THE INFLUENCE OF THE MACKENZIE RIVER PLUME ON MARINE LARVAL FISH ASSEMBLAGES IN THE CANADIAN BEAUFORT SEA SHELF

By

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ABSTRACT

In the Beaufort Sea, freshwater input from the Mackenzie River creates a relatively warm and turbid plume across the coastal shelf region. To determine the effects of the Mackenzie River plume on marine larval fish abundance, distribution and assemblages; this study sampled larval fish by using 500 μm bongo nets and obtaining oceanographic measurements across the plume gradient during July and August of 2007. Three larval fish assemblages were identified within three water masses: the intense plume assemblage was dominated by Pacific herring (*Clupea pallasii pallasii*), the diffuse plume assemblage was dominated by the sub-family Lumpeninae and the oceanic assemblage was dominated by Arctic cod (*Boreogadus saida*). Also, results revealed that there were no significant differences in the total larval fish abundances within these water masses. In conclusion, this study suggests that the Mackenzie River plume might be identified as an Ecologically and Biologically Significant Area (EBSA), based on the uniqueness criteria under Canada's coastal conservation strategy.

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LIST OF ABBREVIATIONS

CTD – Conductivity–Temperature–Depth

DFO – Fisheries & Oceans Canada

EBSA – Ecological and Biological Significant Areas

FTU – Formazine Turbidity Units

PSU – Practical Salinity Units

SD – Standard Deviation

SIMPER – Similarity Percentage

Wildco – Supplier Wildlife Supply Company

Mt – megatonne

µm – microns

ng – nano gram

yr^{-1} – per year

g C m^{-2} – grams of carbon per unit area

100 m^{-3} – 100 cubic meter

km^3 – cubic kilometer (1 km^3 = 1, 000,000,000 m^3)

CHAPTER 1: GENERAL INTRODUCTION

Under Canada's Ocean Act (1997), "conservation, based on an ecosystem approach, is of fundamental importance to maintaining biological diversity and productivity in the marine ecosystem." The Beaufort Sea has been designated a Large Ocean Management Area (LOMA) by the Department of Fisheries and Oceans (DFO) (Cobb et. al. 2008). Canada's Ocean Act (1997) "authorizes DFO to provide enhanced protection to areas of the oceans and coasts which are ecologically or biologically significant" (DFO 2004). Three main "dimensions" have been identified by DFO for evaluating areas in regard to an Ecological and Biological Significance Area (EBSA) (DFO 2004). The dimensions are Uniqueness, Aggregation (animals), and Fitness Consequences.

Discharges of freshwater into coastal marine waters by rivers often result in the formation of a river plume (O'Donnell and Garvine 1983; O'Donnell 1993; Grimes and Kingsford 1996). A thin buoyant "lense" of freshwater is created where the river discharges into the coastal marine water (Bowman and Iverson 1978; Bowman 1988). The river discharge is often more turbid than the marine waters, since the river flow carries suspended sediments (Dagg et al. 2004). A clear frontal or boundary layer often develops between the marine and freshwater masses (e.g., Garvine and Monk 1974; O'Donnell and Garvine 1983; O'Donnell 1993; Largier 1993; Kingsford and Suthers 1994; Grimes and Kingsford 1996). The shape, size, and persistence of boundary layers depend on the river discharge volume, tidal volume, and ocean currents (Garvine and Monk 1974). Concentrations or aggregations of plankton, including larval fish, often occur at the frontal boundaries of river plumes between the freshwater and marine water masses (Le Fèvre 1986; Grimes and Finucane 1991; Kingsford and Suthers 1994; Olson et al. 1994; Peterson and Peterson

2008). A concentration of marine larval fish at a river plume frontal boundary would meet DFO's definition of an aggregation and candidate EBSA (DFO 2004).

Several related hypotheses have been proposed to explain the aggregation of larval fish at plume frontal boundaries (e.g., Grimes and Kingsford 1996). The initial designation of an EBSA is not limited by a lack of understanding of the mechanism(s) causing the aggregation of larval fish (DFO 2004).

Larval fish assemblages associated with river plume fronts often have unique associations of different species, markedly different from the larval fish assemblages associated with the marine and freshwater masses. The occurrence of unique associations of larval fish could also result in the classification of a river plume as an EBSA (DFO 2004). One challenge for the use of the uniqueness dimension as a factor in an EBSA classification is that the plume association of different larval fish species, although unique, often occurs for only a short time (Thorold and McKinnon 1995).

In terms of larval fish, the EBSA dimension of fitness consequence refers to the importance of an ocean feature to the future recruitment of larval fish into the adult population. The role of larval fish aggregations or entrapments in specific water masses has been the subject of considerable research (e.g., Grimes and Finucane 1991; Govoni Grimes 1992; Gibert et al. 1992; Ponton et al. 1993; Fukuwaka and Suzuki 1998; Reichert et al. 2010). The concept that the larval stage is critical to the recruitment to the adult population is generally accepted; however, the actual role that water masses play in this process is not understood. Beck et al. (2001) extensively reviewed the literature related to the concept of marine nurseries for fish and invertebrates. They discovered that although

a long history exists in the biological literature about the nursery-role concept, relatively few studies have demonstrated a strong test of the concept. It has been hypothesized that the nursery role of habitats like river plumes must be compared on a unit area basis (Beck et al. 2001). This is consistent with the EBSA concept adopted by DFO (DFO 2004). In the past, many studies of nursery areas relied on observing a high density of juveniles as proof of the nursery role; however, if these areas cannot be shown to provide more juveniles or more fit juveniles to the adult populations, higher densities do not necessarily demonstrate a nursery role (Beck et al. 2001).

Although the Mackenzie River plume was identified as a possible EBSA during the Beaufort Sea Overview and Assessment Process, it was not identified as an EBSA (Paulić et al. 2009). The river plume was considered an oceanographic feature of the Kugmallit Corridor EBSA (Paulić et al. 2009). Larval fish community uniqueness, aggregation, and fitness consequences were identified as factors supporting the Kugmallit Corridor EBSA (Paulić et al. 2009). The role of the coastal Mackenzie plume front as an oceanographic feature has not yet been assessed as an EBSA.

1.1 GENERAL FEATURES OF RIVERINE PLUMES

The river plume phenomenon occurs in most rivers around the world, ranging from the tropical, subtropical, temperate, and boreal areas to the Arctic. These plumes are the result of freshwater discharging from the river and subsequently spreading outwards over the continental shelf waters of the open sea as a shallow lens within the upper surface layer (Garvine and Monk 1974; Garvine 1977). This freshwater plume layer is less dense than the saline marine water below; as a result, its water buoyancy makes the plume act

like a semi-permanent layer that can be affected by wind and current movements (Moser and Smith 1993). River plumes are different from the marine water, as they contain different chemical and physical properties. River plume water properties are characterized by the concentration of sediments, nutrients, organic matter, and organic carbon that have accumulated and been carried to the shelf (Chant 2008). Also, river plumes are often warmer than the marine water due to the sunlight acting upon the river water as it flows along from the inland and discharges onto the coastal shelf (Retamal et al. 2008). Because the freshwater is less dense, this surface layer is again heated by the direct sunlight (Retamal et al. 2008).

Many large rivers have their own unique characteristics. Some rivers form plumes that are unpredictable and transient, as their plume formation depends on cyclonic rains (Thorrold and McKinnon 1995). For example, on the east coast of Australia, large rivers such as the Burdekin River produce river plumes that increase in size depending on the rainfall events up to many kilometers offshore and northwards along the coast (Wolanski and Jones 1981). However, in general, most river plumes are seasonally persistent, and they reoccur at the same location every year (Belkin and Cornillon 2007) during an average discharge pattern.

The size of the plume is affected by the variation in the river discharge rate (Grimes and Kingsford 1996). The discharge rate can vary on a seasonal basis (Grimes and Kingsford 1996). Also, river plumes are not often confined within an enclosed estuary, but extend into the continental shelf environment (Carmack and Macdonald 2002). Consequently, the plume influences the dynamics of the coastal marine environment by introducing

allochthonous dissolved and particulate materials into the continental shelf, thus modifying the physical structure of the ocean (Smetacek 1986).

1.1.1 Characteristics of River Plumes

River plume water is often noticeably more turbid than marine water masses (Garvine 1977). The plume's turbidity is the result of high sediment loadings that rivers have obtained from their drainage basin, as they often travel long distances to reach their discharge point at the river mouth (Retamal et al. 2008). These materials collected within the river include concentrations of particulate organic carbon (POC), dissolved organic carbon (DOC), inorganic material, and suspended sediment (Dagg et al. 2004; Retamal et al. 2008). Dagg et al. (2004) indicated that majority of the biogeochemical processes occur on the shelf. The magnitude and composition of these materials will differ with each river system, depending on the characteristics of the rivers' catchments (Table 1). For example, DOC levels from the Arctic Rivers such as the Ob, Lena, Yenisey and Mackenzie are lower than those from the tropical Amazon River (Table 1). Once these river-borne materials are delivered to the ocean shelf, they go through a transformation process such as aggregation, flocculation, and desorption within the complex plume structure of the shelf (Dagg et al. 2004). Also, these materials can be retained or exported out of the continental shelf. A large portion of the particulate typically deposits close to the river mouth and decreases steadily because the reduced turbulence is not strong enough to transport suspended material away from the river mouth (Dagg et al. 2004).

Table 1. Drainage basin, annual discharge of water, sediments, dissolved organic carbon (DOC), particulate organic carbon (POC), inorganic nutrients specifically dissolved inorganic nitrogen (DIN), silicate, (Si) and phosphate (P) for selected rivers. Some authors reported a range of values as shown in the table with minimum- maximum values. Other authors reported samples with a standard deviation as plus and minus. Table was modified from Dittmar and Kattner (2003) and Dagg et al. (2004).

RIVER	DRAINAGE BASIN	DISCHARGE						
	(10^6 km^2)	Water (10^9 m^3·yr^{-1})	Sediment (10^6 t·yr^{-1})	DOC (10^6 t·yr^{-1})	POC (10^6 t·yr^{-1})	DIN-N (10^9 g·yr^{-1})	Si (10^9 g·yr^{-1})	P (10^9 g·yr^{-1})
Tropical								
Amazon (Brazil)	6.15	6300	1150	19.1	13	-	-	-
Temperate								
St.Lawrence (Canada)	1.03	450	3	1.6	0.31	-	-	-
Columbia (USA)	0.67	250	8	0.5	-	-	-	-
Mississippi (USA)	3.27	530	210	3.5	0.8	-	-	-
Arctic								
Lena (Russia)	2.49	510	11	3.4	0.46	3.4-46	890-1640	3.5-6.5
Mackenzie (Canada)	1.81*	249-333*	127±6*	1.3*	2.1±0.3*	23.6	470	1.5
Ob (Russia)	2.99	400	16	3.7		20-40	311	7.9-23.5
Yenisey (Russia)	2.58	630	5	4.9	0.17	2.8-70	200-1223	6.0-6.9
Yukon (USA)	0.84	195	60	2.41**	0.35**	-	-	-

References:

Drainage basin = Dagg et al. 2004; (*) obtained from Telang et al. 1991 and Brunskill 1986)
Sediment Discharge: Dagg et al. 2004, (*) obtained from Macdonald et al. 1998
Water discharge = Meade 1996; (*) obtained from Mackenzie River: Telang et al. 1991 and Brunskill 1986
DOC = Dagg et al. 2004; (*) obtained from Macdonald et al. 1998; (**) obtained from Leenheer 1982
POC = Dagg et al. 2004; (*) obtained from Macdonald et al. 1998
DIN (Nitrate + Nitrite + Ammonium) = Dittmar and Kattner 2003
Silicate = Dittmar and Kattner 2003
Phosphate = Dittmar and Kattner 2003

1.1.2 Factors that Influence the Size and Distribution of River Plumes

The dispersal and depth of river plumes can vary greatly, as they depend on several factors including river size, the amount of freshwater discharge, local rainfall, snow melts, tidal current, wind, the topography of the river mouth, and the ocean circulation (Smetacek 1986; Grimes and Kingford 1996; Dagg et al. 2004). The wind and water currents provide transportation for the plume to cross the shelf and enable mixing to occur with the oceanic water (Chant et al. 2008). Some plumes can extend far distances from their originating river discharge points ashore, ranging from 10 km to over 200 km across the shelf (Grimes and Kingsford 1996). For example, the Amazon River in Brazil, which is the largest river in the world by discharge volume, produces the largest measured plume; it extends up to 200 km over the Amazon continental shelf into the Atlantic Ocean (Grimes and Kingsford 1996) with the discharge rate of 209, 000 m^3/s (Martinez et al. 2009). In comparison, other smaller rivers such as the Fraser River in Canada extend 30 to 40 km offshore into the Pacific Ocean (Grimes and Kingsford 1996), with the discharge rate of up to 7,000 m^3/s (Foreman et al. 2001). Thus, the extent and dispersal of these river plumes can increase in response to the amount of fresh water delivery (Yin 1997). In case of the Arctic shelves, including the Beaufort Sea, sea ice can restricts the plume dispersal if ice has not been melted completely during the ocean water season (Carmack and Macdonald 2002).

1.1.3 Importance of the Plume Front: Its Mixing and Exchange Processes

The river plume plays an important role in the dynamics of the shelf, as it affects sediment and water quality, thus influencing the ecological functioning of the ocean,

especially at the plume front. When river plumes discharge into the Continental Shelf, plume front formations often occur (Garvine 1977). Plume fronts are the result of strong salinity and density gradients (both horizontal and vertical) between freshwater and saline water. The zone where the two masses meet is referred to as the transitional zone (Largier 1993; Garvine and Monk 1974) (Figure 1). Studies have shown that the plume frontal zones are part of the plume dynamics; they are believed to attract and enhance the productivity of primary production (e.g., Lohrenz et al. 1997), zooplankton (e.g., Peterson and Peterson 2008), fish (e.g., Grimes and Kingsford 1996; Grimes and Finucane 1991), seabirds (e.g., Dickson and Gilchrist 2002), and mammals (e.g., Harwood and Smith 2002) (see section 1.2.2).

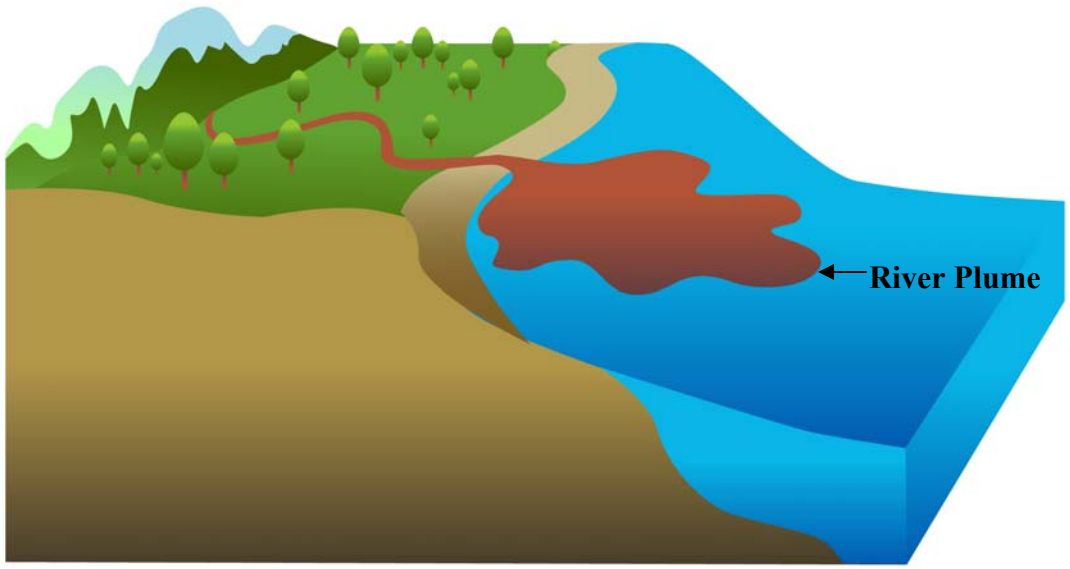


Figure 1. Example of a typical river plume and its associated front. This diagram by Fung Wee is used with permission.

The plume frontal zone is clearly visible since its sharp turbid water properties demarcate the riverine outflow of brackish water compared to the contrasting clear oceanic waters (Fissel et al. 1987). This boundary is unstable and flexible, and it meanders, as it is influenced by the external physical force of wind and water current movements (Fissel et al. 1987). Many studies have described the hydrography and hydrodynamics of plume fronts by using models that emphasize the frontal transport structure and formation (e.g., Garvine and Monk 1974; O'Donnell and Garvine 1983; Garvine 1987; O'Donnell 1993; Nash and Moum 2005; Chant 2008). In some frontal areas, bulge-like recirculation formations (e.g., Chant 2008) or large-amplitude internal waves (e.g., Nash and Moum 2005) can occur at the frontal zone as plume waters disperse across the coastal ocean. The vertical gradient base of the plume and its underlying marine water are observed to have little mixing (O'Donnell 1993). However, more mixing occurs at the frontal zone, as the surface water converges from both sides. This phenomenon is due to the horizontal density gradient at the leading edge of the plume and the pressure that resides within and below the plume (Garvine and Monk 1974). As a result, the mixing and exchanging of water takes place at the frontal zone (Garvine and Monk 1974). The mixing, which allows for further dilution of suspended, dissolved matter, decreases its plume turbidity concentration, since most particles have already been deposited at the river mouth (Dagg et al. 2004). The mixing is an important factor in the transformation of the plume. Firstly, it decreases the turbidity level, which leads to the increase in light attenuation. In addition, it releases nutrients (e.g., nitrogen, phosphorus) from the dissolved organic matter, thus supplementing the stimulation of phytoplankton production due to the uptake of nutrients (Dagg et al. 2004). Thus, the complexity of the transformation which occurs

within the river plume highly affects the chemical and biological processes in the coastal environment (Dagg et al. 2004).

1.1.4 The Role of River Plumes and their Biological Importance

River plumes and their associated water mass fronts can play an important role in coastal ecosystems by providing nutrient-rich waters that support fisheries (Grimes and Kingsford 1996). For example, the Columbia River, which discharges into the Pacific Ocean, contributes significantly to the pacific salmon fishery of the Pacific Northwest (Fukuwaka and Suzuki 1998). River plume water masses often contribute significant amounts of nitrogen, phosphorus, and silica which are essential to phytoplankton production and growth (Dagg et al. 2004). The amount of nutrients delivered by the river plume water mass can vary according to the following factors: seasonal river discharge rates, watershed size, and geography. The Mississippi and Changjiang Rivers, for example, deliver more nutrients to their plume water mass than rivers like the Amazon and Zaire, where the watershed region is less developed and there are fewer anthropogenic contributions to the river nutrient load (Lohrenz et al. 1997; Dagg et al. 2004). In the Mississippi River, suspended sediments carried in the river water result in high turbidity, which limits primary production in the river (Lohrenz et al. 1990). However, once the highly turbid and nutrient-rich river water mixes with the clear and nutrient-poor shelf water, conditions are favorable for increased phytoplankton production (Grimes and Finucane 1991). This increase is the result of enhanced nutrient uptake by the organisms (Franks 1992). In response to increased primary production resulting from nutrient concentrations at the plume front, zooplankton of secondary

production also aggregate because food is available. This increase also enhances larval fish aggregation (Le Fèvre 1986; Grimes and Finucane 1991; Govoni and Grimes 1992; Largier 1993, Kingsford and Suthers 1994). Thus, food within the plume is being channeled through various trophic levels from secondary production (i.e., zooplankton grazing on phytoplankton) and tertiary production (i.e., larval fish grazing on zooplankton).

The plume front was found to have elevated primary and secondary production compared to the production in adjacent coastal ocean water. For instance, the relative abundance of organisms such as zooplankton and ichthyoplankton is found to be the highest in the frontal regions in contrast to the numbers found in the adjacent ocean water. Grimes and Finucane (1991) estimated that the individual surface chlorophyll *a* value is 20-fold, and that ichthyoplankton is 120-fold greater at the plume front, as opposed to within the plume or adjacent to ocean waters. Therefore, frontal areas demonstrate the importance of this habitat to organisms. Also, the plume front most often serves as an area that allows for the co-occurrence of marine and freshwater zooplankton species such as copepods *Calanus glacilis*, *Limnocalanus marurus*, and *Diaptomus sicilis* (Sutherland 1982).

Several mechanisms have been hypothesized to explain the enhanced biomass and aggregation of organism at the river plume fronts. These mechanisms often involved the physical process associated with the plume, along with the physiological response of the organisms at the plume front (Franks 1992). Hydrodynamic convergence is the physical process that has been used by researchers to explain the aggregation of organisms at the plume front. Due to a strong density gradient of the two water masses, thus facilitating

the accumulation of the planktonic organisms toward the front (Garvine and Monk 1974; Grimes and Kingsford 1996) (see section 1.1.3). On the other hand, the concept known as the physiological response of the organism hypothesized that organisms were able to take advantage of the food conditions, therefore increasing the nutrient uptake and enhancing the growth rate of the organisms (Franks 1992; Grimes and Finucane 1991). Moreover, Franks (1992) hypothesizes that the physiological concept alone may not be sufficient to explain the accumulation of the organisms' biomass at the plume fronts; rather, the organisms' swimming behavior, which interacts with the flow at the front, must also be taken into account. He explored this concept that organisms can either float, sink, or swim, thus allowing them to accumulate at the frontal zone (further descriptions are described by Franks 1992).

Plume fronts may provide a transport mechanism, or they may act as a barrier for organisms, leading to a clear community structure within the plume frontal zone. Albaina and Irigoien (2004) found that front-influenced zones in the Bay of Biscay are hot spots for zooplankton concentrations. The distribution and magnitude of these concentrations is determined by the plume's location. They also have distinct zooplankton assemblages compared to the zooplankton community, which is associated with the shelf-break front zone. Plume fronts may also play a potential role by transporting larval fish to the nursery area (e.g., Norcross and Shaw 1984). Also, the seasonal timing and extent of the plume can influence the marine fish dispersion (e.g., Ponton et al. 1993).

Furthermore, debates still continue over the significant advantage of river plume fronts. The actual mechanisms in which plume fronts promote growth, accumulate, and increase

the food availability for larval feeding have not been resolved in the literature (e.g., De Rissik and Suthers 1996; Robertis et al. 2005; Filippino et al. 2009). However, it has been suggested that the abundance and accumulation of the frontal zones are related to the variation of convergence and other factors such as shelf topography, ocean currents, larval behavior, and the amount of freshwater discharge and available food (Grimes and Kingsford 1996). Thus, combinations of these factors may produce variations in the number of organisms aggregating in each plume front. Although the concentration of organisms may not always be the highest, patchiness can still occur (Grimes and Kingsford 1996).

1.2 OCEANOGRAPHIC SETTINGS FOR THE CANADIAN BEAUFORT SEA SHELF

The Canadian Beaufort Sea shelf is located in the southeastern corner of the Western Canadian Arctic. This continental shelf is part of the Beaufort Sea margin that extends across Canada's Banks Island to Point Barrow, Alaska. Although the shelf is shared, the Canadian Beaufort Sea has its own distinct shelf environment due to its local setting (Macdonald et al. 2004). The Canadian Beaufort Sea shelf is bordered by the Amundsen Gulf on the east and the Mackenzie Trough on the west; to the north, the shelf break (~80 to 100 meters depth) is bordered by the Canada Basin and to the south, it contains the fourth largest Arctic river, the Mackenzie River (Figure 2). As well as the Mackenzie Trough, the shelf contains a smaller submarine channel called the Kugmallit Trough. Both troughs provide oceanographic transport of water on and off the shelf, via upwelling (Carmack and Macdonald 2002). The area of the Canadian Beaufort Sea shelf is

approximately 64,000 km^2, and it is 100 km wide in a north-south direction (O' Brien 2006). This shelf is rather small and narrow compared to three other Arctic shelves off of Russia. These include the Laptev Sea Shelf, which is approximately 450,000 km^2 (Naidina and Bauch 2001) and 800 km wide in a north to south direction (Spielhagen et al. 2005); the Kara Sea Shelf at approximately 883,000 km^2; and the Eastern Siberian shelf at approximately 889,000 km^2 (Macdonald 2000). The nearshore portion of the Canadian Beaufort Sea shelf is affected by the annual seasonal differences in sea ice and river discharge, thus making it a dynamic system (Carmack and Macdonald 2002; O'Brien 2006). Like all other Arctic shelves, this shelf is covered with sea ice for part of the year, and the majority of the primary productivity occurs in a period of less than 150 days during the spring and summer months (Carmack and Macdonald 2002; Retamal et al. 2008). One of the characteristics that make this shelf an important biological habitat for marine and freshwater biota is that it has a strong influence of river inflow from the Mackenzie River. The freshwater inflow from the Mackenzie River creates a brackish plume layer on the shelf (Hopky et al. 1994; Carmack and Macdonald 2002). Consequently, this shelf is often referred by Carmack and Macdonald (2002) as a "great estuary", as its river discharge is not confined to a bay, but extends on the shelf and draws in water, nutrients, carbon, and sediments from the run-off and the Arctic Ocean (Carmack and Macdonald 2002).

The discharge of freshwater begins to increase in early May as the ice begins to break up (O'Brien 2006). The river peak discharge rate typically occurs between the third week of May and the beginning of July (O'Brien 2006). The estimated annual freshwater discharge during the summer is approximately 330 km^3, creating a distinct irregular layer

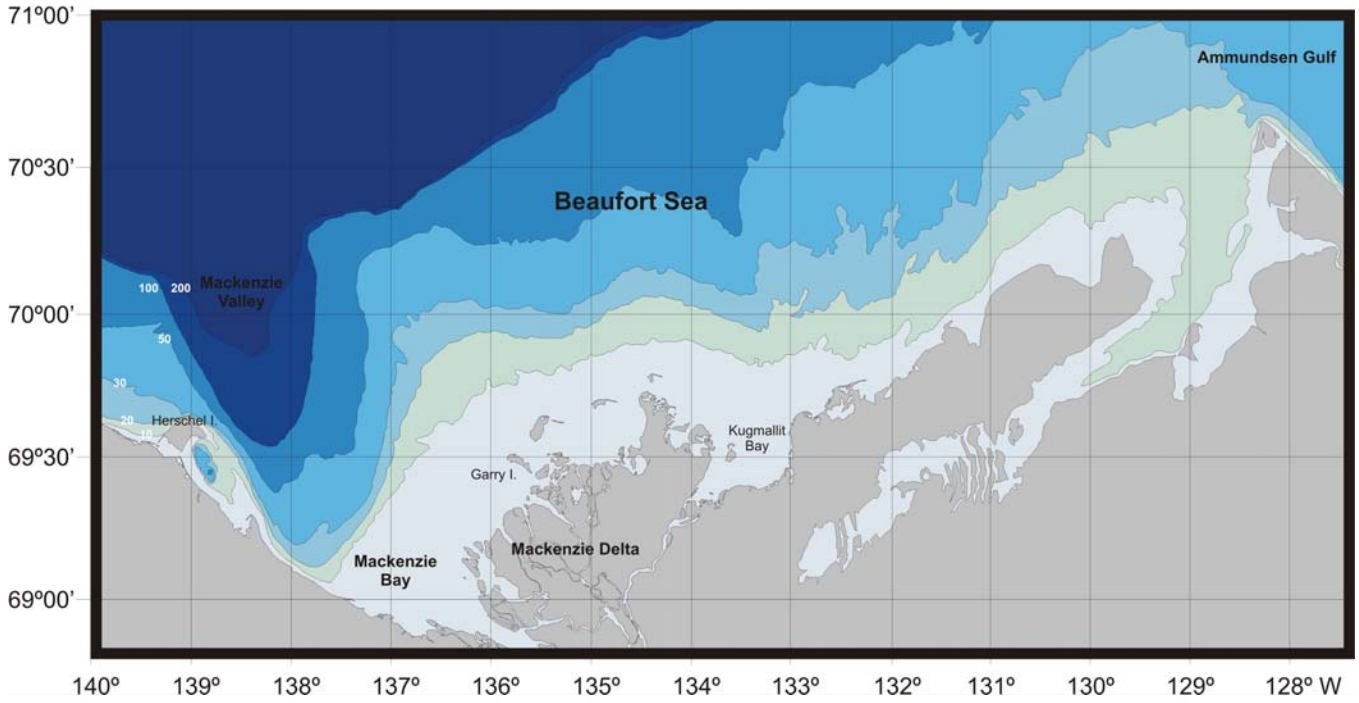


Figure 2. Map showing the location of the Canadian Beaufort Sea. Used with permission of W. Walkusz.

of turbid plume water that can spread approximately 60,000 km^2 over the surface (Macdonald et al. 1989). Because the thickness of the plume layer can reach a depth of six meters due to the immense freshwater run-off to the shelf, thus this shelf is the most estuarine of all Arctic shelves (Macdonald 2000).

The spreading of the Mackenzie River plume onto the shelf depends on the wind, the presence or absence of ice, and the amount of river discharge. Typically, winds during the Arctic summer months will blow the Mackenzie River plume either offshore or along the coast. The northwesterly winds, which favour downwelling, move the plume water eastward along the Tuktoyaktuk Peninsula (Dunton et al. 2006; Carmack and Macdonald 2002; Retamal et al. 2008). The easterly winds move the plume waters up to several hundred kilometers away into the offshore areas (Dunton et al. 2006; Carmack and Macdonald 2002; Retamal et al. 2008) that can extend beyond the shelf break into the Canada Basin (Macdonald et al. 1999). Yamamoto-Kawai et al. (2009) recently observed that in 2007, the southern Canada Basin had become freshened due to the input of freshwater from the Mackenzie River, which extended beyond the shelf into the basin; this observation had not been observed in the early 2000s. If sea ice is present in the vicinity in the summer, it restricts the plume movement and spreads offshore by acting as a barrier (Carmack and Macdonald 2002). In some years, sea ice that is still present close to shore (i.e., not completely melted) can restrict the movement and spread of the plume by limiting it to nearshore areas (Macdonald et al. 1987) rather than pushing it further offshore into the Canada Basin.

