was used for differences in environmental data, based on normalised data (Clarke and Warwick 2001). Differences between a priori defined groups, using permutation/randomisation methods on resemblance matrix was tested with a one way designed analysis of similarities (ANOSIM; Clarke and Warwick 2001).

Similarity matrices were used for classification (complete linkage clustering; Lance and Williams 1967) and ordination (multi-dimensional scaling, MDS; Kruskal and Wish 1978). For the ordination (MDS) dissimilarity values between environmental data were used, while BIO-ENV (Clarke and Ainsworth 1993) was applied for linking community analysis to environmental variables. Four variables (temperature, salinity, depth and sediment type) were used for the BIO-ENV analysis. Spearman-rank correlation was used for comparison of the resemblance matrix of biotic data with the resemblance matrix of the abiotic data. As a result either a single factor or even a combination of factors that seemed to correlate best with the species pattern was identified.

The stress coefficient of the nMDS shows how trustworthy the high-dimensional relationship between samples in the 2-D ordination MDS plot is (Clarke and Gorley 2006). Stress values < 0.05 give an excellent representation. Stress values < 0.1 still give a good ordination, while stress values of > 0.3 are a sign that the data points are randomly placed in ordination (Clarke and Warwick 2001). Points within an MDS that are located close to each other represent stations with very similar species composition. On the contrary, points that are

located far apart from each other have different species compositions (Clarke and Gorley 2006).

Furthermore, it has to be noted that the community analysis (nMDS, cluster analysis and ANOVA) as well as the BIO-ENV analysis were all carried out with two different datasets. The first dataset included all the sorted BIOICE munnopsid species records of this thesis, which occurred in at least three samples, while the second dataset excluded the species records of *E. inermis* and *E. producta*. These species have been suggested to be species complexes (Svavarsson 1987; Wilson 1982b). In order to avoid including cryptic species that could potentially have different ecologies, these putative species complexes were excluded from the analysis. Both runs were carried out in order to see whether the putative species complexes influence the results. Hence, results of both datasets are presented herein.

Box plots of the factors depth, temperature and salinity were generated using R version 2.13.1 (R Development Core Team, 2006) for all species of the BIOICE dataset, which were present in at least three samples. For this thesis box plots with whiskers of a maximum interquartile range (IQR) of 1.5 were used. Data outside this range were labelled as outliers and indicated with small circles. The size of the box is limited by the lower quartile (Q1), the median (Q2) and the upper quartile (Q3), while the length of the whisker or an outlier indicates minimum and maximum values respectively. Skewedness pattern of box plots give an impression about how data are distributed within the dataset. In detail, a box plot is e.g. skewed to the right, when the distance between Q2 and Q3 is larger than between Q1 and Q2, which also means that the mean value is on the right side of the median.

In addition to Cluster Analysis and Multidimensional Scaling and BIO-ENV, Canonical Correspondence Analysis (CCA; Campbell and Atchley 1981) was accomplished with R in order to better understand the relationship between the predictors (temperature, salinity, sediment type, latitude and longitude) and to infer which of them mainly drive species distribution. Indeed this analysis calculates eigenvectors of species distribution under constrain of environmental conditions (Hill 1973; Legendre and Legendre 1998).

Further a permutation test (based on 4999 cycles) was applied to CCA, calculated eigenvectors in order to test for significance of constrains. All calculations were performed using R. Particularly CCA and permutation test were performed using the vegan package (Oksanen et al. 2006).

5 Results

5.1 Oceanography – Evaluation of NISE data

5.1.1 Analysis of near-bottom temperature & salinity data

The spatial distribution of all evaluated near-bottom temperature values of the NISE dataset is shown in figure 8. The spatial distribution of near-bottom salinity was very similar although 3,814 fewer station records were included in the salinity dataset (figure not shown). The highest sampling effort occurred mainly in the shelf regions around Iceland and the Faroe Islands, as well as along the GSR, whereas the least sampling effort was carried out in the deep-sea of the Irminger and the Iceland Basin and deeper areas of the Iceland and Norwegian Sea. Figure 15 shows how the whole research area was grouped into rectangular grid cells with a grid cell size of 11 km and sums up the sampling effort of the research area. Each grid cell features the number of stations that were falling within this area. It has to be noted that for the benefit of a better visualisation a scale from 0 to ≥ 30 stations per grid cell was used. For instance, there were also grid cells present with more than 300 relevant measurements. Figure 9 and figure 12 figure show the near-bottom mean values of temperature and salinity per grid cell throughout the whole time span of the NISE dataset. The interpolated near-bottom temperature and salinity values for the whole research area are shown in figure 10 and figure 13.

First of all the tendency of decreasing temperature and salinity values from South to North could be noticed. The GSR separated warm waters of the South from cold waters of the North. Near-bottom temperatures in depths greater than 400 m in the Iceland and Norwegian Sea were between -1°C and -0.5°C, whereas salinity in this region ranged mainly around 34.8 to 34.9. In comparison, the Iceland and the Irminger Basins were characterized by water temperatures of ~2°C to 3°C and salinities of ~34.8 to 34.9.

The surface East Greenland Current and the Denmark Strait overflow waters flow southwestwards along the Greenlandic coast and shelfbreak, influencing the region between Greenland and Iceland. Bottom temperatures in the southern part of this region were ~3°C, while bottom temperatures on the Greenlandic shelf ranged between -1°C and 2°C. Salinity close to the Greenlandic shore was fairly low (33.6 to 33.7) compared to all other regions of the whole research area, but it increased up to 34.6 to 34.8 in a depth of 400 m. The deepest part of the Denmark Strait was characterized by water temperatures of around 0°C or even less in its deepest parts and up to 4°C in its shallower parts. Also, this region was

characterized by the same salinities (~34.8 to 34.9) as the deeper parts of the GIN seas as well as in the deep Irminger and Iceland Basins.

The North Icelandic Irminger Current is the westernmost branch of inflowing water from the North Atlantic along the Icelandic shelf into the GIN seas. The north-western part of the Icelandic shelf featured temperatures of up to 7°C and decreased to about 2.5°C in the north-eastern part of the Icelandic shelf. Salinity in the north-western part of the Icelandic shelf was between 35.1 and 35.2, while the northern part of the Icelandic shelf featured salinities between 34.7 and 34.8. Salinity close to the eastern and north-eastern shore of Iceland featured values of ~34.4, which was lower compared to the rest of the Icelandic shelf.

The major part of the North Atlantic Current flows east of Iceland through the GSR. The shallowest region of the GSR between Iceland and the Faroe Islands featured bottom temperatures of up to 4.5°C and mean salinities of 35 to 35.1. The water temperatures on the coastal region around the Faroe Islands (~8.5°C) and on the Faroe Plateau (10 °C to 11°C) showed the highest temperatures within the whole considered area. Salinity values in this part were between 35.1 and 35.3. In addition, cold overflowing waters (-1°C to -0.5°C) could be recognized through the Faroe Bank Channel southeast of Iceland between the Faroe Bank and the Faroe Plateau. It could be also noticed that the water flowing through the channel was subsequently getting warmer when entering the North Atlantic. Salinity in the Faroe Bank Channel was the same as in the GIN seas (34.8 to 34.9). As in temperature a slight increase of salinity (to a value of ~35 to 35.1) could be recognized when the water was entering the North Atlantic.

5.1.2 Variation within the dataset

The gridded standard deviation of the bottom temperature did not show large differences in the deeper areas north and south of the ridge as well as the region of the Reykjanes Ridge. Standard deviation values in the deepest parts of the Denmark Strait ranged between 1°C and 2°C. Areas close to the shore in the south-western part of Iceland also featured high standard deviation values of up to 4°C. Northeast of Iceland in a depth of 400 to 500 m a fairly high standard deviation of ~2.5°C that followed the depth contour could be seen. Highest standard deviation values occurred around Iceland and the Faroe Island shelf, as well as along the GSR (figure 11). Especially the area between Iceland and the Faroe Islands and in the Faroe Bank Channel featured a fairly high standard deviation with values of ~3°C or even higher.

The gridded standard deviation of salinity showed a similar pattern as it could be seen in the temperature standard deviation. Standard deviation in the deeper ocean regions was rather