There are differences in the amount of discharge during an open-water and an ice-covered season. In the winter, pack ice covers the offshore and seasonal landfast sea ice in the inner shore (Carmack and Macdonald 2002). The Mackenzie River discharge rate itself is reduced to 15 % of its annual volume (Macdonald et al. 1998). This freshwater inflow is primarily concentrated near the mouth delta of the Mackenzie River, and it usually forms a stable salt-wedge estuary (O'Brien 2006) or a floating freshwater lake behind the Stamukhi Dam (i.e., formed as a result of broken ice plates and floes) (Carmack and Macdonald 2002). In the middle of the shelf, a flaw lead may often develop, separating the pack ice and the landfast ice and creating an open area of water (Carmack and Macdonald 2002).

1.2.1 Mackenzie River Plume

The melting of sea ice also contributes to the surface freshwater layer by providing additional freshening to the Beaufort Sea shelf; however, the Mackenzie River plume is distinct from ice melt because of its water properties (Carmack and Macdonald 2002). The Mackenzie plume is composed of a freshwater layer that is less dense than the ocean water. This density difference produces buoyancy in the plume layer that keeps it afloat on the surface. One characteristic of the Mackenzie River plume is its turbidity; as a result of this turbidity, the Mackenzie River carries a tremendous amount of sediment into the shelf. The Mackenzie River drains the watersheds that have both temperate and arctic region elements (Dunton et al. 2006), as the flow travels a distance of 1706 km, originating at Great Slave Lake (61° N, 115° W) and ending at the Beaufort Sea (69° N, 135° W) (Brunskill 1986). Therefore, the runoff that discharges into the shelf can reach

up to 8 °C, reflecting the source of water from the southerly latitudes and the exposure to solar heat during the water's long transport (Retamal et al. 2008). In general, the Mackenzie River drains an area of 1.8 million km^2 encompassing the boreal forest in the southern area and the Arctic tundra in the north (Brunskill 1986). The materials drained from the basin and delivered to the shelf include sediments, nutrients, and biota (Carmack and Macdonald 2002). Therefore, the brackish-turbid plume layer can be easily distinguished with the naked eye and with the aid of satellite images that clearly indicate a separation between the plume and its adjacent oceanic water (Figure 3).

Macdonald et al. (1998) reported that the Beaufort Shelf receives the majority of its inorganic sediments from the Mackenzie River. A lesser amount comes from coastal erosion, smaller rivers, the atmosphere, and ice. The Mackenzie River supplies about 127±6 Mt yr^{-1} of inorganic sediment, 2.1 Mt yr^{-1} of particulate organic carbon, and 1.3 Mt yr^{-1} of dissolved organic carbon into the Canadian Beaufort Sea (Macdonald et al. 1998). During the summer peak flows, the dispersal of sediments is the highest when about 90% of the sediment is delivered by the Mackenzie River (O'Brien 2006). It is estimated that approximately 40 % of the sediments are trapped on the shelf, 50 % of the sediments are deposited on the delta, and the remaining 10 % pass out of the shelf region (MacDonald et al. 1998). Macdonald et al. (1998) concluded that the Mackenzie River mouth contains the highest concentration of organic carbon in sediments, thus suggesting that the Mackenzie River is an important source of carbon to the Beaufort Shelf.

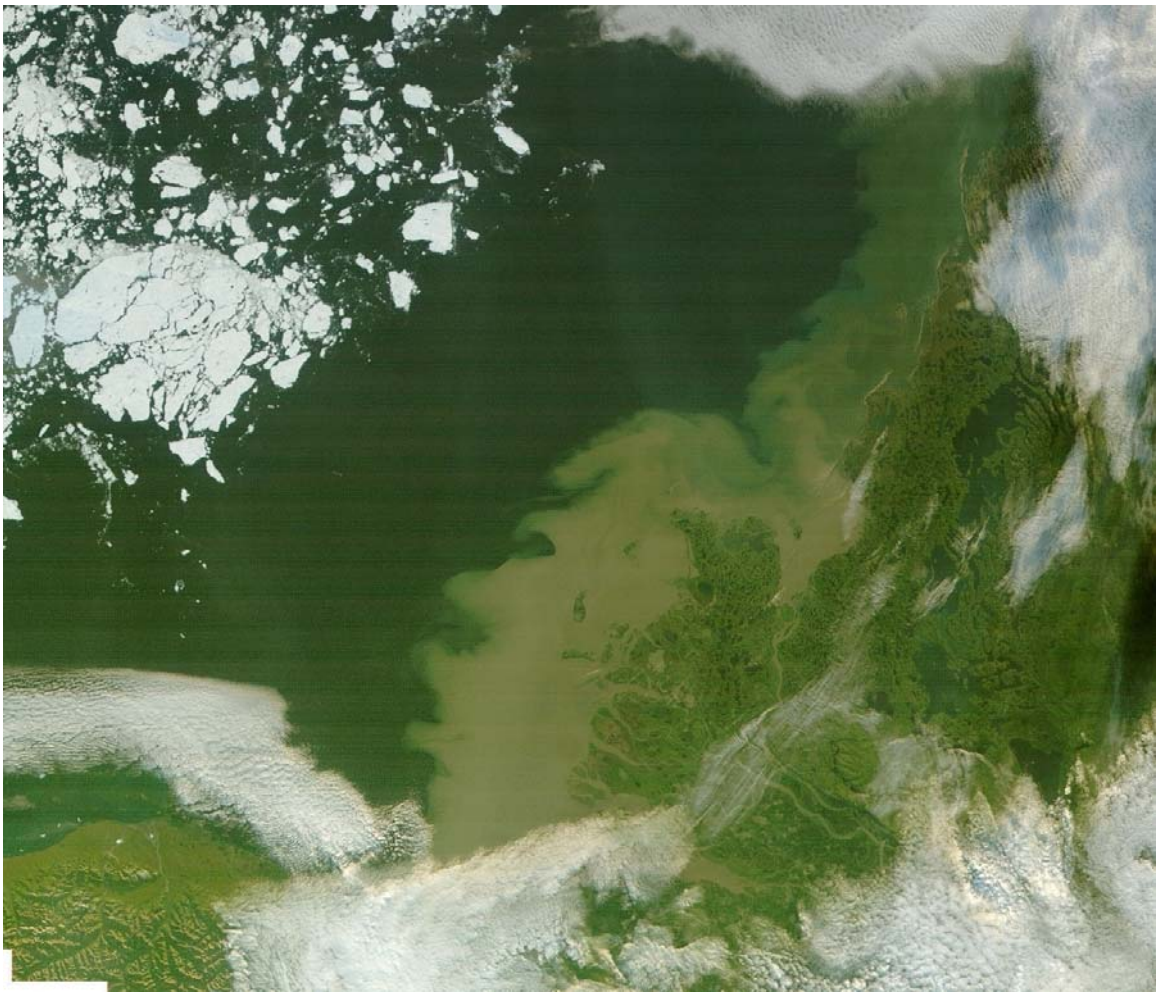


Figure 3. A MODIS true-color satellite image of the coastal Canadian Beaufort Sea on July 26, 2007, showing the visible extent of the Mackenzie River plume with ice scattering nearby to the northwest. The top right-hand picture shows the differences between the clear oceanic water and the turbid Mackenzie River plume water properties. *Sources:* satellite image at http://rapidfire.sci.gsfc.nasa.gov/ from the NASA/GSFC, MODIS Rapid Response Team at NASA GSFC.

Fissel (1987) categorizes the Beaufort Sea into three distinctive water masses: intensive plume, diffuse plume, and oceanic water zone. In contrast, other authors (e.g., Craig 1984; Hopky 1990) characterize the plume as an estuarine zone without classifying it any further. The intense plume is located closest to the Mackenzie Delta, where it contains the highest freshwater content and highest turbidity as a result of direct runoff from the river.

It is also the warmest, and it is visually clearly distinguishable from the oceanic water. The diffuse plume is a transitional zone between the brackish freshwater plume and the oceanic water, and some authors refer to this zone as a plume front (e.g., Garvine 1987). Because this zone is further offshore than the intense plume zone, the freshwater concentration of the diffuse plume is greatly reduced. Also, there is less turbidity in the diffuse zone compared to the intense plume. The boundaries of the diffuse plume zone vary with the effects of river flow, wind and ice conditions. The water of the oceanic zone is mostly composed of Beaufort Sea Shelf marine water that is colder and has higher salinity than the other two zones, and is less affected physico-chemically by the Mackenzie River.

1.2.2 Productivity of the Canadian Beaufort Sea Shelf

The marine biota of the Beaufort Sea experience both seasonal and annual climate differences that include extreme cold weather conditions that are prevalent throughout most of the year. Because its annual biological production is often limited to a small window of time during spring and summer, the polar marine ecosystem is more oligotrophic than most other marine ecosystems (Dayton et. al. 1994). Carmack et al. (2004) estimated that the total primary production of 12 to 16 g C m^{-2} had occurred from April to September in 1987.

In the Beaufort Sea, the onset for the primary production is triggered by the melting of sea ice as light levels increase (Carmack et al. 2004). The availability of nutrients is suggested to be determined by the accumulated supplies of nutrients over the winter from the input of the Mackenzie River (Carmack et al. 2004). Nonetheless, in the summer, the

Mackenzie River delivers a supply of nutrients to the shelf, thus revealing that nutrients are the limiting factors in primary production: an inner shelf of less than 20 m is phosphorus limited; a middle shelf between 20 to 80 m and an outer shelf at shelf break are nitrogen limited (Carmack et al. 2004).

The Mackenzie River plume regulates the upper ocean stratification and the light attenuation of the water column (Carmack and Macdonald 2002). Parson et al. (1988, 1989) observed that the Beaufort Shelf promotes two different types of productivity: autotrophic and heterotrophic. The autotrophic production is the result of decreased turbidity and increased light penetration into the deeper water column, which subsequently triggers higher photosynthetic rates. This phenomenon was reported to occur some distance from shore and was observed near the plume frontal zone area (at a depth of 15 to 30 metres). This autotrophic production provides a food supply for herbivorous copepods which are believed to be a potential food source for some marine fish. More recently, Walkusz et al. (2010) observed that the frontal zone influences the zooplankton community, as this zone contains the highest zooplankton diversity and promotes the co-existence of marine and freshwater copepods. In contrast to the autotrophic production, in the nearshore region closest to the Mackenzie River mouth, the heterotrophic production is prevalent as a result of the highly dissolved organic carbon (Parson et al. 1988, 1989). Macdonald et al. (1998) observed that the highest terrigenous organic carbon content is near the mouth.

Furthermore, the nearshore brackish plume waters provide biological productivity and habitats for both marine residents and migratory species (Carmack and Macdonald 2002).

These waters play an important part in the life history of a number of marine mammals and anadromous fish that enter the Beaufort Sea marine ecosystem each summer, including species that are unique to the coast (Craig 1984; Frost and Lowry 1984, Carmack and Macdonald 2002). For example, marine mammals such as the beluga whale migrate from the Bering Sea to the Beaufort Sea during the summer from late June to August, and they utilize the nearshore habitats because the warmer and less saline water is suitable for the annual moulting process that renews their skin (Harwood and Smith 2002). They also utilize this nearshore area for rearing calves and foraging for fish (e.g., Pacific herring, Arctic cisco, least cisco, rainbow smelt, inconnu) and invertebrates (Harwood and Smith 2002). Anadromous fish such as least cisco, broad whitefish, lake whitefish, inconnu, lake trout and Arctic char migrate from the Mackenzie River to the nearshore area to feed during the summer months as well (Percy et al. 1974). These feeding regimes in the nearshore Beaufort Sea indicate the importance of an abundant food supply in the area, and they also indicate that warmer water temperatures are preferable for anadromous fish in order to optimize their growth (Craig 1984). Adult marine fish are frequently found distributed in the offshore waters; however, some marine species such as Pacific herring and saffron cod are reported to be found in the coastal nearshore areas where salinity is relatively low (Percy et al. 1974; Percy 1975, Cobb et al. 2008); whereas, Arctic cod (*Boreogadus saida*) and fourhorn sculpin are also found to enter the coastal areas as salinities increase (Craig 1984). *Boreogadus saida* is the keystone marine fish species that is commonly distributed in circumpolar areas. Arctic cod exhibit schooling behavior in the Arctic shallow coastal areas of the Barrow Strait, but the reason for their schooling is still unknown (Welch et al. 1993). Most of the

early life ecology for Arctic marine fish is incomplete; especially the location of their spawning sites (Cobb et al. 2008). Reports have indicated that Pacific herring spawn during the spring in the nearshore area of the Mackenzie Delta (Cobb et al. 2008). Pacific herring are generally known to enter into the shallow brackish waters and spawn close to the river mouth and nearby bays (Percy 1975). Chiperzak et al. (2003 a,b,c) reported that marine larval fish from the families: Gadidae, Cottidae, Stichaeidae, Cyclopteridae were captured in the Canadian Beaufort Sea shelf from July to September. Although, the abundance and distribution for these marine larval fish varies across the shelf, and their distribution suggests that they utilize the nearshore region throughout the summer. However, their studies did not investigate what effect the Mackenzie River plume has on the distribution, assemblages and growth of these marine larval fish.

1.3 LARVAL FISH SURVIVAL

Understanding the relationship of survival, dispersal mechanisms, habitat selection, predation, environmental factors and early growth rates in larval fish is often the quest of fisheries biologists, as they provide critical information regarding the success of recruitment into adult populations. The ichthyoplankton stage is an important time in the life cycle of fish, as this is when they undergo continuous growth development. Also, due to their size and less developed swimming capabilities, they are vulnerable to potential hazards (Govoni 2005). Larval fish are susceptible to potential hazards such as starvation, predation and environmental factors that affect their survival (Doyle et al. 1993). Because of these hazards, the mortality rate of fish in the early stages of their life is considered

high, and any changes in the mortality rate can change the strength of their year class (Bagenal and Braum 1978).

Several mechanisms that can affect the larval assemblages and recruitments have been hypothesized to enhance the survival of larval fish (Doyle et al. 1993). Fish spawning strategies are a widely explored concept to examine ways in which larval fish can increase their chances of survival. Because larval fish have limited swimming ability, they are most often passively transported by currents from their spawning grounds to the nursery grounds (Omori and Ikeda 1984). Dispersion is one hypothesized spawning mechanism that fish use to facilitate dispersal of fish larvae to areas that are favorable for growth. Spawning patterns are different among fishes; some fish strategize themselves to concentrate in certain areas (e.g., cod *Gadus morhua*, pollock *Pollachius virens*), while others strategize themselves to distribute all over the shelf (Sherman et al. 1984). Sherman et al. (1984) concluded that fishes in the northeastern United States, such as the sand eel, silver hake and other hakes distribute their eggs and larvae over wide geographic ranges and have a longer spawning period. This strategy is used to increase the chances that some of the larvae will take advantage of the opportunity when food conditions become favorable, thus allowing larvae to grow and expand their population quickly (Sherman et al. 1984).

Synchronizing the food supply with the timing of spawning is another hypothesis for a fish-spawning strategy which examines the increased probability of survival for larval fish. This is a well-known match or mismatch concept formulated by Cushing (Cushing 1972; Cushing 1975; Cushing 1990). For example, fish may time their spawning by

synchronizing this with the peak production of zooplankton. In the study of fishes of the northeastern United States between the continental shelf waters of Cape Hatteras and Cape Sable, it was revealed that haddock, cod, redfish, bluefish, anchovy and searobin time their spawning to match the peak cycle of zooplankton (Sherman et al. 1984). Food supply is believed to be an important factor after the larval fish are hatched, since an abundance of food allows fish to grow faster. A study by Bailey and Houde (1989) revealed that when comparing two separate groups of fish larvae of the same age, the faster-growing fish have a higher chance of survival; since the faster-growing fish have better swimming capabilities, they are better equipped to escape predation. Moreover, Aronovich et al. (1975) performed a laboratory experiment on *Boreogadus saida* and determined that these fish larvae need to feed within 20 days after hatching; if food is not found, starvation will occur. The starvation process is an irreversible process known as the point of no return (Blaxter and Hempel 1963). This irreversible condition does exist, because if food is given to *Boreogadus saida* larvae, the larvae will not be able to feed on it due to failure of the liver and gastro-intestinal tract (Aronovich et al. 1975). Hence, where food is readily available, the success of a first-feeding event is an important part for the survival and increased growth of fish.

Optimal environmental conditions are hypothesized to play a role in increasing the chances for fish survival, since environmental conditions can regulate the fish growth rate and swimming performance (Frank and Leggett 1982). In the Arctic, fish are subjected to extreme cold and harsh environmental conditions during the winter. Houde (1989) reported that there are differences in marine fish spawning strategies in the higher latitudes versus the lower latitudes, due to growth constraints caused by colder water

temperature. Marine fish in the higher latitudes encounter conditions that thwart growth, compared to favourable conditions in the lower latitudes. Thus, the higher latitude newly-hatched larvae have a longer larval stage because of their slower growth (Houde 1989). Therefore, it was revealed that to combat adverse environmental conditions in the Arctic, *Boreogadus saida* larvae in the Greenland Sea have two potential reproduction strategies for winter survival (Fortier et al. 2006). Fortier et al. (2006) reported that the early spawners produce a spring cohort under heavy ice cover but the percent hatch is low. The explanation is that the spring cohort takes advantage of a growing season that is one month longer than the late spawners' season, which is in the summer (Fortier et al. 2006). Although the early spawners produce larvae under unfavorable conditions, it is predicted that these larvae have more time for growth and as consequence their much larger pre-winter body size allows for better winter survival. Bouchard and Fortier (2008) also supported this concept of early winter spawning for *Boreogadus saida* for the Laptev Sea and other seas, such as the Kara and Beaufort Seas, which have a short ice-free season. Both studies suggested that the occurrence of winter polynyas provided more favorable conditions for faster growth due to the polynyas' providing a minimum light intensity that helps visual feeders such as *Boreogadus saida* to find prey.

Additional studies investigated fish spawning strategies in relation to hydrographic features such as cyclonic eddies, river plumes, gyres, upwelling, and hydrographic fronts. It is speculated that these features transport fish larvae to suitable nursery areas or help to prevent fish larvae from dispersing in order to take advantage of areas with a higher food supply (Norcross and Shaw 1984). All these physical factors may play a role in the fish recruitment process (Norcross and Shaw 1984) and planktonic community structure

(Munk et al. 2003). For example, adult fish such as goby, estuary perch, and anchovy have adapted reproductive behavior that selects the spawning time and location to match hydrological and biological conditions that influence larval growth, thus enhancing their survival (Newton 1996). In contrast, Lobel and Robinson (1986) have indicated that the mesocale eddy and current system in Hawaiian waters may entrap larvae close to their spawning ground to complete their pelagic development. This retention pattern is also hypothesized to occur in plume waters. Grimes and Kingsford (1996) hypothesized that a plume area helps to retain fish in the vicinity because the convergent flow at the plume front facilitates larval entrapment. River plume waters and their associated front in the mid-latitudes are reported to contain enriched nutrients that increase primary production and subsequently support larval development (Grimes and Kingsford 1996).

In addition to enhancing larval survival through physical mechanisms, hydrological phenomena also influence fish larval assemblages. Munk et al. (2003) reported that on the west coast of Greenland, hydrographic fronts influence the distribution of larval assemblages across the shelf. The observed distribution of fish larvae was related to habitat preferences that corresponded to both polar water mass and temperate water mass (Munk et al. 2003). Also, larval communities corresponded to the location of coastal and offshore regions (Munk et al. 2003). In the subarctic region of the Hudson Bay, Ponton et al. (1993) indicated that the Great Whale River plume affects the distribution of the fish larvae of freshwater, anadromous, and marine origins. *Boreogadus saida*, *Ammodytes* sp., and *Lumpenus fabricii* were among the species affected by the distribution of the Great Whale River plume. This suggests that the Mackenzie River plume in the Arctic region of the Beaufort Sea may in turn affect larval distribution.

1.4 OVERVIEW OF RESEARCH OBJECTIVES

In the Beaufort Sea, many studies have looked at phytoplankton (e.g., Parsons et al. 1988; Parsons et al. 1989; Carmack et al. 2004; Retamal et al. 2008) and zooplankton (e.g., Walkusz et al. 2010) distribution, diversity, and biomass in relation to the coastal brackish plume water of the Beaufort Sea; nevertheless, there is still a lack of understanding about larval fish. Studies that were done in the mid-1970s and early 1980s surveyed larval fish and provided important information regarding taxonomy, characteristics on habitat areas, and spatial and temporal larval distribution (e.g., Ratynski 1983; Hopky et al. 1994; Chiperzak et al. 2003 a,b,c). More recently, Paulić (2009) described the general distribution of marine larval fish composition and distribution up to 50 m isobath, along with their associated hotspots. Although these studies are important to the management of the Canadian Beaufort Sea shelf, they have been sporadic, and they do not provide enough important information for the understanding of the Mackenzie River plume; as a result, its effects on the Arctic marine larval fish remain unclear.

As mentioned in the previous sections, there is evidence that the coastal shelf of the Beaufort Sea is influenced by the Mackenzie River run-off which delivers terrigenous sediment with a high total carbon content. In the summer, anadromous and marine fish have also been known to feed in the Beaufort Sea coastal area (Craig 1984; Cobb et al. 2008). The role of the Mackenzie River plume has been hypothesized by researchers to be important to larval fish (Cobb et al. 2008); however, its true role is still unknown and

debatable. Without detailed research of larval fish across the plume gradient, it is difficult to state conclusively that the plume has an affect on marine larval fish in the Arctic.

The goal of the present study is to investigate the Mackenzie River plume and its associated plume front in order to determine whether or not they affect assemblages, density and diversity of the larval fish. One view generally held by researchers is that the most vulnerable stage in a fish's life cycle is from the spawning stage to the early life stages of development. Understanding the nearshore dynamics of the freshwater plume and how it influences marine larval fish is critical, as it can be used as a predictor of change and as a way of assessing the productivity status of the Beaufort Sea. As mentioned in the general introduction, Fisheries and Oceans Canada has proposed strategies to protect marine biological areas by using the ecosystem approach, Ecologically and Biologically Significant Areas (EBSA). This strategy relies on gaining further knowledge of the marine ecosystem and identifying unique or ecologically significant functions of an area. Results from this study will help determine if the Mackenzie River plume should be designated as an EBSA in relation to its role in the ecology of larval fish. Therefore, to better understand the potential association of larval fish ecology within the Mackenzie River plume, a series of objectives and hypotheses were developed, and they are outlined below.

1.4.1 Objectives

1. Characterize the ranges in salinity, temperature, and turbidity associated with the intense plume, diffuse plume, and oceanic water masses across the Mackenzie River Plume on the Canadian Beaufort Sea during the summer.

2. Characterize the abundance and diversity of the larval fish assemblages along the Mackenzie River plume front and across the plume gradient.

3. Determine the relationship between fish larvae and zooplankton.

4. Determine if the Mackenzie River plume represents an area that is Ecologically and Biologically Significant (EBSA) for marine larval fish, as defined by the Fisheries and Oceans Canada (DFO). Under the definition of DFO, compared to other areas, an area defined as EBSA will suffer far greater consequences if it is disturbed.

1.4.2 Hypotheses

(I) We hypothesize that if the Mackenzie River plume is an EBSA for larval fish, then this status will be supported by observations of increased larval fish abundance, increased larval fish diversity, unique fish assemblages, or higher larval fish weight and length on average across the Mackenzie River plume relative to non-plume regions.

(II) We hypothesize that if the Mackenzie River plume is not an EBSA to larval fish, then the larval fish assemblages formed along the intense plume, diffuse plume, and open sea environmental gradient will have lower or equivalent abundance and diversity, and will not possess unique fish assemblages (abundance/composition).

If evidence supports hypothesis (I), then the Mackenzie River plume represents an EBSA to the marine larval fish ecology in the Canadian Beaufort Sea shelf. If the results of this thesis support the Mackenzie River plume as an EBSA, then conservation measures to the plume area would be warranted.

CHAPTER 2: METHODS

2.1 STUDY OUTLINE

The Methods Section is divided into four main sections. Section (2.2), the General Study Area gives an overview of the sampling locations and dates. Section (2.2) provides a description of the research vessel (2.2.1), criteria for site selection and sampling strategies (2.2.2), naming of stations (2.2.3), and sampling stations (2.2.4).

Section (2.3) describes sampling protocols, which are divided into two parts: primary (2.3.1) and secondary (2.3.2) sampling. Primary sampling is the core sampling method used for this study, which includes the use of bongo nets to capture larval fish. The secondary sampling describes methods for oceanography (conductivity-temperature-depth) and meso-zooplankton sampling. As a result of working with a multi-disciplinary team on a research ship, these data sets are provided by the other scientists. The oceanography data sets were provided by oceanographer, Dr. Bill Williams, in a raw data format and then analyzed by Sally Wong for the thesis. The meso-zooplankton identification was analyzed by Dr. Wojciech Walkusz and Sally Wong assisted with sampling and the laboratory analysis (wet weight measurements).

Section (2.4) describes the identification of ichthyoplankton and it is divided into different parts for each larval fish family. This subsection also describes the methods used for measuring and weighing the larval fish.

Section (2.5) includes data analysis such as**:** calculations for the bongo net and filtered water volume, pooling of tows, oceanographic data, diversity, Recurrent Group analysis,

Cluster and Simper analyses, standard length and weight analysis, and zooplankton and larval fish analysis.

2.2 GENERAL STUDY AREA

Larval fish samples were collected in the nearshore environments of the Beaufort Sea in a depth range of 5 to 55 m. Samples were collected during the open-water season of July 24-27, 2007, and August 16-17, 2007, in an area located directly north of Kugmallit Bay/Mackenzie Delta (Figure 4); 69° 30’ N, 133° W to 70° N, 135° W.

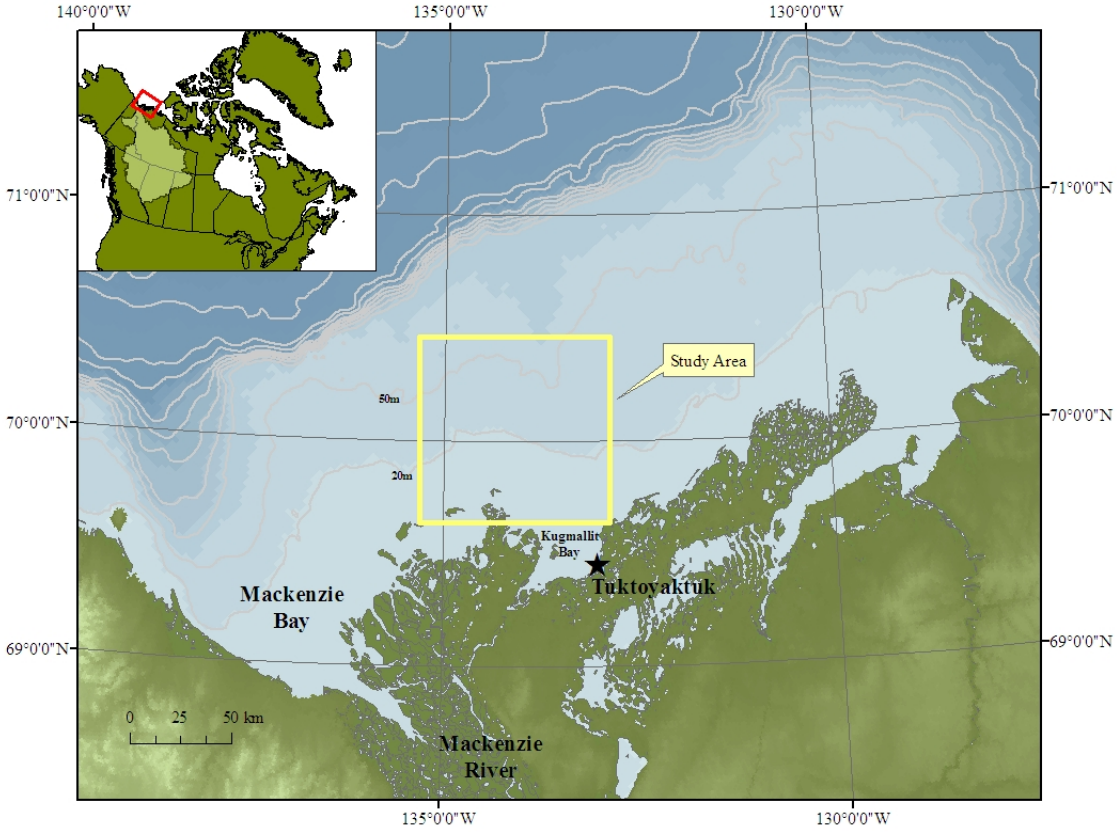


Figure 4. Map showing the study area in the Canadian Beaufort Sea located north of Kugmallit Bay (Mackenzie Delta). Map created by Sally Wong based on data from Fisheries & Oceans Canada.

2.2.1 Research Vessel – CCGS Nahidik

The sampling was conducted from the *Canadian Coast Guard Ship (CCGS), Nahidik* (Figure 5); which was used as a research platform due to its well-established configuration for science work. The *Nahidik* is a river vessel with a shallow draft and a large work deck forward, which are suitable for science activities. The *Nahidik's* length is 53.35 m, breadth 15.24 m and draft of 1.98 m allowing it to work in areas that larger ships (i.e., icebreakers) cannot access. The shallow draft of the ship has the capability to enter near coastal waters to the minimum 5 m depth required for this study. The *Nahidik* is essential for coastal science, as it is fitted with instrument winches and a laboratory module for conducting research. The *Nahidik* is not an ice-strengthened ship and fortunately, during the cruise, no ice was encountered and the winds were favorable; thus, unimpeded sampling was occurred.

This research project is part of the larger Northern Coastal Marine Study Program, a multi-disciplinary program that includes several components: physical oceanography, phytoplankton, zooplankton, ichthyoplankton, fish, and benthos to survey and characterize the physical and biological systems of the Beaufort Sea (Williams et al. 2007). The purpose is to provide baseline data and sound scientific advice for the protection of fish and their habitat by using an ecosystem approach under the key regulatory responsibility of Fisheries and Oceans Canada. Although, this research study was a component within the Northern Coastal Marine Study Program, it was solely dedicated to examining the Mackenzie River plume and its affects on larval fish assemblages during the time allotted on the expedition as a master's thesis project.

Therefore, this study also utilized supporting raw data provided by other scientists on the expedition (section 2.3.2), including oceanographic data using a Conductivity–Temperature–Depth (CTD) Rosette and meso-zooplankton data.

Figure 5. The *Canadian Coast Guard Ship Nahidik* used as a platform for the Northern Coastal Marine Study. Photo by: Sally Wong

2.2.2 Specific site selection and sampling strategies across the Mackenzie River Plume Gradient

The sampling area was selected based on previous studies of larval fish ecology in the Canadian Beaufort Sea shelf. Specifically, Paulić (2009) identified this area as a 'hotspot' for larval fish distribution compared to other parts of the Canadian Beaufort Sea shelf.

Paulić (2009) based her findings on the estimated larval density and diversity using 2003-2005 data combined with data from the Northern Oil and Gas Action Program (Chiperazak et al. 2003 a,b,c). This location correlates with the winds that were dominant from the east and southeast during the study period, which tend to move the Mackenzie River plume offshore. This wind data was obtained from the ship's on board meteorological system, AVOS (Automatic Voluntary Observing Ships System). Carmack and Macdonald (2002) indicate that easterly winds push the Mackenzie River plume waters offshore and move deeper Arctic Ocean waters onto the shelf surface via upwelling.

To examine how the Mackenzie River plume influences larval fish distribution, transects were specifically designed for sampling across the plume gradient. This gradient includes three distinct water masses: oceanic water, diffuse plume, and intense plume (Table 2). These water mass descriptions, which were modified from Fissel et al. (1987) and were previously used for the oceanographic description of the Canadian Beaufort Sea shelf (Fissel et al. 1987; Paulić 2009).

The decision was to sample three transects for July and resample two transects during August. The criteria for selecting transects were as follows: transects were within the study area, they transected the three water mass gradients, and they were spaced approximately >15 km apart. The actual stations across the transects (i.e., three stations for each transect) were selected aboard the ship because the Mackenzie River plume is a flexible, wind-driven layer, making the diffuse plume (i.e., plume front) difficult to locate beforehand.

Table 2. Characteristics of the intense plume, diffuse plume and the oceanic water zones. Description was modified from Fissel et al. 1987.

Water mass	Water mass properties
Oceanic water	Oceanic water is the coldest and most saline water type of the three water masses, and it is composed mainly of the Beaufort Sea (Arctic) shelf water. The oceanic water is far from the direct influence of the river discharge; thus, the water is clear compared to turbid-fresh riverine water.
Diffuse plume	This zone is often known as a transition zone where freshwater meets the marine water. The outer boundary often protrudes outward and meanders with the force of the wind; thus, it is highly variable between different locations. The water properties of the plume take on the characteristics of both freshwater and marine sources. However, it is not as turbid as the intense plume, since it is not in the direct source of the river plume at the river mouth. Thus, its turbidity properties are greatly reduced.
Intense plume	The intense plume is the warmest and least saline water, since it is the direct source of freshwater discharge from the Mackenzie River mouth. Thus, it contains high turbidities compared to the other two types of water masses. The Mackenzie River carries a tremendous amount of sediment, causing turbid properties to form an intense plume and make the plume clearly distinguishable from the clearer marine water.

The selection of stations within transects was done based on the results of the CTD/Rosette (Seabird SBE 25) (Appendix 5(C)) data that was collected the evening prior to the transect sampling. The CTD/Rosette records the ocean's physical properties including temperature, salinity, fluorescence, and light transmission. The CTD sampling was done overnight on the same transect to be sampled for the larval fish plume study during the following day. Measurements were coordinated by the CTD physical oceanography program led by Dr. Bill Williams (Institute of Ocean Sciences, DFO). CTD/Rosette profiles were provided to the larval fish plume study team and used to determine the sample locations. The first station identified was the diffuse plume in order

to establish the interface between the plume and oceanic water. The oceanic water stations and intense plume stations were then identified on the same transect.

The diffuse plume stations were also verified by observations made by me and Dr. Michael Papst (Freshwater Institute, DFO), based on the visual presence of the turbid plume front. The diffuse plume is illustrated in Figure 6, which shows the differences between the turbid Mackenzie River plume water and the clearer oceanic water.

Figure 6. Photo of the plume front. Photo courtesy of Bill Williams (Fisheries and Oceans Canada)

Three stations were sampled across the plume gradient for each transect. Data from two additional stations were collected but were not included in this thesis due to lack of hydrographic data (Appendix 3 and Appendix 12). Once a station was selected, the sampling was done at the site in an area within a 2 nm × 2 nm (nautical mile) box. All sampling efforts (i.e., larval fish, zooplankton and water chemistry) were made within the same boundary. This defined boundary was coordinated by the bridge team of the ship using GPS (Global Positioning System) and then overlaid onto a computerized electronic screen grid with latitude and longitude coordinates to ensure that the bongo net towing and all other supplementary data collections fall within this boundary.

2.2.3 Naming of Stations

This project is within the larger umbrella of the Northern Coastal Marine Study Program, and naming of the stations was not consistent between the various research teams. Consequently, two sets of station-naming systems were developed. The primary set of station names was created by chief scientist, Dr. Bill Williams and was used as the main reference for the entire Northern Coastal Marine Study Program (Appendix 1). The secondary set of station names was created especially for this study (larval fish) and the zooplankton research team. Since the two original stations, Plume 4 and Plume 7 were removed because of the lack of hydrographic data. The "final secondary station names" was used throughout this thesis (Appendix 1).

2.2.4 Sampling Stations

In total, five transects were sampled in July and August (Figure 7 and Table 3). Three transects were sampled in July and two were sampled in August. The reduced number of transects in August was the result of limited ship time.

The Mackenzie River plume is affected by the movement of ice, river discharge volumes, currents, and wind action. Therefore, it was important to sample the water masses for larval fish more than once during the open-water season. This sampling strategy was done so that some degree of inter-season variability would be included in the study.

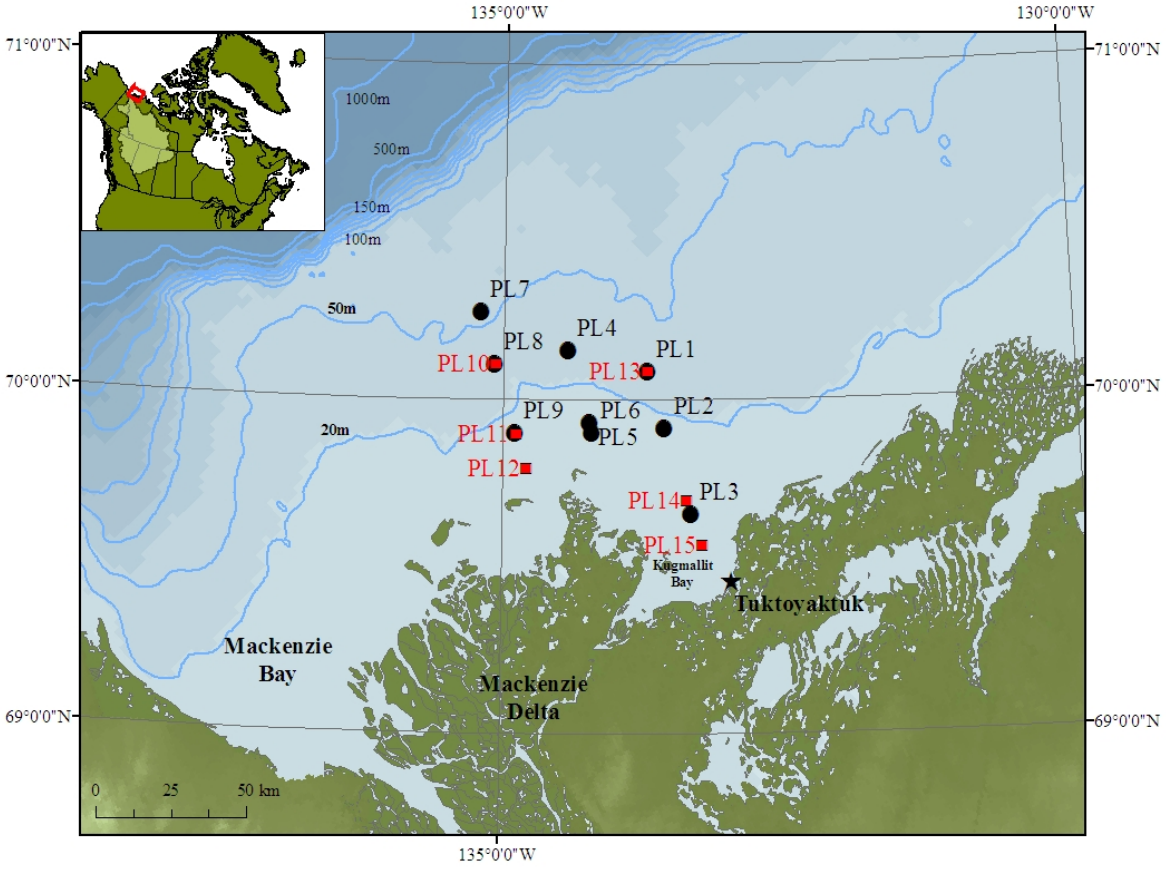


Figure 7. Map of the Canadian Beaufort Sea shelf showing sample stations across five transects in July (black circles) and August (red squares) of 2007. Blue lines in the map represent the bathymetry of the ocean (depth in meters).

Table 3. List of stations; including sampling date, geographical coordinates, depth, number of tows per station and plume classification.

	Station	Date	Latitude (N)	Longitude (W)	Depth (m)	Number of Tows	Plume category
Transect 1	PL1	24-Jul-07	70° 05.03'	133° 44.23'	33	2	Oceanic
	PL2	24-Jul-07	69° 54.75'	133° 35.72'	16	2	Diffuse
	PL3	24-Jul-07	69° 39.28'	133° 22.48'	6	1	Intense
Transect 2	PL4	27-Jul-07	70° 08.75'	134° 25.93'	33	2	Oceanic
	PL5	25-Jul-07	69° 55.73'	134° 14.67'	11	2	Diffuse
	PL6	25-Jul-07	69° 54.03'	134° 13.33'	11	1	Intense
Transect 3	PL7	28-Jul-07	70° 15.48'	135° 12.38'	53	2	Oceanic
	PL8	28-Jul-07	70° 06.27'	135° 04.53'	39	2	Diffuse
	PL9	28-Jul-07	69° 53.82'	134° 53.47'	13	2	Intense
Transect 4	PL10	16-Aug-07	70° 06.17'	135° 04.12'	38	2	Oceanic
	PL11	16-Aug-07	69° 53.70'	134° 53.17'	14	2	Diffuse
	PL12	16-Aug-07	69° 47.55'	134° 47.75'	8	3	Intense
Transect 5	PL13	17-Aug-07	70° 05.03'	133° 44.30'	32	2	Oceanic
	PL14	17-Aug-07	69° 41.82'	133° 24.67'	7	2	Diffuse
	PL15	17-Aug-07	69° 33.83'	133° 17.00'	4	2	Intense

2.3 SAMPLING PROTOCOLS

The sampling protocol at each station is separated into primary measurements (Section 2.3.1) and supporting measurements (Sections 2.3.2). The primary measurements were focused on the capture of larval fish and fish identification. The supporting measurements were prioritized for zooplankton, chlorophyll *a*, along with measurements of the CTD/Rosette from each station. CTD/Rosette sampling was conducted in the early morning hours, while bongo net sampling was conducted from approximately 10:00 am until 1:30 am on the following day. Sampling dates refer to the day when each transect sampling was started. Due to the number of daylight hours in the Arctic, light intensity was similar throughout the sampling.

Aboard the ship, the typical daily sampling structure was as follows: 1. CTD/Rosette cast upon arrival at the station (using aft deck hydro-winch); then vertical net casts (to catch

meso-zooplankton using the aft deck hydro-winch). 2. Bongo net tows (to catch ichthyoplankton using the fore deck's large winch and crane).

2.3.1 Primary Measurements to Capture Larval Fish using Bongo Nets

A bongo net (see Appendix 4 for photo illustrations) was deployed by using the ship's main crane and deck winch. A bongo net is designed to collect ichthyoplankton and zooplankton, as this design gives better filter efficiency (UNESCO 1968). This bongo net is the same design as used in previous studies of the Canadian Beaufort Sea larval fish (Hopky et al. 1994; Paulić 2009). Bongo net towing methodologies used in this study were the same as those used by Paulić (2009), with the exception of tow time, which was extended from an average 15 minutes to 20 minutes for the deeper stations.

The bongo net (Wildco) consists of a pair of conical nets with a mesh size of 500 μm mounted side by side on a common frame (Appendix 4(A)). Each net opening diameter is 61 cm, while the net itself is 317 cm long. A flow meter (Appendix 4(B)); Model 2030 General Oceanic) was attached at the mouth of each net to measure the volume of water filtered. At the central base of the frame, there is a large depressor, weight ~ 18 kg, (Appendix 5(A)), used to ensure that the net stays horizontal in the water as it is being hauled. The net is hauled by the crane with a cable that is marked every meter to indicate depth. However, when the bongo net is towed horizontally (oblique tow) in the water column, the crane cable is not towed vertically. Thus, in order to compensate for the angle of the bongo net cable and establish actual sampling depth net, a hand-held clinometer was used to calculate the actual depth (Wildco Model No. 59-D10). The clinometer (Appendix 4(C)) is designed to measure the angle of the bongo net cable in

reference to the horizontal by using basic trigonometry. The angle of the cable was measured every two minutes to ensure that the line of cable was set at the correct depth. A chart had been created beforehand with information on the cosine angles referenced at certain depths to determine how much cable was required to ensure that the bongo net was kept at the desired depth. This chart was used for easy reference during sampling (Appendix 10)

The bongo sampling involved a series of double oblique tows from the surface to within approximately a meter from the seafloor. Tows ranged from 15 to 20 mins each, depending on the station depth; the greater the depth, the longer the sampling. This method was based on the experience of Paulić (2009); towing duration is a compromise between sampling long enough and ensuring that the net does not become clogged with suspended sediments or algae. If the depth was <10 m, then the bongo net would be towed obliquely three times to ensure that the sampling was conducted for at least 15 minutes, as this length of time is the minimum standard duration for this study.

During the time of hauling, the ship would make a slow port turn at a speed of approximately 1.0 to 1.5 knots to allow the net to stream away and prevent it from getting caught under the ship. At least two replicate tows were made at each station to determine sampling error. The PL6 shallow station was towed once due to time constraints (Table 3). The result was corrected during the subsequent analysis when the density of larval fish per station was calculated. The calculation of the larval density per station uses the average density for the tows (see 2.5.4 Pooling of tows). While sampling at some shallow stations where the depth was approximately 5 m, if the cable was lowered too far, the

bongo could collect mud from the bottom of the seafloor (see Appendix 5(B) for a picture of the bongo net collecting mud). Once the bongo net caught the mud, the only way to remove it was by carefully spraying down the net with the ship's deck hose; then, the tow would have to be repeated. This procedure impacted the sampling plan for the ship, as time allotted for this project was limited.

An experimental DST-CTD (Depth, Salinity, Temperature CTD) tag system (Star-Oddi) was attached to the bongo to measure conductivity, temperature, and depth at two-second intervals during each tow. This DST-CTD tag system was used to determine if oceanographic information obtained directly from the tow would be accurate. This is an experimental system; due to the number of technical problems, the DST-CTD data was not used in this study.

2.3.1.1 Station procedure for Bongo Net Tows

The ship is stopped on-station and the depth is confirmed with the bridge team. The towing data recorded included station name and number, date, start and finish time of net towing, net depth, length of cable out, flow meter reading start and finish, wind speed, wind direction and remarks.

Naming the tow involves this default numbering system: BongoNet-Year-StationName-TowNumber. For example, the sampling name for the second tow at station #1 was named BN-07-01-02.

2.3.1.2 Target Tows

At some stations, tows were performed at specific depths and were referred to as target tows, but they were not analyzed for my thesis. However, the target tow data will be used in collaboration with the acoustic program led by John Jorgenson of Fisheries and Oceans Canada, a member of the Northern Marine Costal Study Program. Data for the target tows are included in Appendix 2 and Appendix 11.

2.3.1.3 Initial Treatment of Samples and Laboratory Processing

At the end of each bongo tow, the nets were rinsed with seawater to the cod ends (see Appendix 4(D)) with a deck hose to prevent any organisms from being stranded in the mesh as the net was hauled aboard. Afterwards, the contents of the cod ends (i.e., larval fish and zooplankton) were transferred into a collection bucket (Appendix 4(E)). Immediately after the completion of a tow, the bucket's contents of plankton organisms were sorted in the ship's laboratory, with larval fish separated from the plankton sample (Appendix 4(F)). The first step was to pour a portion of the zooplankton sample (e.g., larval fish, copepods, jellyfish, arrow worms, and mysids) into the metal sampling tray and pick out larval fish by using a pair of soft tweezers, as they are visible to the naked eye. All larval fish were then placed into a large Petri dish containing seawater to prevent the fish from drying out (Appendix 6(C)). Preliminary identification was then done quickly to obtain a rough estimate of the number and type of fish captured. Then all larvae for each tow were placed in 30 ml plastic vials (Nalgene® Wide-Mouth HDPE Bottles Supplier: Cat No. 02-893-5A Fisher Scientific) containing with 10 % buffered (disodium tetraborate) formalin in seawater and then labeled with the station information

and number of fish (Appendix 6(B)). The sorting and preserving process was usually done within an hour after sampling, and all larval fish were sorted from the plankton sample because they were the main focus of this study, and it would have been difficult to sort the samples after preservation. The remaining portion containing zooplankton was sieved (330 μm mesh, Hoskin Scientific) so that excess sea water could be removed, and preserved in 10% formalin in seawater in 500 ml or 1000 ml bottles (Nalgene® Wide-Mouth HDPE Bottle) for a taxonomical analysis, which is not included in this study (Appendix 6(B)). All larval fish and zooplankton were preserved with 5 % buffered formaldehyde solution in seawater (equivalent to 10 % buffered formalin). At the end of the expedition, sample bottles were packed and shipped to the Freshwater Institute (Winnipeg, Manitoba) for further analysis.

2.3.2 Secondary (supplementary) sampling

Supplementary sampling was done in order to fully characterize the biological and physical environment in which larval fish are distributed. These additional measurements were as follows: hydrographic sampling, chlorophyll *a* sampling, and meso-zooplankton sampling. It is noted that chlorophyll *a* sampling was collected for this study. However, the information collected was not evenly distributed by depth; therefore, the chlorophyll *a* sampling was not used in this analysis.

2.3.2.1 Conductivity–Temperature–Depth (CTD)

The hydrographic information was collected and provided by Dr. Bill Williams (Institute of Ocean Sciences, DFO) using a standard Seabird Conductivity–Temperature–Depth

(CTD)/Rosette system (Seabird Model SBE25). The CTD collected data at a sampling rate of 8 Hz, and it was lowered 0.5 m/s down into the water column (Williams et al. 2007). Salinity (PSU), temperature (°C), depth (pressure dbar), fluorescence, and turbidity (FTU) variables were measured at all stations.

Separate from the CTD/Rosette, a hand-held hydrolab probe (Hach® Environmental Hydrolab Quanta sonde**)** was also used to collect depth (m), turbidity (FTU), salinity (parts per thousand), total dissolved solids (g/L), and temperature as back-up data for CTD. This hydrolab probe data was not used in this study, as all of the CTD/Rosette data were used.

2.3.2.2 Meso-zooplankton

The analysis of meso-zooplankton samples (i.e., biomass, composition, and abundance), was performed by Dr. Wojciech Walkusz (Freshwater Institute, DFO). At each station, a 153 μm conical plankton net (Appendix 5(D)) (Wildco) was towed vertically, approximately one meter off the sea floor to the surface. Two replicates were taken at each station and combined into one sample. Taxonomical identification and biomass/abundance calculations were performed according to Walkusz et al. (2010).

2.4 LABORATORY PROCESSING AND IDENTIFICATION OF ICHTHYOPLANKTON

The initial laboratory processing at the Freshwater Institute (DFO) involved re-examining all total zooplankton samples to determine if any larval fish were missed during the onboard laboratory process. The number of missed fish was very low for all samples: only 10 fish in total were missed out of the 915 fish caught during the onboard sorting. Larval fish that were originally preserved with a non-buffered formalin solution were transferred at this stage into 70 % ethanol to allow for safe handling during identification and for long-term storage. All fish for each tow were stored in the same bottle. To aid in identification, fish from each bottle were then individually placed into a separate vial (i.e., 7 ml 7450 Solvent Saver scintillation vial made of borosilicate glass with an aluminum sealed cap (Thermo Fisher Scientific) with an ID number. These vials are used for temporary storage only during the identification process. As suggested by the Atlantic Reference Center during training, for long-term storage of the larval fish, those vials are to be replaced with vials that have poly-sealed caps (Lou Van Guelpen, Atlantic Reference Center, pers comm.).

Training to identify larval fish was held at the Atlantic Reference Centre, Huntsman Marine Science Centre in St. Andrews, New Brunswick, with the Curator of Fishes and Collection Manager, Lou Van Guelpen.

Identification was performed in the laboratory using the stereoscope zoom microscope (Nikon SMZ1000 with binocular eyepiece tube and fiber-lite M1-150 high intensity illuminator from Dolan-Jenner Industries). This microscope has superior optics to ensure

high magnification (0.8 – 8X) and zoom (10X zoom). Other laboratory equipment for identification included soft tweezers, a drop bottle filled with distilled water (used to fill the petri dish), a petri dish filled with distilled water (to put larval fish in) and calipers.

All fish larvae samples were sorted and identified to the lowest possible taxonomic level, preferably to species, based on the available literature: Faber (1976); Fahay and Markle (1984); Moser et al. (1984); Matarese et al. (1989); (Van Guelpen 1989); Grigor'yev (1992); Fahay (2007 a,b).

Once the individual fish were stored in vials with ID numbers, the ID process began by identifying all fish within the same family. This identification can be done only when one knows the general features of that family. The developmental stage for each larva was determined during the identification process. There are four developmental stages in larval fish: egg yolk, preflexion, flexion (Appendix 8), and postflexion (Appendix 9). The developmental stages were determined by using the references from Kendall et al. (1984) and the Ichthyoplankton Information System (IIS) of the Alaska Fisheries Science Center (2010).

For some taxa (i.e., sub-family Lumpeninae of the family Stichaeidae and family Cottidae), detailed identification to the species level was technically challenging, since the fish larvae were not fully developed with definable features. In the case of Lumpeninae, distinguishing between *Anisarchus medius* and *Leptoclinus maculatus* was not possible due to their extreme similarity in meristics, specifically in their gut position and myomers count which was used to identify each speciemen. Myomers in larval fish corresponds to the number of vertebrae in the adult fish, thus with overlapping number of

myomers, a miscount could occur. Therefore, *Anisarchus medius* and *Leptoclinus maculatus* are treated at the sub-family level throughout this thesis. In addition, identifying *Icelus spatula* and *Icelus bicornis* (Cottidae family) was difficult, due to the lack of information, so the identification was to genus only.

By contrast, confidence in my identification for the Gadidae family was very high, as this group can be easily distinguished by examining their meristics.

2.4.1 Remarks on Identification of Fish Species

Larval fish identification is challenging, since comprehensive taxonomic keys for all the families in my study were not available. If the identification of a specimen was uncertain, identification was to family. My comments (see sections 2.4.2 to 2.4.7) relate to the identification of larval fish by family and include specific taxonomic keys used.

2.4.2 Family Clupeidae

Clupea pallasii pallasii has an elongated body shape, and its diagnostic characteristics may be identified through the location of its gut, the number of myomeres, and the pigment of its gut (Matarese et al. 1989). It is an abundant species found in an area from the Beaufort Sea to the Amundsen Gulf (Coad and Reist 2004). The Clupeidae family is distinguishable from the Osmeridae family in that it has neither an adipose fin nor a single row of mid-ventral melanophores below the gut; rather, it has a double row (Matarese et al. 1989). The Clupeidae family also has fewer myomere counts (Matarese et al. 1989).

C. pallasii pallasii is distinguishable from *Mallotus villosus* in that it has dorsal spots at its notochord tip.

Identification *of C. pallasii pallasii* primarily used the key of Matarese et al. (1989).

2.4.3 Family Gadidae

Boreogadus saida (Arctic cod) (Appendix 6(E)) are the most common fish found in the Beaufort Sea and the circumpolar seas (Welch et al. 1993). Some literature refers to Arctic cod as species *Arctogadus glacialis* (e.g., von Dorrien et al. 1991, Süfke et al. 1998) and to Polar cod as *Boreogadus saida* (e.g., Lønne and Gulliksen 1989, Gjøsæter and Ajiad 1993, Bouchard and Fortier 2008, Nahrgang et al. 2009). In this study, to be consistent with other research conducted within the Beaufort Sea (e.g., Craig 1984; Bradstreet et al. 1986; Welch et al. 1993; Hopky et al. 1994; Chiperzak et al. 2003 a,b,c; Coad and Reist 2004; Paulić 2009), Arctic cod is referred to as *Boreogadus saida*.

The identification keys used to distinguish between *Boreogadus saida* and *Eleginus gracilis* were from Matarese et al. (1989) and Fahay (2007 a, b). *Eleginus gracilis* has distinct melanophore pigment(s) on the isthmus and double row of ventral pigment(s) along the gut surface on each side of the midline (Dunn and Matarese 1984; Matarese et al. 1989). *Boreogadus saida* is absent in both diagnostic features (Matarese et al. 1989).

2.4.4 Family Cottidae

Identifying *Icelus bicornis* (twohorn sculpin) and *Icelus spatula* (spatulate sculpin) was difficult since these two species were not extensively studied and there are no taxonomy keys (Fahay 2007 b; Matarese et al. 1989). Consequently, identification to genus.

The Cottidae family was identified mainly using the keys of Van Gulpen (1989) and Fahay (2007 b). In Appendix 7 (E) and (F), photos illustrating *Gymnocanthus tricuspis* can be found.

2.4.5 Family Agonidae

Ulcina olrikii (Appendix 7 (C) and (D)) was abundant species in the Beaufort Sea to the Amundsen Gulf ecozone (Coad and Reist 2004). *Ulcina olrikii* was easily distinguished from *Leptagonus decagonus* by four dark bands and no mid-ventral pigmentations connecting the four bands. The identification keys were from Fahay (2007 b) and Van Gulpen (1989).

2.4.6 Family Liparidae

Liparis species (Appendix 6(F)) are fish that are characterized by a suction disc on their pelvic area; thus, it is easy to distinguish them from other species. The diagnostic characteristics that distinguish *Liparis fabricii*, *Liparis tunicatus* and *Liparis gibbus* include gill slit length (Appendix 7(A)), disc (Appendix 7(B)) and eye diameter size, body type, and head size. Meristics such as the dorsal and anal fin ray counts were also useful. Of the three species, *L. tunicatus* has the smallest gill slit. *L. fabricii* and *L. gibbus* have a gill slit that covers more than eight pectoral fin rays; therefore, distinguishing these two species from each other was the main challenge. However, most often, identification was done by looking at the disk and eye diameter ratio, body type, and pigmentation.

Only one individual of *Liparis* sp. was unidentifiable in this project, since the pectoral fin counts were difficult to obtain accurately in order to determine the size of the opening of the gill slit.

The identification key used to identify *L. fabricii*, *L. gibbus* and *L. tunicatus* was primarily from Fahay (2007 b).

2.4.7 Family Stichaeidae: sub-family Lumpeninae

Since the Stichaeidae family was difficult to identify and identification was to the sub-family level, Lumpeninae. However, the diagnostic features used to distinguish this family from other families (i.e., Clupeidae and Osmeridae) were based on examining the length of the anus/gut which is usually ¾ of the fish length. Identification also used

meristics, by counting the number of myomeres and the number of anal fin rays. Thus, I was able to reduce the species identification to two possibilities: either *Anisarchus medius* or *Leptoclinus maculatus.* Both of these species were very similar in their characteristics, including overlapping vertebrae counts. It was difficult to confirm the count, as the process could easily result in errors. The possibility of being *Sticheaus punctatus punctatus* was ruled out since *S. punctatus punctatus* is a much smaller species with fewer vertebrae.

The identification keys used to identify Lumpeninae (Appendix 6(D)) were from Grigor'yev (1992) and Fahay (2007 b).

2.4.8 Measuring and Weighing Larval Fish

After the taxonomical identification in the laboratory was done, the length of the larvae was measured to the nearest millimeter (0.01 mm) using an electronic caliper (Mastercraft digital caliper) under the microscope. All fish are measured at a standard length, which is from the "tip of the snout to the posterior edge of hypural bones" (Fahay 2007 a,b). Afterwards, all fish were wet-weighed to the nearest 0.0001 g using an electronic balance (Mettler Toledo AE 160 Scale). Prior to weighing, larval fish were washed in distilled water and blotted on filter paper to remove excess water.

2.5 DATA ANALYSIS AND PROCESSING

The purpose of the data analysis and processing section is to describe the calculations and statistical analyses that were used for analyzing larval fish. Section (2.5.1) is the analysis of the oceanographic data. Section (2.5.2) calculates the volume of water filtered through

the bongo net after it was towed in order to determine the number of fish at a given volume (i.e., per 100 m^3). Section (2.5.3) provides equations, including calculation for density (individual larval per 100 m^3), relative abundance (taking into account the number of larval fish caught rather than incorporating the set volume), and occurrence (percentage of individual fish species that appeared). Section (2.5.4) calculates the bongo net data at each station by pooling the tows, since two or three tows were taken at the majority of the stations (except for station PL3 and PL6). Section (2.5.5) analyzes the diversity within the three water masses using Shannon's diversity index. Section (2.5.7) analyses the co-occurrence of fish species, using the Recurrent Group analysis. Section (2.5.8) determines the larval fish assemblages using the Cluster and Simper analyses. Section (2.5.9) determines the standard length and weight analysis. Section (2.5.10) determines the relationship between zooplankton and larval fish.

2.5.1 Oceanographic Data

In order to reorganize the oceanographic data collected from the CTD/Rosette casts into a graphical representation, the data needed to be processed before inputting it into the Ocean Data View (ODV) graphical software (Version 3.4.0 Schlitzer 2009). The processing requires the export of raw data into Excel to convert the data into an exportable format that has proper headings so that it can be imported into ODV software. The salinity, temperature, turbidity, and fluorescence were graphed to show the cross-sectional profiles across the plume transects.

2.5.2 Calculating Volume of Filtered Water from the Bongo Nets

The formula used to calculate the volume of filtered water through the bongo nets is illustrated in equations below and values are given in cubic meters. Since there were two nets in a bongo, the water volumes for net 1 and net 2 were calculated separately. After volumes for net 1 and net 2 were calculated, they were combined to give an average of the volume filtered per tow. These data were subsequently used to calculate the number of larval fish per 100 m^3.