low. Regions close to the shore in the southern and south-eastern part of Iceland as well as regions close to the shore of Greenland showed high values of standard deviation of up to 0.7. The highest standard deviation values occurred in the shelf regions around Iceland and the Faroe Island shelf, as well as along the GSR. However, overall values mainly ranged between 0.1 and 0.2 (figure 14).
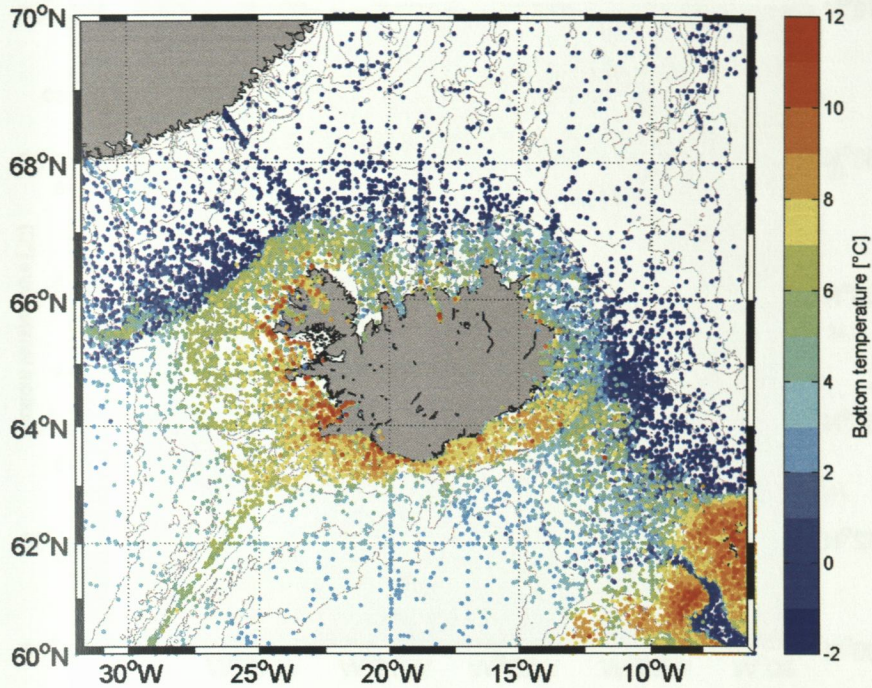
Figure 8: Locations of the 48,833 near-bottom temperature measurements of the NISE dataset. Only stations with a maximum distance of 80 m between employed gear and sea-bottom were included in this figure and accordingly used for further analysis. The colour scale indicates the measured near-bottom temperature in °C. The bottom depth is taken from ETOPO2 bathymetry and contours give the [3000 2000 1500 1000 500 300 100] m depth levels.
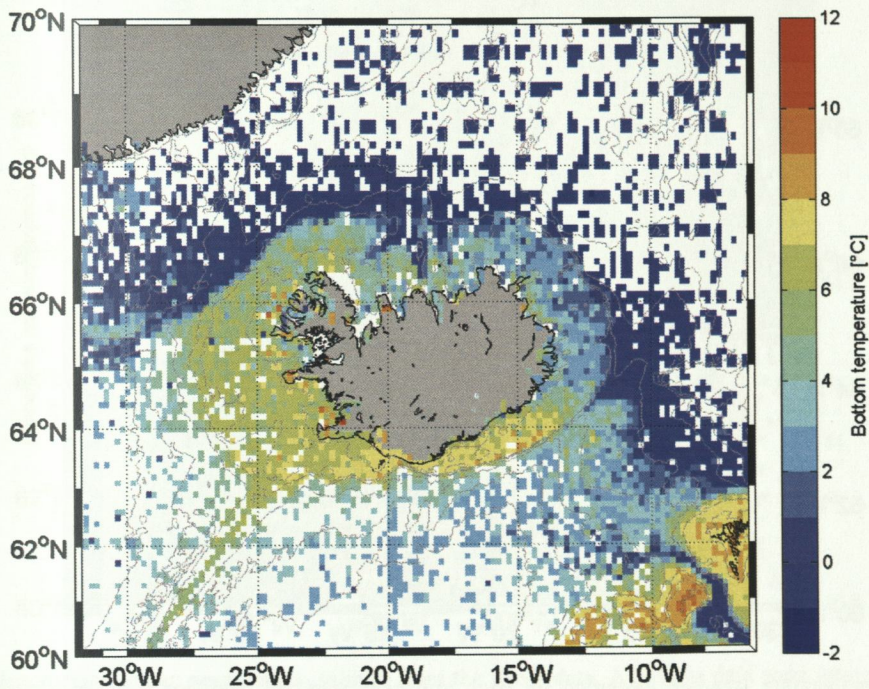
Figure 9: Mean near-bottom temperature calculated from the NISE data on a grid with a rectangular grid size of 11 km. The colour scale gives the mean near-bottom temperature in °C. The bottom depth is taken from ETOPO2 bathymetry and contours give the [3000 2000 1500 1000 500 300 100] m depth levels.
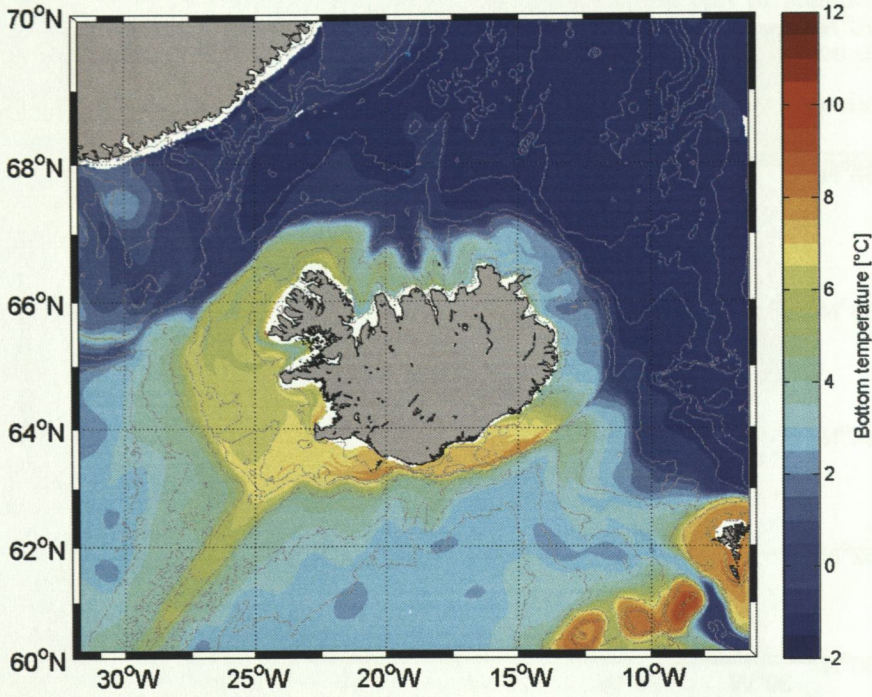
Figure 10: Interpolated mean near-bottom temperature from the NISE data. Available data were interpolated along topography. The colour scale indicates the interpolated mean near-bottom temperature in °C. The bottom depth is taken from ETOPO2 bathymetry and contours give the [3000 2000 1500 1000 500 300 100] m depth levels.
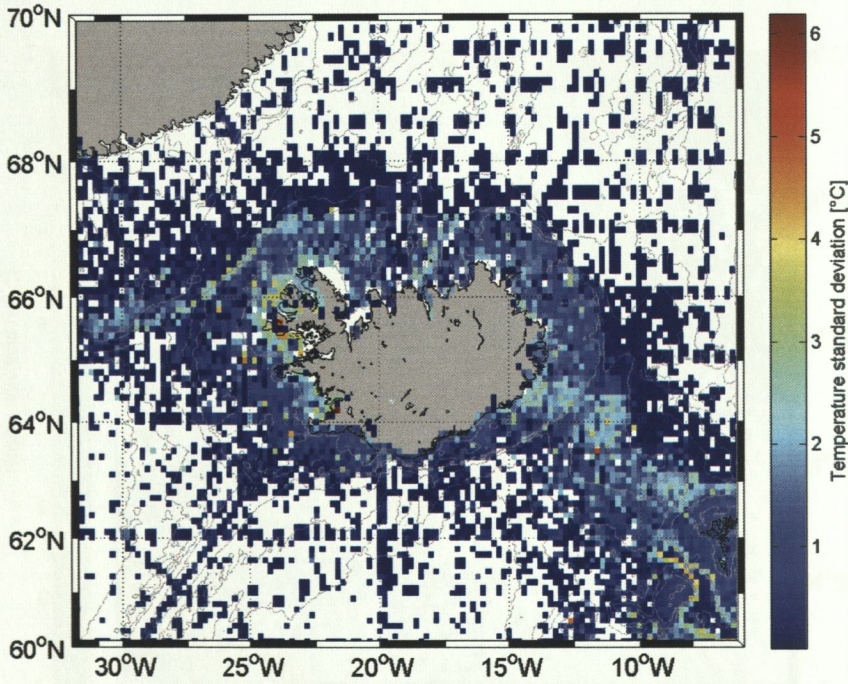
Figure 11: Temperature standard deviation for each grid cell. Standard deviation was calculated from the gridded mean temperature of each rectangular grid cell. The colour scale indicates the standard deviation of near-bottom temperature in °C. The bottom depth is taken from ETOPO2 bathymetry and contours give the [3000 2000 1500 1000 500 300 100] m depth levels.
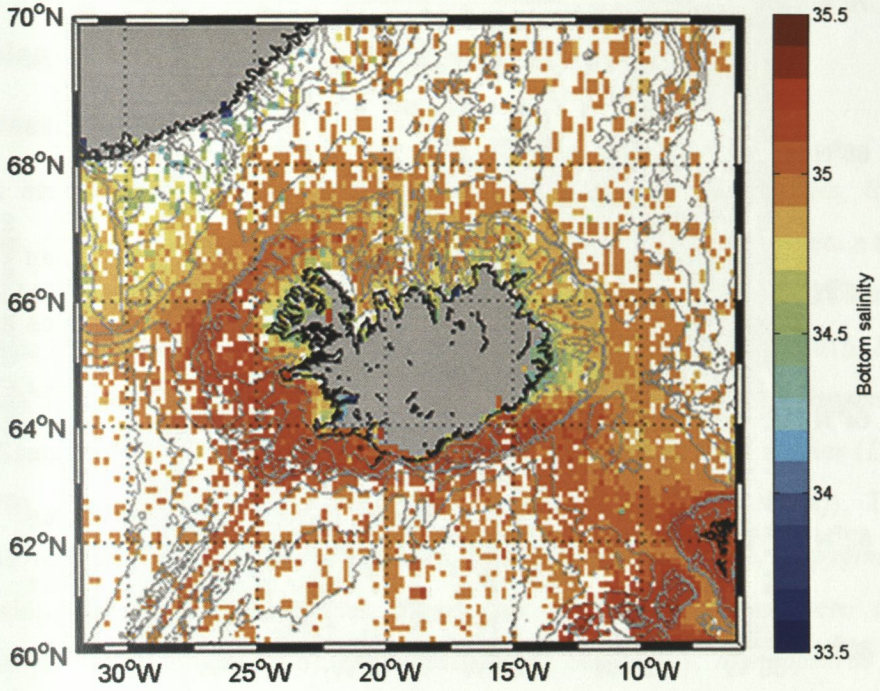
Figure 12: Mean near-bottom salinity values calculated from the NISE data on a grid with a rectangular grid cell size of 11 km. The colour scale gives the mean near-bottom salinity. The bottom depth is taken from ETOPO2 bathymetry and contours give the [3000 2000 1500 1000 500 300 100] m depth levels.
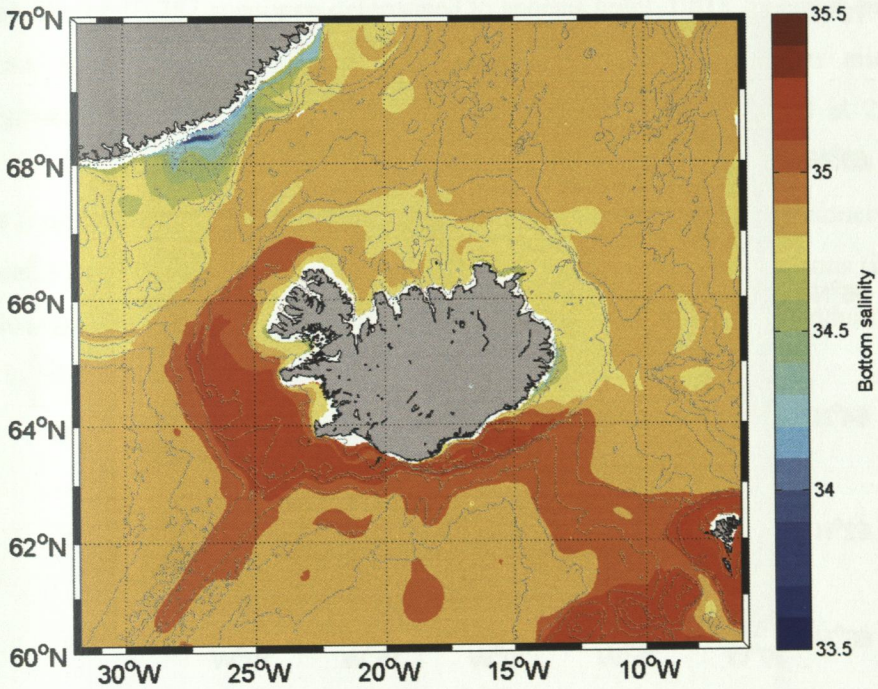
Figure 13: Interpolated mean near-bottom salinity from the NISE data. Available data were interpolated along topography. The colour scale indicates the interpolated mean near-bottom salinities. The bottom depth is taken from ETOPO2 bathymetry and contours give the [3000 2000 1500 1000 500 300 100] m depth levels.
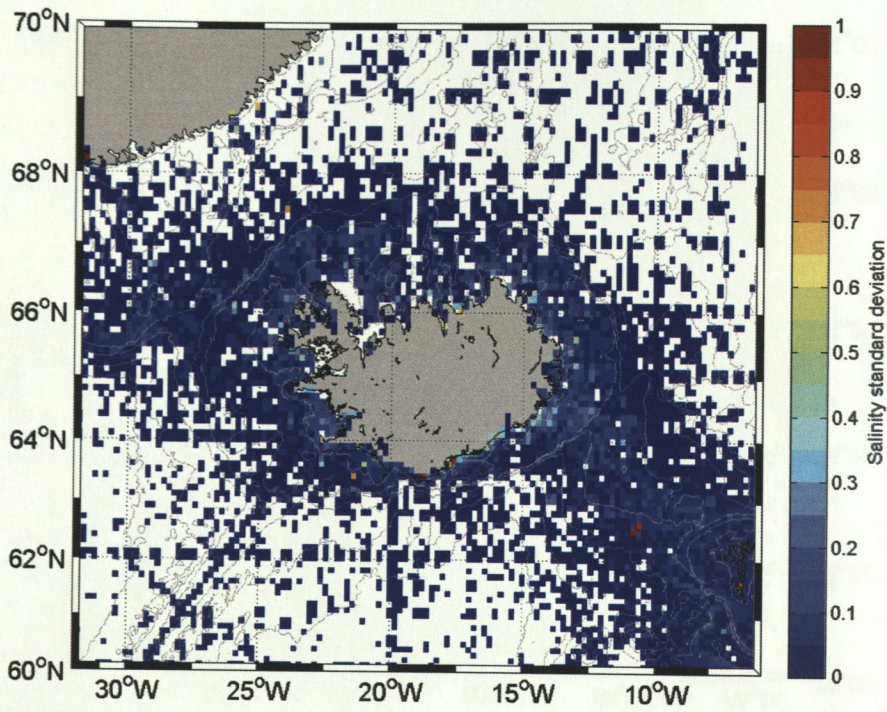
Figure 14: Salinity standard deviation for each grid cell. Standard deviation was calculated from the gridded mean salinities of each rectangular grid. The colour scale indicates the standard deviation of near-bottom salinity. The bottom depth is taken from ETOPO2 bathymetry and contours give the [3000 2000 1500 1000 500 300 100] m depth levels.
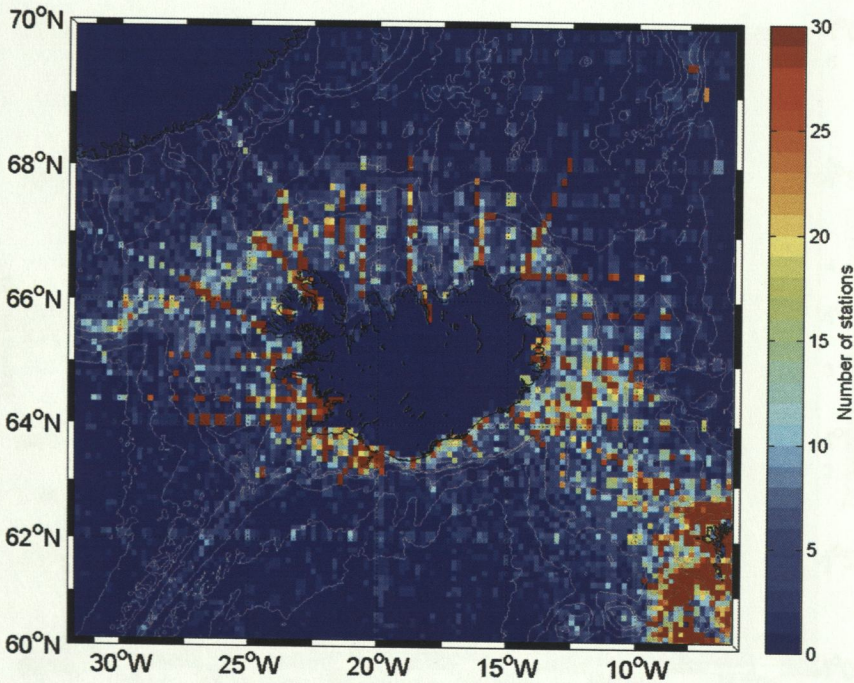
Figure 15: Number of stations per grid cell. The colour scale indicates the number of stations present in each grid from 0 to ≥ 30. The bottom depth is taken from ETOPO2 bathymetry and contours give the [3000 2000 1500 1000 500 300 100] m depth levels.

5.2 Ecology – Evaluation of BIOICE & IceAGE material

5.2.1 General faunal pattern

The focus of this study was on the selected munnopsid genera *Baeonectes*, *Belonectes*, *Disconectes*, *Eurycope*, *Munnopsurus*, and *Munnopsis*. Of the considered genera a total of 15 species could be identified. The genus *Eurycope* was represented with seven different species, of which one has not yet been, described (*E.* sp. A, *E. brevirostris* Hansen, 1916, *E. cornuta* (Sars, 1864), *E. dahli* Svavarsson, 1987, *E. hanseni* Ohlin, 1901, E. *inermis* Hansen, 1916, *E. producta* Sars, 1868), the genus *Disconectes* was represented with three species (*D. furcatus* (Sars 1870), *D. latirostris* (Sars, 1882) and *D. phalangium* (Sars, 1864)). The genus *Baeonectes* was represented with two species (*B. muticus* (Sars 1864), *B. pygmaea* (Sars, 1870)), while the genera *Belonectes, Munnopsis* and *Munnopsurus* were monotypic (*Belonectes parvus* (Bonnier, 1896); *Munnopsis typica* Sars, 1861; *Munnopsurus giganteus* (Sars, 1879)).

Eurycope producta occurred at most stations (69), which accounts for 63.89 % of all evaluated stations, followed by *E. inermis*, which was present at 52 stations (i.e. 48.15 % of all stations). Of the 10,787 specimen determined to species level, 1,818 specimen belonged to *E. producta*, while 4,447 specimen belonged to *E. inermis*. *Baeonectes muticus* and *D. phalangium* were also present at several stations. The former occurred at 25 stations (i.e. 23.15 % of all stations) with a total of 227 individuals, whereas the latter was present at 23 stations (i.e. 21.3 % of all the stations) with a total of 2,472 individuals. *Belonectes parvus* (8 individuals) and *D. latirostris* (6 individuals) were only present at two stations (i.e. 1.85 % of all stations). A summary of the number of presence records of each individual species is presented in table 1.

Table 1: List of the evaluated munnopsid species occurring in the study area, with information on the number and percentage of stations each species was present, the total number of individuals, minimum and maximum recorded depth [m], area, minimum and maximum temperature [°C] and salinity values, water masses (Arctic/Polar Water, *A/PW*; Coastal Water, *CW*; Labrador Sea Water, *LSW*; Modified East Icelandic Water, *MEIW*; Modified North Atlantic Water, *MNAW*; Norwegian Sea Arctic Intermediate Water, *NSAIW*; Norwegian Sea Deep Water, *NSDW*) and sediment types (clay, *Cl*; gravel, *Gr*; sand, *Sa*; silt, *Si*).Values in brackets and marked with a star (*) indicate values only based on the BIOICE dataset.

Species	Number of stations	Percentage of occurence	Number of Individuals	Depth minimum [m]	Depth maximum [m]	Area	Temperature minimum [°C]	Temperature maximum [°C]	Salinity minimum	Salinity maximum	Water mass(es)	Sediment types(s)
Eurycope cornuta	16 (15*)	14.81	917 (890*)	229	1320	N	-0.664	1.891	34.843	34.928	A/PW, NSAIW, NSDW	Cl, Gr, Sa, Si
Eurycope dahli	6 (4*)	5.56	43 (25*)	1624	2590	N	-0.995	-0.752	34.885	34.921	NSDW	Sa
Eurycope brevirostris	4 (1*)	3.7	13 (6*)	893	2135	N	-0.938	-0.642	34.888	34.916	NSDW	Cl
Eurycope hanseni	4 (3*)	3.7	142 (141*)	893	2590	N	-0.933	-0.642	34.885	34.928	NSDW	Cl, Sa
Beeonectes muticus	25 (25*)	23.15	227 (227*)	103	1028	NS	-0.493	7.308	34.829	35.188	A/PW, MNAW, NSAIW, NSDW	Cl, Sa, Si
Beeonectes pygmaea	8 (8*)	7.41	37 (37*)	184	841	NS	3.776	6.955	34.941	35.18	A/PW, MNAW	Cl, Sa
Belonectes parvus	2 (2*)	1.85	8 (8*)	841	1677	NS	-0.877	5.282	34.915	35.049	MNAW, NSDW	Cl
Disconectes phalangium	23 (14*)	21.3	2472 (2295*)	120	1396	NS	2.936	7.105	34.899	35.188	A/PW, MNAW	Cl, Sa
Eurycope inermis	52 (36*)	48.15	4447 (4175*)	302	2752	NS	-0.995	6.955	34.87	35.18	MNAW, NSAIW, NSDW	Cl, Gr, Sa, Si
Eurycope producta	69 (51*)	63.89	1818 (1701*)	103	2752	NS	-0.995	6.706	34.662	35.147	A/PW, MEIW, AW, NSAIW, NS	Cl, Gr, Sa, Si
Munnopsis typica	18 (18*)	16.67	259 (259*)	123	1153	NS	-0.421	7.105	34.882	35.188	A/PW, MEIW, MNAW, NSAIW	Cl, Gr, Sa, Si
Munnopsurus giganteus	11 (10*)	10.19	38 (28*)	391	1028	NS	-0.642	6.837	34.877	35.172	MNAW, NSAIW, NSDW	Cl, Gr, Sa, Si
Disconectes furcatus	5 (4*)	4.63	43 (29*)	1028	2137	S	2.561	5.552	34.972	35.096	MNAW, LSW	Cl, Sa, Si
Disconectes latirostris	2 (1*)	1.85	6 (1*)	140	175	S	4.823	6.697	34.88	35.142	MNAW	Cl
Eurycope sp. A	5 (3*)	4.63	47 (16*)	1153	2752	S	2.561	4.356	34.962	34.996	MNAW	Cl, Si

5.2.2 Species distribution

Distribution maps of the evaluated munnopsid species are shown in figures 16 to 20. Brix and Svavarsson (2010) grouped the isopod families Desmosomatidae Sars, 1897 and Nannoniscidae Hansen, 1916 into five categories. On the basis of their grouping the munnopsid species of this thesis were classified into the following six categories:

- Northern species – *Eurycope cornuta, Eurycope hanseni*
- North-eastern species – *Eurycope brevirostris, Eurycope dahli*
- Southern species – *Eurycope* sp. A, *Disconectes furcatus, Disconectes latirostris*
- Species occurring north, south and west of Iceland – *Munnopsis typica*
- Southern species with a tendency to cross the GSR towards north – *Baeonectes pygmaea, Disconectes phalangium*
- Northern and southern species – *Baeonects muticus, Belonectes parvus, Eurycope inermis, Eurycope producta, Munnopsurus giganteus*