Calculation of the filtered water volume (m^3) was done using the formula given in the General Oceanics Digital Flowmeter Mechanical and Electronic Operators Manual:

Equation 1.

$$\text{Distance(meters)} = \frac{[(\text{Difference(Counts)}]\times(\text{Rotor Constant})}{999999}$$

Equation 2.

$$\text{Volume}(\text{meters}^3) = \frac{(3.14)\times(\text{Net Diameter(m)})^2(\text{Distance (m)})}{4}$$

where, Rotor Constant (Standard Speed) = 26873

Difference in Counts of individual net = the initial flow meter reading minus the final flow meter reading

Net Diameter = 0.61 m

To make the calculation easier, the two formulas are partially combined to come up with a constant that can be multiplied by the difference in counts to obtain the volume cubic meters.

Equation 3

$$\text{Constant} = \left(\frac{(\text{Rotor Constant}) \times (3.14) \times (\text{Net Diameter (m)})^2}{(999999) \times (4)} \right) = 0.00837$$

The average water volumes filtered for each tow ranged from 197.73 to 701.08 m^3 and with an average of 339.10 m^3 in this study.

2.5.3 Ichthyoplankton Density, Relative Abundance and Occurrence Values

The density (Equation 4) in this study refers to the number of fish larvae, taking into account the amount of water that was filtered through the net per 100 m^3. A constant volume of 100 m^3 to determine the density of fish larvae will be used to allow for a consistent measurement for all samples and allow for easy spatial comparisons within the areas or between regions. The relative abundance (Equation 5) is a percentage that is based on the number of larvae per individual species over the total number of larvae captured without taking into account the volume filtered through the net. The occurrence (Equation 6) is basically a way to determine whether the individual species is present at the stations; thus, the presence and absence data were used to determine the percentage of occurrence. In this study, when referring to the abundance value or total number of fish caught, these figures indicate the number of fish, without taking into account the volume filtered by the bongo nets. All three formulas for calculating the density, relative abundance, and occurrence were taken from Paulić (2009) and are illustrated below.

Equation 4.

$$\text{Density} = \frac{\text{Number of Fish Larvae}}{\text{Volume Filtered (per 100 m}^3\text{)}}$$

Equation 5.

$$\text{Relative Abundance (\%)} = \frac{\text{Total Number of Larvae per individual taxon (n)}}{\text{Total Number of All Larvae Captured (N)}} \text{ X (100)}$$

Equation 6.

$$\text{Occurrence (\%)} = \frac{\text{Number of stations a taxon was present (n)}}{\text{Total Number of stations}} \text{ X (100)}$$

Larval fish composition was calculated by using the density values, and all graphs were made using SigmaPlot 11.0 (Systat Software, Inc.).

2.5.4 Pooling at each Station

The Wilcoxon Signed Rank Test from Statistica 9 was used to determine if there was a difference in larval densities between tow 1 and tow 2 at each station. In order to allow for the two tows to be pooled, the Wilcoxon Signed Rank Test is a nonparametric test similar to a t-test to correlate samples, but is used for two-sample designs (StatSoft Inc. 2011). The two independent tows are repeated measures from the same population at the same station, using the same sampling method; as such, the two tows are expected to display similar catch sizes from the particular station.

There were two nets in a bongo; therefore, the larval density for a bongo tow was measured by first calculating the larval fish density (see density 2.5.4) of each net, then

pooling the results. Therefore, larval fish density at each station is the total average larval fish density for all the tows done at that particular station.

2.5.5 Shannon Diversity Index

The Shannon Diversity Index (H) was used to describe the diversity within each of the three water masses: intense plume, diffuse plume, and oceanic water. The Shannon Diversity Index is a better alternative to calculate diversity than species richness, which does not consider the relative abundance of species (Lande 1996). This diversity index increases in a community, as indicated by a higher H value; it is also sensitive to the abundance of rare species in a community (Krebs 1998). The Shannon Diversity Index Equation used in this study was described by Lande (1996); Krebs (1998) and Hill (1973).

Equation 7.

$$H=\sum_{i=1}^{s} p_i \ln p_i$$

where, H = the Shannon Diversity Index

S = total number of species in the community

p_i = proportional abundances of the *n* species

$\sum$ = sum of species 1 to species S

In order for H to be expressed in species terms, Hill (1973) recommended that H be transformed and expressed as N, which refers to the effective species richness or the diversity number.

Thereby,

$$N_1 = e^H$$

where, N_1 = the diversity number

e = base of natural logarithm 2.71828

H = Shannon Diversity Index

2.5.6 Spatial Patterns of Larval Distribution

The spatial distribution analysis was done for July and August in order to look at the spatial patterns of larval distribution across the three water masses. The average total density of larvae fish per 100 m^3 for each station was used for this analysis. These maps were produced using ArcGIS 9.2.

2.5.7 Recurrent Group Analysis

The Recurrent Group analysis was used to determine the affinity that the species have with each other, and thus describes larval fish assemblages (Fager 1959; Moser et al. 1987; Doyle et al. 1995). In other words, the recurrent group is used to calculate the relative frequency of occurrence for the fish larval species that frequently co-occur in samples (Fager 1959). Some larval fish regularly appear together and are part of each

other's environment, which may result in creating a defined larval assemblage (Fager 1959, Moser et al., 1987). In this study, the composition of the recurrent groups used the Recurrent Group Analysis by Fager (1957). The Recurrent Group Analysis calculates the affinity index using the presence/absence larval fish data set in a station (i.e. occurrences), does not use the abundance value (Kendall and Dunn 1985). The formula for the index was obtained from Doyle et al. (1995) and Kendall and Dunn (1985), as illustrated below (Affinity Index Formula).

The affinity index equation calculates the relative frequency of occurrence between two species using their sum of occurrences and includes a correction for sample size (Moser et al. 1987). The analysis involves two steps: the calculation of an affinity index for each pair of taxa that co-occur in the sample, and the formation of groups based on the affinity index value of a minimum of 0.4 or greater for all pairs that are considered to have significant occurrences (Moser et al. 1987). The critical affinity index value of 0.4 has been used by numerous researchers (e.g., Kendall and Dunn 1985; Doyle et al. 1995; Brodeur et al., 1995). Kendall and Dunn (1985), had indicated from their experience of analyzing a number of large data sets, the affinity index value of 0.4 was found to be sensitive enough to detect co-occurrences.

Individual species with an affinity of ≥ 0.4 (high affinity grading) were grouped together and consisted of members displaying the greatest affinity with each other (Doyle et al. 1995). These individual species may also have an association with other groups or other individual species (Doyle et al. 1995). The remaining taxon or individual species referred to as "affiliate," are those that are not part of a group but are related to an individual

within a group member with an affinity index of ≥0.4 (Moser et al., 1987). All data from July and August were used in the analysis, and all members displayed some form of affinity with each other.

Affinity Index Formula (taken from Doyle et al. (1995) and Kendall and Dunn (1985)):

Equation 8.

$$I = \frac{(N_j)}{(\sqrt{N_a N_b})} - \frac{1}{\sqrt[2]{N_b}}$$

where , I = the affinity index (range 0-1);

N_j = the number of joint occurrences;

N_a = the number of occurrences of taxon a, the less common taxon;

N_b= the number of occurrences of taxon b, the more common taxon

2.5.8 Cluster and SIMPER Analyses

The larval fish family structure and assemblages are often unique to the water masses or plume fronts (Grimes and Kingsford 1996, Doyle et al. 1993). If this is the case in the Beaufort Sea, one would expect that the stations in this study which were selected based on water mass would have unique larval fish assemblages. The agglomerative hierarchical cluster analysis was used to test out these relationships. The cluster analysis is a hierarchical classification that classifies the abundance similarity between stations. Therefore, it is used to test whether the water masses classification for each station

corresponds to the presence of unique larval fish assemblages. The grouping of stations based on Cluster analysis of larval fish was compared to the original grouping of stations based on oceanography characteristics. The larval fish density data was used for the Cluster analysis, and this density data was transformed by using a square root prior to performing the analysis, since transformation lessens the bias associated with less common species (Clarke and Warwick 2001).

In the cluster analysis, there are two steps in the analysis that are automatically performed by the Primer V.6 statistical software (Plymouth Marine Laboratory, UK). The Bray-Curtis similarity matrix and the weighted average-group were applied to perform the analysis, which helps to define rules for constructing a dendrogram as a visual representation for the cluster analysis (Clarke and Warwick 2001). The first part of the analysis involves creating the Bray-Curtis similarity matrix using the original data. The Bray-Curtis matrix is a common matrix used by ecologists to cluster sites into groups based on their similar observed communities (Clarke and Warwick 2001). The second part of the analysis is used to determine if the distance between the two clusters is similar enough to be linked. This study used the weighted average-group linkage to define the distance between groups based on an average fusing strategy (Clarke and Warwick 2001). Therefore, hierarchical groups were formed as a result of their similarities, and the groups themselves were further divided into clusters (Clarke and Warwick 2001).

The SIMPER analysis was performed to provide an exploratory evaluation to the groupings that resulted from the Cluster analysis. The SIMPER analysis calculated the percentage of each species that contributed to the observed similarities in the classified

groupings (Clarke and Warwick 2001). The species with the highest percentages of contribution within each group (based on ranking) was the indicator species for each grouping. The SIMPER procedure utilizes the Bray-Curtis similarity matrix.

The larval fish density data was used for the Cluster and SIMPER analyses, and this density data was transformed by using a square root prior to performing the analyses, since transformation lessens the bias associated with less common species (Clarke and Warwick 2001).

2.5.9 Standard Length and Weight Analysis

The standard length was statistically analyzed to compare the growth in each of the three water masses by using the Kruskal-Wallis test which is a non-parameteric rank test for *Boreogadus saida.* This test was used to compare more than two independent samples; thus, it was applied to the July samples for *B. saida*. Since the August samples were taken, *B. saida* appeared only once in the intense water mass sample; therefore, the Mann-Whitney test was chosen to compare the diffuse plume and the oceanic water masses.

Furthermore, the biomass of the total larval fish population of the three water masses was analyzed using the Krsukal-Wallis test.

2.5.10 Relationship between Zooplankton and Larval Fish

The relationship between the zooplankton biomass and the total fish larvae biomass was analyzed using the Pearson Product Moment Correlation.

CHAPTER 3: RESULTS

3.1 GENERAL OCEANOGRAPHY OF WATER MASSES

There were three general water masses distinguished during the current study: oceanic, diffuse plume, and intense plume. The oceanic water mass had a lower temperature and a higher salinity than the diffuse and intense plume water masses (Table 4). The diffuse plume water mass was warmer than the oceanic mass, and it had a higher average salinity than the intense plume water mass (Table 4). The oceanic water mass temperature was consistently stratified (Figure 8, Figure 10, Figure 12, Figure 14 and Figure 16). The water temperature was not consistently stratified at the diffuse plume water mass stations (Figure 8, Figure 10, Figure 12, Figure 14 and Figure 16). The water temperature profile was stratified for the diffuse plume stations PL2, PL5, PL8 and PL11, while station PL14 showed slight stratification. The water temperature for the intense plume stations exhibited some degree of stratification in temperature; station PL9 exhibited significant stratification from 0 to 10 ºC (Figure 12), and station PL3, in the intense plume, exhibited no stratification.

Overall, there was limited stratification in salinity for the oceanic water masses (Figure 8, Figure 10, Figure 12, Figure 14 and Figure 16). The degree of salinity stratification varied among the diffuse plume water mass stations. Oceanic station PL8 exhibited the strongest stratification, with salinity varying from 15 PSU at the surface to 32 PSU at the bottom. Diffuse plume stations PL2, PL5, and PL11 had surface salinity similar to that observed in the oceanic water mass. All intense plume stations showed some degree of salinity stratification and the presence of fresher water at the top of the surface (i.e., PL6,

PL9, PL12 and PL15); only PL3 did not have salinity stratification. Overall, the intense plume station PL3 had lower salinity than the oceanic and diffuse water masses from the same transect (Figure 1).

The oceanic water mass was observed at the offshore stations (e.g., PL1, PL4, PL7, PL10, and PL15) with salinity levels >31 PSU (range 31.12 to 31.65 PSU) and with temperatures <2 ºC (range 0.37 °C to 1.51 °C) (Figure 8, Figure 10, Figure 12, Figure 14 and Figure 16).

The proportion of freshwater in the water column decreased as the depth increased further offshore; thus, the diffuse plume formed the outer boundary of the intense plume where the intensity of the river plume was greatly reduced (i.e., PL2, PL5, PL7, PL11 and PL14) (Figure 8, Figure 10, Figure 12, Figure 14 and Figure 16). Overall, examination of the whole water column revealed that the diffuse plumes exhibited average salinity values ranging from 27.36 PSU to 31.02 PSU, with a temperature range from 1.16 to 6.12 °C (Figure 8, Figure 10, Figure 12, Figure 14 and Figure 16). However, the surface salinity within the 5 m depth was approximately 27 PSU, and the base of the halocline ended around 10 m, where it transitioned into the more saline water (Figure 8, Figure 10, Figure 12, Figure 14 and Figure 16).

The intense plume stations (i.e., PL3, PL6, PL9, PL12, and PL15) exhibited the lowest salinity values, ranging from 14.56 to 27.49 PSU. However, station PL9 had a higher salinity value, since it was located furthest offshore within the 20 to 30 m water depth. Other intense plume stations were located in less than 10 meters of water. Water

temperature ranged from 3.11 °C to 9.63 °C (Figure 8, Figure 10, Figure 12, Figure 14 and Figure 16) for the intense plume water mass.

3.1.1 Temperature and Salinity Comparison during July and August

There was an overall increase of the average temperature from July to August (Table 4). There were no noteworthy changes in the average salinity values in either the oceanic or the diffuse plume water masses. Between July and August, the salinity declined greatly in the intense plume water mass from an average salinity of 26.59 down to a salinity of 20.98 PSU (Table 4).

Table 4. Overall average temperature (°C) (±SD) and salinity (PSU) (±SD) for both the July and August stations.

		Oceanic	Diffuse Plume	Intense Plume
July	**Avg. Temperature (°C)**	0.70 (±3.20)	1.69 (±3.59)	4.58 (±4.20)
	Temperature Ranges (°C)	-1.59 to 8.94	-1.58 to 10.52	-0.96 to 10.60
	Avg. Salinity (PSU)	31.30 (±1.99)	30.39 (±3.35)	26.59 (±5.25)
	Salinity Ranges (PSU)	23.40 to 32.56	15.75 to 32.50	13.38 to 32.26
August	**Avg. Temperature (°C)**	1.44 (±3.36)	4.38 (±2.82)	7.23 (±3.35)
	Temperature Ranges (°C)	-1.33 to 8.35	-0.25 to 8.95	3.01 to 12.55
	Avg. Salinity (PSU)	31.38 (±1.44)	29.60 (±2.92)	20.98 (±9.31)
	Salinity Ranges (PSU)	28.21 to 32.37	20.90 to 32.17	3.52 to 30.79

3.1.2 Overall Turbidity

The overall turbidity reflected the characteristics of the plume and helped to further explain the classification of the designated stations. The observed turbidity had steadily

decreased as the freshwater mass dispersed, with the highest turbidity revealed at the inshore stations (Figure 9, Figure 11, Figure 13, Figure 15 and Figure 17). On average, the intense plume stations were observed to have the highest turbidity, with values ranging from 14.33 to 51.17 FTU (Table 5). Based on turbidity, the suspended sediments in the water column were distributed relatively uniformly (Figure 9, Figure 11, Figure 13, Figure 15 and Figure 17). There was a high degree of variability in the average turbidity across the transects in the intense plume water mass. The diffuse plume stations, on the other hand, were significantly less turbid than the intense plume stations, with the average turbidity ranging from 5.61 to 19.95 FTU. This average turbidity here was less variable than the intense plume. At the diffuse plume stations, the suspended sediment distribution in the water aggregated from a depth of 9 meters to the bottom. The one exception was station PL8, where the surface water had a higher turbidity. Of the three water masses, the ocean water stations exhibited the lowest turbidity with average values ranging from 4.44 to 4.88 FTU. There was little turbidity variability in the ocean water mass across the five transects (Table 5).

Table 5. Average turbidity values for all three water masses and the five transects for both the July and August samples.

Water mass category	**Average Turbidity (FTU)**				
	Transect 1	**Transect 2**	**Transect 3**	**Transect 4**	**Transect 5**
Oceanic	PL1= 4.88	PL4= 4.47	PL7= 4.64	PL10= 4.44	PL13= 4.84
Diffuse Plume	PL2= 13.79	PL5=19.95	PL8= 5.61	PL11= 6.60	PL14= 13.07
Intense Plume	PL3= 35.21	PL6= 17.55	PL9= 14.33	PL12= 15.87	PL15= 51.17

3.1.3 Fluorescence

The fluorescence values for July and August varied across transects. Fluorescence for the oceanic stations was uniform from top to the bottom, ranging from 0.12 to 0.38 (Figure 9, Figure 11, Figure 13, Figure 15 and Figure 17). Fluorescence in the diffuse plume water mass varied over depth for four transects (Figure 9, Figure 11, Figure 13, Figure 15 and Figure 17). Stations PL2, PLl5, PL8, and PL11 in the diffuse plume water mass had higher fluorescence at the bottom. Overall fluorescence for the diffuse water mass was higher than that observed in the oceanic water mass.

In the intense water mass, the fluorescence was higher than it was in the oceanic water mass. Fluorescence in the intense plume stations PL6 and PL9 varied from the surface to the bottom, with higher values occurring at the bottom. Intense plume stations (PL3, PL12, and PL15) exhibited little stratification of fluorescence from surface to bottom.

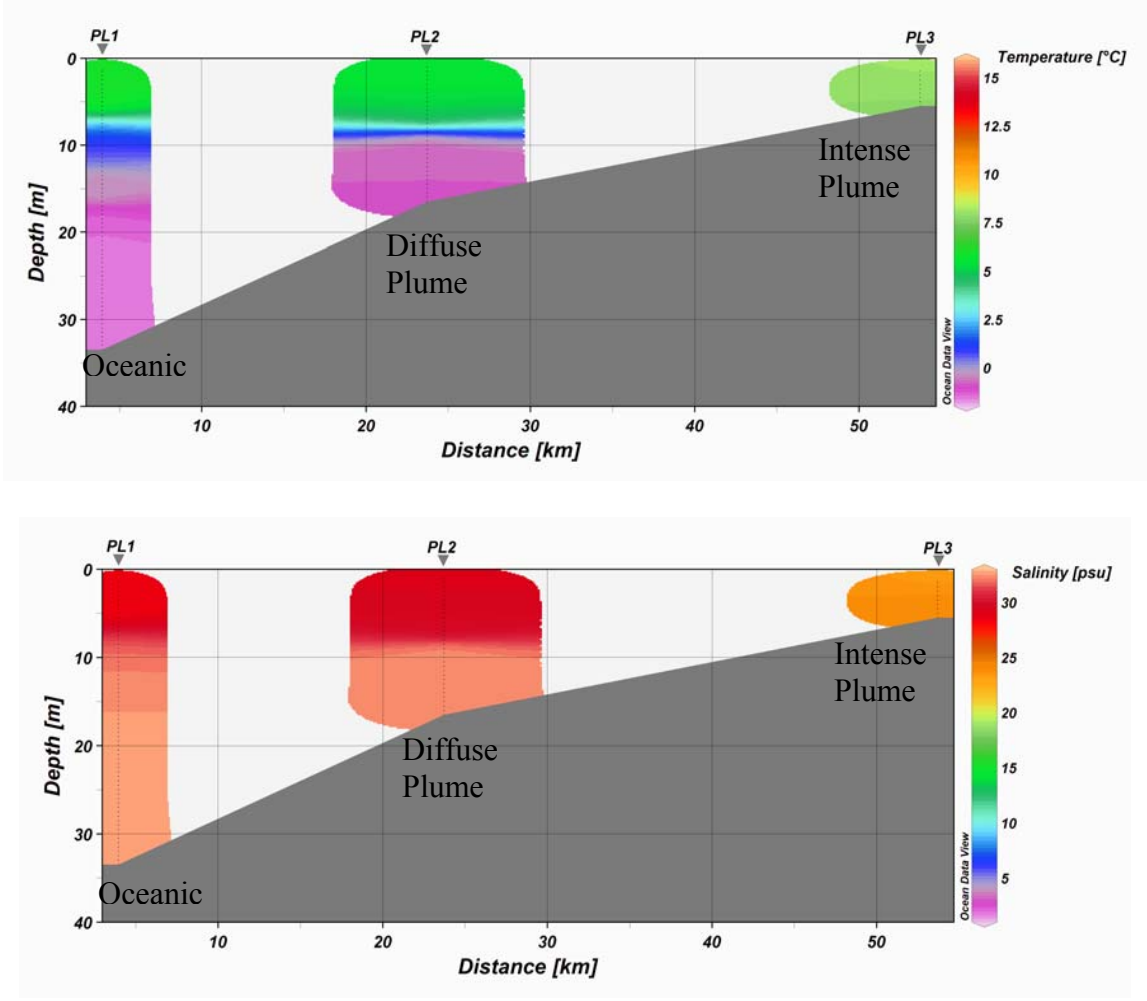


Figure 8. Cross-sectional profiles of temperature and salinity along Transect 1 from stations PL1 to PL3 in July 2007.

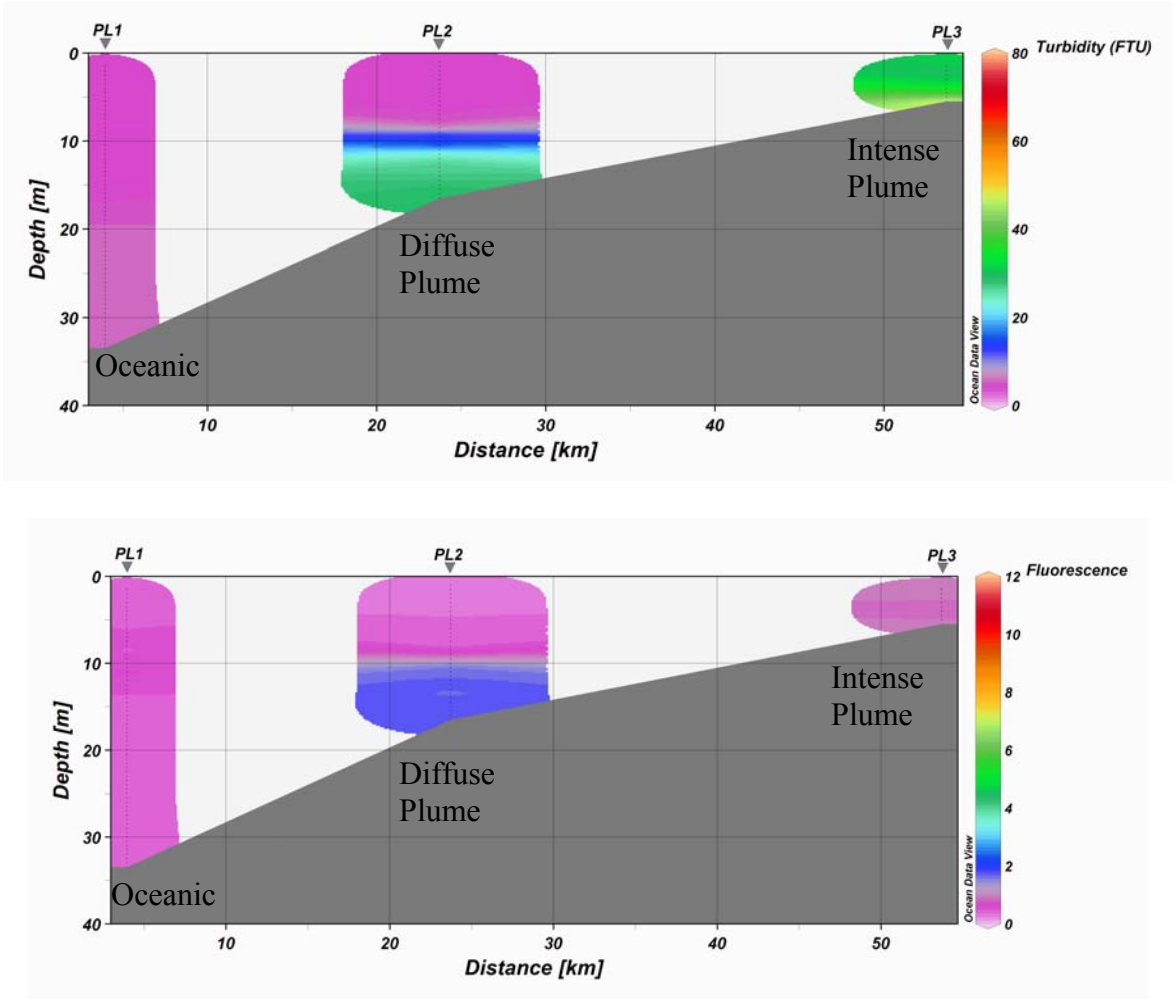


Figure 9. Cross-sectional profiles of turbidity and fluorescence along Transect 1 from stations PL1 to PL3 in July 2007.

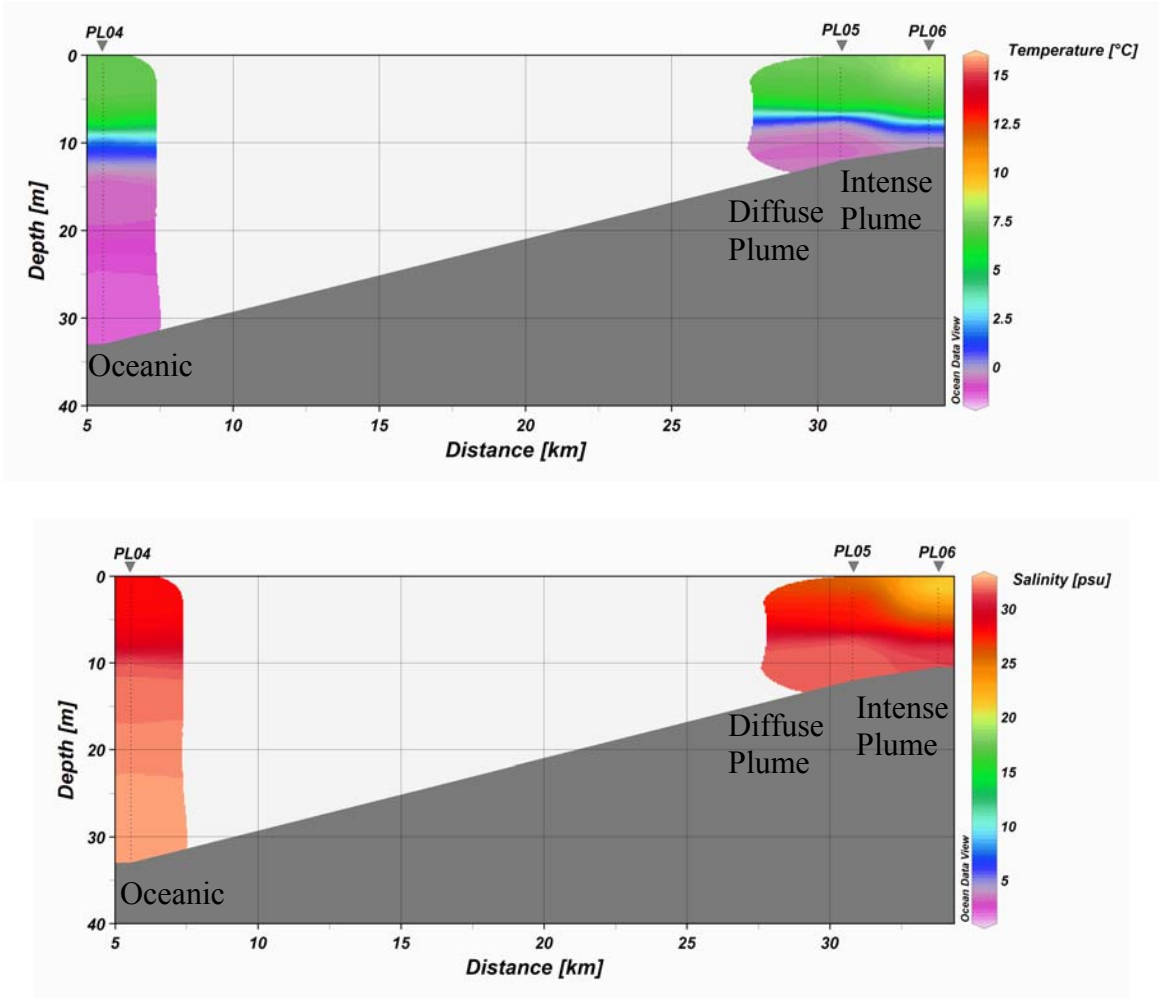


Figure 10. Cross-sectional profiles of temperature and salinity along Transect 2 from stations PL4 to PL6 in July 2007.

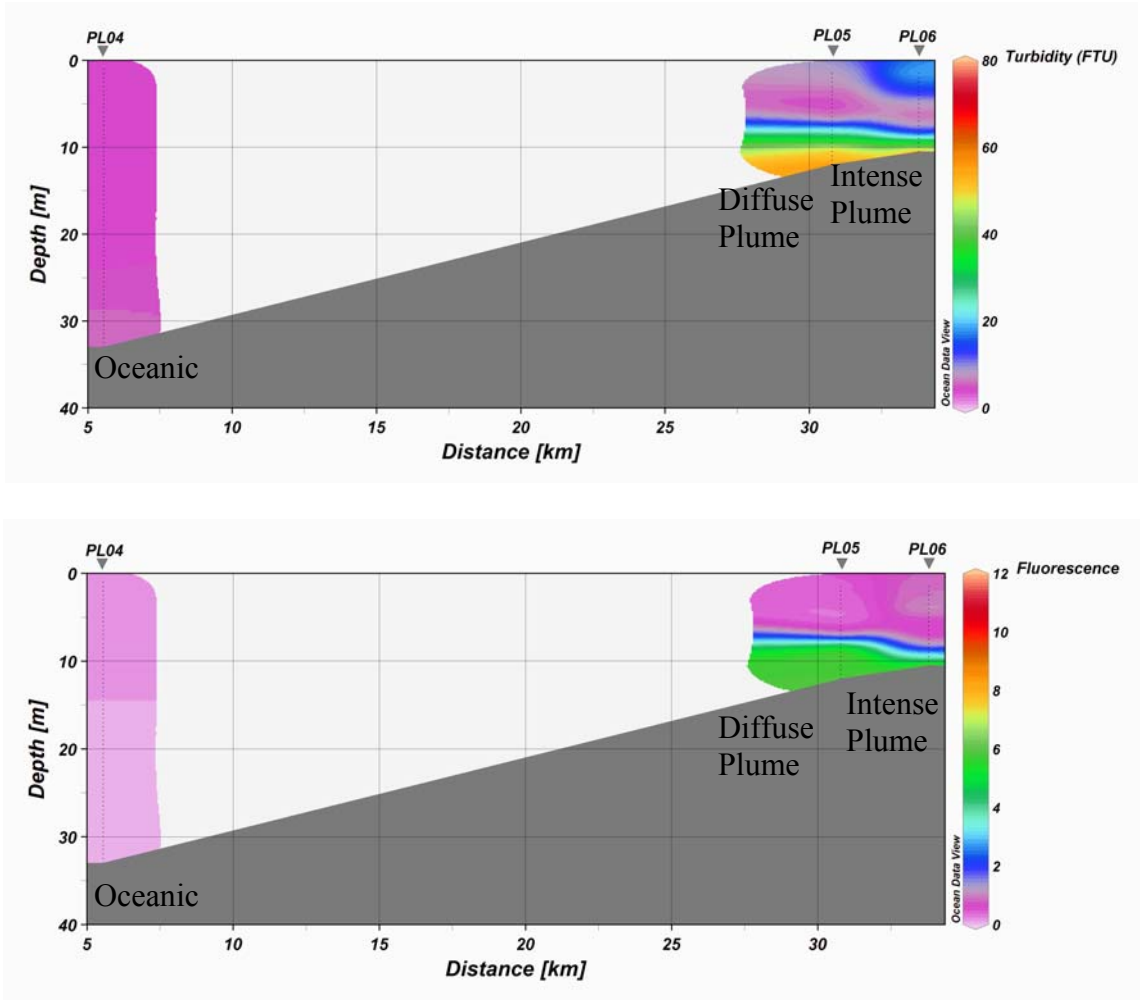


Figure 11. Cross-sectional profiles of turbidity and fluorescence along Transect 2 from stations PL4 to PL6 in July 2007.

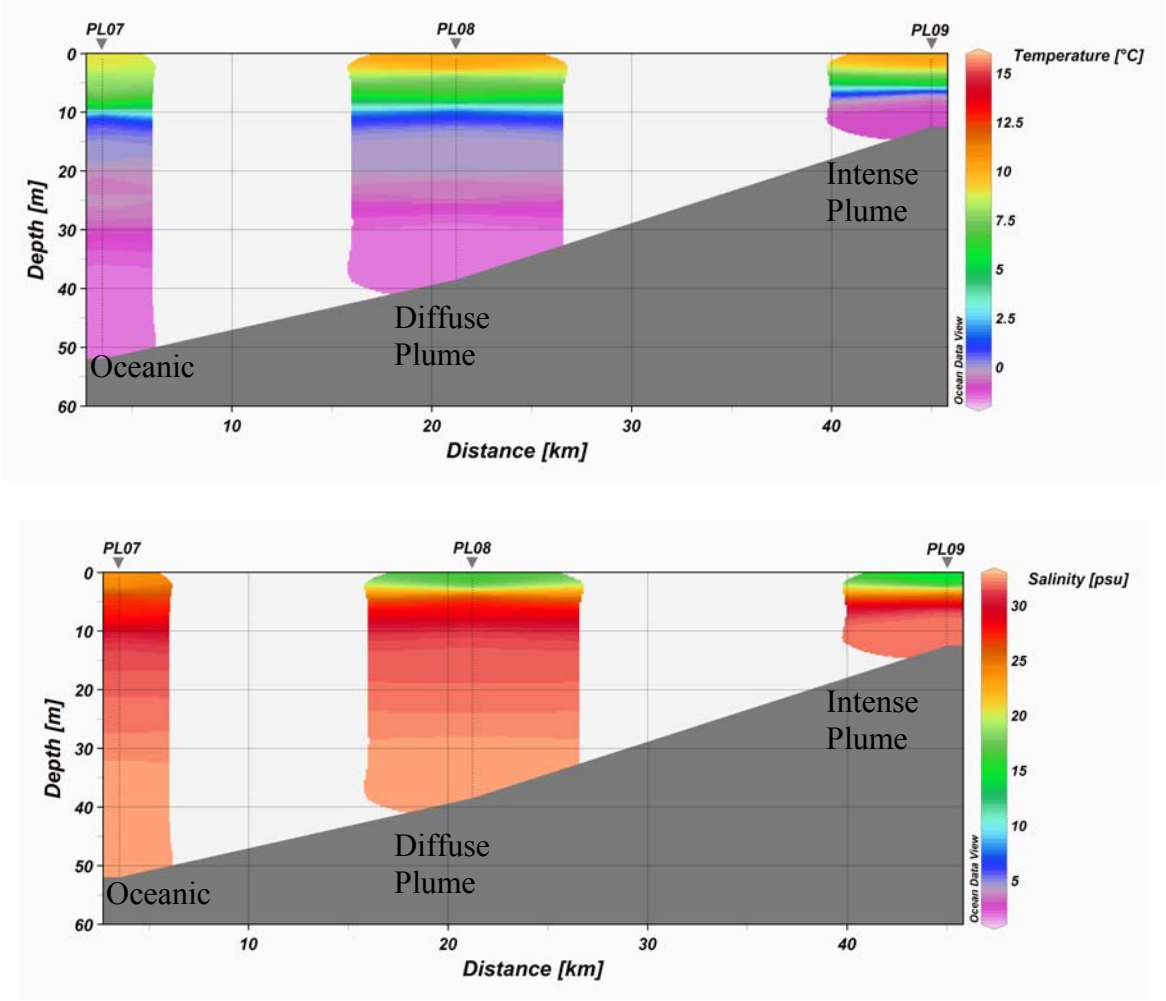


Figure 12. Cross-sectional profiles of temperature and salinity along Transect 3 from stations PL7 to PL9 in July 2007.

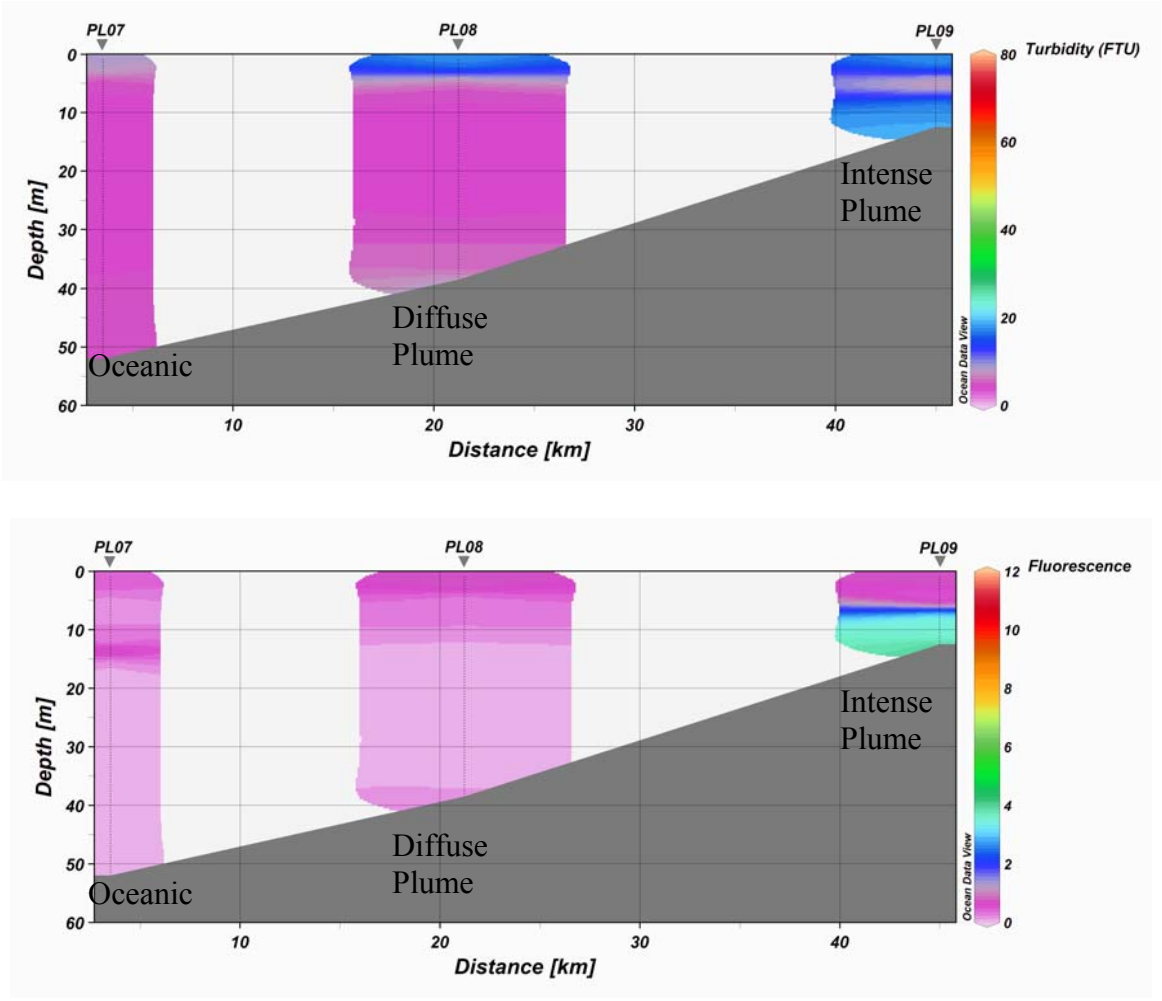


Figure 13. Cross-sectional profiles of turbidity and fluorescence along Transect 3 from stations PL7 to PL9 in July 2007.

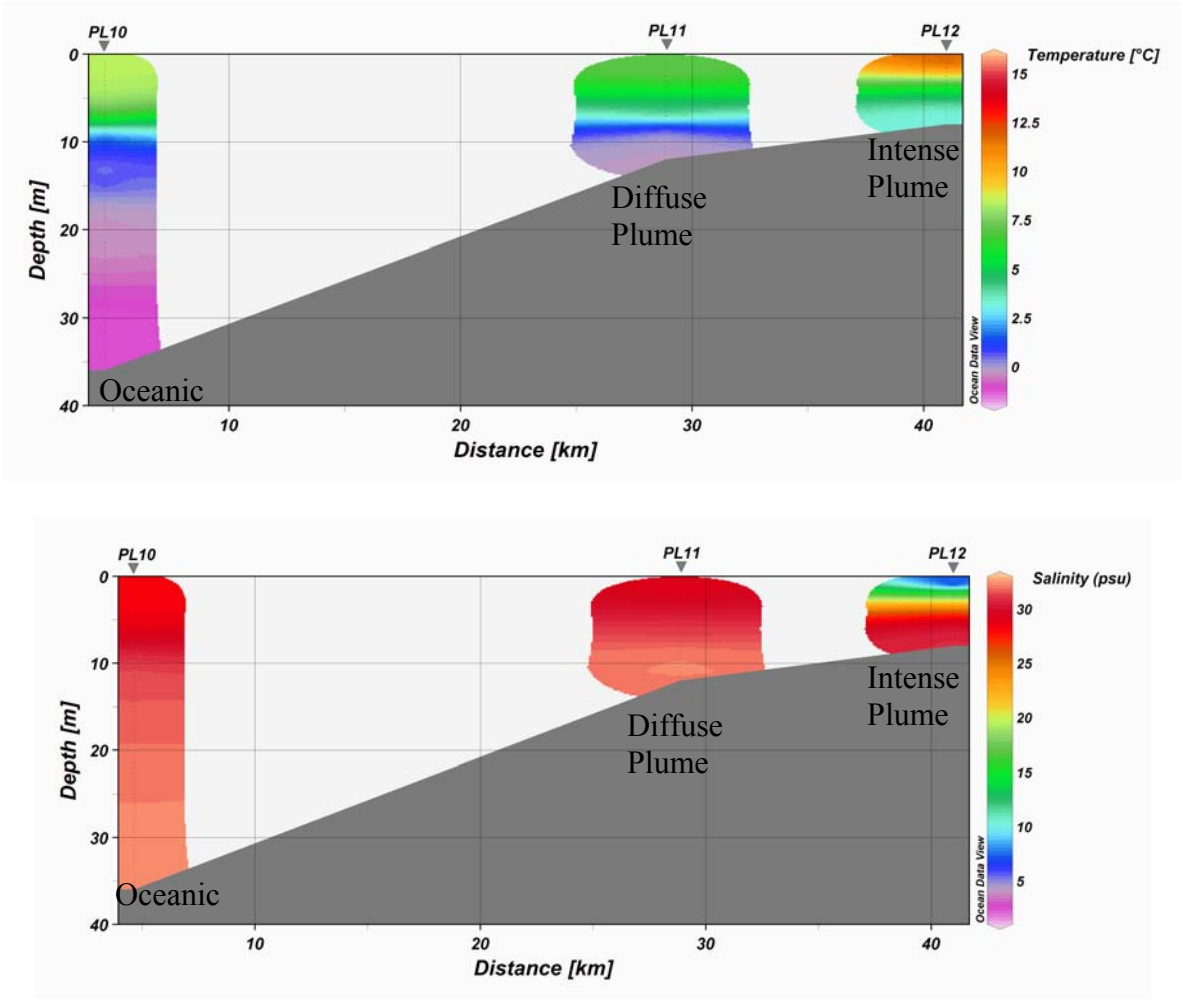


Figure 14. Cross-sectional profiles of temperature and salinity along Transect 4 from stations PL10 to PL12 in August 2007.

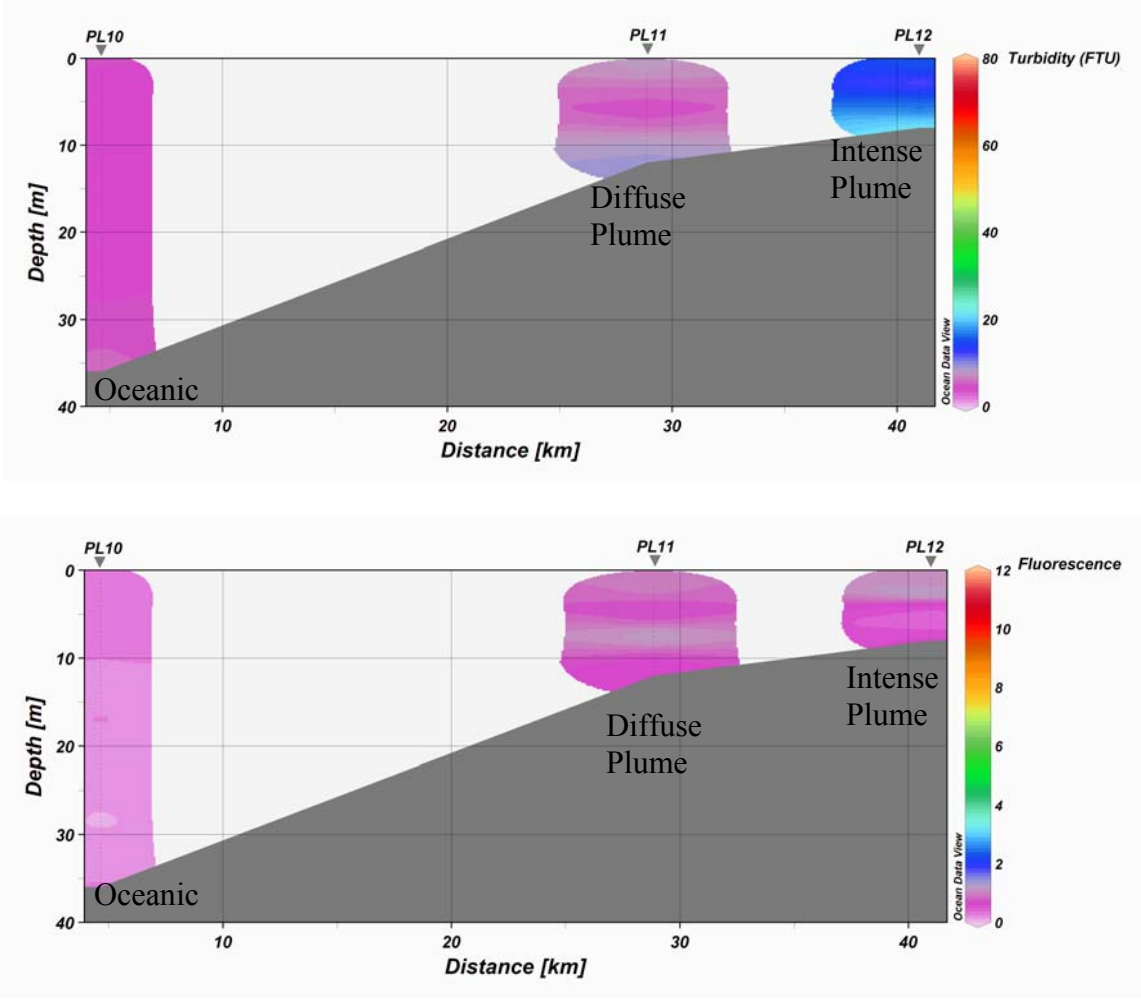


Figure 15. Cross-sectional profiles of turbidity and fluorescence along Transect 4 from stations PL10 to PL12 in August 2007.

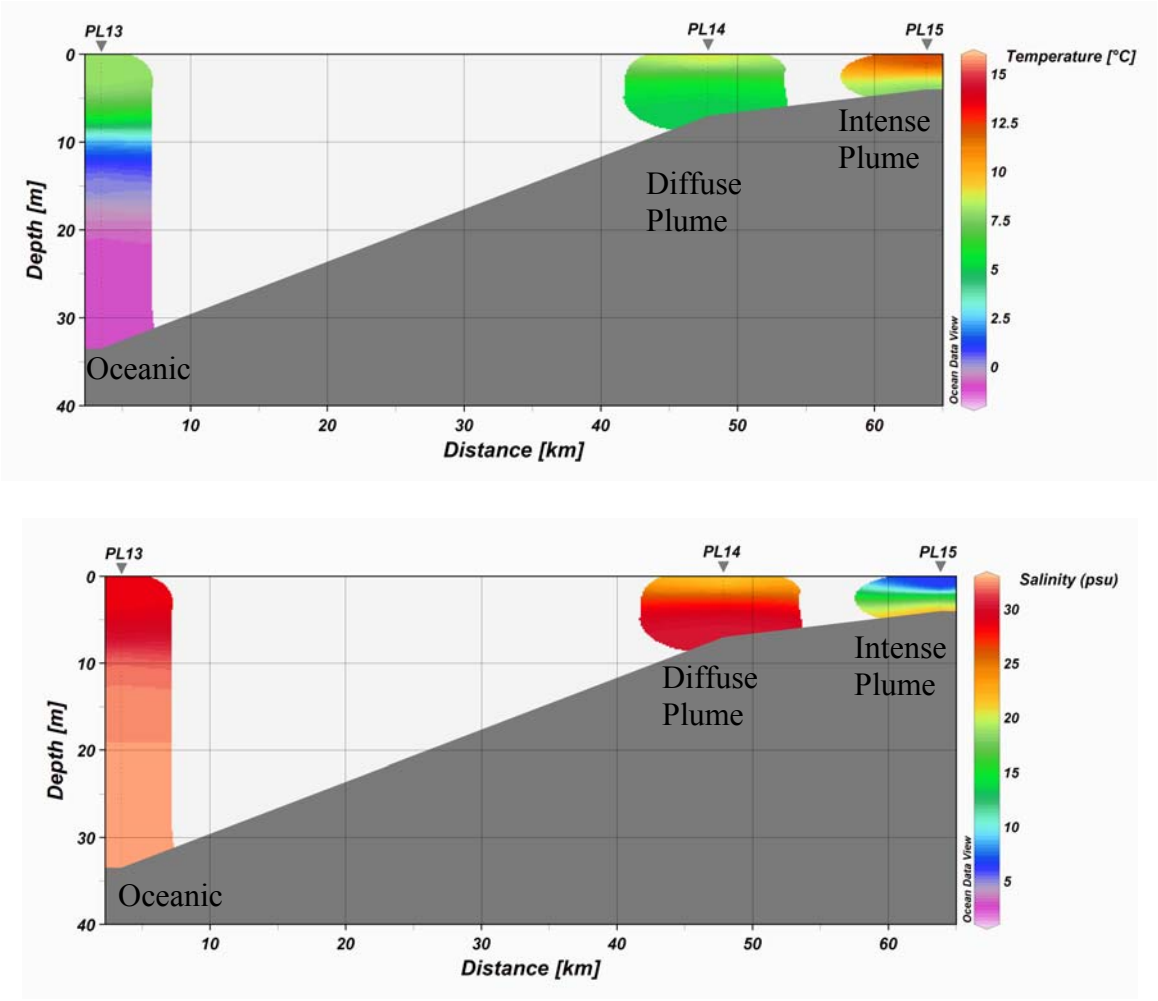


Figure 16. Cross-sectional profiles of temperature and salinity along Transect 5 from stations PL13 to PL15 in August 2007.

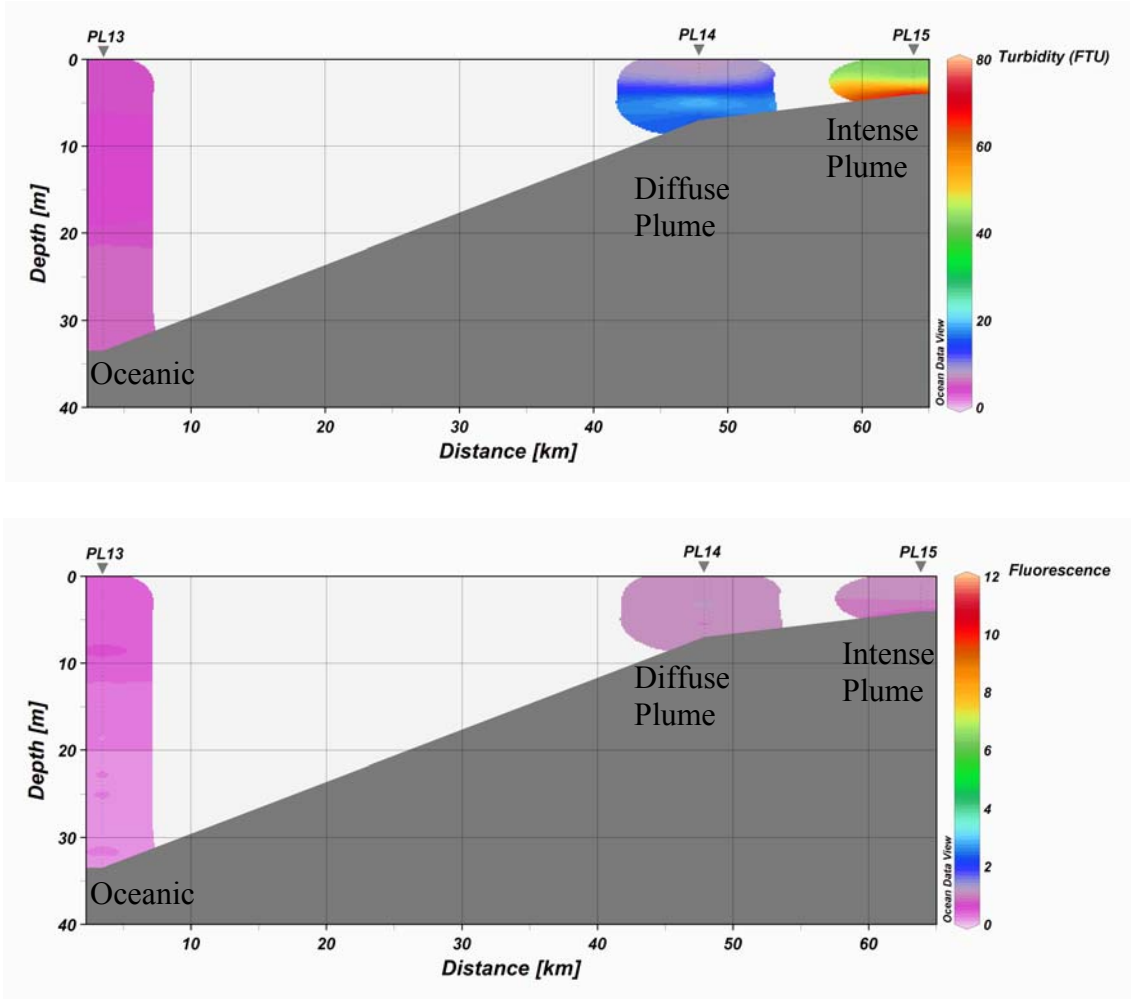


Figure 17. Cross-sectional profiles of turbidity and fluorescence along Transect 5 from stations PL13 to PL15 in August 2007.

3.2 LARVAL FISH COMMUNITIES

3.2.1 Taxonomic Composition and Total Larval Fish Density Related to Water Masses

In total, 915 larval fish were caught using bongo nets with both oblique and target tows. Out of that total, 585 larval fish were caught with 33 oblique tows; these larval fish were used in this study. The total catch contained representatives of twelve taxa from six families: *Clupea pallasii pallasii*, *Boreogadus saida*, *Eleginus gracilis*, Lumpeninae (sub-family of Stichaeidae), *Gymnocanthus tricuspis*, *Triglops nybelini*, *Icelus* sp., Liparis *sp.*, *Liparis tunicatus*, *Liparis fabricii*, *Liparis gibbus* and *Ulcina olrikii*. The list of taxa and their common names is shown in Table 7.

The results of the Wilcoxon Signed Rank Test suggested that there was no significant difference between two samples from the same tow at a particular station (T= 30, Z= 1.083228, p= 0.278708). Therefore, samples from the same tow were pooled in this study.

The total densities of larval fish for the three water masses are close in value (

Figure **18**). The intense plume stations had the highest total larval density of 18.22 larvae per 100 m^3 (±1.06), and the diffuse plume density was the second highest, with only a slightly lower value of 17.66 larvae per 100 m^3 (±0.82). Lastly, the oceanic water revealed an average of 15.00 larvae per 100 m^3 (±0.60). Although the intense plume had the highest total density, its standard deviation revealed that it had the greatest variation in density within its water mass stations.

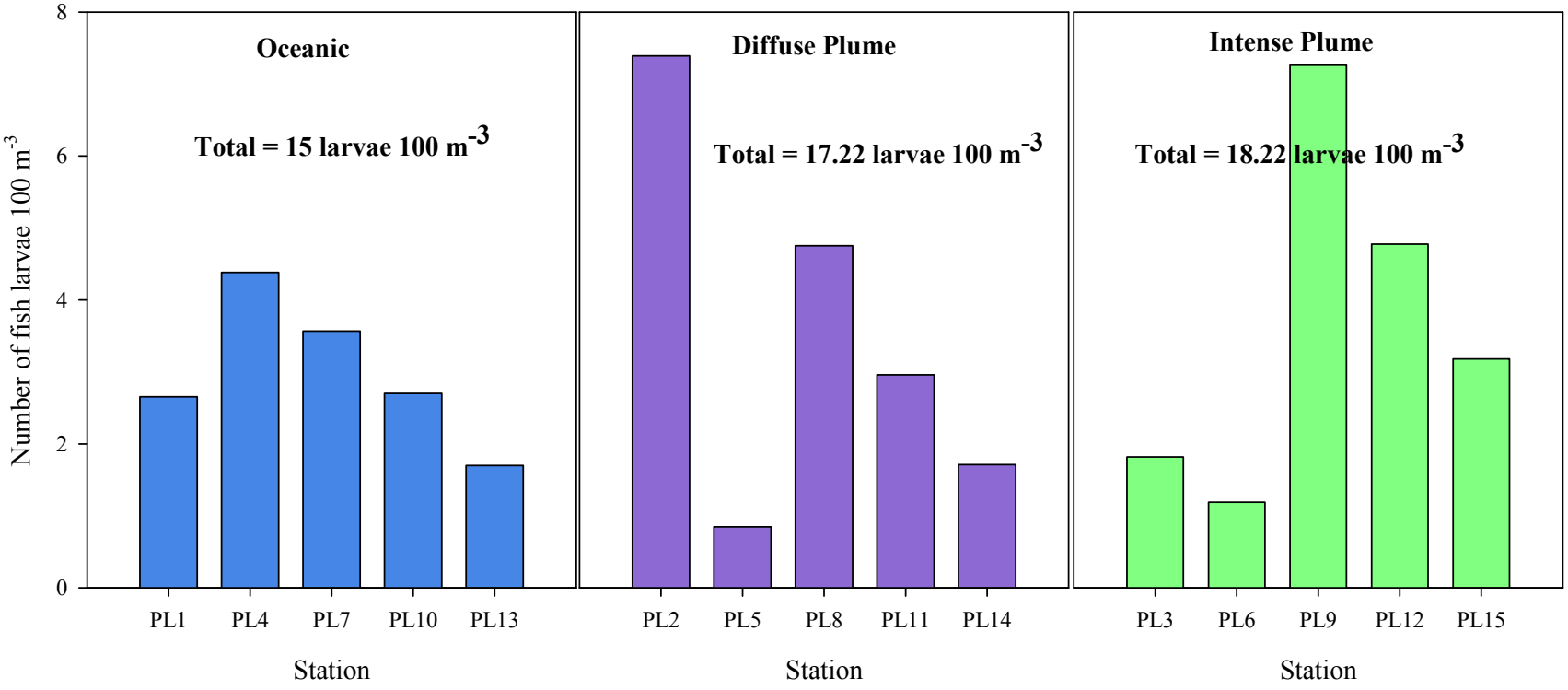


Figure 18. Total number of larval fish (larvae 100 m^{-3}) grouped by water mass properties for samples collected in July and August 2007.

3.2.2 Diversity of Larval Fish Assemblages

Overall, the diffuse plume water mass stations had the highest diversity number (N_1) of 5.29 (Table 6). The N_1 values of the oceanic water and intense plume water masses were 3.57 and 2.57, respectively. This diversity separation was also evident in July and August (Table 6).