Altogether 12 species were found north of the GSR, whereas 11 species were present south of the GSR. However, it has to be considered that a total of eight species occurred on both sides of the GSR. Tough, four species (*E. brevirostris, E. cornuta, E. dahli, E. hanseni*) were only found north of the ridge and three species (*Eurycope* sp. A, *D. furcatus, D. latirostris*) were restricted to the area south of the GSR.
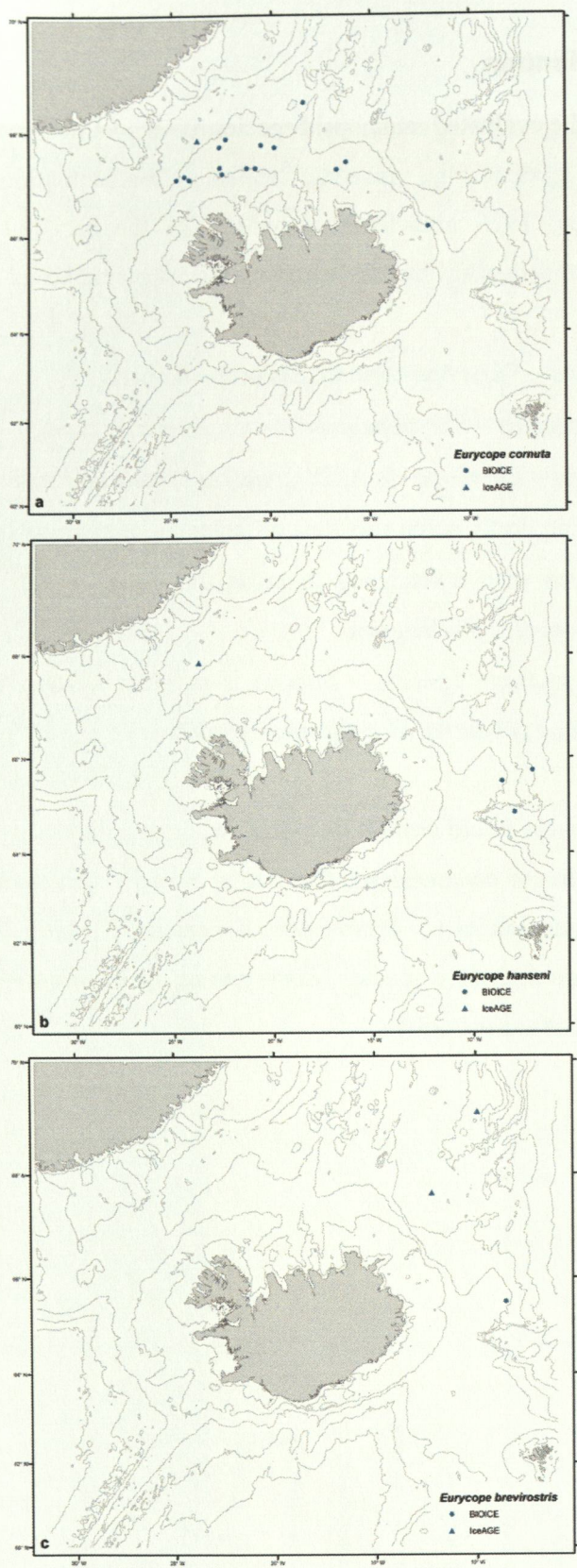
Figure 16: Distribution of species within the study area. Northern species: **a** *Eurycope cornuta*, **b** *Eurycope hanseni*. North-eastern species: **c** *Eurycope brevirostris*. The bottom depth was taken from ETOPO2 bathymetry and contours give the [3000 2000 1500 1000 300 100] m depth levels.
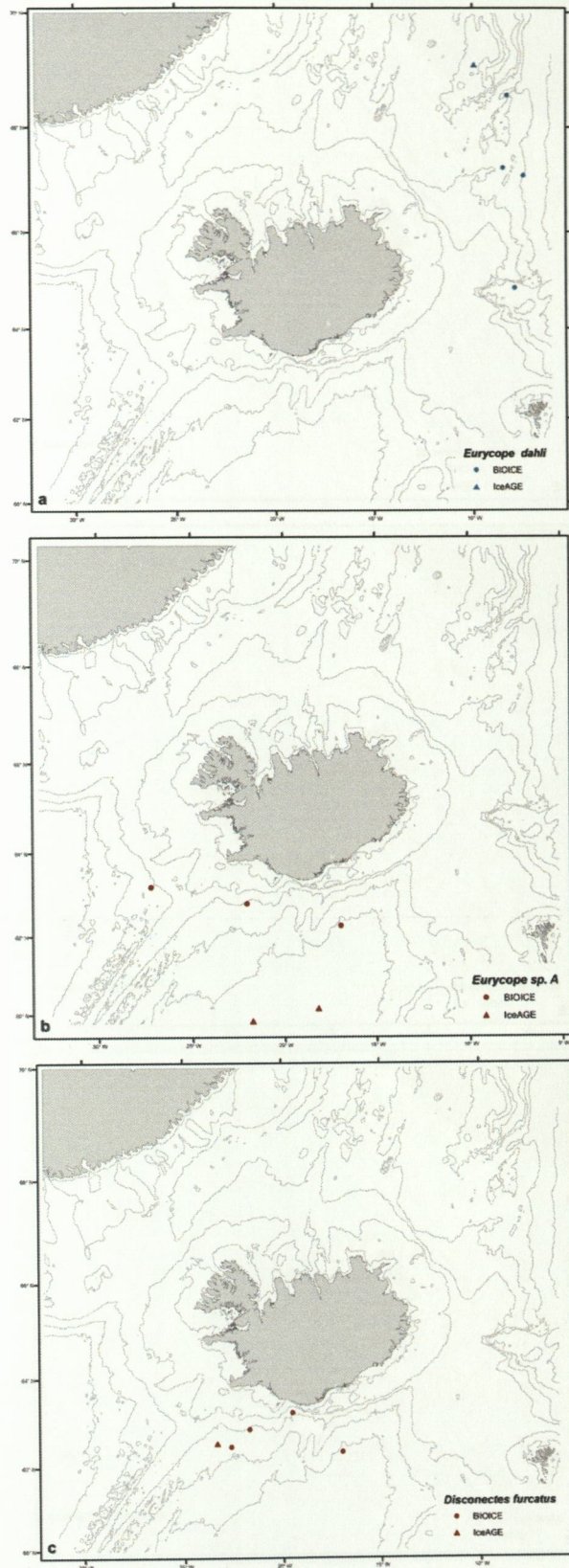
Figure 17: Distribution of species within the study area. North-eastern species: **a** *Eurycope dahli*, southern species: **b** *Eurycope* sp. A, **c** *Disconectes furcatus*. The bottom depth was taken from ETOPO2 bathymetry and contours give the [3000 2000 1500 1000 300 100] m depth levels.
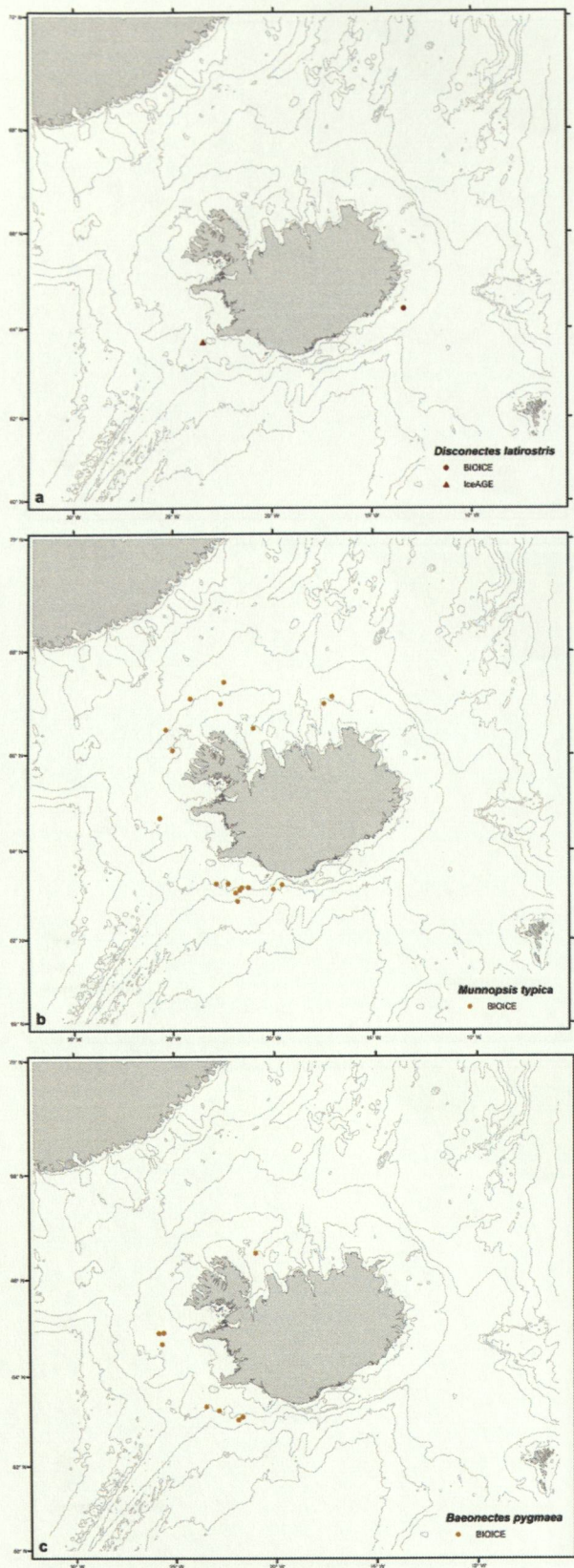
Figure 18: Distribution of species within the study area. Southern species: **a** *Disconectes latirostris*, species occurring north, south and west of Iceland: **b** *Munnopsis typica*, southern species with a tendency to cross the GSR towards north: **c** *Baeonectes pygmaea*. The bottom depth was taken from ETOPO2 bathymetry and contours give the [3000 2000 1500 1000 300 100] m depth levels.
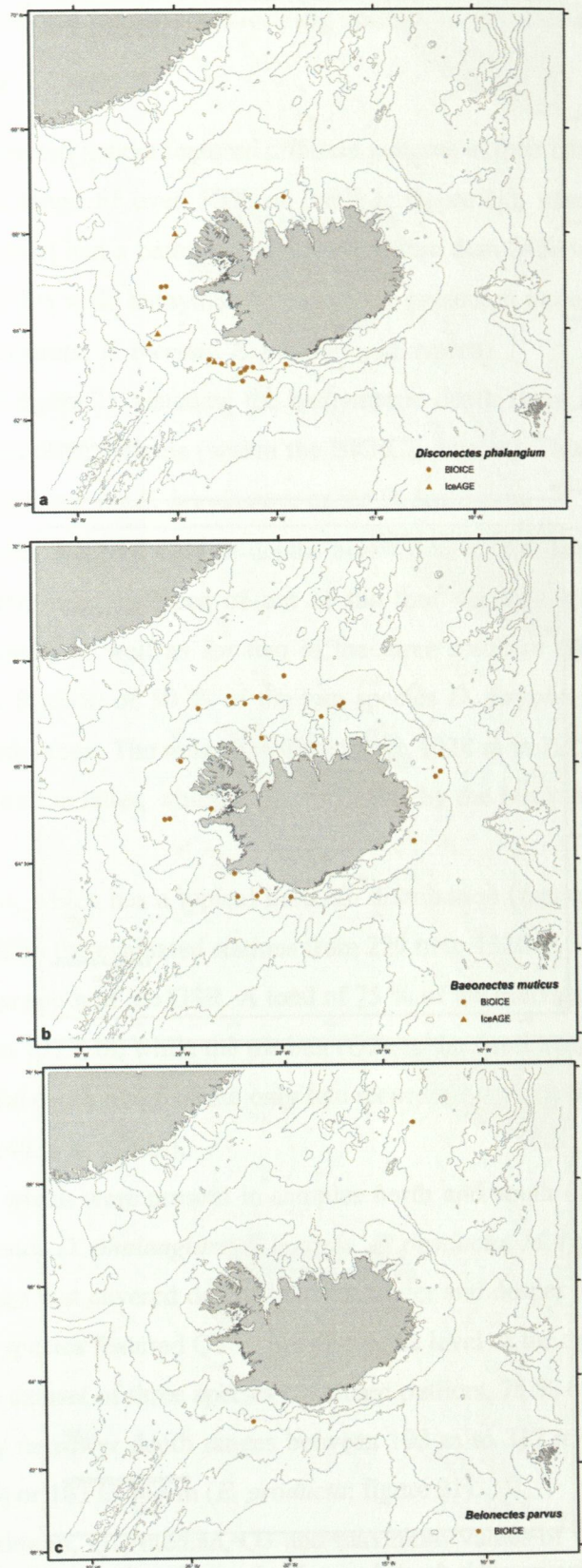
Figure 19: Distribution of species within the study area. Species with a tendency to cross the GSR towards north: **a** *Disconectes phalangium*, northern and southern species: **b** *Baeonectes muticus*, **c** *Belonectes parvus*. The bottom depth was taken from ETOPO2 bathymetry and contours give the [3000 2000 1500 1000 300 100] m depth levels.
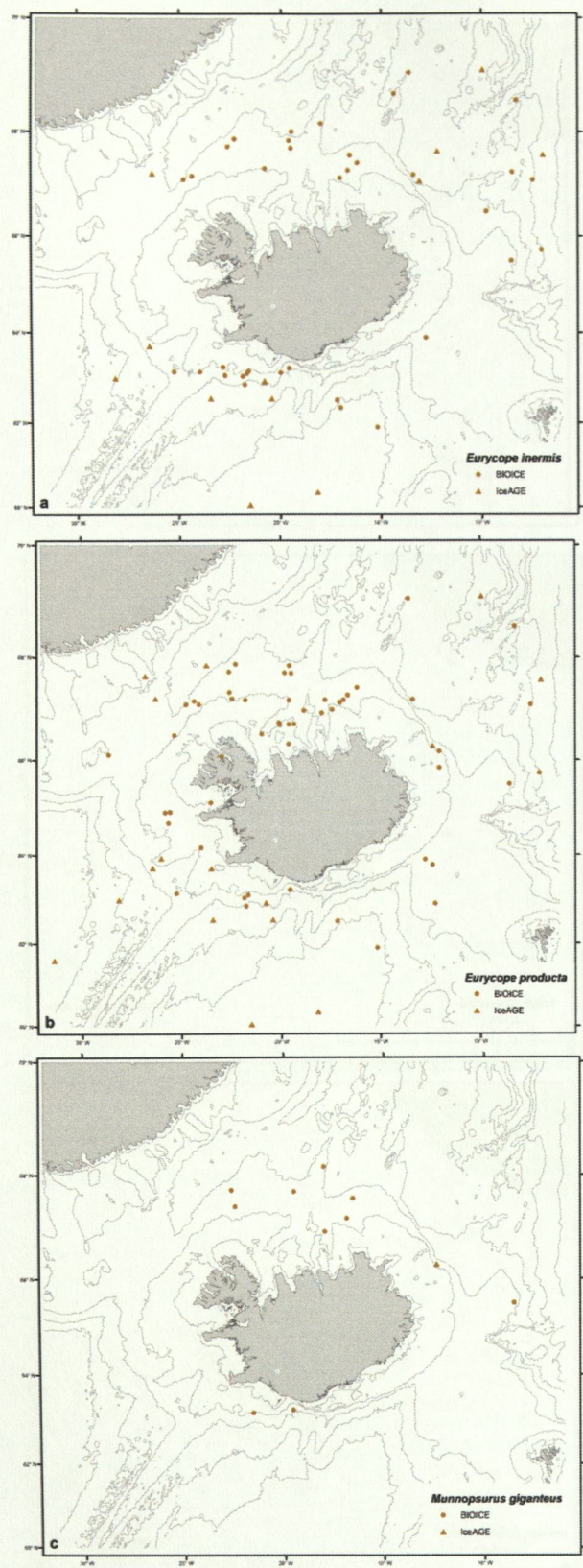
Figure 20: Distribution of species within the study area. Northern and southern species: **a** *Eurycope inermis*, **b** *Eurycope producta*, **c** *Munnopsurus giganteus*. The bottom depth was taken from ETOPO2 bathymetry and contours give the [4000 3000 2000 1500 1000 300 100] m depth levels.

5.2.3 Analysis of single factors influencing species distribution

Bathymetric ranges

The species of the selected genera featured different patterns in their bathymetric ranges. Nine species had a depth range of over 1000 m (table 1; figure 21), whereas two of them (*E. producta* and *E. inermis*) had a bathymetric range of more than 2400 m. Five out of the nine species that featured this wide bathymetric range were present at more than fourteen stations (*D. phalangium*, *E. cornuta*, *E. inermis*, *E. producta*, *M. typica*).

The box plots of figure 21 visualize the bathymetric depth range of all the species that occurred at more than three stations (within the BIOICE dataset). Thus, neither a box plot is presented for *B. parvus*, nor for *E. brevirostris* or for *D. latirostris*.

In total five species occurred only in depths below 840 m (the deepest depression of the GSR), which was the case for three of out of the four northern species (*E. brevirostirs*, *E. dahli* and *E. hanseni*) as well as for two of the three southern species (*D. furcatus* and *Eurycope* sp. A). A fraction of 50 % of the two species *D. furcatus* and *E. sp. A* occurred within a narrow depth range. The range accounted from 1028 m to 1213 m for the former and 1153 m to 1235 m for the latter, which is also reflected by the box plots being skewed to the left.

Eurycope cornuta, which has a typical northern distribution (figure 16a), featured a fairly high depth range within the evaluated stations from 229 m to 1320 m. However, there were no records of *E. cornuta* south of the GSR. A total of 75 % of the individuals occurred in a depth range from 229 m to 737.8 m, while the median (Q2) of the depth range of *E. cornuta* was at 571.5 m. Besides, the depth range of the only two recorded southern findings of *D. latirostris* was quite narrow (140 m to 175 m).