Table 6. Shannon Index value H and the effective species richness N_1 for July and August across the three water masses.

		Oceanic	Diffuse	Intense
July	H	1.07	1.53	0.80
	$N_1=e^{\wedge H(\alpha)}$	2.92	4.63	2.23
August	H	1.04	1.32	0.73
	$N_1=e^{\wedge H(\alpha)}$	2.84	3.74	2.07

3.2.3 Spatial Distribution of the Larval Fish Density

The fish density varied across transects from July and August (Figure 19 and Figure 20, respectively). In July, Transect 3 had the highest total larval density, 15.58 larvae per 100 m^3, followed by transect 1 with 11.86 larval per 100 m^3, and then transect 2, with the lowest total density of 6.42 larval per 100 m^3. In comparison, the two August transects 4 and 5 had a total density of larval fish per 100 m^3 of 10.44 and 6.57, respectively.

The intense plume station PL9 in Transect 3 and the diffuse station PL2 in Transect 1 had the highest larval density in July (Figure 19).

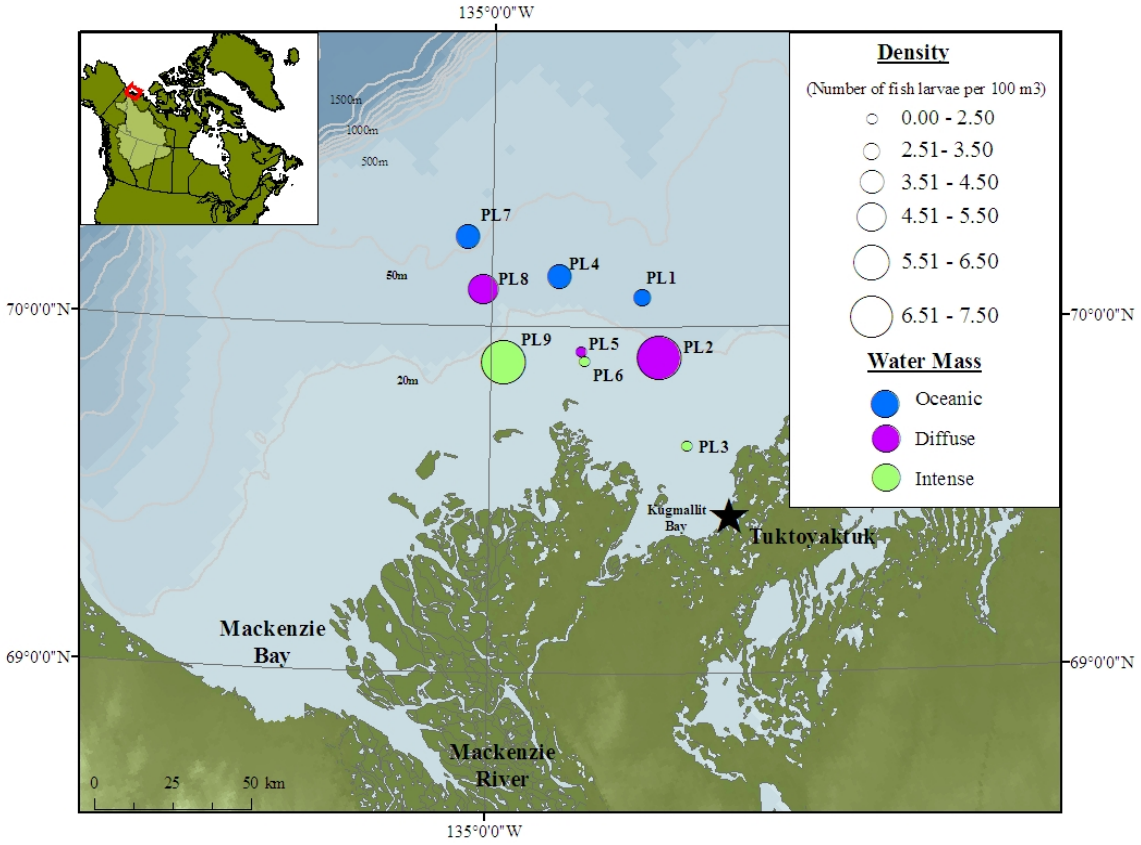


Figure 19. Spatial distribution of all fish larvae (larvae 100 m^{-3}) at each station across the Canadian Beaufort Sea, resulting from total density data obtained on the July 2007 cruise (made up of transects 1, 2 and 3). Density value range is indicated by the size of the circle where fish larvae were caught. Water masses are indicated by distinct colors. Basemap from Fisheries & Oceans Canada.

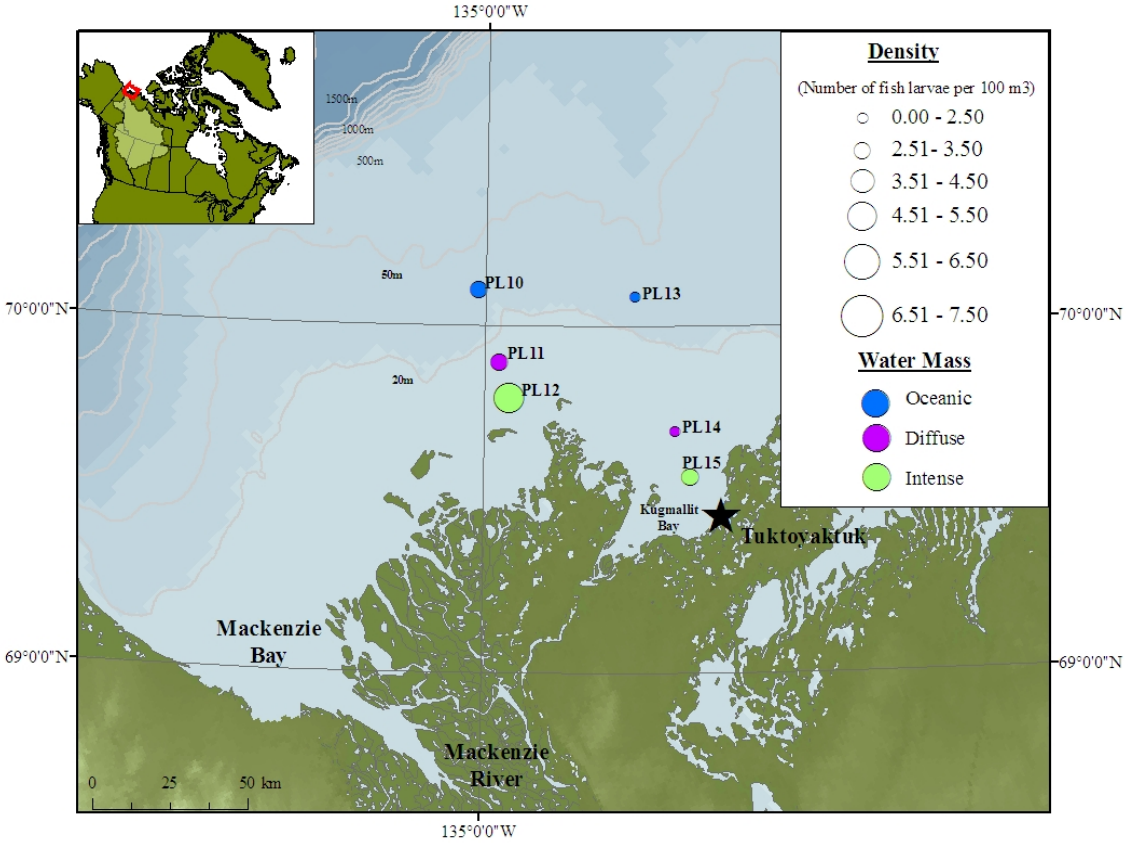


Figure 20. Spatial distribution of all fish larvae (larvae 100 m^{-3}) at each station across the Canadian Beaufort Sea, resulting from total density data obtained on the August 2007 cruise (made up of transects 1, 2 and 3). Density value range is indicated by the size of the circle where fish larvae were caught. Water masses are indicated by distinct colors. Basemap from Fisheries & Oceans Canada.

3.2.4 Larval Fish Species Occurrence; Relative Abundance and Density on Transects

Overall, the total number of larval fish caught for July was higher than the August samples, with n= 342 and n= 243, respectively. Lumpeninae (i.e., subfamily of Stichaeidae) and *B. saida* (Arctic cod) were the two most abundant taxa, which made up 40 % and 30 %, respectively, of the total number of fish caught for both months (Table 7). However, in contrast to their relative abundance, *B. saida* appeared more frequently in the samples, as they occurred 87 % of the time compared to Lumpeninae, which occurred only 67 % of the time (Table 7).

The highest density of Lumpeninae was recorded at the intense plume station PL9 (Figure 23), while only a small number of Lumpeninae were found in the two oceanic stations, PL1 (Figure 21) and PL10 (Figure 24). In August, transect 5 was the only transect where no Lumpeninae were captured (Figure 25). The abundance of *C. pallasii pallasii* (Pacific herring) increased as the summer progressed (Figure 24 and Figure 25). *C. pallasii pallasii* had the highest density in the August samples; they were found strictly in the vicinity of the diffuse and intense plume stations, with the intense plume having the highest concentration (i.e., PL12 and PL15).

Boreogadus saida larvae, the second most abundant taxon, were captured at all stations in July. The highest concentrations of this species were observed in the vicinity of the oceanic and diffuse plume water masses (Figure 21, Figure 22 and Figure 23). However, the relative abundance of *B. saida* declined as sampling moved from the oceanic water mass toward the intense plume water mass (Figure 21, Figure 22 and Figure 23). The relative abundance of *B. saida,* which was 67 % in the oceanic water mass, declined to

7 % in the intense plume. This pattern was not observed for transect 3, where the diffuse plume station PL8 had higher numbers of this fish than the oceanic PL7 station (3.58 vs. 2.16 fish larvae per 100 m^3, respectively). Comparing the July and August stations, the *B. saida* densities decreased sharply as the summer progressed and were mainly restricted to the oceanic water mass stations (i.e., PL10 and PL13). Only a small number of *B. saida* larvae were found in the diffuse plume (i.e., PL11) and the intense plume (i.e., PL12), with 0.17 and 0.06 larvae per 100 m^3, respectively.

Another species of cod, *E. gracilis* (Saffron cod), was also found; however, only a few of them were captured at the intense (i.e., PL6) and diffuse plume stations (i.e., PL5 and PL14).

Over the entire sampling period, most marine fish were found in the oceanic and diffuse plume stations rather than in the intense plume stations, and fish numbers were highly variable. Marine fish species other than *B. saida* occurred in low numbers and included: *G. tricuspis, T. nybelini, Icelus* sp.*, Liparis* sp.*, L. tunicatus, L. fabricii, L. gibbus and U. olrikii* (Table 7). The number of marine species collected in July was greater than the number collected in the August samples.

Table 7. Summary of fish larvae collected during the study. Information includes the scientific and common names after Fahay (2007), the total number of fish collected, relative abundance (%) and percent of occurrence (%).

Scientific Name	Common Name	Taxonomic code	Total Number Caught	Percent of occurrence %	Relative Abundance %
Family Gadidae					
*Boreogadus saida (Lepechin 1774)**	Arctic cod	AC	197	80.00	33.68
*Eleginus gracilis (Tilesius 1810)**	Saffron cod	SC	20	33.33	3.42
Family Stichaeidae					
Lumpeninae (sub-family)	Unidentified pricklebacks	LE	209	60.00	35.73
Family Clupeidae					
*Clupea pallasii pallasii (Valenciencess 1847)***	Pacific herring	PH	79	46.67	13.50
Family Cottidae					
Gymnocanthus tricuspis (Reinhardt 1832)	Arctic staghorn sculpin	GT	10	40.00	1.71
Icelus sp.	Unidentified sculpins	IS	6	33.33	1.03
Triglops nybelini (Jensen 1944)	Bigeye sculpin	TN	2	6.67	0.34
Family Liparidae					
Liparis tunicatus (Reinhardt, 1837)	Kelp snailfish	LT	23	40.00	3.93
Liparis fabricii (Krøyer, 1847)	Gelatinous snailfish	LF	10	26.67	1.71
Liparis gibbus (Bean, 1847)	Dusky snailfish	LG	16	26.67	2.74
Liparis sp.	Unidentified snailfish	LS	1	6.67	0.17
Family Agonidae					
Ulcina olrikii (Lütken 1876)	Arctic alligatorfish	AA	12	33.33	2.05

*Name after Matarese et al. 1989
**Name after Fish Base http://www.fishbase.org/search.php

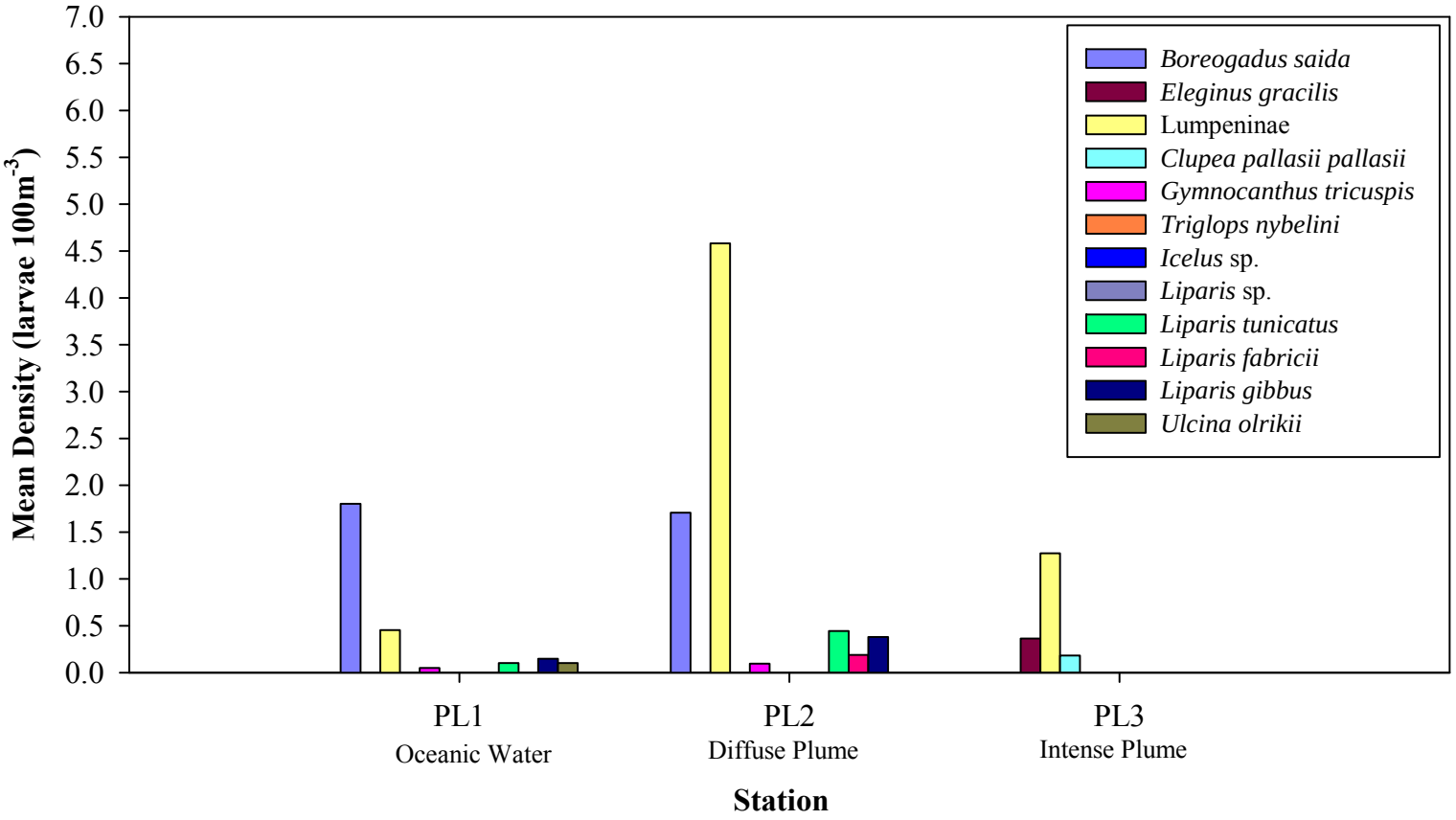


Figure 21. Taxonomic composition of larval fish catches for each station along Transect 1, July 2007.

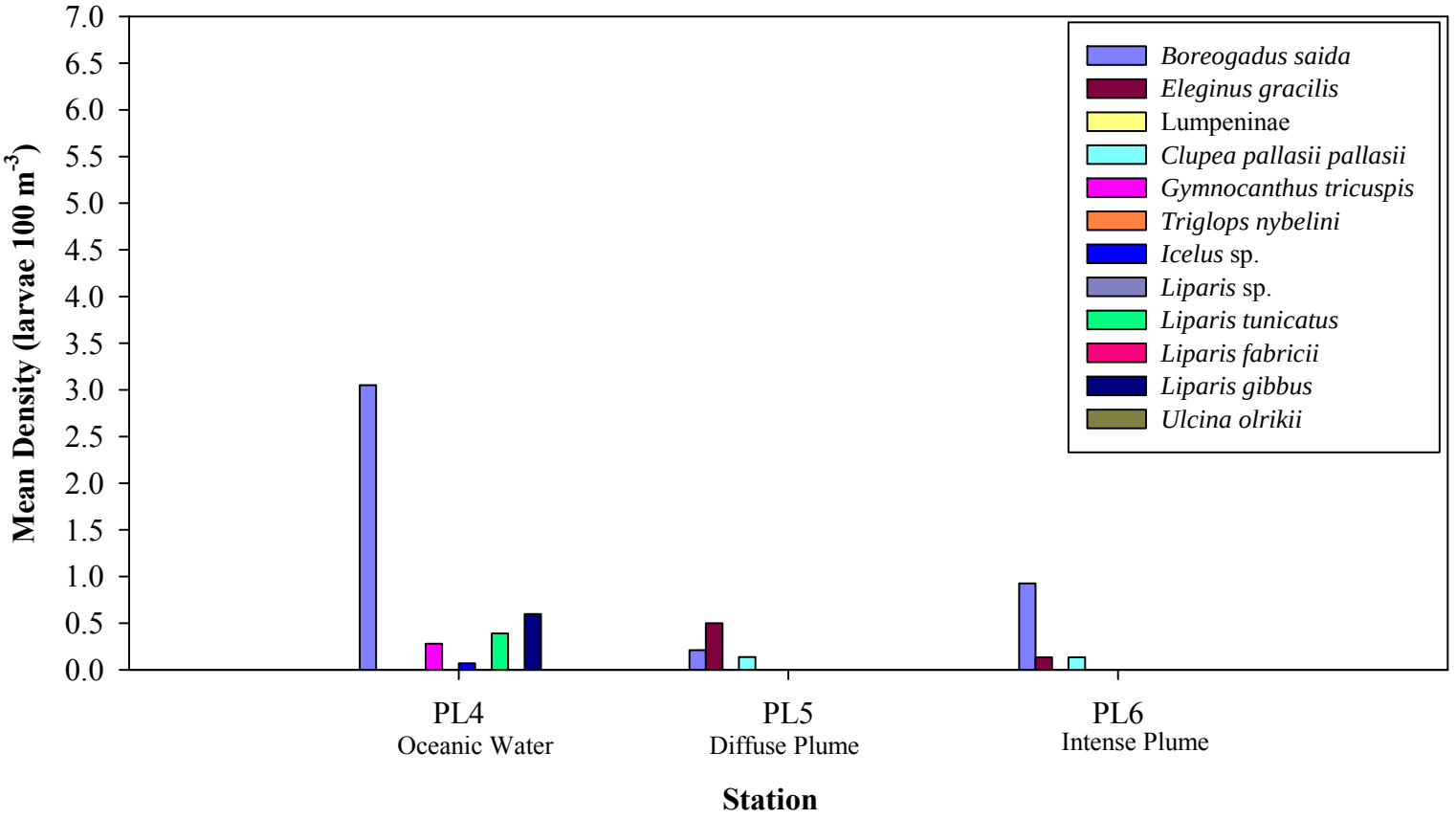


Figure 22. Taxonomic composition of larval fish catches for each station along transect 2, July 2007.

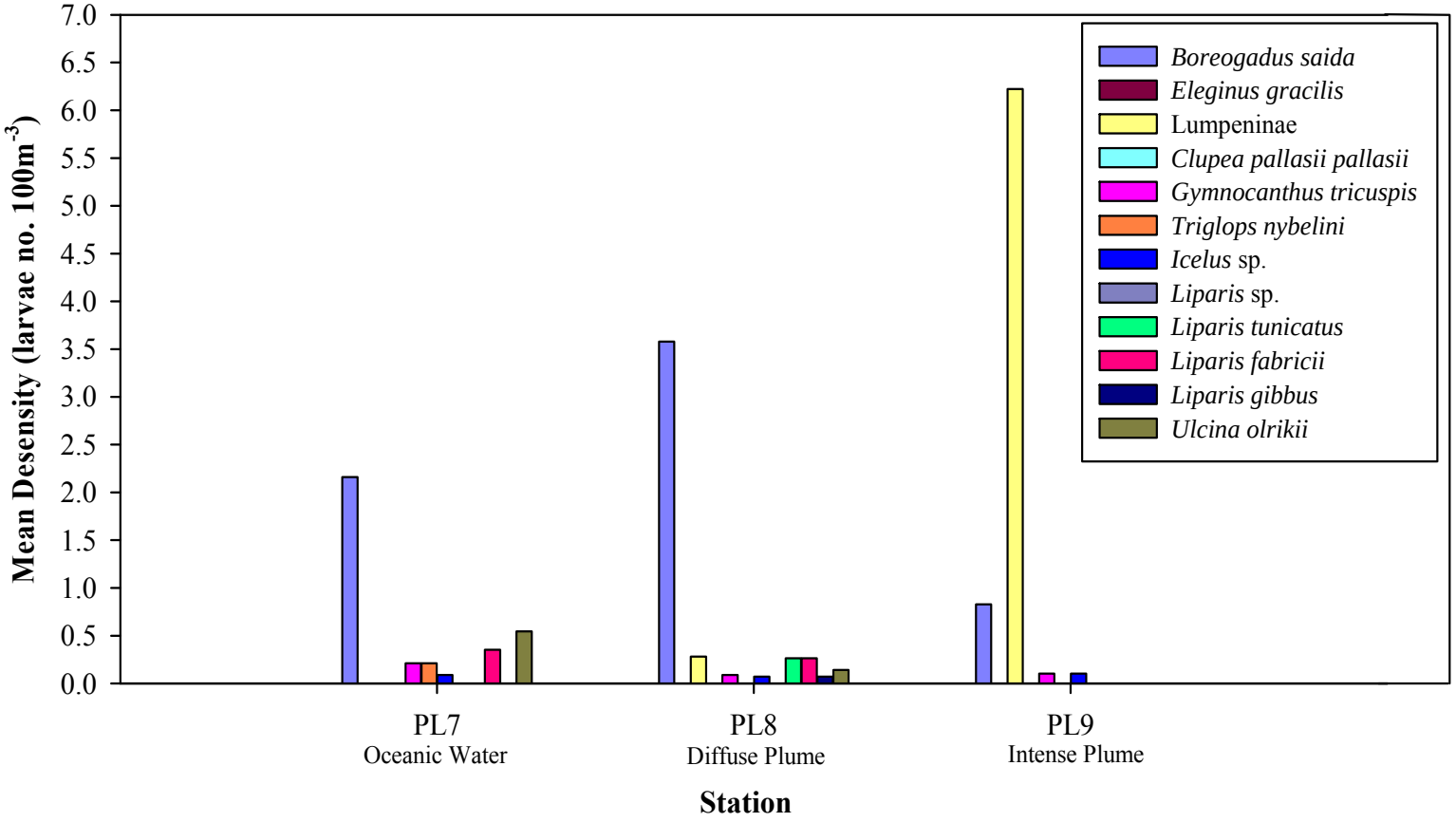


Figure 23. Taxonomic composition of larval fish catches for each station along transect 3, July 2007.

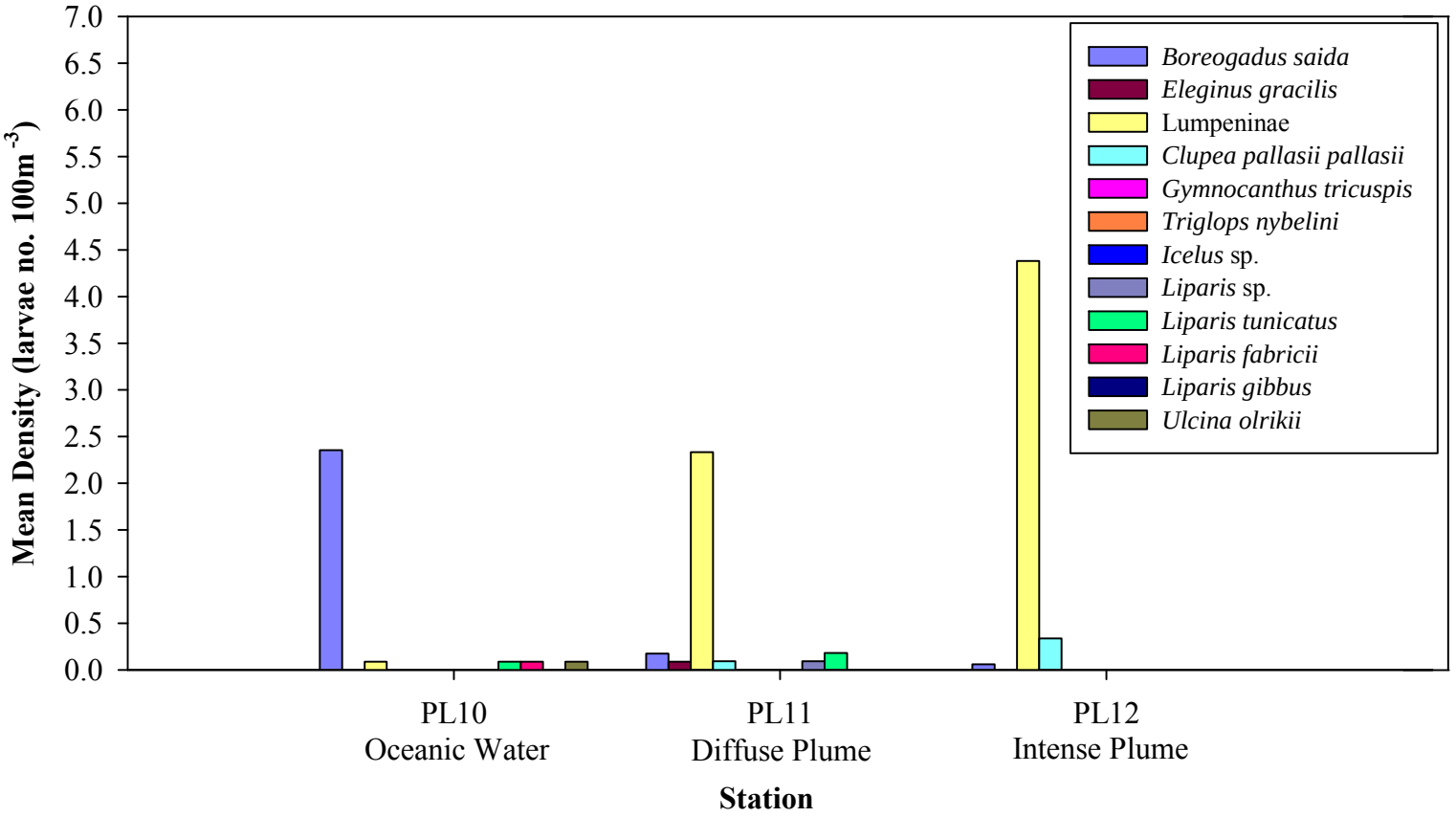


Figure 24. Taxonomic composition of larval fish catches for each station along transect 4, August 2007.

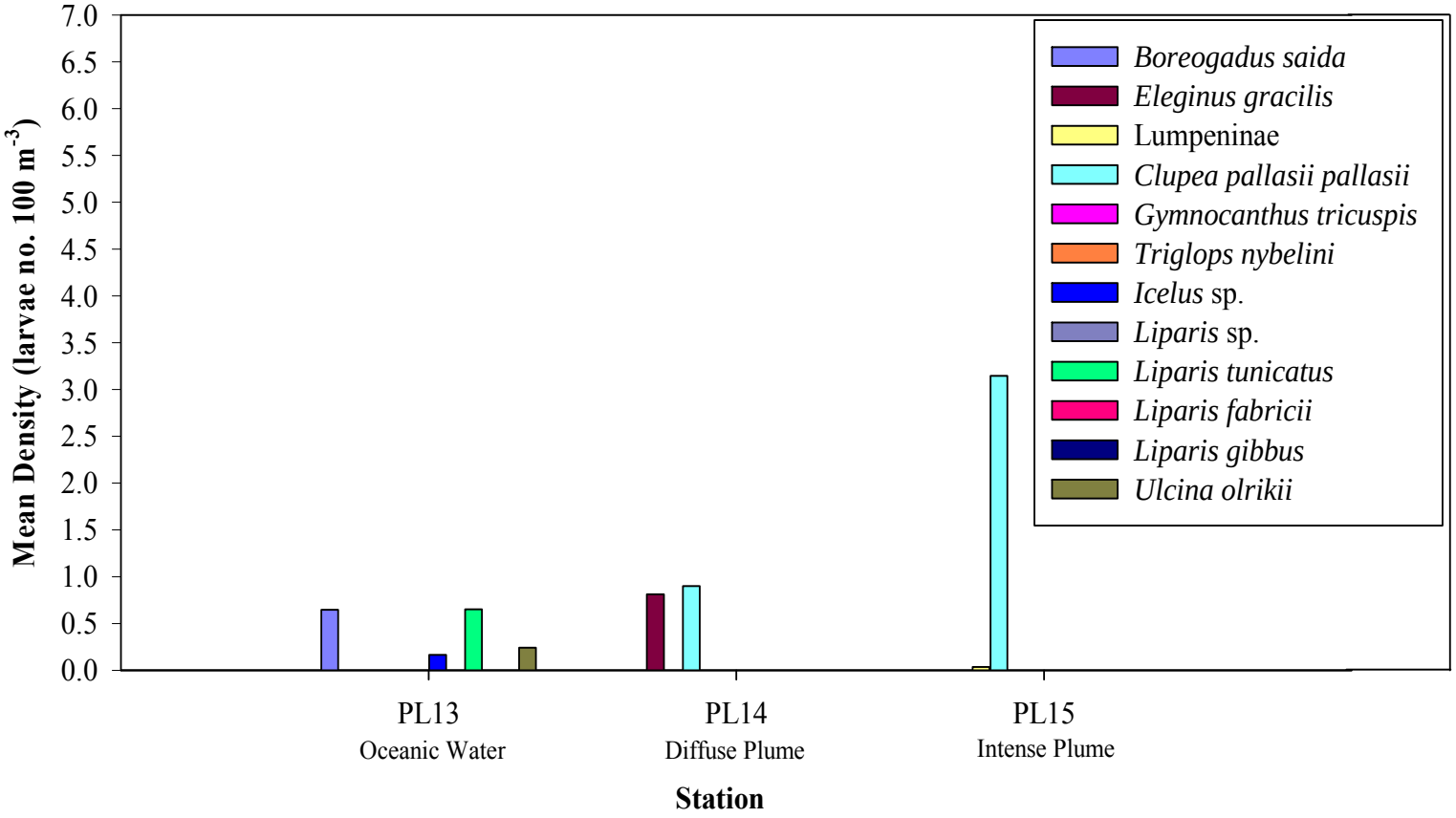


Figure 25. Taxonomic composition of larval fish catches for each station along transect 5, August 2007.

3.2.5 Recurrent Group Analysis

A Recurrent Group analysis was applied to all the data in both the July and August 2007 samples. From the Recurrent Group analysis, three groups were formed from twelve taxa, and all of which fall within an affinity level of ≥0.4 (Figure 26).

The first group (Group 1) contained four taxa and had more taxa than any of the other groups. This group taxa included *B. saida*, *G. tricuspis, L. tunicatus,* and *L. gibbus,* as illustrated in Figure 26. Within this group, individual species of *B. saida*, *G. tricuspis* and *L. tunicatus* have an additional association with Lumpeninae. Also, *B. saida* and *G. tricuspis,* displayed an association with *L. fabricii* and *L. gibbus*, but did not display any association with *L. fabricii,* as the affinity index was 0.3, which is lower than the affinity index level set.

The second group (Group 2) was comprised of *Icelus* sp. and *U. olrikii* (Figure 26). *Ulcina olrikii* was the only species that had an association with *L. fabricii*. These two major groups also displayed an intergroup affinity with each other, forming one large complex. The *Icelus* sp. displayed affinity with *B. saida* and *G. tricuspis* whereas *U. olrikii* displayed an affinity with *B. saida*.

The third group (Group 3) exhibited an affinity between *C. pallasi pallasii* and *E. gracilis* (Figure 26). This group was isolated from the other two groups, and it was the only group that did not display an affinity with other groups and species.

Lumpeninae and *L. fabricii* were the only two taxa that were not part of any group; however, both taxa did display linkages with species from Group one.

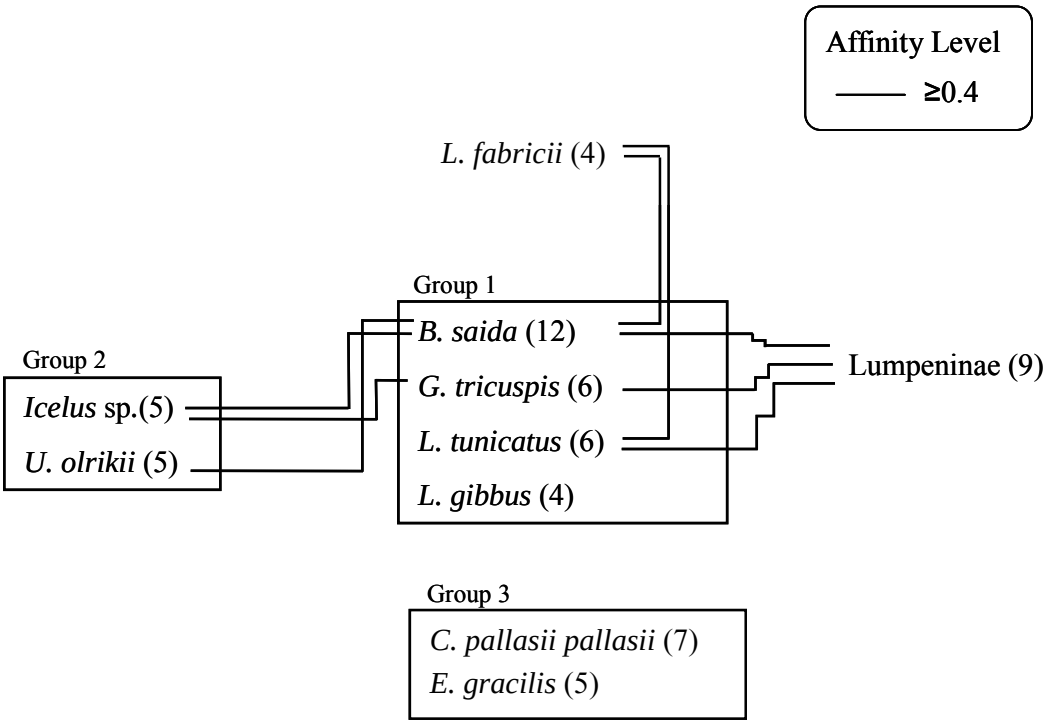


Figure 26. The results of the Recurrent Group Analysis: displaying the three main groupings within the enclosed boxes and the two associated taxa outside the box. The affinity index level is set at 0.4, and the occurrences of each taxon are indicated by the numbers within the parentheses.

The three recurrent groups showed a positive association with the three water masses across the Mackenzie River plume. Larval fish assemblages from Group 1 and Group 2 were found in the oceanic water mass. The diffuse plume contained all three groups of larval assemblages, and the intense plume contained only Group 3 assemblage.

3.2.6 Cluster and SIMPER Analyses

A cluster analysis based on larval fish abundance and occurrence divided stations into three different groupings. However, out of the three groupings, two groups did not

directly correspond to the original identification of water masses, which was based on CTD observations (Figure 27). Only Group 2 contained all oceanic stations (Figure 27). Groups 1 and 3 consisted of a mixture of diffuse and intense plume water mass stations.

The only non-oceanic station identified in Group 2 was PL8, a diffuse plume station that was located furthest offshore in deeper water than the other diffuse plume stations (Table 3).

Group 1 contained diffuse plume stations, PL5 and PL14, and intense plume stations, PL6 and PL15 (Figure 27). The depth of stations in group 1 ranged from 4 to 11 m.

Group 3 contained intense plume stations PL3, PL9, and PL12, and diffuse stations PL11 and PL2 (Figure 27). The depth for this grouping ranged from 6 to 16 m.

The SIMPER analysis identifies the similarity contribution of each taxon to the resulting cluster analysis groupings. *Boreogadus saida* was the only species common to all three water mass groupings (Table 8). *Boreogadus saida* was the dominating similarity contributor to group 2, with 58 % similarity within this group.

Clupea pallasii pallasii was the dominant similarity contributor to group 1, with 57.88 % similarity. Lumpeninae was the dominant contributor to the grouping 3, with 77.50 % similarity. *Clupea pallasii pallasii* and *E. gracilis* (Table 8) contributed to the similarity between Group 1 and Group 3 because both species were found in each group.

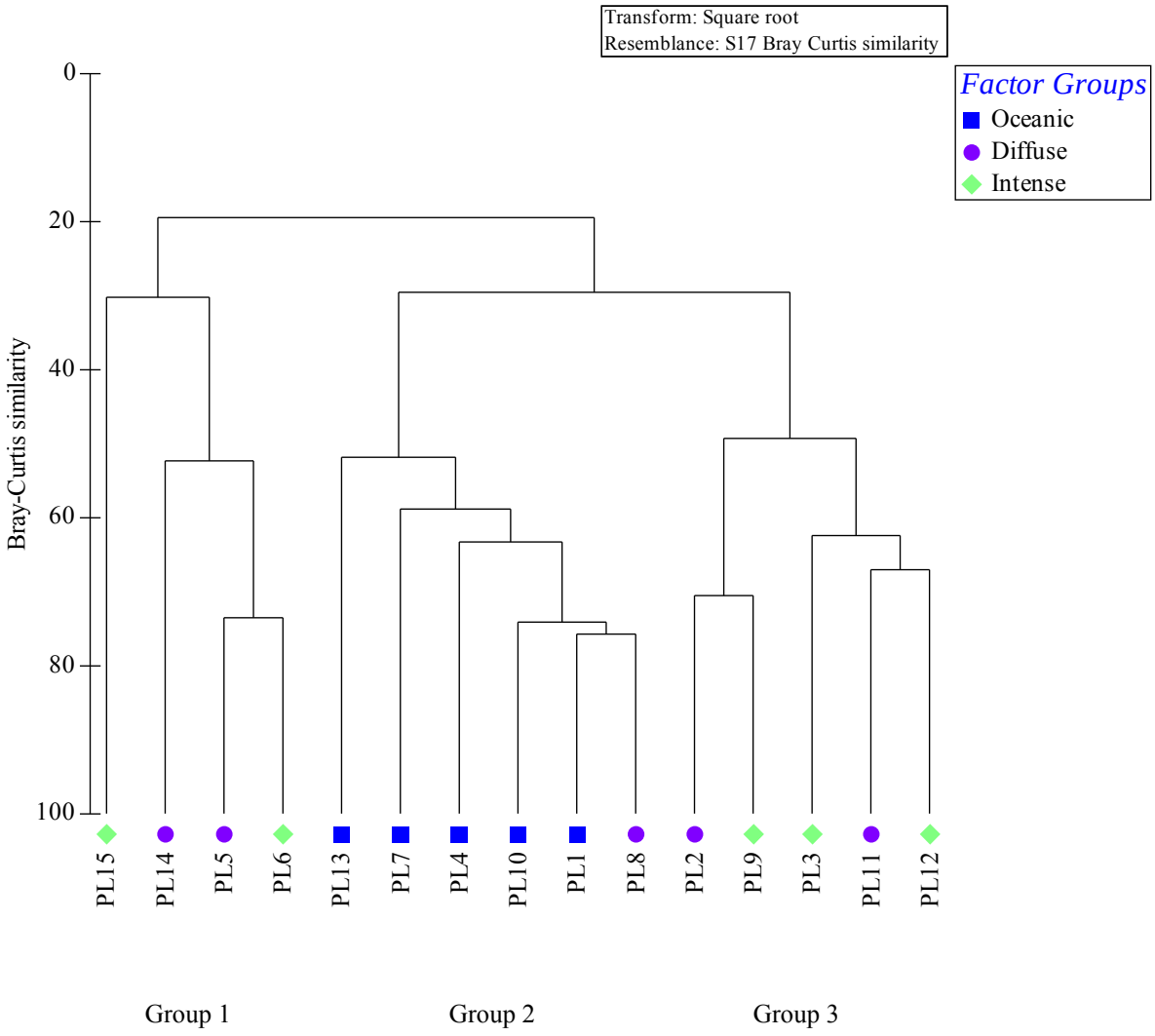


Figure 27. Dendrogram for hierarchical agglomerative clustering (using group-average link) based on results of fish densities at all stations. Each station was represented by its water mass classification. The Bray-Curtis Similarity Matrix was applied for the analysis.

Table 8. Summary results of the SIMPER analysis showing the percentage of similarity contribution of each taxon within the three water mass/ecological zones.

Group 1 in Cluster Analysis				Group 2 in Cluster Analysis				Group 3 in Cluster Analysis			
Species	Av.Abund	Contrib%	Cum.%	Species	Av.Abund	Contrib%	Cum.%	Species	Av.Abund	Contrib%	Cum.%
Clupea pallasii pallasii	0.86	57.88	57.88	*Boreogadus saida*	1.46	58.00	58.00	Lumpeninae	1.88	77.5	77.50
Elegenius gracilis	0.49	31.55	89.43	*Liparis tunicatus*	0.43	12.28	70.28	*Boreogadus saida*	0.58	10.87	88.37
Boreogadus saida	0.36	10.57	100	*Ulcina olrikii*	0.37	10.99	81.27	*Clupea pallasii pallasii*	0.26	6.79	95.16
				Icelus sp.	0.20	4.8	86.07	*Elegenius gracilis*	0.18	1.94	97.10
				Gymnocanthus tricuspis	0.25	4.75	90.82	*Liparis tunicatus*	0.22	1.74	98.84
				Lumpeninae	0.25	3.44	94.26	*Gymnocanthus tricuspis*	0.13	1.16	100
				Liparis fabricii	0.23	3.15	97.41				
				Liparis gibbus	0.24	2.59	100				
Average similarity: 44.85%				Average similarity: 60.58%				Average similarity: 55.86%			

Av.Abund = Average abundance
Contrib% = Contribution percentage of each taxon
Cum.% = Cumulative percentage of each taxon

3.2.7 Developmental Stages

The developmental stages of the larval fish from the bongo oblique tows (N= 585) are illustrated in Figure 28. The majority of larval fish captured in both July and August were in the postflexion and flexion stages, 67.69 % (n= 395) and 24.44 % (n= 143), respectively. The preflexion stage was the third-lowest percentage observed, and the early juvenile stage made up only 5.64 % (n= 33). The larval fish in the postflexion stage were found mostly in the intense plume, and both oceanic and diffuse water masses were relatively equal in numbers. The flexion stage was generally distributed evenly across the three water masses. The preflexion stage was most dominant in the diffuse and intense water masses. The early juvenile stage was observed mostly in the oceanic water; there were no occurrences in the intense plume, and only one fish was found in the diffuse plume.

There were some differences in the developmental stages of the larval fish between July and August (Figure 29). Overall, in July the preflexion, flexion, and postflexion stages were present in all three water masses; however, the flexion and postflexion stages were more dominant in the oceanic and diffuse plume water masses (Figure 29). The postflexion stage was the most abundant compared to all the other developmental stages, and it was distributed evenly with 23.68 % (n= 81) each within the oceanic water and diffuse plume water masses. This stage was observed to be less abundant within the intense plume, with only 19.88 % (n= 68). The flexion stage number was slightly higher in the oceanic water mass, with 12.87 % (n= 44); in contrast, in the diffuse plume and the intense plume, there were 8.77 % (n= 30) and 3.22 % (n=11) flexion stage fish,

respectively. There was only a small percentage of larval fish caught in the preflexion stage 7.89 % (n= 27) within the three water masses. The intense plume mass had more larvae in the preflexion stage 3.51 % (n= 12), compared to the oceanic water mass of 1.46 % (n= 5). The diffuse plume water mass contained slightly fewer fish larvae during the preflexion stage than the intense plume did 2.92 % (n =10). There were no early juvenile fish found in the July samples.

In August, postflexion and flexion were the dominant developmental stages in the samples. The postflexion stage was observed to be more abundant within the intense plume 39.09 % (n= 95) than in the oceanic water 16.46 % (n= 40) and in the diffuse plume 12.76 % (n= 31). Although fish larvae in the flexion stage were not observed in the oceanic water mass, a greater number were found in the intense plume with 44.00 % (n= 18) and in smaller numbers within the diffuse plume water mass with 5.76 % (n= 14). The preflexion stage fish larvae, which were comprised mainly of *E. gracilis* and one *Liparis* sp., were found only in the diffuse plume with 2.47 % (n= 6). In July, no fish were found in the early juvenile stage. In the August samples, *B. saida* was the only species found in the early juvenile stage, at 5.35 % (n= 13).

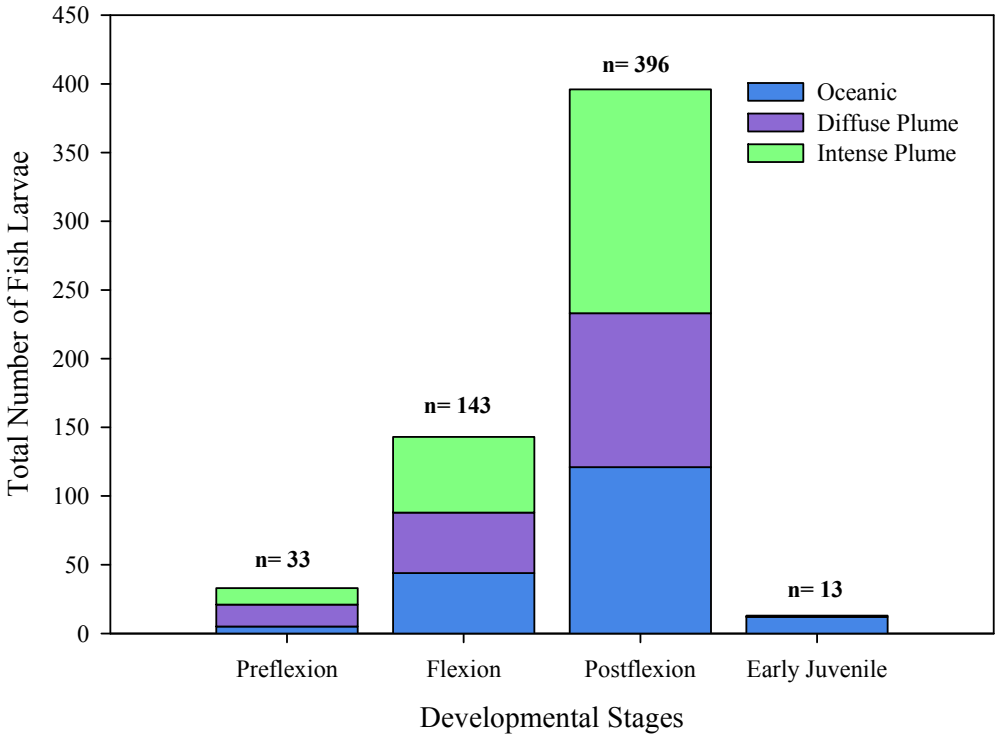


Figure 28. The Developmental stages for the total number of fish larvae examined from the oblique bongo tows in July and August 2007, combined (N= 585).

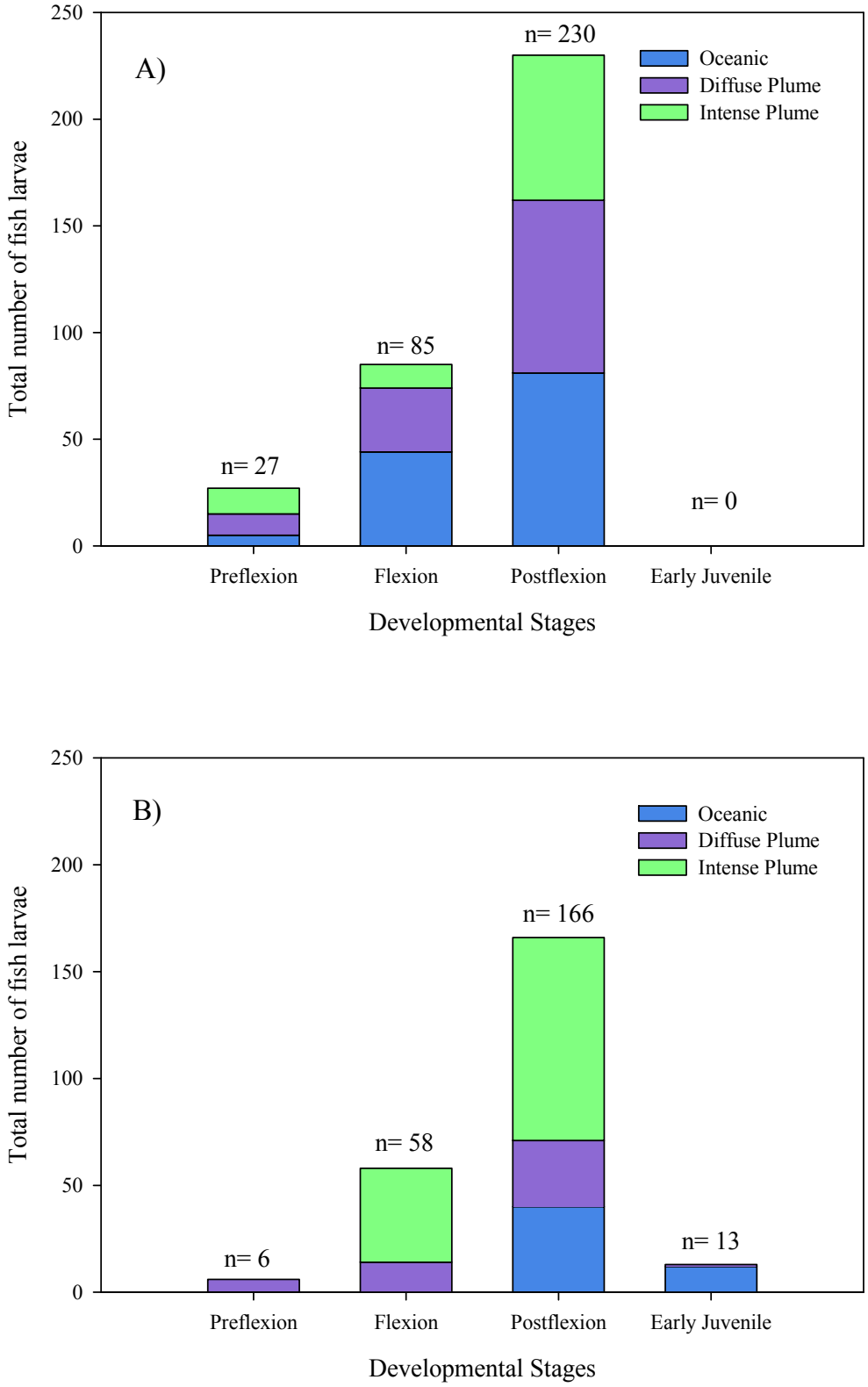


Figure 29. The developmental stages for the total number of fish larvae for; A) July and B) August of 2007, based on water mass properties.

Table 9. Developmental stages for each taxon and the total number of fish larvae caught.

	Preflexion	Flexion	Postflexion	Early Juvenile	Total number of fish larvae
Family Gadidae					
Boreogadus saida	15	49	120	13	197
Eleginus gracilis	13	7	0	0	20
Family Stichaeidae					
Lumpeninae (sub-family)	1	3	205	0	209
Family Clupeidae					
Clupea pallasii pallasii	1	56	22	0	79
Family Cottidae					
Gymnocanthus tricuspis	0	1	9	0	10
Icelus sp.	0	0	6	0	6
Triglops nybelini	0	0	2	0	2
Family Liparidae					
Liparis tunicatus	0	8	15	0	23
Liparis fabricii	1	4	5	0	10
Liparis gibbus	1	15	0	0	16
Liparis sp.	1	0	0	0	1
Family Agonidae					
Ulcina olrikii	0	0	12	0	12

Table 9 classifies the developmental stages of the larval fish according to their taxonomical affiliations. Lumpeninae and *B. saida* had the majority of their development in the postflexion stage. *B. saida* was the only species represented in all three larval developmental stages, including a few in the early juvenile stage.

3.2.8 Standard Length and Weight Analysis

The standard length distribution for the two most dominant species (Lumpeninae and *B. saida*) found in the study is illustrated in

Figure **30** and Figure 31, respectively. In July, the average standard length for Lumpeninae was higher at the intense and diffuse plume stations, compared to the oceanic stations. At the diffuse and intense plume stations, Lumpeninae had an average standard length of 28.71 (±4.45) mm and 24.08 (±3.48) mm respectively. PL1 was the only oceanic station where the average standard length of Lumpeninae captured was 22.77 (±1.60) mm. In August, the average standard length of Lumpeninae increased at the intense plume stations compared to July, with an average standard length of 36.06 (±2.65) mm. Both the oceanic and diffuse stations showed an increase in standard length for Lumpeninae. However, only one station from each of these two water masses contained Lumpeninae with an average standard length of 39.51 at the oceanic station and 34.90 mm at the diffuse station.

The average standard length for *B. saida* showed an increase from the intense plume to the oceanic stations. During the month of July, at the intense plume stations, the average standard length of *B. saida* was 10.84 (±5.54) mm, which was shorter than the average standard length found in the diffuse and oceanic stations. The average standard length at the diffuse stations was 17.98 (±4.88) mm, and the average standard length at oceanic stations was 17.86 (±3.78) mm. When this relationship was tested using the Kruskal-Wallis ANOVA by Ranks test, the results showed that there were significant differences between the larvae in the three water masses ($H= 19.45$ and $p= 0.0001$).

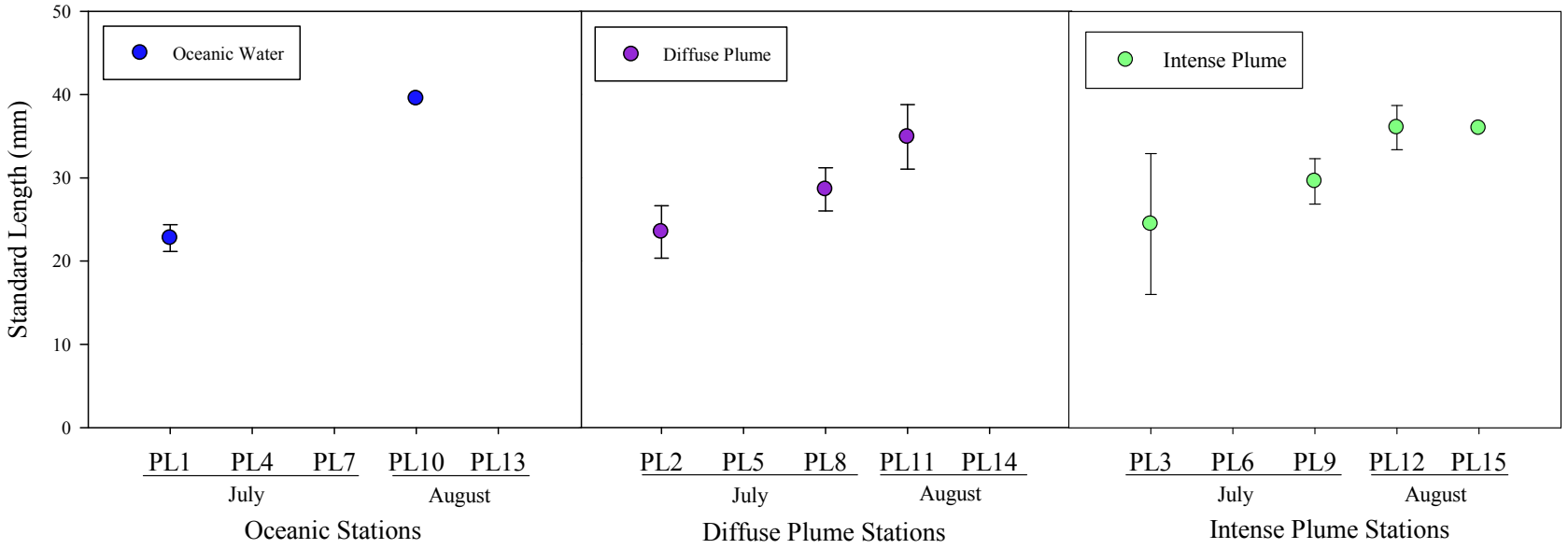


Figure 30. Standard length for Lumpeninae in the July and August 2007 stations, separated into the three water masses. Vertical bars represent standard deviation.

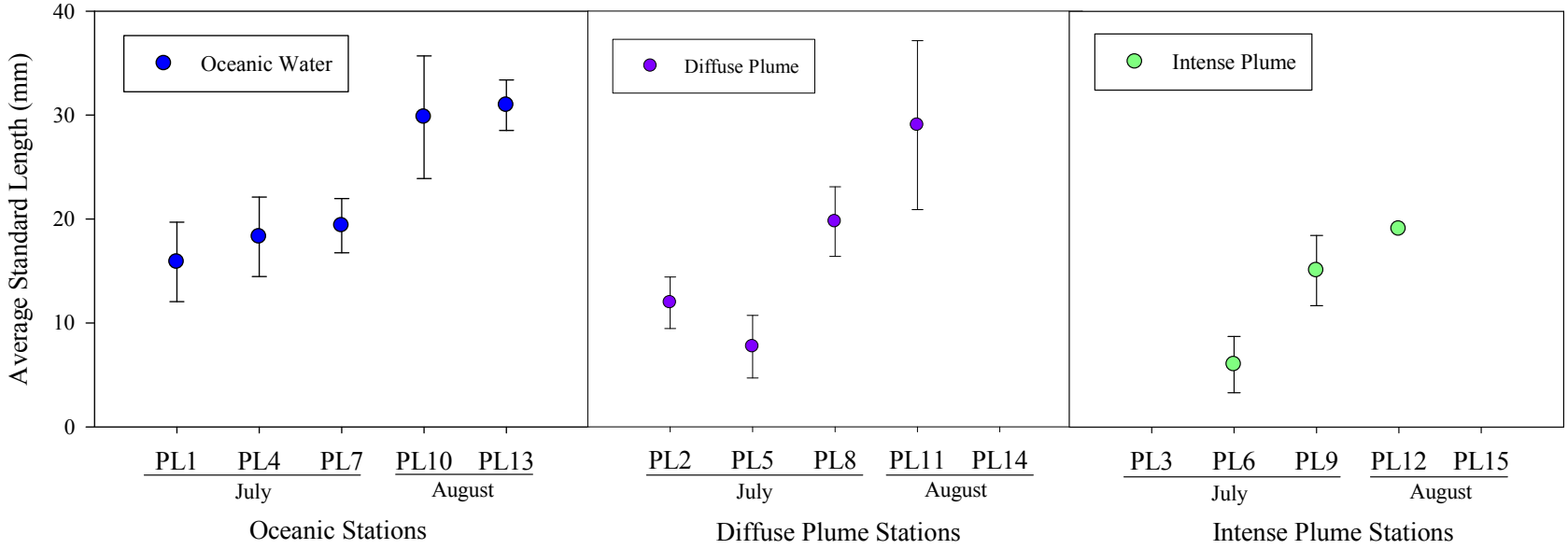


Figure 31: Standard length for *B. saida* in the July and August 2007 stations, separated into the three water masses. Vertical bars represent standard deviation.

In August, *B. saida* showed an increase in growth at the diffuse and oceanic stations. The average standard length at the oceanic stations increased to 30.07 (±5.29) mm, while the average standard length at the plume stations increased to 20.02 (±8.10) mm. At the intense plume stations, no average standard length was found because there was only one *B. saida* caught with a standard length of 19.06 mm. The standard length of *B saida* was significantly different in the oceanic and diffuse water masses (Mann-Whitney test, Z= 0.2014 and p= 0.8403).