All the species, which were present in samples north and south of the GSR (*B. muticus*, *B. pygmaea*, *B. parvus*, *D. phalangium*, *E inermis*, *E, producta*, *M. typica* and *M. giganteus*) showed a depth range that covered depths both shallower and deeper than 840 m. It has to be noted that all those species featured Q2 values above the level of the deepest depression of the GSR. Although the dataset of three species contained outliers, 75 % of each species occurred within considerably narrower depth ranges between 103 m to 317 m (*B. muticus*), 302 m to 1057 m (*E. inermis*) or 103 to 715 m (*E. producta*; figure 21).

The precise minimum, Q1, median, Q3 and maximum values of the box plots indicating the bathymetric ranges of each individual species, which occurred at more than three stations is presented in Appendix C.

Temperature ranges

Temperature ranges of the different species varied considerably. Three of the four northern species (*E. dahli, E. hanseni* and *E. brevirostris*) occurred in water temperatures below -0.6°C, while their total temperature range was less than 0.5°C. *Eurycope cornuta* as the forth northern species differed from that pattern. It occurred from -0.52°C to 1.89°C. But the Q2 value of the box plot showed that the major part of the samples was present in water temperatures below -0.3°C within a quite narrow range. Overall, the box plot of this species appeared to be very skewed to the right, which means that more specimen of *E. cornuta* were present in low temperatures than in higher temperatures. In addition, 75 % of the *E. cornuta* samples occurred in temperatures below 0.49°C.

Five out of the eight species that were present both north and south of the GSR (*B. muticus, E. inermis, E. producta, M. typica* and *M. giganteus*) showed a fairly high temperature range of over 7.4°C (table 1; figure 22), while each of those species occurred in at least ten stations. In detail, *B. muticus* was present in temperatures from -0.5°C to 7.3°C with a median at 2.46°C. Interestingly, the box plot of *E. inermis* was very skewed to the right with a low median ~-0.37°C. This means that 50 % of the *E. inermis* samples occurred within a temperature range of -1°C to -0.37°C. The other 50 % of the samples occurred within the wider temperature range between -0.37°C to 6.96°C. *Eurycope producta* was present at temperatures between -1°C to 6.71°C with a median of 1.36°C. *Munnopsis typica* occurred in a temperature range from -0.42°C to 7.11°C, but most stations (75 %) where this species was collected had bottom temperatures ranging between 3.84°C to 7.11°C. *Munnopsurus giganteus* also featured a box plot, which was very skewed to the right. The median of the dataset was at a temperature of -0.38°C. Fifty per cent of the samples occurred within temperatures from -0.64°C to -0.38°C. In addition, 75 % of the samples occurred at temperatures less than 1.45°C. Moreover, the temperature box plot of this species also featured two outliers one at ~5.5°C and another one at 7°C. In comparison to those five species, the other two species that occurred at both sides of the GSR (*B. pygmaea* and *D. phalangium*) featured much narrower temperature ranges. *Baeonectes pygmaea* was present between 3.78°C to 6.96°C, with the major part of data between temperatures of 5.85°C to 6.37°C. In addition, *D. phalangium* occurred in temperatures between 2.94°C and 7.11°C, whereas 75 % of the data fell within the temperature range from 5.35°C to 7.11°C.

Two of the three southern species (*D. furcatus* and *E.* sp. A) appeared in temperatures above 2.56°C. *Disconectes latirostris* was present from temperatures of 4.8°C. Besides, *D. furcatus* had a temperature range of about 3°C and samples seemed to be equally

distributed within the whole temperature range of the species. Samples of *Eurycope* sp. A and *D. latirostris* both featured a temperature range of a little less than 2°C.

The precise minimum, Q1, median, Q3 and maximum values of the box plots indicating the temperature ranges of each individual species, which was present at more than three stations is presented in Appendix D.

Salinity ranges

All the observed species occurred within a salinity range between 34.66 and 35.19. Two of the three northern species (*E. dahli* and *E. hanseni*) were present in a quite narrow salinity range between 34.88 to 34.92 for the former and 34.88 to 34.9 for the latter species. In contrast, *E. cornuta* was present from 34.84 to 34.92, but the major part of the stations (75 %) fell within a salinity range between 34.89 and 34.92.

Six of the eight species that occurred in areas north and the south of the GSR (*B. muticus, D. phalangium, E. inermis, E. producta, M. typica* and *M. giganteus*) featured wide salinity ranges (figure 23). Notably, the box plots of *B. muticus, E. inermis* and *E. producta* appear to be very skewed to the right. *Baeonectes muticus* was present from 34.83 to 35.19, whereof 75 % of all the samples fell within a salinity range from 34.83 to 35.02 with a Q2 of 34.9. *Disconectes phalangium* was present in a salinity range between 34.9 to 35.19, but the majority of the samples (75 %) ranged between salinities from 35.06 to 35.19. Fifty per cent of *E. inermis* samples fell within a salinity range of 34.87 to 34.92, while the other 50 % of the samples occurred up to a salinity of 35.18. Specimens of *E. producta* were present in a salinity range from 34.83 to 35.15, with a median at 34.91. Samples of *M. typica* were almost equally distributed within the salinity range from 34.88 to 35.19. Most samples of *M. giganteus* (75 %) were present in a salinity range from 34.89 to 34.92 with two outliers that did not fall within the 1.5 IQR of the boxplot (35.1 and 35.18). *Baeonectes pygmaea* featured the narrowest salinity range of all the species that occurred on both sides of the GSR. Salinity values were almost equally distributed throughout the salinity range from 34.94 to 35.18.

Out of the three species that only occurred south of the GSR, *D. latirostris*, which only occurred at two stations (figure 18a), featured the widest salinity range between 34.88 and 35.14. *Disconectes furcatus* was sampled in a salinity range between 34.99 and 35.1, with a median at 35.0. *Eurycope* sp. A featured a salinity range between 34.99 and 35.0.

The precise minimum, Q1, median, Q3 and maximum values of the box plots, indicating the salinity ranges of each individual species, which occurred at more than three stations is presented in Appendix E.

Water masses

Most species were present in more than one water mass. Only five species occurred within a single water mass (*E. dahli, E. brevirostris, E. hanseni, D. latirostris, E.* sp. A), but it has to be noted that those species had very limited distributions and were only sampled at six or even fewer stations. Another four species were present in two water masses (*B. pygmaea, B. parvus, D. phalangium, D. furcatus*). The remaining six species occurred in three or more water masses (*B. muticus, E. cornuta, E. inermis, E. producta, M. typica, M. giganteus*; table 1). The distribution of all the BIOICE stations with allocated water masses is presented in figure 5.

The northern species *E. dahli, E. brevirostris* and *E. hanseni* only occurred within NSDW. In comparison, *E. cornuta* was present in three water masses with temperatures of less than 2°C (A/PW, NSAIW, NSDW). All species sampled in regions north and south of the GSR occurred in more than one single water mass. They were likewise present in warm and cold water masses. *Eurycope pygmaea* and *D. phalangium* were both present in cold water (A/PW) and warm water (MNAW). *Belonectes parvus*, which was only sampled at two stations (figure 19c), was detected in the cold NSDW and the warm MNAW. *Eurycope inermis* (figure 20a) was restricted to three water masses. It was present in rather cold (NSAIW, NSDW) waters, but also in rather warm water masses (MNAW). *Baeonectes muticus* was observed in three cold water masses (A/PW, NSAIW, NSDW) and one warm water mass (MNAW). The species that was present at most stations, *E. producta* (figure 20b) occurred in a total of six water masses, three cold water masses (A/PW, NSAIW, NSDW), one warm water mass (MNAW) and in MEIW (1°C to 3°C). *Munnopsis typica* occurred in two cold water masses (A/PW, NSAIW), in "intermediate" MEIW waters and in the warm MNAW. *Munnopsurus giganteus* occurred in purely arctic waters (NSAIW, NSDW) as well as in the rather warm MNAW.

The southern species *D. latirostris* and *Eurycope* sp. A were only present in MNAW, while *D. furcatus* occurred in two different water masses (MNAW and LSW), but both being characterized by rather warm water temperatures of more than 3°C.
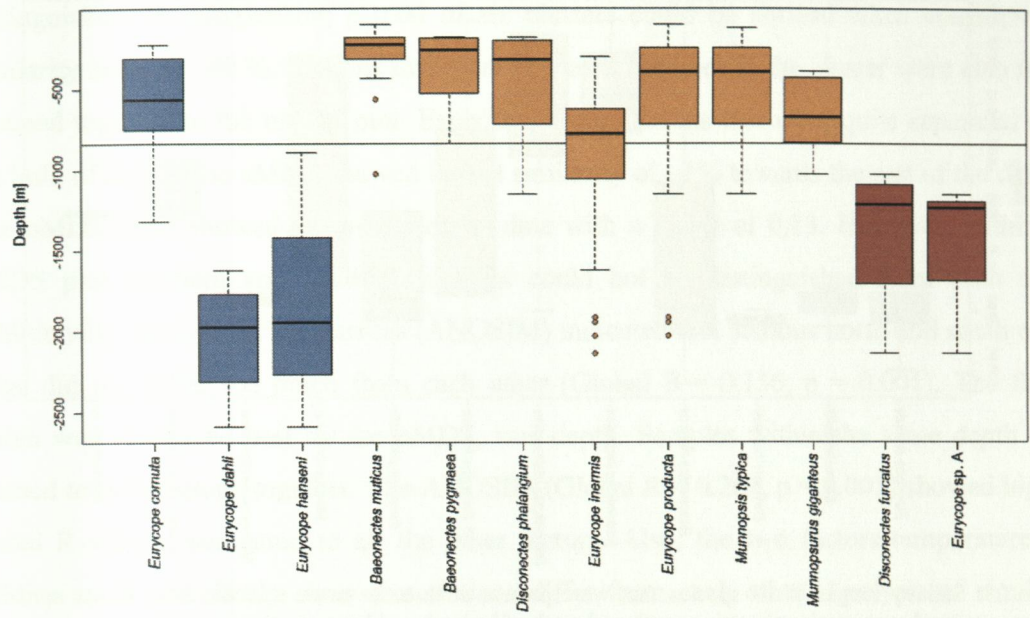
Figure 21: Bathymetric ranges of all species that were present at three or more stations. **Blue boxes** northern species; *orange boxes* species occurring south and north of Iceland; **red boxes** northern species; horizontal line at 840 m depth indicates the deepest depression of the GSR.
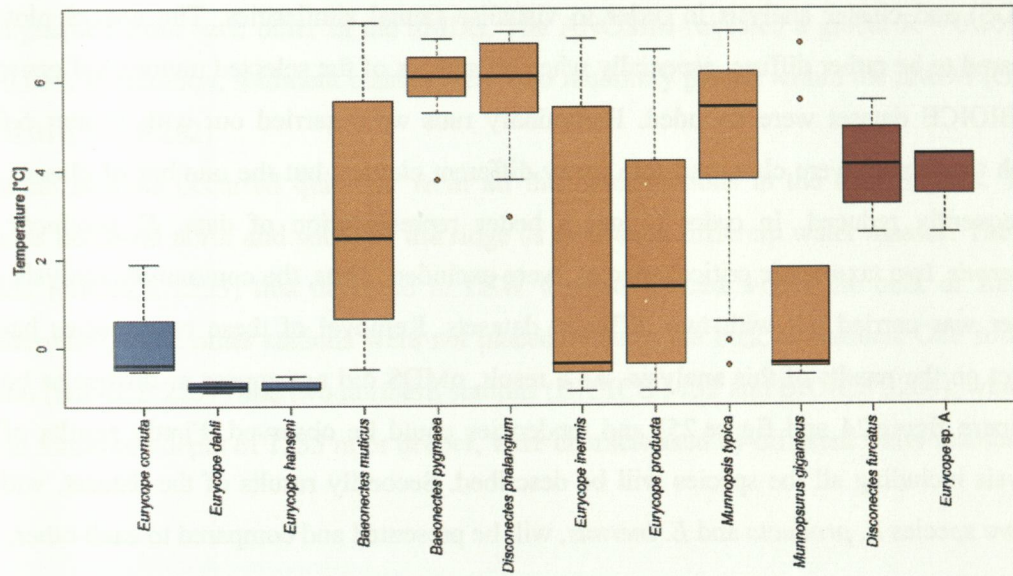
Figure 22: Temperature ranges of all species that were present at three or more stations. **Blue boxes** northern species; *orange boxes* species occurring south and north of Iceland; **red boxes** northern species.
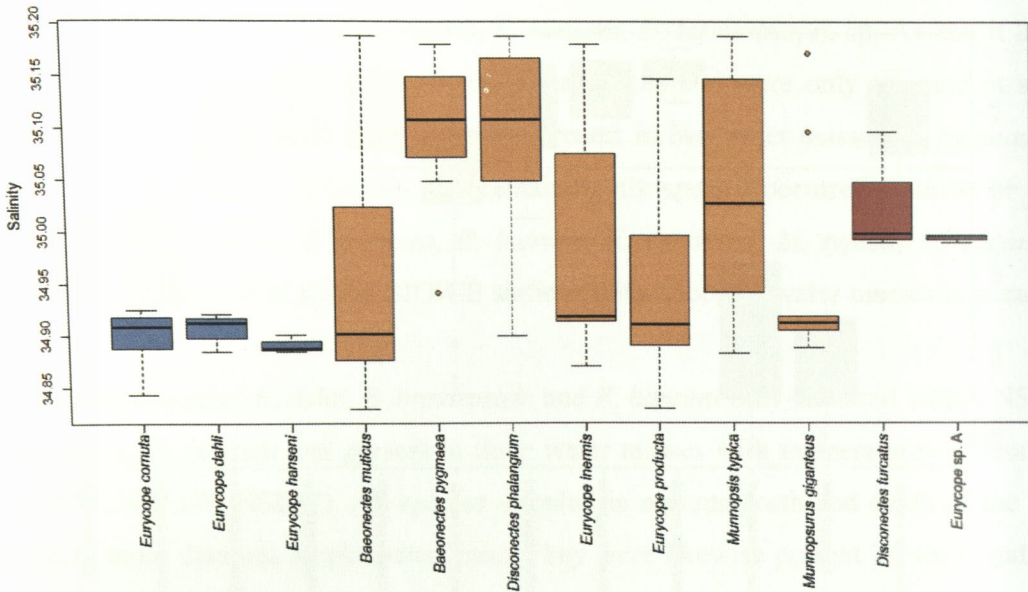
Figure 23: Salinity ranges of all species that were present at three or more stations. **Blue boxes** northern species; ***orange boxes*** species occurring south and north of Iceland; ***red boxes*** northern species.

5.2.4 Community analysis

Patterns of species composition were analysed using non-metric multidimensional scaling (nMDS) and cluster analysis in order to visualise faunal similarities. The nMDS plots all appeared to be rather diffuse, especially when all species of the selected munnopsid genera of the BIOICE dataset were included. Preliminary runs were carried out with Primer 6.0, in which the factors were classified into many different classes, but the number of classes was subsequently reduced. In order to get a better representation of data, *E. producta* and *E. inermis,* two taxonomic critical species, were excluded. Thus, the community analysis with Primer was carried out with two different datasets. Removal of these two species had an impact on the results of this analysis. As a result, nMDS did not appear as diffuse as before (compare figure 24 and figure 25) and tendencies could be observed. Firstly results of the analysis including all the species will be described. Secondly results of the dataset, without the two species *E. producta* and *E. inermis,* will be presented and compared to each other.

Patterns of species composition including all species

Four groups within the cluster on a similarity level of ~20 % with three outliers could be distinguished. In comparison, a total of six clusters could be noticed when considering a similarity level of ~40 %. Stations that were clustered together in the cluster were also rather grouped together in the nMDS plot. Especially three stations that were quite separated from the bulk of data in the nMDS showed lowest similarity of ~1% towards the rest of the dataset. The nMDS plots showed an ordination of data with a stress of 0.13. However, within the nMDS plot northern and southern stations could not be distinguished from each other. Additionally, analysis of similarities (ANOSIM) indicated that stations north and south of the ridge did not differ too much from each other (Global $R = 0.156$, $p = 0.001$). The factor, which was visualized best by the nMDS, was depth. Samples within the same depth class seemed to rather group together. The ANOSIM (Global $R = 0.262$, $p = 0.001$) showed highest global R values, compared to all the other factors. Also, the two factors temperature and salinity could not clearly show that stations differ from each other. Analysis of similarity revealed a global $R = 0.141$ and $p = 0.002$ for the former and global $R = 0.145$ and $p = 0.001$ for the latter. For the temperature nMDS it could be noticed that colder temperatures ($< 0°C$) were rather present in the upper part of the plot, while stations with temperatures $> 3°C$ were mainly present in the lower part of the plot. The different water masses could not be distinguished from each other in the nMDS. The ANOSIM revealed a global $R = 0.109$ and $p = 0.014$. In addition, sediment classes were also randomly placed within the nMDS (Global $R = 0.016$, $p = 0.282$).

Some stations occurred quite far from all the other stations in the nMDS plots. These stations occurred north and south of the ridge as well as in different water masses. The only station (BIOICE 2293) that occurred in LSW was not placed within the bulk of stations. Furthermore, three other stations were not placed close to the bulk of stations. One southern station (BIOICE 2257) and two northern stations (BIOICE 3132 and BIOICE 3204), which all had at minimum depth of 1235 m or deeper, were characterised by different water masses.

Patterns of species composition excluding *E. inermis* & *E. producta*

Seven groups within the cluster could be distinguished on a similarity level of ~40 %. In addition, stations that were clustered together in the cluster (figure 25g) were also rather closely grouped within the nMDS plots. The nMDS plots featured a stress value of 0.05. At first glance the nMDS plots looked a little less diffused compared to the results that were achieved as all species were taken into account for the community analysis. However, within the nMDS northern and southern species could not be clearly distinguished form each other. Stations of the two different regions appeared a little more separated from each other (in comparison to figure 24a). Southern species were mainly in the upper part of the plot present. The result of the ANOSIM (Global R = 0.146, p = 0.002) did not help to definitely clarify the separation between northern and southern stations of the dataset, which included all species.

Again depth was the factor that was represented best in the nMDS as well as in ANOSIM (Global R = 0.385, p = 0.001). Deepest stations were more or less clustered together, apart from the bulk of data. BIOICE station 2856 was for example located far away from the other stations of this group, which could be partly caused because the station was located in the South and all other deep stations were located north of GSR. In addition, the shallowest stations (< 500 m) seemed to cluster together in the middle of the nMDS (figure 25b). The overall representation of depth still looked diffuse, but showed much more of a trend than the results achieved by taking into account the whole dataset. Within the nMDS plot lower temperatures (< 0°C) were represented in the lower part of the plot. Stations with intermediate temperatures (> 0 °C to 3°C) were present in the middle of the plot, whereas stations with highest temperatures (> 3°C) were located in the upper part of the plot. Analysis of similarity of temperature revealed a global R of 0.281 and a p of 0.001. The overall impression of the distribution of water masses within the nMDS seemed to match with the temperature classes. Water masses with temperatures below 0°C (NSDW and part of NSAIW) were located in the lower part of the nMDS, whereas water masses with temperatures over 0°C, but with a maximum of 3°C (LSW, A/PW, MEIW and part of NSAIW) were mainly present in the middle of the plot. Water masses with temperatures over 3°C (MNAW) were represented in the top of the plot. Anyway, those tendencies with a global R of 0.253 and a p of 0.001 could be seen. Aditionally, nMDS plots of salinity (figure 25d) and sediment type (figure 25f) looked very diffused and were not considered to be important for the explanation of the visualized pattern of the nMDS (Global R = 0.092, p = 0.009 for the former and Global R = -0.001, p = 0.518).

Additionally, patterns of species composition were analysed, excluding *B. muticus*, *E. inermis* and *E. producta*, due to their broad temperature, salinity and depth ranges. Though the dataset became very small the overall result of the nMDS and the cluster analysis plots were not considerably improved (data not shown).
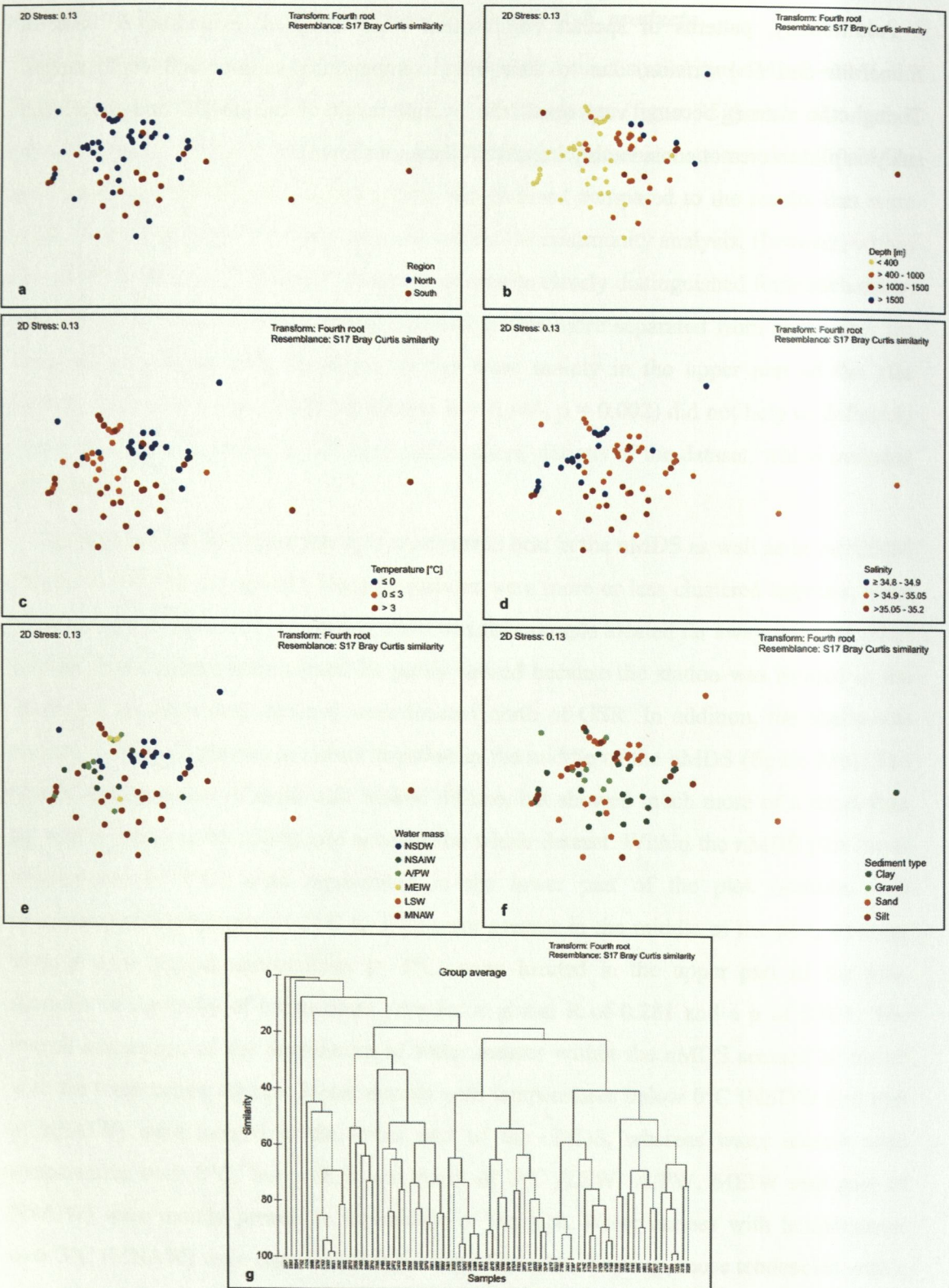
Figure 24: Results of multivariate analysis of the species composition including all species that occurred in at least three different samples. Two-dimensional nMDS, which is based on Bray-Curtis similarities *a* factor region, *b* factor depth, *c* factor temperature, *d* factor salinity, *e* factor water mass, *f* factor sediment type, *g* results of cluster analysis.
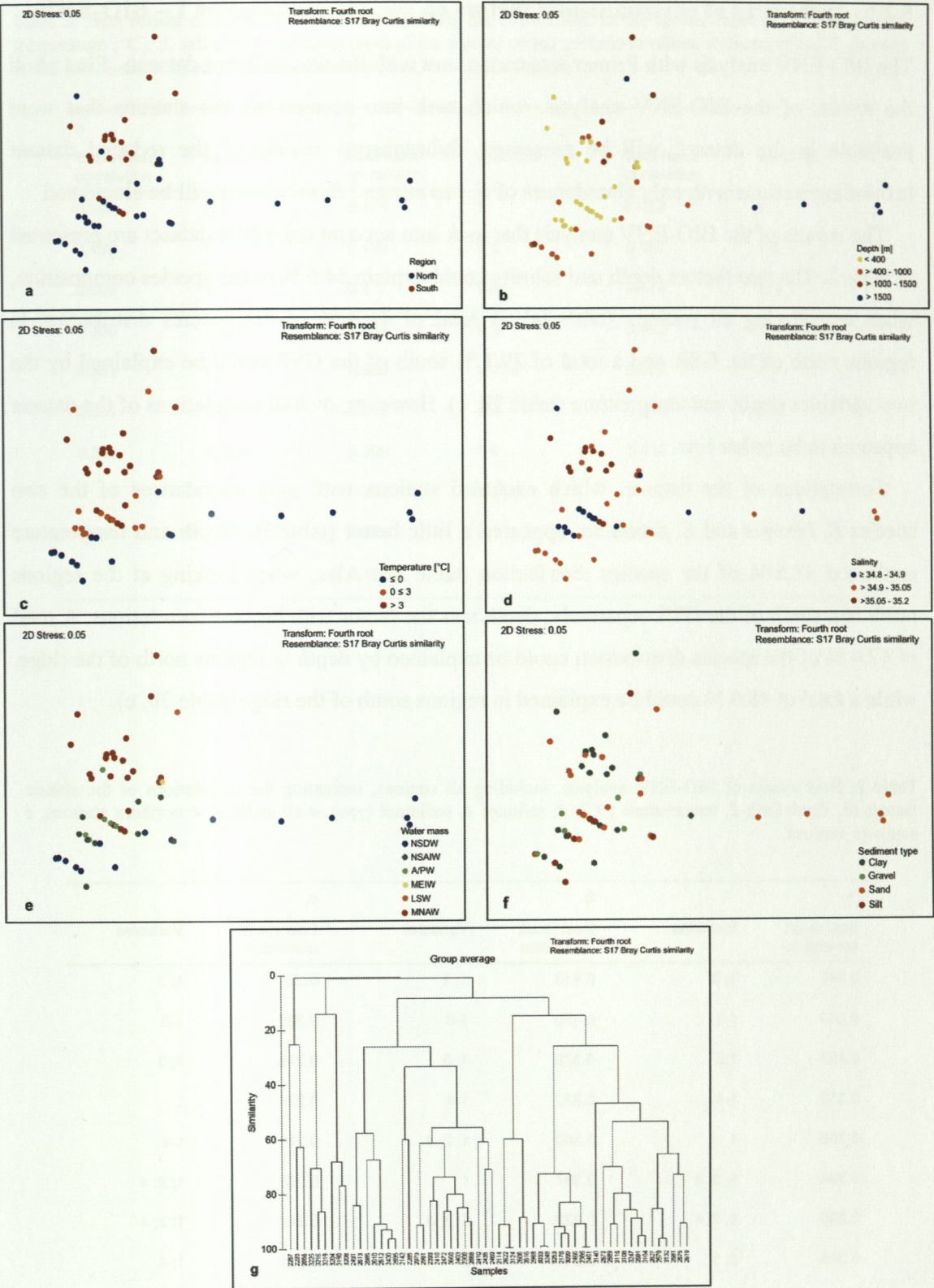
Figure 25: Results of multivariate analysis of the species composition without the two species *E. inermis* and *E. producta*. Two-dimensional nMDS which is based on Bray-Curtis similarities *a* factor region, *b* factor depth, *c* factor temperature, *d* factor salinity, *e* factor water mass, *f* factor sediment type, *g* results of cluster analysis.

5.2.5 Influences of environmental factors on species composition I – BIO-ENV

The BIO-ENV analysis with Primer was carried out with the two different datasets. First of all the results of the BIO-ENV analysis, which took into account all the stations that were available in the dataset, will be presented. Subsequently results of the reduced dataset (excluding stations with only abundances of *E. inermis* and *E. producta*) will be elucidated.

The results of the BIO-ENV analysis that took into account the whole dataset are presented in table 2. The two factors depth and salinity could explain 34.5 % of the species composition, when considering all stations (table 2a). A total of 41.3 % of the species distribution in regions north of the GSR and a total of 29.1 % south of the GSR could be explained by the two variables depth and temperature (table 2b, c). However, overall correlations of the dataset appeared to be rather low.

Correlations of the dataset, which excluded stations with only abundances of the two species *E. inermis* and *E. producta*, appeared a little better (table 3). Depth and temperature explained 48,5 % of the species distribution (table 3a). Also, when looking at the regions north and south of the GSR separately, depth was the factor with highest correlations. A total of 47.4 % of the species distribution could be explained by depth in regions north of the ridge, while a total of 48.9 % could be explained in regions south of the ridge (table 3b, c).

Table 2: Best results of BIO-ENV analysis, including all stations, indicating the correlations of the abiotic factors (*1*, depth [m]; *2*, temperature [°C]; *3*, salinity; *4*, sediment type). *a* all stations, *b* northern stations, *c* southern stations.

a.		b.		c.	
Best result correlation	Variables	Best result correlation	Variables	Best result correlation	Variables
0.345	1; 3	0.413	1; 2	0.291	1; 2
0.340	1-3	0.403	1-3	0.282	1-3
0.337	1;2	0.379	1; 3	0.278	1; 3
0.313	1-4	0.372	1-4	0.276	1
0.309	1	0.369	1; 2; 4	0.271	1-4
0.294	1; 3; 4	0.367	1	0.268	1; 2; 4
0.290	1; 2; 4	0.322	1; 3; 4	0.247	1; 3; 4
0.245	2; 3	0.311	2	0.221	1; 4
0.221	2	0.303	2; 3	0.220	2; 3
0.221	1; 4	0.277	1; 4	0.194	2-4

Table 3: Best results of BIO-ENV analysis, indicating the correlations of the abiotic factors (*1*, depth [m]; *2*, temperature [°C]; *3*, salinity; *4*, sediment type) of the dataset which excluded stations with records of *E. inermis* and *E. producta*. *a* all stations, *b* northern stations, *c* southern stations.

a.		b.		c.	
Best result correlation	Variables	Best result correlation	Variables	Best result correlation	Variables
0.485	1; 2	0.474	1	0.489	1
0.439	1	0.450	1; 2	0.481	1-3
0.396	1-3	0.377	1-3	0.474	1; 3
0.396	1; 2; 4	0.364	1; 3	0.472	1; 2
0.381	1; 3	0.355	1; 2; 4	0.427	1-4
0.351	1-4	0.319	1; 4	0.419	2; 3
0.309	1; 3; 4	0.309	1-4	0.413	1; 3; 4
		0.282	1; 3; 4	0.402	1; 2; 4
		0.241	2	0.354	2
		0.166	2; 3	0.348	2-4

5.2.6 Influences of environmental factors on species composition II – CCA

The first CCA axis separated species along the factor depth, while the second CCA axis separated species along latitude. Sediment and salinity point in opposite directions. In the CCA the first axis was the most important one (figure 26). Eigenvalues above 0.5 usually indicate a good dispersal of species along the respective axis. Additionally, these axis are suggested to explain the major part of variance of species composition (ter Braak 1986).

Accomplishing CCA revealed depth as the most significant factor driving the distribution of the selected munnopsid genera. In addition, Monte Carlo test on variables terms (PERMANOVA) also emphasized depth as the significant factor that mostly influenced the species distribution (table 4 and table 5).

The graph of the CCA indicates that the distribution of *D. latirostris* was highly dependent on depth. In addition, *M. giganteus* and *E. producta* were also highly depending on the factor depth, while *E. cornuta*, *B. pygmaea* and *M. typica* seemed to be rather influenced by sediment, but also by depth and latitude. In comparison, *Eurycope* sp. A, *E. hanseni*, *E. dahli* and *D. furcatus* were influenced by depth and also by temperature and longitude, while *E. inermis* and *D. phalangium* were least influenced by depth, sediment and latitude but rather by salinity, temperature and longitude. *Baeonectes muticus* seemed to be most influenced by longitude, sediment and depth (figure 26).

As in nMDS, the CCA indicated that depth is the main factor influencing species distribution patterns. The other factors (sediment, temperature, salinity, latitude and longitude) seemed to play less important roles in driving the distribution of the evaluated genera (table 5).

Table 4: Eigenvalues of CCA.

	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6	Axis 7
CCA Eigenvalues	0.31	0.16	0.13	0.07	0.05	0.05	0.005

Table 5: Results of variance analysis. * indicates significant results.

Factor	Chi-square	F	Pr (> F)
Longitude	0.0523	0.8863	0.8102
Latitude	0.1017	1.7238	0.4204
Depth	0.2656	4.5018	0.0122 *
Temperature	0.0625	1.0597	0.6864
Salinity	0.0679	1.1503	0.6366
Sediment	0.0359	0.6079	0.9110
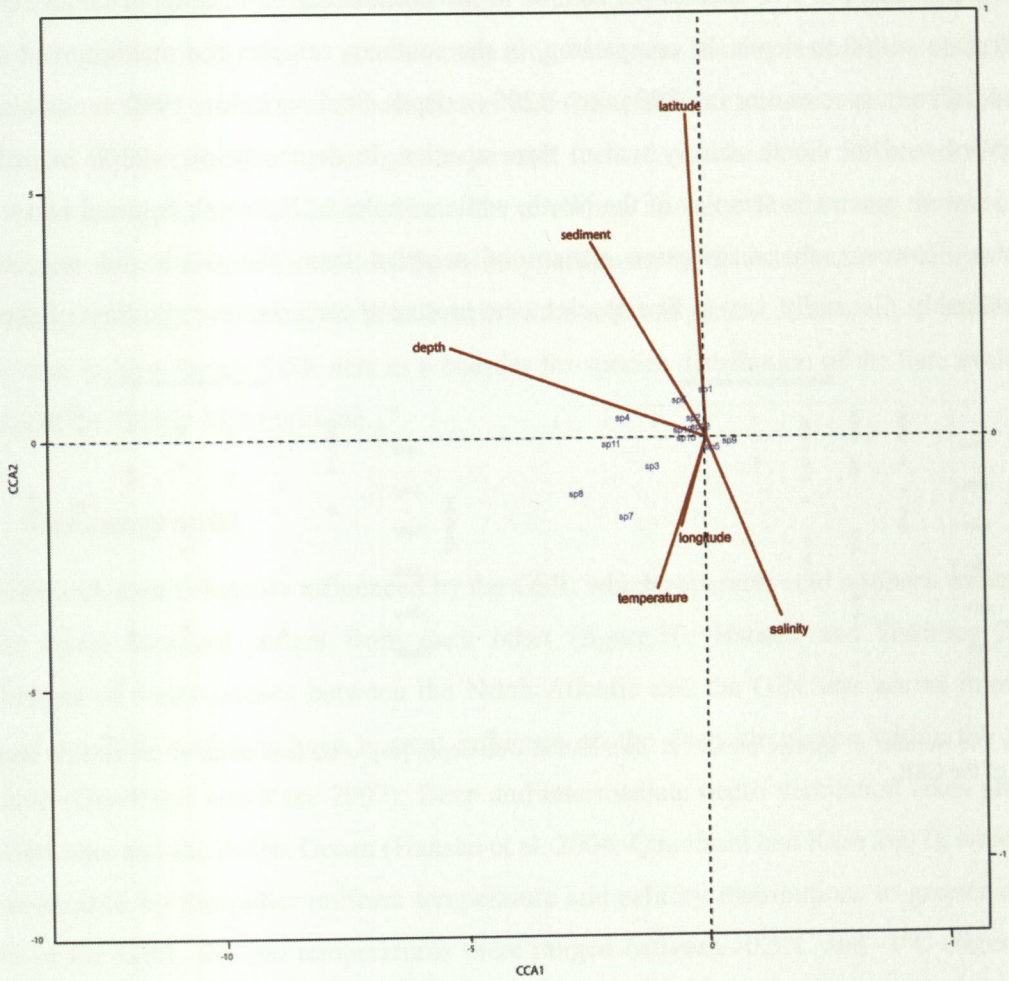
Figure 26: Graphic result of CCA. *Sp1* B. muticus, *sp2* B. pygmaea, *sp3* D. furcatus, *sp4* D. latirostris, *sp5* D. phalangium, *sp6* E. cornuta, *sp7* E. dahli, *sp8* E. hanseni, *sp9* E. inermis, *sp10* E. producta, *sp11* E. sp. A, *sp12* M. typica and *sp13* M. giganteus.

5.2.7 Species richness patterns

The total number of species present at one station differed notably (figure 27a, b). Samples of stations in areas north of the GSR contained up to five species of the evaluated genera, while samples in areas south of the GSR contained up to seven different species. Most stations in the north featured one to three different species, while stations south of the GSR contained mostly one to four different species.

The maximum of five species per sample in the north occurred in a depth range between ~200 m to ~1000 m depth. In comparison, in the southern samples the maximum of six or seven different species was in ~800 m to ~1200 m depth. Stations below 1000 m contained in the North and the South mainly two to three species. In depths below ~2300 m just two species were present in samples of the North, while samples of the south featured two to five species. However, the distribution pattern of samples from the south did not change considerably. Generally, two to five species were present at each station regardless of depth.
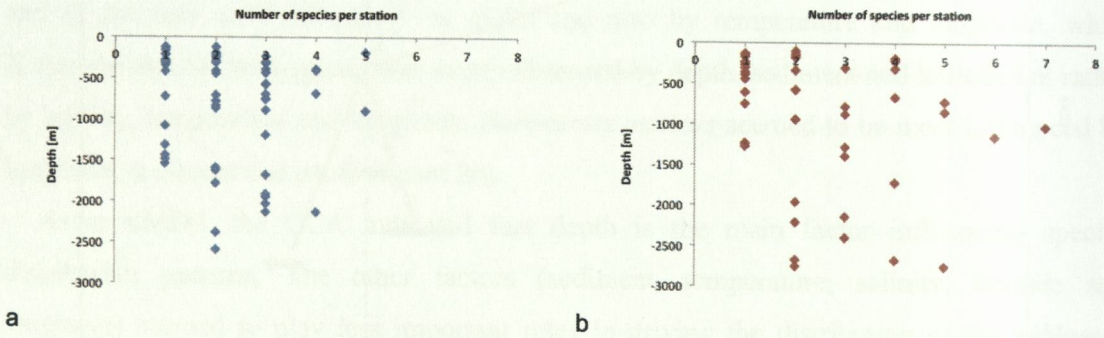
Figure 27: Number of species present at each station with depth [m]. *a* stations north of the GSR, *b* stations south of the GSR.

6 Discussion

More than 70 % of the Earth's surface forms the habitat for marine benthic communities, whereat the benthic biodiversity community structure and trophic interactions are likely to be influenced by climate change. Already Stefánsson and Jónsdóttir (1974) stated that the distribution of near-bottom temperatures is of great importance for marine ecologists. In addition, benthic communities play a major role within the marine food web (Renaud et al. 2008) and therefore deserve special attention.

The aim of this thesis was to present mean long-term near-bottom temperature and salinity conditions, to show variability of these factors and their potential influence on the distribution of selected munnopsid genera and species around Iceland as a basis for further monitoring, e.g. on the background of possible effects due to climate changes. Furthermore, it was aimed to evaluate which abiotic factor (depth, salinity, sediment type, water mass or temperature) was most important in driving the distribution of the selected genera. Moreover, it was desired to explore in how far the GSR acts as a boarder for species distribution of the here evaluated genera of the family Munnopsidae.

6.1 Oceanography

The research area is heavily influenced by the GSR, which separates cold northern waters and rather warm southern waters from each other (figure 10; Hansen and Østerhus 2000). Exchanges of water masses between the North Atlantic and the GIN seas are an important part of the THC and thus have a great influence on the deep circulation within the North Atlantic (Quadfasel and Käse 2007). Deep and intermediate depth ventilation takes place in the GIN seas and the Arctic Ocean (Hansen et al. 2004; Quadfasel and Käse 2007), which can be recognized by the rather uniform temperature and salinity distributions in greater depths north of the GSR. Bottom temperatures there ranged between -0.5°C and -1°C (figure 10), while salinity values were between 34.8 and 34.9 (figure 13). Thus, the GIN Sea basins north of the GSR contain the cold-water reservoir.

The waters of the East Greenland Current get transformed within the GIN seas – e.g. by the melting of sea ice. It flows southward along the Greenlandic shelf (ICES 2008), which is reflected in cold temperatures and low salinities (figure 10 and figure 13). These waters close to the shore of Greenland were much colder (-1°C to -0.5°C and partly up to 1.5°C) than those along the Icelandic coast (figure 10; up to 7°C in the north-western part of the Icelandic shelf). Three different currents influence the region between Greenland and Iceland. Firstly,

the surface outflow to the South along the Greenlandic shelf, secondly the Irminger current west of Iceland over the Icelandic shelf, which transports warm and saline water into the GIN seas, and thirdly at depth the overflow of water with temperatures below 0°C and salinities of roughly 34.9. This intermediate and deep water (dense, cold and intermediate salinity) becomes part of the North Atlantic Deep water (Voet 2010; Quadfasel and Käse 2007). The Polar Front separates the northwards flowing Irminger Current from the southwards flowing East Greenland Current (ICES 2008).

The North Atlantic Current transports water across the Iceland Faroe Ridge, meeting colder and less saline waters at the Iceland Faroe Front (Hansen and Østerhus 2000). The water masses MEIW, NSAIW and NSDW are known to flow at depth though the Iceland-Faroe Ridge, while NSAIW and NSDW are known to flow though the Faroe-Shetland Channel, the Wyville-Thomson Ridge and the Faroe Bank Channel (Hansen and Østerhus 2000). In the near-bottom mean temperature and salinity layers, overflow of deep dense and cold waters (-1°C to -0.5°C; 34.8 to 34.9) from the North over the GSR could be noticed (figure 10 and figure 13). Salinity and temperature of the waters increased slightly while passing the ridge through the Faroe Bank Channel due to entrainment. Overflow waters leaving the Faroe Bank Channel, the Wyville-Thomson Ridge and the Iceland-Faroe Ridge are always already diluted (figure 10; Hansen and Østerhus 2000).

The standard deviation of temperature and salinity was calculated in order to assess the variability of the measurements. The conditions in the deeper areas north and south of the GSR were more constant, compared to the much shallower regions across the GSR, which is supported by the low standard deviation values or even mostly by a standard deviation of close to zero in those deep basins on both sides of the ridge, which can be explained by the low variability of deep water characteristics. Cooling of surface waters and loss of heat to the atmosphere leads to higher densities and sinking of the water in the GIN seas and the Arctic Ocean (Quadfasel and Käse 2007; Quadfasel 2011). Part of this deep water flows through the GSR as overflows, and sinks to greater depth after passing the ridge due to its high density, while entrainment takes place (Quadfasel and Käse 2007; Quadfasel 2011). Highest variability occurred in frontal areas and in areas with strong seasonal variation, like the shallower parts of the Denmark Strait and in the region of the Greenland Iceland Front (figure 11 and figure 14). The variability on the eastern and northern Icelandic shelf (~2°C) can be connected to inter-annual variations of hydrography. Warm waters were present on the shallower parts of the Icelandic shelf (figure 10). Thus the temperatures and salinities on the northern Icelandic shelf decrease on their path east due to shelf mixing of Atlantic and Arctic

waters (ICES 2008). The standard deviation of salinity data appeared to be for example highest in regions close to the shore of Iceland, which can be connected to river discharges. The relatively high standard deviation values of the temperature dataset especially along the Iceland Faroe Ridge (figure 11) indicate the strong local variability of the overflow across this part of the GSR (Voet 2010). Overflow across this part of the ridge occurs rather intermittently. The overflow water of the GIN seas is mainly located lower than the depth at this part of the ridge, but the occurrence of mesoscale eddies occasionally lifts the interface and thus overflow occurs (Østerhus et al. 2008; Quadfasel and Käse 2007). Variability was also higher in the Faroe Bank Channel and the Wyville-Thomson Ridge. The overflow through the Faroe Bank Channel is not steady. Hence it can be rather described as a 'bolus of cold water' passing through the channel. The overflowing water reaches after leaving the channel the slope region of the Iceland Basin, which causes variable flows and strong mixing with the surrounding North Atlantic waters (Hansen and Østerhus 2000), which induced the high standard deviation values. The overflow through the Wyville-Thomson Ridge is spatially and temporally intermittend, which was reflected in high standard deviation values of temperature and salinity (figure 11 and figure 14).

The created temperature and salinity mean values contain data from 1900 to 2008, whereat the major part of data was sampled between 1950 and 2008 (figure 7). For observations of changes within the region an additional analysis of long-term trends and seasonal cycles within the study area will be carried out.

6.2 Ecology

The climatic sensitive region around Iceland is very much influenced by the GSR and thus Iceland as island on top of this Ridge is located in a zoogeographic key position (Ekman 1935; Dahlgren et al. 2000). This huge topographical feature, the GSR, which separates the North Atlantic deep sea and the Arctic Ocean abyssal basins (Bouchet and Warén 1979) from each other, is particularly interesting when considering species distribution. Former studies showed differences in species composition of some benthic groups between areas south and north of the GSR (Stephensen 1940; Svavarsson et al. 1990; Svavarsson et al. 1993b; Gudmundsson 1998; Weisshappel and Svavarsson 1998; Weisshappel 2000; Negoescu and Svavarsson 1997; Svavarsson 1997; Weisshappel 2001; Dijkstra et al. 2009; Brix and Svavarsson 2010).

Formation of the GSR took place in the time span from 57 to 16 m.y. ago (Larsen 1983). The water exchange between the northern North Atlantic and the GIN seas was presumably

:rrupted due to a land bridge of the western part of the GSR during times of lower sea level liede 1983; Larsen 1983). Deepening of the Iceland-Faroe Ridge below sea level posedly took place 24 to 14 m.y. ago (Berggren and Schnitker 1983). Moreover, in the ciations 2.5 m.y. ago the water temperatures of the GIN seas and the Arctic Ocean changed m rather high temperatures to cold waters (Dahl 1972).

In addition, the deep GIN seas and the Arctic Ocean are characterized by a rather low /ersity fauna, which can be explained by the short evolutionary time span of the fauna as a ld-water fauna. Hence, the fauna can be considered to be rather recent (Svavarsson et al. 93b). In addition, the North Polar Sea and the Greenland and Norwegian Seas only possess mmunication with the other world oceans through shallow passages (Coachman and igaard 1974). The Bering Strait with a maximum depth of 45 m and the ridges between eenland and Scotland with a maximum depth of 840 m (Coachman and Aagaard 1974; nsen and Østerhus 2000).

The northern North Atlantic and the GIN seas host a diverse composition of munnopsid pods. The selected munnopsid genera *Baeonectes, Belonectes, Disconectes, Eurycope, unnopsurus* and *Munnopsis* appeared to be very abundant, whereas the genus *Eurycope* was presented with the major part of specimen (e.g. *E. inermis* and *E. producta*). Comparison of e species composition of this study (Appendix A) with previous publications dealing with unnopsids of the northern North Atlantic and the GIN seas (Svavarsson et al. 1993b; Brandt)96; Stransky and Svavarsson 2010) revealed that most species found within this study iuld be expected.

The maximum number of species present per station slightly differed between stations in e North and the South. Stations in the North contained a maximum of five species, while ations south of the GSR featured up to seven species. North of the GSR a maximum of iur to five species per sled occurred at depths roughly between 200 m and 1000 m, with one xceptional station in a depth of 2300 m, which also contained four different species of the xamined genera. In comparison, in the South maximum five to seven species per sled ccurred in depths from 800 m to 1200 m, with one exception in 2600 m depth. Total species umbers per sled were a little less in areas north of the GSR compared to regions south of the dge. No real trend of declining species numbers in areas north of the GSR could be revealed. iut these results have to be interpreted with care, due to the fact that only certain genera were sed for data evaluation. Svavarsson et al. (1990) and Svavarsson (1997) described a decrease 1 species numbers per sled with depth in the eastern and western part of the GIN seas.

the ~300 globally known members of the family Munnopsidae (Merrin 2004), ~32 are

n to be present in the GIN seas (Svavarsson et al. 1993b). A total of 12 species of the

d munnopsid genera *Baeonectes, Belonectes, Disconectes, Eurycope, Munnopsurus*

unnopsis was present in areas north of the GSR, while 11 species were present in areas

of the GSR. Interestingly, eight species were detected on both sides of the GSR. For

opsids the number of species between north and south did not vary considerably.

al other deep-sea families like for instance Desmosomatidae, Nannoniscidae (Brix and

rsson 2010), Anthuroidea (Negoescu and Svavarsson 1997) and Haploniscidae Hansen,

(Svavarsson et al. 1993b) feature lower species numbers north of the ridge than south,

can be explained by the isolation of the GIN seas and the Arctic Ocean deep-sea basins

the North Atlantic (Svavarsson et al. 1993b). Especially the deep-sea family

niscidae features low species numbers (N = 2) in areas north of the GSR, although

wide ~100 species are already known to science (Svavarsson et al. 1993b). On the

ary, Weisshappel (2001) detected a different distributional pattern in calliopiid amphipod

es, with more species being present north of the GSR than south.

ree out of the four northern species (*E. brevirostris, E. dahli* and *E. hanseni*) and two of

ree southern species (*D. furcatus* and *Eurycope* sp. A) only occurred in depths deeper

the deepest depression of the GSR. However, it has to be noted that *E. brevirostris* has

dy been observed in shallower water depths of 160 m (Svavarsson et al. 1993b). In

ion, new records of this species showed that it was present to depths as deep as 2135 m,

Svavarsson and Stromberg et al. (1993b) so far documented a depth range from 160 m

01 m. In comparison, *E. dahli* was present both, shallower and deeper than known from

ture, whereas all *E. hanseni* and *D. furcatus* samples ranged in depths already known.

northern species *E. cornuta* and the southern species *D. latirostris* both occurred

ower than the deepest depression of the ridge, but neither seemed to cross the ridge.

onectes latirostris* occurred only at two stations south of the ridge in rather warm water

eratures. It has to be assumed that this species is very rare or patchily distributed. In

ion, all the species that were present on both sides of the GSR featured a depth range

r shallower as the geological barrier (*B. muticus* and *B. pygmaea*) or ranges that included

ridge depth (*D. phalangium, E. inermis, E. producta, M. typica* and *M. giganteus*).

nectes parvus* were just present at two stations, which were far apart from each other.

station was located in the south (841 m depth) and the other one was located north of the

(1677 m depth). Differences in morphological features between the two samples could

not be distinguished. However, due to the large differences between the two stations, the possibility of cryptic species should be considered.

It is worth mentioning that a high number of species occurred on both sides of the GSR. Thus, the ridge might not be the most important factor in shaping the distribution of the selected munnopsid genera after all (ANOSIM: Global R = 0. 156, p = 0.001 for the analysis including all species and Global R = 0.146, p = 0. for the analysis excluding the two species *E. inermis* and *E. producta*). It is highly possible that Munnopsidae disperse more easily between the two ocean regions, due to their reasonably good swimming abilities. Results of BIO-ENV analysis indicated that depth was the factor driving the distribution of the observed species. Highest correlations and best representation within the nMDS plots as well as in the CCA plot were seen and emphasise these findings (ANOSIM: Global R = 0.262, p = 0.001 for the analysis including all species and Global R = 0.385, p = 0.001 for the analysis excluding the two species *E. inermis* and *E. producta*). Accessorily, the factors temperature and water mass seemed to play a slightly more important role when the two putative species complexes *E. inermis* and *E. producta* were not considered for evaluation (ANOSIM temperature: Global R = 0.141, p = 0.002 for the analysis including all species and Global R = 0.281, p = 0.001 for the analysis excluding the two species *E. inermis* and *E. producta* and ANOSIM water mass: Global R = 0.109, p = 0.014 for the analysis including all species and Global R = 0.253, p = 0.001 for the analysis excluding the two species *E. inermis* and *E. producta*). Most species occurred in more than one certain water mass. Only species that were sampled at just a few stations (N ≤ 6) occurred in a single water mass. *Eurycope cornuta*, the only northern species that was present in more than on water mass, was only present in water masses with temperatures below 2°C. Also, the southern species *D. furcatus* was present in two different water masses, but with similar properties. In comparison species with an extremely wide geographic distribution were present in warm and cold water masses (*B. muticus, E. inermis, E. producta, M. typica, M. giganteus*). Brix and Svavarsson (2010) also observed species with wide temperature ranges (e. g. *Eugerda* cf. *globiceps* Meinert, 1890 and *Oecidiobranchus nanseni* Just, 1980). Within the context of extremely wide distributed species, the occurrence of cryptic species seems to be very likely.

The distributional pattern of *E. cornuta* differs from the pattern observed in *E. brevirostris* and *E. dahli*. This variation in the distribution might not only be influenced by temperature, but also by other ecological conditions occurring in those regions. Moreover, the factors sediment and salinity did not seem to strongly influence the distribution of the observed species (see BIO-ENV and CCA results). However, diversity of Peracarida Calman, 1904

seems to be influenced by numerous factors. Their interaction and combination influences distributional patterns. Commonly known environmental factors limiting and shaping the distribution of Peracarida are e.g. temperature, depth, sediment type, microhabitat heterogeneity (influenced by themselves or other small animals), predation, food availability and also hydrography (Rex 1981; Pineda 1993; Brandt 1995, 1993, 1997b; Brandt and Piepenburg 1994; Brandt et al. 1996). Observed patterns always have to take into account analysis scales (Levin 1992; Fortin and Dale 2005). The factors food availability, competition and sediment type act on a small scale (Pearson and Rosenberg 1987; Carey Jr 1991), whereas currents and climate are more important at a large scale (Levin et al. 2001; Tuya and Haroun 2006).

Asellote isopods are known to be rather restricted in their distribution, due to their nature of brooding and their lack of larval dispersion (Sanders 1977; Sanders and Grassle 1971). Nevertheless, Munnopsidae can use their natatory legs in order to swim quite efficiently (Hessler and Strömberg 1989), which enhances their potential for dispersal (Wilson 1983b). Most munnopsid species examined within this thesis showed quite far distributions. Their ability to swim probably allows them to overcome geographical barriers like the GSR. Stransky and Svavarsson (2010) also documented that no specific pattern could be seen in munnopsid distribution, which probably leads to the assumption of a generally fairly active dispersal of the members of this family (Stransky and Svavarsson 2010).

In any case, food supply plays a key role in benthic community structures (Dayton and Oliver 1977), but feeding habits of most Peracarida are hardly known. Peracarida feature various feeding types (filter feeding, surface deposit feeding, carnivory, omnivory and foraminifory (Gudmundsson et al. 2000; De Broyer et al. 2004; Riisgard and Schotge 2007; Krapp et al. 2008; Dennell 1934; Würzberg et al. 2011). Thus, the benthic species will be influenced by changes in food supply, when changes within the benthic environment occur (e.g. Dauvin and Ruellet 2007). Deep-sea asellote Isopoda were commonly presumed in the past to be detritus feeders (Wolff 1962). However, munnopsids of the genus *Eurycope* feed on foraminiferans (Svavarsson et al. 1993a; Gudmundsson et al. 2000). Svavarsson et al (1993a) detected that some Munnopsidae contain foraminiferans in their guts. In addition, their selection on the type of foraminiferans depends on the structure of their mouthparts (Svavarsson et al. 1993a). *Eurycope inermis* features a narrow head with slender mandibles and an incisor process with three teeth and does not crush the foraminiferans while eating. In comparison, Il*yarachna hirticeps* Sars, 1870 possesses a wide head with strong muscles connected to very robust mandibles and is able to crush foraminiferans (Svavarsson et al.

1993a). Fragments of foraminiferans in the guts of various isopods suggest that foraminivory could be more common within Isopoda than previously assumed (Menzies 1956; Wolff 1962; Wilson and Thistle 1985; Brandt 1997a). Fatty acid analysis of Würzberg et al. (2011) also confirmed the specialisation on foraminiferans as a food source. Hence, specialisation on foraminiferans as a food source seems to be beneficial in benthic deep-sea communities (Gudmundsson et al. 2000) because they are in some cases the most abundant organisms (Shires et al. 1994; Gooday et al. 1997) and thus account for a huge amount of biomass (Altenbach and Sarnthein 1989). Furthermore, foraminiferans utilize phytodetritus flux to the deep sea, which makes them a very important component of the deep-sea food web (Gooday et al. 1997). Also, Scaphopoda (Davies 1987), Sipuncula (Heeger 1990), boring gastropods (Arnold et al. 1985), chaetodermomorph (=caudofoveate) Aplacophora (Todt et al. 2008) and probably Nematoda (Heeger 1990) feed on foraminiferans. In addition, phytodetritus from the upper water column is not available throughout the whole year, but foraminiferans are (Brandt et al. 1994). The success of the genus *Eurycope*, especially when taking into account the high abundances and far distributions of this genus within the study area, might also be explained due to this specialization in food. The good mobility of the members of the family Munnopsidae seems to favour them in the search for habitats with good living conditions. However, areas with the best living conditions are most likely favoured, because less energy is needed for life (Brandt and Berge 2007).

The wide geographical distribution as well as wide temperature, salinity and depth ranges of the two species *E. inermis* and *E. producta* appears to be very interesting. Wilson (1985) noted that exceedingly widespread species tend to show, even documented in literature, as yet unexplained high levels of variation. Elucidation of those variations in species characters will lead to better recognition of species boundaries and knowledge of their distributions could improve the knowledge of deep-sea biogeography (Wilson 1985). Already, Wilson and Hessler (1981) alluded that the genus *Eurycope* is probably the most troublesome and complex genus of eurycopids (Wilson and Hessler 1981). *Eurycope inermis* has a very broad distribution spanning quite different environments and showing variation between individuals (Wilson 1985, 1982). Wolf 1962 discovered that adults of *E. inermis* from warmer regions of the Norwegian Sea were smaller compared to those from "colder" areas. But one has to keep in mind that size is an inconclusive species character. This could be also due to ecological adjustments of populations to local conditions. Svavarsson (1987) described variation within *E.producta* and suggested that there is likely a species complex instead of a single species. In addition, *M. giganteus* was so far only recorded in the Arctic and the Pacific Ocean

(Svavarsson et al. 1993b). However, specimens of the species were present at two stations south of the GSR. Until today two subspecies are already known to science. *Munnopsurus giganteus giganteus* (present from Iceland, western Norway, the Siberian Shelf, the Bering Sea and the Sea of Ochotsk) and *M. giganteus ochotensis*, which only occurs in the Sea of Ochotsk (Svavarsson et al. 1993b). Hence, rather active dispersal of *M. giganteus* through the GSR into the northern North Atlantic seems possible, due to its good swimming ability.

Basford et al. (1990) postulated that epifaunal communities are rather depending on depth than on sediment. Depth was the most important abiotic factor in driving the species distribution of the here evaluated dataset (nMDS, ANOSIM, BIO-ENV and CCA). Brandt et al. (2007) also distinguished depth as the main abiotic factor influencing species composition and distribution for deep-sea isopods in the Atlantic part of the Antarctic Ocean. Even though depth was distinguished to be the most important factor in driving munnopsid distribution patterns it has to be considered that changes in especially temperatures will affect the habitat and living conditions tremendously. Some evidence on increasing temperatures in Arctic and subarctic regions and shallower regions around Iceland could be observed within the past 10 years (Astthorsson et al. 2007) as well as in the area west of Greenland (Yashayaev 2007; Holland et al. 2008). Physical changes in the Arctic have already been causing changes in the marine ecosystem and thus shifts in species distribution patterns have already been observed (Holland et al. 2008; Moline et al. 2008). Notably reports mostly focus on changes in planktonic species and fish. But it has to be considered that the benthic community is not going to be only influenced by rising bottom temperatures, but also by changes in food availability. Changes in particulate matter might eminently influence the benthic community structures (Morata et al. 2008) Changes in food supply will most likely also affect the here evaluated genera of Munnopsidae. Thus, changes within the community will be especially interesting when considering that peracarid crustaceans are of major importance in structuring the benthic fauna (Duffy and Hay 2000), particularly in providing the food source for other epibenthic invertebrates or fish. In addition, commercially harvested fish like cod and plaice, as well as invertebrates like shrimp and lobsters highly depend on benthic invertebrates, at least during one part of their life (Renaud et al. 2008).

7 Summary & Conclusion

The GSR heavily influences the region around Iceland. This topographical feature influences the hydrographic conditions of the whole study area and the global thermohaline circulation. The overflows across the ridge are of major importance for the whole deep circulation of the North Atlantic. Variation of especially temperatures across the ridge showed the great variability of the overflows occurring in that region, while conditions in the deeper basins north and south of the GSR seemed to be rather stable, which can be explained by the low variability of deep-water characteristics.

The overflows through the GSR are eminently important for the stability of the THC. If a reduced southward flow of dense waters will occur, it would presumably lead to less inflow of warm Atlantic water in the GIN seas. Climate projections forecast a weakening of the THC and thus it is important to examine overflow processes and variabilities in order to trace trends in overflow dynamics (Voet 2010; Hansen et al. 2001). Furthermore, within the last few years, slight increases in temperature could be detected especially in Arctic, subarctic regions, west off Greenland as well as in shallower regions around Iceland (Astthorsson et al. 2007).

The present investigation has revealed that the northern North Atlantic and the GIN seas host a quite diverse composition of Munnopsidae. The distributions of the evaluated munnopsid genera *Baeonectes*, *Belonectes*, *Disconectes*, *Eurycope*, *Munnopsurus* and *Munnopsis* were heavily influenced by depth. Temperature and water mass also seemed to play a role in driving the distributional pattern of Munnopsidae, but not to the extent as depth. Moreover, salinity and sediment type were not influencing the species distribution within the study area. Due to their swimming abilities species were widely dispersed around Iceland and their mobility probably allows them to actively change places and thus reach habitats with favourable and sufficient food conditions. In addition, specialisation of munnopsids on foraminiferans as a food source is presumably also a great advantage.

In contrast to other deep-sea families, (e. g. Desmosomatidae, Nannoniscidae, Anthuroidea and Haploniscidae) the number of species between areas north and south of the GSR did not vary too much. The isolation of the GIN seas from the northern North Atlantic through the GSR most likely does not affect the here evaluated genera as much as other deep-sea families. Hence, the GSR does not seem to act as an insurmountable barrier for them.

8 Outlook

In the context of climate change, variations and disturbances within special habitats become especially important. Ecological consequences such as the alteration of species distribution and species composition of benthic communities might occur as a consequence of changes in climatic conditions (Macdonald et al. 2005; Walther et al. 2002; Harley et al. 2006; Barber et al. 2008). Changes in climate will likely influence benthic community structures, including the evaluated genera.

Overflows through the GSR are important for the stability of the THC. Climate change scenarios predict a weakening of the THC strength. Therefore, it would be interesting to investigate the variation within near-bottom temperatures and salinities further, focussing on the region of the GSR. Thus, evaluation of long-time trends and seasonal cycles of bottom circumstances would also add new information for a more precise characterization of the benthic habitat around Iceland. In addition, this would also help to assess how much variation of these factors the benthic community, especially in regions with strong overflows, may possibly tolerate.

More information on the spatial distribution of benthic species is definitely needed. In addition, future analysis should include all genera of the family Munnopsidae, in order to have the ability to estimate for example species richness patterns. Additionally, more abiotic factors (e.g. particulate organic carbon, chlorophyll, oxygen) should be included for further analysis. Although the Icelandic fauna is quite well known, undescribed species are present and waiting for description within the BIOICE and IceAGE 1 samples. Those species will have to be described, in order to ensure the best possible distributional pattern dataset of munnopsid species.

Further it would be interesting to compare distribution patterns of different asellote isopod families with different lifestyles. For instance, it would be helpful to compare walking swimming families (Desmosomatidae, Nannoniscidae), walking non-swimming (Haploniscidae), walking burrowing (Macrostylidae Hansen, 1916) families and the swimming family Munnopsidae with each other.

Eurycope producta and *E. inermis* (Appendix B, figure 20a, b) are extremely widespread species of deep-sea isopods each suggested to represent species complexes (Svavarsson 1987; Wilson 1982b). While examining material of the BIOICE project, morphological variation within both species could be already seen. During the recent IceAGE 1 expedition, large collections of each species were made from stations incorporating a wide range of oceanographic habitats and were fixed in precooled 96 % undenatured ethanol. All

individuals of the IceAGE subsamples are ready to be used for genetic analysis. It would be desirable to address the issue of whether these two species are indeed two species complexes, by examining genetic, morphological and habitat diversity within each. The area around Iceland is a major oceanographic divide and an area of importance in climate and deep-ocean circulation. Understanding species boundaries in this area and their relationship to current conditions will allow us to better measure changes in the deep sea using biological indicators and to predict how these deep-sea species will be impacted by the changes that have been set in motion by climate change. Thus, faunal changes due to temperature changes or other disturbances within the habitat should be monitored. The ultimate goal would be to examine the distribution of the resolved species complexes and the other genera of the family Munnopsidae in the context of changing climate conditions within the climatically interesting region around Iceland.

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11 Appendix

Appendix A – Species abundances

	B. muticus	B. pygmaea	B. parvus	D. furcatus	D. latirostris	D. phalangium	E. cornuta	E. dahli	E. brevirostris	E. hanseni	E. inermis	E. producta	E. sp. A	M. typica	M. giganteus
2027	0	0	0	0	0	0	0	0	0	0	10	12	0	0	0
2091	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
2100	0	0	0	0	0	0	0	0	0	0	358	0	0	0	0
2107	0	0	0	0	0	0	0	0	0	0	240	140	0	0	0
2114	0	0	0	0	0	0	0	0	0	0	9	42	0	0	2
2124	0	0	0	0	0	0	0	0	0	0	0	31	0	0	0
2128	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0
2137	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0
2142	0	0	0	0	0	1	0	0	0	0	0	36	0	0	0
2149	0	0	0	0	0	0	0	0	0	0	0	59	0	0	0
2150	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
2167	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
2178	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2213	0	0	0	1	0	0	0	0	0	0	0	5	0	0	0
2257	0	0	0	0	0	104	0	0	0	0	0	0	10	0	0
2268	0	2	0	0	0	0	0	0	0	0	29	70	0	0	0
2282	0	0	0	0	0	0	0	0	0	0	73	0	0	0	0
2285	2	0	0	0	0	3	0	0	0	0	0	0	0	0	0
2293	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2303	0	0	0	0	0	0	0	0	0	0	614	0	0	0	0
2308	0	2	0	0	0	0	0	0	0	0	1	0	0	16	0
2332	0	0	0	0	0	0	0	0	0	0	0	194	0	0	0
2385	2	0	0	0	0	0	0	0	0	0	0	0	0	8	0
2393	12	0	0	0	0	160	0	0	0	0	117	15	0	115	0
2403	0	4	5	0	0	166	0	0	0	0	42	9	5	5	0
2410	0	0	0	22	0	86	0	0	0	0	0	0	0	0	0
2418	0	0	0	0	0	140	0	0	0	0	0	0	0	12	0
2430	0	0	0	0	0	0	0	0	0	0	2	0	0	12	0
2435	1	0	0	4	0	41	0	0	0	0	41	54	0	13	1
2451	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2466	1	0	0	0	0	32	0	0	0	0	0	0	0	0	0
2469	0	0	0	0	0	0	0	0	0	0	154	0	0	3	7
2472	0	6	0	0	0	849	0	0	0	0	445	24	0	17	0
2491	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0

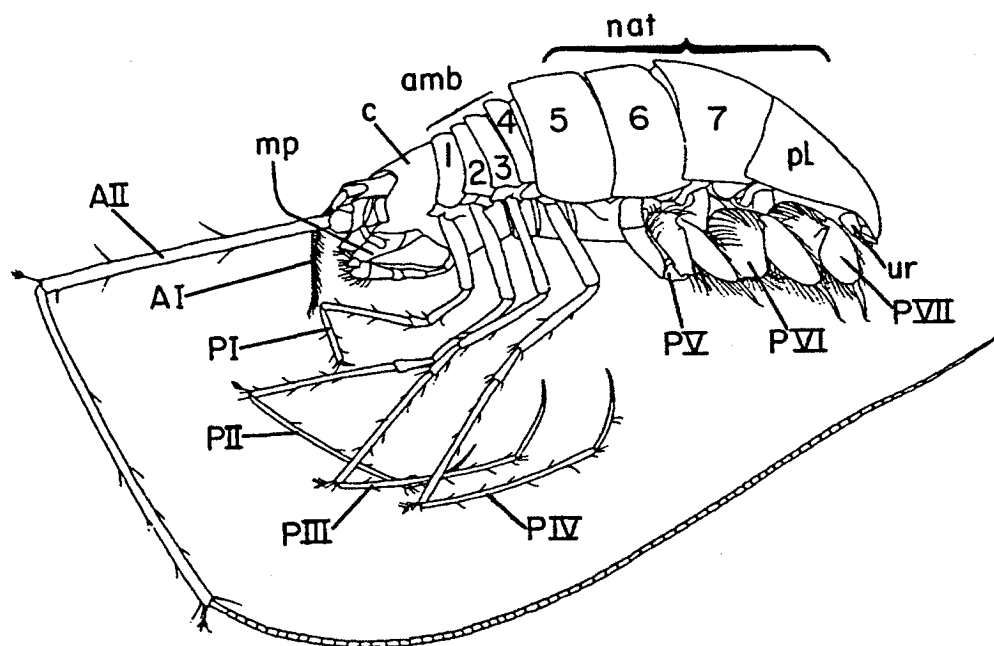|	B. muticus	B. pygmaea	B. parvus	D. furcatus	D. latirostris	D. phalangium	E. cornuta	E. dahli	E. brevirostris	E. hanseni	E. inermis	E. producta	E. sp. A	M. typica	M. giganteus
2512	0	0	0	0	0	0	0	0	0	0	0	109	0	18	0
2573	19	0	0	0	0	0	91	0	0	0	0	42	0	1	0
2575	0	0	0	0	0	0	20	0	0	0	3	117	0	0	0
2579	0	0	0	0	0	0	314	0	0	0	7	30	0	0	0
2581	0	0	0	0	0	0	21	0	0	0	4	76	0	10	2
2585	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
2589	3	0	0	0	0	0	5	0	0	0	0	2	0	0	0
2591	6	0	0	0	0	0	9	0	0	0	0	6	0	9	0
2595	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
2606	3	0	0	0	0	0	0	0	0	0	0	5	0	6	0
2610	0	0	0	0	0	0	0	0	0	0	1	1	0	6	0
2613	1	0	0	0	0	0	0	0	0	0	0	4	0	0	4
2616	1	0	0	0	0	0	0	0	0	0	0	10	0	0	0
2619	0	0	0	0	0	0	10	0	0	0	11	1	0	0	1
2622	0	0	0	0	0	0	0	0	0	0	52	0	0	0	0
2627	0	0	0	0	0	0	92	0	0	0	77	12	0	0	0
2743	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0
2856	0	0	0	0	0	120	0	0	0	0	18	0	1	3	0
2868	0	7	0	0	0	0	0	0	0	0	0	5	0	0	0
2969	46	0	0	0	0	54	0	0	0	0	0	1	0	0	0
2979	11	3	0	0	0	49	0	0	0	0	0	0	0	0	0
2981	3	9	0	0	0	0	0	0	0	0	0	31	0	0	0
3023	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3025	0	0	0	0	0	0	0	0	0	0	20	5	0	0	0
3033	23	0	0	0	1	0	0	0	0	0	0	73	0	0	0
3072	0	0	0	0	0	0	0	0	0	0	24	0	0	0	0
3099	9	0	0	0	0	0	0	0	0	0	0	8	0	0	0
3104	6	0	0	0	0	0	16	0	0	0	0	23	0	0	0
3108	17	0	0	0	0	0	46	0	0	0	2	0	0	0	0
3115	2	0	0	0	0	0	2	0	0	0	0	46	0	0	1
3124	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
3132	0	0	0	0	0	0	249	0	0	0	0	0	0	0	0
3140	0	0	0	0	0	0	1	0	0	0	2	6	0	0	0
3158	0	0	0	0	0	0	0	0	0	0	0	193	0	0	0

	B. muticus	B. pygmaea	B. parvus	D. furcatus	D. latirostris	D. phalangium	E. cornuta	E. dahli	E. brevirostris	E. hanseni	E. inermis	E. producta	E. sp. A	M. typica	M. giganteus
3198	0	0	0	0	0	0	0	0	6	47	52	1	0	0	3
3204	0	0	0	0	0	0	0	1	0	26	0	0	0	0	0
3208	0	0	0	0	0	0	0	0	0	68	18	18	0	0	0
3216	0	0	0	0	0	0	0	3	0	0	4	11	0	0	0
3219	0	0	0	0	0	0	0	1	0	0	326	0	0	0	0
3225	0	0	0	0	0	0	0	20	0	0	124	29	0	0	0
3247	24	0	0	0	0	0	12	0	0	0	0	11	0	0	0
3249	22	0	0	0	0	0	0	0	0	0	0	9	0	0	0
3253	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3522	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0
3621	0	0	0	0	0	0	0	0	0	0	528	0	0	0	0
3652	0	0	3	0	0	0	0	0	0	0	417	2	0	0	0
3655	0	0	0	0	0	0	0	0	0	0	345	0	0	0	0
3668	1	5	0	0	0	490	0	0	0	0	0	3	0	4	0
963*	0	0	0	0	0	0	0	0	0	0	11	6	29	0	0
967*	0	0	0	0	0	0	0	0	0	0	18	4	0	0	0
979*	0	0	0	0	0	0	0	0	0	0	9	9	2	0	0
983*	0	0	0	14	0	0	0	0	0	0	6	3	0	0	0
1006*	0	0	0	0	0	0	0	0	0	0	8	1	0	0	0
1010*	0	0	0	0	0	111	0	0	0	0	83	21	0	0	0
1017*	0	0	0	0	0	3	0	0	0	0	11	0	0	0	0
1019*	0	0	0	0	0	42	0	0	0	0	6	2	0	0	0
1032*	0	0	0	0	0	2	0	0	0	0	6	0	0	0	0
1043*	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
1045*	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
1054*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
1072*	0	0	0	0	0	0	0	0	0	0	19	6	0	0	0
1082*	0	0	0	0	5	0	0	0	0	0	0	5	0	0	0
1086*	0	0	0	0	0	14	0	0	0	0	5	3	0	0	0
1090*	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
1104*	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
1119*	0	0	0	0	0	0	0	0	0	0	3	6	0	0	0
1132*	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
1148*	0	0	0	0	0	0	27	0	0	1	0	13	0	0	0

Appendix B – General external morphology of Munnopsidae

External morphology of a typical munnopsid, *Eurycope iphthima* Wilson (1981) in lateral view. The main body parts are: the cephalon *c*; ambulosome *amb*, which is made of pereonites (thorax segments that bear the legs) *1-4*, and the natasome, which consists of the pereonites *5-7* and the pleotelson *pl*. Antennula *AI*, the antenna *AII*, mouth parts *mp* (with only the mandible and maxilliped visible), the ambulatory pereopods *PI-IV*, natatory pereopods or natapods *PV-VII*, and the uropod *ur*. This figure was taken from Wilson (1989).
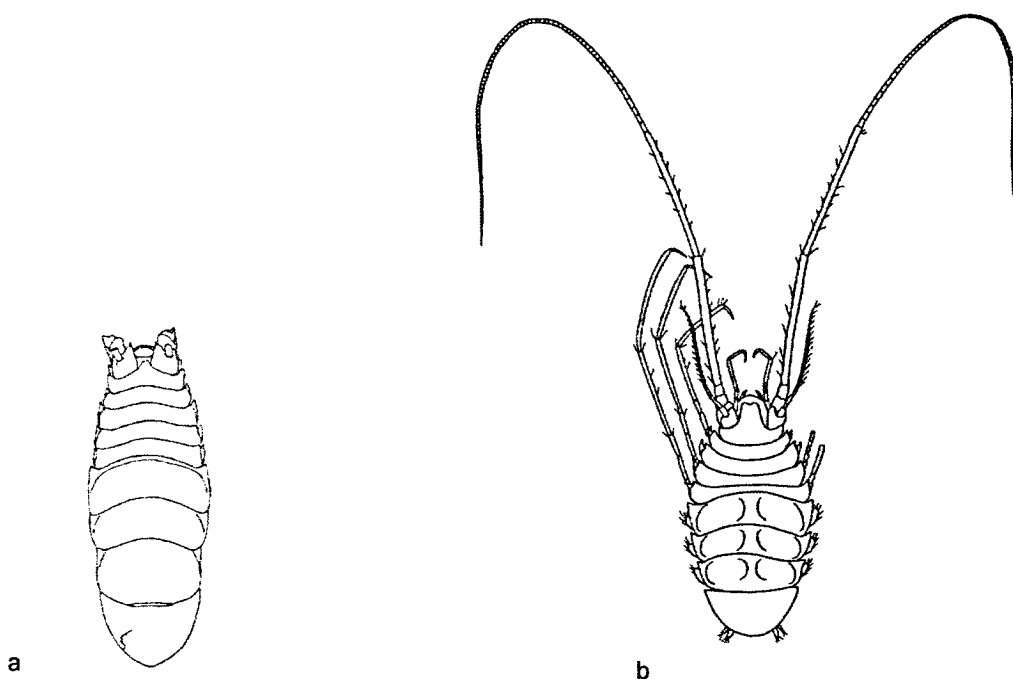

Illustration of *Eurycope inermis* Hansen, 1916 and *Eurycope producta* (Sars, 1868). Drawings were taken from the original species descriptions.

Appendix C – Individual depth ranges of species

Eurycope cornuta	
Min.	229.0
1st Qu.	314.8
Median	571.5
Mean	578.5
3rd Qu.	737.8
Max.	1320.0
No stations	15

Eurycope dahli	
Min.	1624.0
1st Qu.	1842.0
Median	1972.0
Mean	2040.0
3rd Qu.	2169.0
Max.	2590.0
No stations	4

Eurycope hanseni	
Min.	893.0
1st Qu.	1418.0
Median	1944.0
Mean	1809.0
3rd Qu.	2267.0
Max.	2590.0
No stations	3

Baeonectes muticus	
Min.	103.0
1st Qu.	184.0
Median	229.0
Mean	286.5
3rd Qu.	317.0
Max.	1028.0
No stations	25

Baeonectes pygmaea	
Min.	184.0
1st Qu.	188.5
Median	262.5
Mean	373.1
3rd Qu.	433.2
Max.	841.0
No stations	8

Disconectes phalangium	
Min.	184.0
1st Qu.	207.0
Median	323.0
Mean	494.4
3rd Qu.	708.0
Max.	1153.0
No stations	14

Eurycope inermis	
Min.	302.0
1st Qu.	623.5
Median	777.0
Mean	935.1
3rd Qu.	1057.5
Max.	2137.0
No stations	36

Eurycope producta	
Min.	103.0
1st Qu.	251.2
Median	399.0
Mean	554.5
3rd Qu.	715.2
Max.	2029.0
No stations	51

Munnopsis typica	
Min.	123.0
1st Qu.	262.8
Median	397.0
Mean	502.9
3rd Qu.	708.0
Max.	1153.0
No stations	18

Munnopsurus giganteus	
Min.	391.0
1st Qu.	431.2
Median	676.0
Mean	655.6
3rd Qu.	821.2
Max.	1028.0
No stations	10

Disconectes furcatus	
Min.	1028.0
1st Qu.	1122.0
Median	1213.0
Mean	1398.0
3rd Qu.	1489.0
Max.	2137.0
No stations	4

Eurycope sp. A	
Min.	1153.0
1st Qu.	1194.0
Median	1235.0
Mean	1508.0
3rd Qu.	1686.0
Max.	2137.0
No stations	3

Appendix D – Individual temperature ranges of species

Eurycope comuta	
Min.	-0.52300
1st Qu.	-0.46450
Median	-0.38100
Mean	0.02457
3rd Qu.	0.49775
Max.	1.89100
No stations	15

Eurycope dahli	
Min.	-0.9950
1st Qu.	-0.9357
Median	-0.8710
Mean	-0.8722
3rd Qu.	-0.8075
Max.	-0.7520
No stations	4

Eurycope hanseni	
Min.	-0.9330
1st Qu.	-0.9245
Median	-0.9160
Mean	-0.8303
3rd Qu.	-0.7790
Max.	-0.6420
No stations	3

Baeonectes muticus	
Min.	-0.493
1st Qu.	0.656
Median	2.460
Mean	3.290
3rd Qu.	5.558
Max.	7.308
No stations	25

Baeonectes pygmaea	
Min.	3.776
1st Qu.	5.845
Median	6.107
Mean	5.916
3rd Qu.	6.365
Max.	6.955
No stations	8

Disconectes phalangium	
Min.	2.936
1st Qu.	5.349
Median	6.107
Mean	5.783
3rd Qu.	6.839
Max.	7.105
No stations	14

Eurycope inermis	
Min.	-0.9950
1st Qu.	-0.5605
Median	-0.3730
Mean	1.8925
3rd Qu.	5.4170
Max.	6.9550
No stations	36

Eurycope producta	
Min.	-0.995
1st Qu.	-0.385
Median	1.356
Mean	2.087
3rd Qu.	4.191
Max.	6.706
No stations	51

Munnopsis typica	
Min.	-0.421
1st Qu.	3.836
Median	5.417
Mean	4.462
3rd Qu.	6.183
Max.	7.105
No stations	18

Munnopsurus giganteus	
Min.	-0.642
1st Qu.	-0.442
Median	-0.376
Mean	1.180
3rd Qu.	1.449
Max.	6.837
No stations	10

Disconectes furcatus	
Min.	2.561
1st Qu.	3.524
Median	4.101
Mean	4.079
3rd Qu.	4.655
Max.	5.552
No stations	4

Eurycope sp. A	
Min.	2.561
1st Qu.	3.450
Median	4.338
Mean	3.752
3rd Qu.	4.347
Max.	4.356
No stations	3

Appendix E – Individual salinity ranges of species

Eurycope cornuta	
Min.	34.84
1st Qu.	34.89
Median	34.91
Mean	34.90
3rd Qu.	34.92
Max.	34.92
No stations	15

Eurycope dahli	
Min.	34.88
1st Qu.	34.90
Median	34.91
Mean	34.91
3rd Qu.	34.92
Max.	34.92
No stations	4

Eurycope hanseni	
Min.	34.88
1st Qu.	34.89
Median	34.89
Mean	34.89
3rd Qu.	34.89
Max.	34.90
No stations	3

Baeonectes muticus	
Min.	34.83
1st Qu.	34.88
Median	34.90
Mean	34.95
3rd Qu.	35.02
Max.	35.19
No stations	25

Baeonectes pygmaea	
Min.	34.94
1st Qu.	35.08
Median	35.11
Mean	35.10
3rd Qu.	35.15
Max.	35.18
No stations	8

Disconectes phalangium	
Min.	34.90
1st Qu.	35.06
Median	35.11
Mean	35.09
3rd Qu.	35.16
Max.	35.19
No stations	14

Eurycope inermis	
Min.	34.87
1st Qu.	34.91
Median	34.92
Mean	34.98
3rd Qu.	35.08
Max.	35.18
No stations	36

Eurycope producta	
Min.	34.83
1st Qu.	34.89
Median	34.91
Mean	34.95
3rd Qu.	34.98
Max.	35.15
No stations	51

Munnopsis typica	
Min.	34.88
1st Qu.	34.94
Median	35.03
Mean	35.04
3rd Qu.	35.14
Max.	35.19
No stations	18

Munnopsurus giganteus	
Min.	34.89
1st Qu.	34.91
Median	34.91
Mean	34.95
3rd Qu.	34.92
Max.	35.17
No stations	10

Disconectes furcatus	
Min.	34.99
1st Qu.	34.99
Median	35.00
Mean	35.02
3rd Qu.	35.02
Max.	35.10
No stations	4

Eurycope sp. A	
Min.	34.99
1st Qu.	34.99
Median	34.99
Mean	34.99
3rd Qu.	35.00
Max.	35.00
No stations	3