The length and weight relationships were analyzed for all the fish captured in both months. The relationship between total standard length and total weight for all taxa is illustrated in Figure 32. This relationship was insignificantly linear (R= 0.53); thus, the mean standard length and weight of the total fish larvae were not correlated.

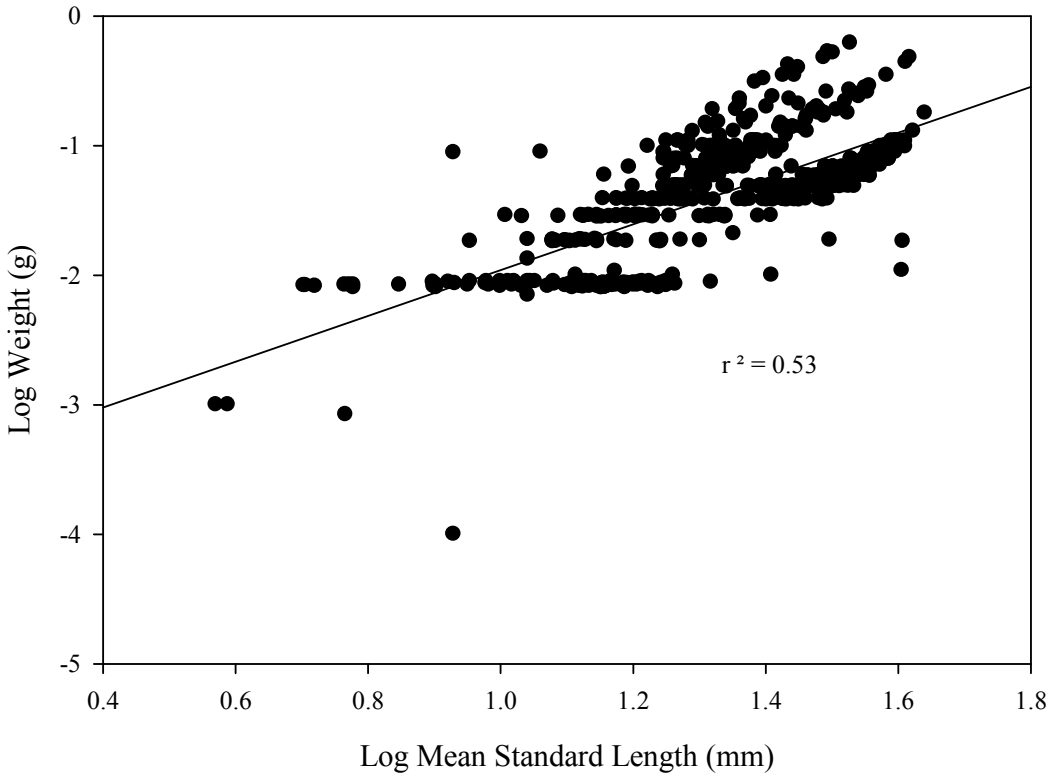


Figure 32. The mean standard length (mm) in relation to the weight (log transformed).

3.2.9 Total Fish Larvae Biomass

The biomass for all larval fish is illustrated in Table 10. The oceanic station had the highest total larvae biomass for both July and August, with 1331.73 mg 100 m^{-3} and 1867.61 mg 100 m^{-3}, respectively. The biomass at the diffuse plume stations was much higher in the July samples, than the August samples with 1112.25 mg 100 m^{-3} compared to 591.34 mg 100 m^{-3}. The intense plume mass in July had a higher biomass of 736.91 mg 100 m^{-3}, when compared to the August biomass of 708.60 mg 100 m^{-3}. There were no significant differences for the biomass relationship among the three water masses from

the results of the Kruskal-Wallis by Ranks test. The significant difference was observed at H= 3.38 with p = 0.1845.

Table 10. The total larvae biomass (mg 100 m^{-3}), with standard deviation (SD) for July and August.

	Water Mass	Total Larvae Biomass (mg 100 m^{-3})	SD ±
July	Oceanic	1313.73	7.59
	Diffuse Plume	1112.25	7.31
	Intense Plume	736.91	4.20
August	Oceanic	1867.61	22.41
	Diffuse Plume	591.34	14.70
	Intense Plume	708.60	4.25

3.2.10 Relationship between Zooplankton and Larval Fish

There was no correlation between the zooplankton (meso-zooplankton) biomass and the total fish larvae biomass (Pearson Product Moment Correlation p= 0.221, r^2 = 0.12) or between the zooplankton biomass and the total fish larvae density (Pearson Product Moment Correlation p= 0.796, r^2= 5.80) (Figure 33). These relationships were also tested for zooplankton and the dominant fish species, *B. saida*. No correlation was found between the zooplankton biomass and the *B. saida* biomass (Pearson Product Moment Correlation p= 0.08, r^2= 0.23), as well as between the zooplankton biomass and the total *B. saida* density (Pearson Product Moment Correlation p= 0.295, r^2= 0.09) (Figure 34).

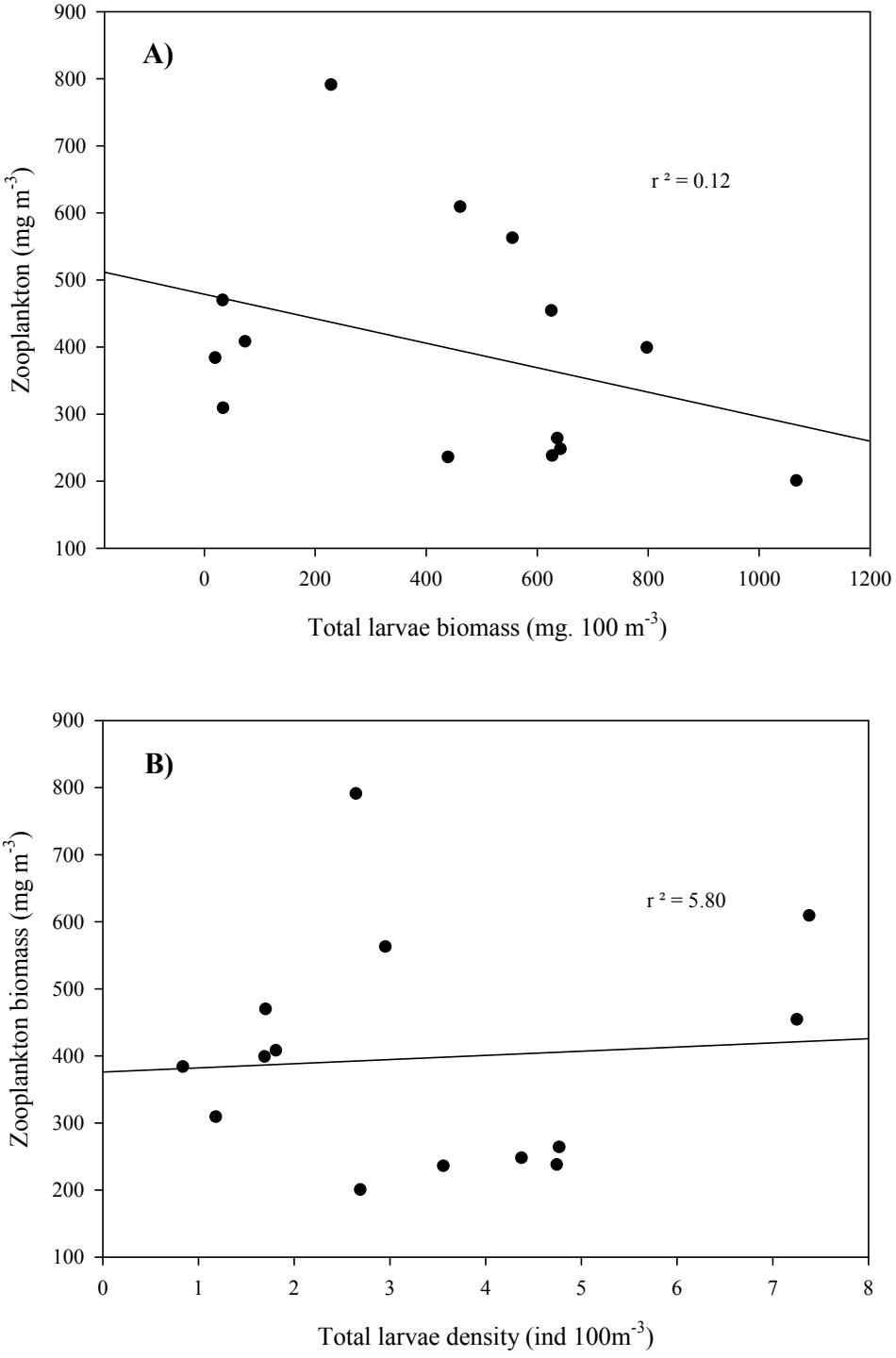


Figure 33. Regression graphs for; A) zooplankton biomass (mg m^{-3}) in relation to the total fish larvae biomass (mg 100 m^{-3}) and B) zooplankton biomass (mg m^{-3}) in relation to the total fish larvae density (larvae 100 m^{-3}).

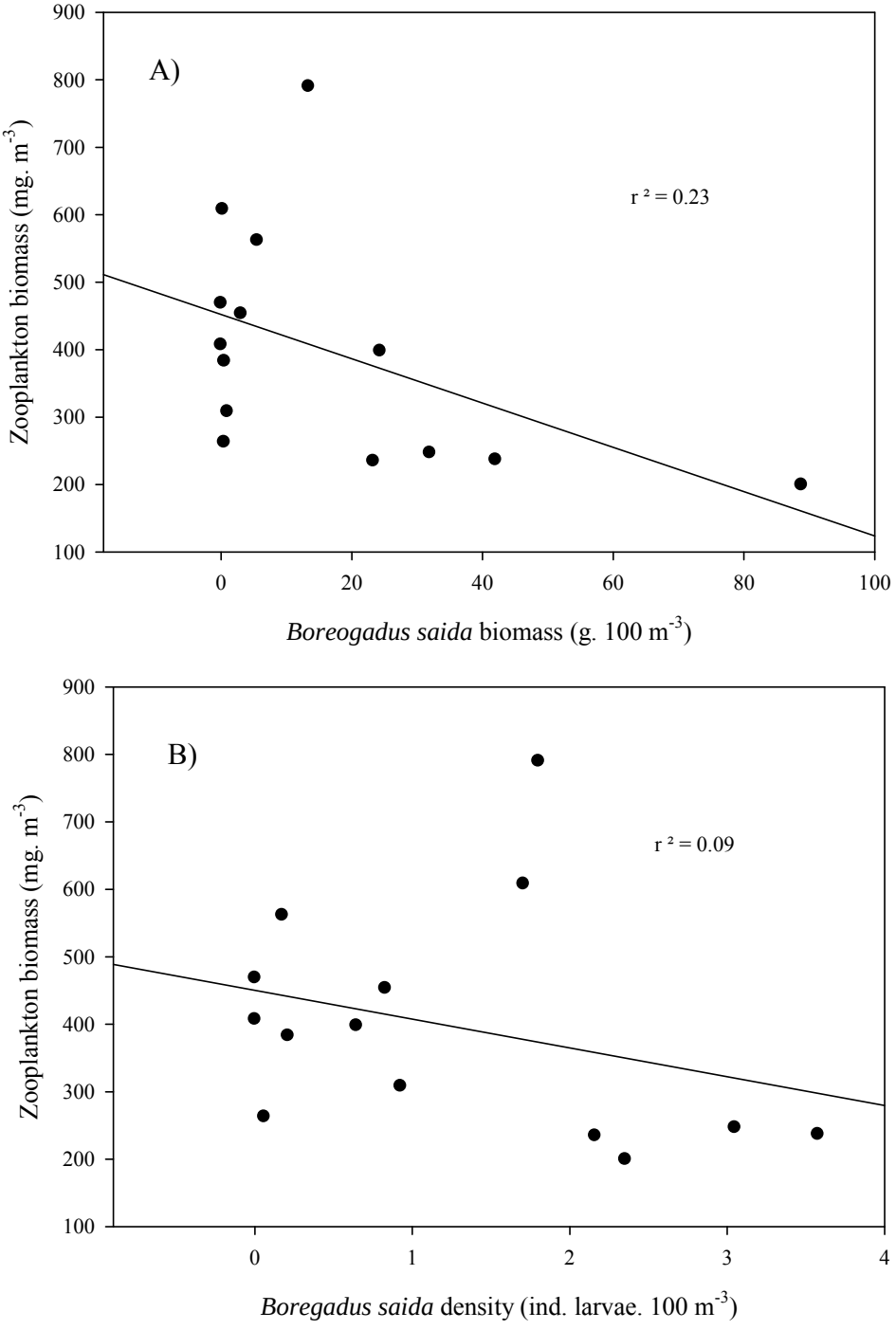


Figure 34. Regression graphs for; A) zooplankton biomass (mg m^{-3}) versus *B. saida* biomass (g 100 m^{-3}) and B) zooplankton biomass (mg m^{-3}) versus *B. saida* density (larvae 100 m^{-3}).

CHAPTER 4: DISCUSSION

4.1 WATER MASS DISTRIBUTION

Water mass distribution is used by physical oceanographers to describe the oceanography over the continental shelves. This distribution also serves as an indicator of the relationship between an organism's habitat and its community structure. The oceanographic patterns of the Canadian Beaufort Sea shelf have been described in other studies (e.g., Carmack et al. 1989; Macdonald et al. 1989; Carmack and Macdonald 2002). The hydrographic profiles from the current study corroborate these previous oceanographic descriptions of the shelf (Figure 9 to Figure 17) and once again demonstrate the influence of the freshwater inflow of the Mackenzie River. The warm Mackenzie River plume is distributed over the Canadian Beaufort Sea shelf; however, the dispersion pattern of the freshwater is erratic, and the plume does not uniformly spread across the shelf (Figure 9 to Figure 17), likely due to the effects of wind action (Macdonald et al. 1989). The non–uniform distribution of plume water and the effects of water currents observed in the study area resulted in a lack of consistency in water mass stratification among station types (Figure 9 to Figure 17). Near-shore, intense plume stations with water depths up to 10 m were observed to have stronger vertical salinity stratification (Figure 10, Figure 12, Figure 14 and Figure 16). The stability observed in the vertical stratification of water masses in near-shore stations resulted, in part, from their close proximity to the river plume source, where the distribution of the plume water was more uniform, and where current effects were minimized.

The initial identification of sample stations in this study was based on the assumption that the inflow of river water that has higher turbidity, higher temperatures and lower salinity than the marine water masses on the Beaufort Sea Shelf would produce three identifiable station types. It was expected that the riverine discharge would create three types of stations: an intense plume area where the river water mass dominates; an oceanic-type station where the cold and highly saline marine water mass dominates; and a diffuse plume (frontal zone) composed of a mixture of fresh plume water and cold ocean water masses. This assumption that the plume inflow would produce three identifiable station types based on water mass characteristics was based on results from studies in lower latitudes (e.g., Garvine 1987; Grimes and Finucane 1991). In lower latitude plume studies, the plume frontal zone was observed to be identified by its abrupt transition between turbid and clear water masses, sharp salinity gradient, and hydrodynamic compression at the horizontal surface. For example, the Mississippi plume front is easily detected during its peak river discharge, as it can occupy a water column up to 12 m or more (Govoni and Grimes 1992). Another river frontal zone (i.e., Botany Bay, Australia) can accumulate flotsam; thus, algae at the plume front (Kingsford and Suthers 1994) visually mark that area. In contrast, stability in the distribution of water masses of the Mackenzie plume has not always been observed, as the front, which appears to be highly flexible, changes in response to wind variations. Mulligan et al. (2010) reported that a modest easterly wind of 5 to 10 m s^{-1} was sufficient to transport the plume offshore. Fissel et al. (1987) reported that the Mackenzie River plume front was difficult to detect; as a result, it was referred to as diffuse plume water. The flexible plume front condition has also been reported to occur in the Great Whale River in Hudson Bay (Ingram 1981).

Carmack et al. (1989) described that the outer portion of the Mackenzie River plume front is a complex and variable structure, with its front forming filaments and wisp-like structures at the outer edge that can be dissipated in less than a week. Carmack et al. (1989) also suggested that one cannot view the plume as a single plume formation, as water discharges from the river to form a simple two-layer structure over the shelf water. The plume is a complex, multiple-layered structure with variations of temperature, salinity, and turbidity at any given time. At the base of the interface, where the two layers meet, there is no sharp transition, but rather a mixed layer. These descriptions of the Mackenzie Plume are consistent with the observations found in this study that the water-mass-based classification of station types consistently defined the ocean and intense plume stations, but failed to consistently identify the diffuse station type. These similarities in plume behavior are also reflected in the vertical salinity stratification for the diffuse plume stations where the stratification was inconsistent and varied.

The apparent lack of stability for water mass distribution in the Beaufort presents problems in identifying the boundaries of the plume front areas. This would also appear to make it difficult to identify the EBSA boundaries in the Beaufort Sea for the Mackenzie River plume, based principally on water mass distribution.

4.2 LARVAL FISH DENSITY BASED ON WATER MASS CLASSIFICATION

The physical nature of water masses has an influence on the occurrence and density of larval fish (Cowen et al. 1993; Doyle et al. 1993). It is often hypothesized, for example, that a diffuse plume water mass can support higher densities of larval fish because water temperatures there are higher than those of marine water masses. While salinities are

lower than marine water masses, they are not so low as to exclude many marine species; moreover, nutrients concentrated at plume fronts increase overall productivity (Grimes and Finucane 1991). In a system where the inflow of river water produces a defined plume front and a clear delineation of water masses, one would anticipate that larval fish density would correlate with differences in water masses. In this study, among the three water masses, the total larval fish densities were similar in values and not significantly different. Thus, the diffuse plume water mass did not show significantly higher numbers in the overall total larval fish density within this vicinity, as would be predicted. However, when examining each individual water mass, the diffuse and intense plume water masses had more stations that were significantly higher in larval fish density than most of the oceanic stations. For example, stations PL2 in the diffuse plume water mass and PL9 in the intense plume water mass had the highest larval fish density compared to the oceanic stations. These high density values had been the result of the sub-family Lumpeninae occurring in large numbers where stations had average salinity values of 30.90 PSU at station PL2 and 27.49 PSU at station PL9. *Anisarchus medius* preferred warmer waters at 3 to 5 ºC and salinity values above 30 PSU (Andriyashev 1964). Although, there are reports in the Laptev Sea that found *Anisarchus medius* within a salinity range of 25.3 to 29 PSU and also in the White Sea at a salinity level of 24.6 PSU (Andriyashev 1964). Differences were also found in primary productivity among the three water masses. At both stations, the fluorescence was much higher than at the oceanic stations. The fluorescence occurs in both diffuse and intense plume stations, indicating the existence of deep chlorophyll *a* maxima, which were found from 10 m to the bottom of the seafloor. Walkusz et al. (2010) suggested such an environment is

ultimately a stable area that contains high nutrient levels. This vertical interface results from nutrients coming from freshwater and marine water. These nutrients plus the higher light intensity levels are suitable for phytoplankton growth (Walkusz et al. 2010). Results of this study indicated that there was no significant evidence of larval fish aggregations. Nevertheless, results suggest that both the diffuse and intense plume stations are influenced by the Mackenzie River plume, despite high larval fish aggregations.

A Cluster analysis, based on larval fish densities and species communities, calculated similarities among the three water mass stations. The Cluster analysis separated the data into three groupings (Figure 27). One group was the oceanic water mass station type, but the other two density-based groups contained a mixture of both diffuse and plume stations. A single diffuse plume station PL8 was included in the group with the oceanic stations. This was not unexpected, given that station PL8 was at a depth of 38 m, which was further offshore than other diffuse stations and contained more of the oceanic water mass local properties. Therefore, in the Cluster analysis, not all water mass stations were grouped as expected from the original water mass designations. This is due to the difficulty in coupling the biological and physical components together, since water masses, particularly at the diffuse plume, were not absolute barriers. Despite the challenge of coupling biological and physical components, larval fish taxa have been used in many studies to describe the corresponding specific types of water masses (Cowen et al. 1993; Doyle et al. 1993; Doyle et al. 1995; Marancik et al. 2005). The reasoning behind the Cluster analysis groupings were explained in the Simper analysis. The Simper analysis illustrates the contribution of each fish species in defining water

mass habitat groupings. Consequently this study describes three distinct larval fish assemblages, each within one of the three water masses.

The most sharply delineated boundaries with the most stable and definitive larval assemblages were found in the oceanic water mass with high salinity values. The oceanic assemblage is located further offshore (>30 m depth) on the shelf, where it is mostly dominated by *B. saida,* and to a lesser extent *L. tunicatus,* and *U. olrikii.* Other species, which occur in smaller numbers, but were also important to this oceanic assemblage, included *G. tricuspis,* Lumpeninae*, L. fabricii* and *L. gibbus.* This group of assemblages dominated by *B. saida* has also been documented in Paulić (2009), which in their study was referred to as the coastal assemblage.

The presence of a larval assemblage was found in the diffuse plume, which was dominated by Lumpeninae. The diffuse plume assemblage was closely related to the oceanic assemblage, since the oceanic and diffuse plume water masses have similar community structure. This is due to a less distinct boundary and the overlap *of B. saida*, Lumpeninae*, L. tunicatus* and *G. tricuspis* between the two water masses. However, the presence of a high abundance of Lumpeninae in the diffuse plume clearly differentiates this assemblage from the oceanic assemblage; hence, Lumpeninae acts as an indicator for diffuse water mass assemblage. Other species, such as *C. pallasii pallasii* and *E. gracilis,* were also important to the assemblage. Thus, the contribution of these species to this assemblage suggests the presence of a transitory (diffuse) area where the changes in fish community has occurred, thereby indicating the existence of the water mass zones due to

a shift from a lower salinity gradient and the existence of a faint boundary between the two assemblages.

The intense plume water mass assemblage was located closer to shore in a water depth less than 13 m, and it is clearly dominated by the highest abundance of species *C. pallasii pallasii* and *E. gracilis*. These two species were rarely found within the oceanic water mass during the study period, but were observed in small percentages in the diffuse water mass area. This assemblage is indicative of the influence of fresh water from the Mackenzie River. The zooplankton study in the region by Walkusz et al. (2010) found that, closer to shore, the intense plume water mass contained smaller-sized brackish taxa, such as *P. leuckarti*, *Copepoda nauplii* and *Pseduocalanus* spp., which are foraged by fish larvae, including *C. pallasii pallasii* (as cited in Walkusz et al. 2010). Therefore, this supports the present study findings of a defined intense plume water mass assemblage. A further validation is that, historically, *C. pallasii pallasii* has been documented as a marine species that inhabits the nearshore areas of the Beaufort Sea and has migratory behaviour for spawning in the Mackenzie Delta (Cobb et al. 2008). Spawning for this species occurs during early June to mid-July (Stewart 1993) and as expected, the majority of the *C. pallasii pallasii* were in flexion stage of development. Accordingly, this coincided with the spawning sites that were identified along the Tuktoyaktuk Peninsula (Bond 1982; Gillman and Kristofferson 1984), Liverpool Bay (Gillman and Kristofferson 1984), and recently in the area near Garry Island (Paulić 2009). In general, the distribution of larval fish assemblages are the result of adult fish behavior; specifically spawning locations associated with food supply (e.g., Lara-Lopez and Neira 2008) and oceanographic processes to facilitate larval transport (e.g., Epifano and Garvine 2001).

The results of this study show that in a plume system without a uniform plume front, larval fish do not appear to aggregate to a specific water mass. However, the inclusion of both community composition and density did result in the identification of three distinct groupings of larval fish. It was observed that water depth can be used to help identify specific intense plume and diffuse plume larval fish communities. This suggests that the establishment of boundaries for EBSAs in the Beaufort Sea Plume will have to include water mass characteristics, water depth, and larval fish community structure in the definition of boundaries.

4.3 RECURRENT GROUP ANALYSIS

Water masses, which include plume fronts, often have unique larval fish assemblages (e.g., Doyle et al. 1995). In the section above, observations from the Simper analysis (section 4.2) demonstrated that there are three distinct larval fish assemblages associated with the Mackenzie River plume. To examine larval fish assemblages in another way is to investigate assemblages through species co-occurrences. The affinity index defines recurrent groups based on their frequency of co-occurrence, and this is based on the concept that larval fish assemblages result when species co-occur as part of each other's environment. The use of this analysis has been investigated by researchers to determine the inter-specific processes that are attributed to larvae abundance and distribution (Fager 1957). Doyle et al. (1995) indicated that the advantage of a recurrent group is that by using occurrence data, it removes the bias against a small number of rare species. The traditional methods of analyzing larval assemblages using fish abundance data puts more weight on common species and downplays the importance of rare species. Based on the

Recurrent Group analysis, three larval fish assemblages were identified (Figure 26), which revealed similar and corresponding results to the Simper analysis. One assemblage was principally associated with the ocean water mass. Given that the oceanic stations were well defined in this study by both the water mass and Simper analysis, it is not surprising that the Recurrent Group analysis identified an assemblage associated with this group of stations. The assemblage was composed of the main group dominated by *B. saida*, *L. tunicatus*, *L. gibbus,* with a strong association with the second group that is composed of *Icelus sp.* and *U. olrikii*. Both groups are essentially oceanic assemblages that are found in the Simper analysis; also, they are marine species that co-occur in the same higher salinity environment. As indicated in the Simper analysis above, the diffuse plume fish composition was closely related to the oceanic grouping. For the Recurrent Group analysis, results demonstrated the same condition; Lumpeninae was shown to have a strong affinity to the oceanic grouping, suggesting a similarity in co-habiting in the same environment. However, it is in itself still a separate assemblage with higher Lumpeninae species and few core species that are common in both water masses. The intense plume group was represented by the *C. pallassii pallasii* and *E. gracilis*, which illustrates the similarity of the nearshore environment in the results of the Simper analysis. This suggests that both species are often co-occurring to create a unique separate grouping of the intense plume assemblage.

Results from the present study support the concept of using co-occurrence data to define larval fish assemblages to aid in the identification of EBSAs. Even in areas where the physical boundaries of an area like the water masses in this study might vary, the examination of species assemblages can help define areas that support specific groups of

species or may potentially be important in the ecology of species. One advantage of including such analysis is that it is based on occurrence rather than on abundance data. It is often more feasible to collect occurrence data on a large scale; then abundance data and results are often less affected by sampling errors or inconsistencies (Doyle et al. 1993). Combined with information on the physical environment and species diversity, co-occurrence information can identify unique environments potentially requiring special conservation measures.

4.4 RELATIVE ABUNDANCE COMPARISON TO OTHER PREVIOUS SURVEYS OF LARVAL FISH IN THE BEAUFORT SEA

Relative larval fish abundance and occurrence were consistent with the observations that were reported by other studies in the Beaufort Sea (e.g., Hopky and Ratynski 1983; Hopky et al. 1994; Chiperzak et al. 2003 a,b,c; Paulić 2009). The waters of the Beaufort Sea originate mainly from the Arctic Ocean, and these waters were determined to be composed of a polar mixed layer that occupies approximately the top 50 m, and an upper halocline layer originating from the Pacific Ocean, which occupies a depth of 50 to 200 m below the surface (Carmack and Macdonald 2002). Hence, arctic fishes are widespread across the Beaufort Sea, and as a result of the freshwater input from the Mackenzie River, larval marine species are recorded to be found in the nearshore environment, having adapted to lower surface salinity levels. Marine fish species that are able to tolerate low salinity levels in the nearshore may take advantage of more abundant food (Craig 1984). Larval fish aggregations in the plume frontal areas have shown high numbers from numerous investigations of large rivers in the southern latitude (e.g., Grimes and

Finucane 1991; Govoni and Grimes 1992). The present study did not demonstrate a high abundance of larval fish at the diffuse plume water mass compared to the adjacent waters of oceanic and intense plume water masses. Instead, the overall larval fish relative abundance for the three water masses was similar (Figure 18). The higher abundance of larval fish at the diffuse plume within the Mackenzie River plume system was not reported by previous studies, but these studies did not focus on this water mass (e.g., Hopky and Ratynski 1983; Hopky et al. 1994; Chiperzak et al. 2003 a,b,c; Paulić 2009).

In this study, the Shannon's Diversity Index was used to assess differences in species diversity across the plume gradient (Table 6). Overall, the diffuse plume water mass was found to have higher species diversity than the oceanic and intense plume water masses throughout the months of July and August. The higher diversity in the diffuse plume results from the occurrence of larval marine species similar to the oceanic water mass and a few overlapping species from the intense plume (freshwater) water mass. This observation is to be expected, considering that the diffuse plume zone has properties from the two water masses, and thus contains species that can tolerate characteristics of both water masses. One hypothesis is that larval fish that can withstand broader temperature and salinity ranges have increased dispersion (Grothues and Cowen 1999). Increased dispersion can result in an increased survival rate, resulting from an increased opportunity to access areas of higher food supply or reduced predation.

Lumpeninae and *B. saida* are the two main dominant species found in the present study. Near the coast, at less than 15 m water depth, Lumpeninae was the most common taxa. It had the highest relative abundance, and it dominated the diffuse plume area. This result

differs from the results reported by Paulić (2009), where the highest relative abundance for the nearshore environment was *C. pallasii pallasii*, which dominated the water depth less than 20 m. The current study observed *C. pallasii pallasii* mostly in the intense plume, at less than 5 m of water depth. Although the identification of Lumpeninae was done only to the subfamily level in this current study, based on previous studies, species expected in the area were only either *Anisarchus medius* or *Leptoclinus maculatus*. Chiperzak et al. (2003 b,c) found a high percentage of *Anisarchus medius* during sampling in July, August and September of 1986 and 1987.

Boreogadus saida is known as a keystone species that is widely spread across the pan-Arctic and sub-Arctic regions (Welch et al. 1993; Bradstreet et al. 1996). Although *B. saida* is abundant in terms of its distribution, it is not a target species for commercial fisheries in the Arctic (Stewart 1993). The relative abundance observations for *B. saida* for this study are consistent with previous research, which had shown that *B. saida* was one of the dominant species (e.g. Chiperzak et al. 2003 a,b,c; Paulić 2009; Majewski 2009). The results from this current research reveal that *B. saida* has the second highest relative abundance, which is comparable to the relative abundance of Lumpeninae (Table R3). However, *B. saida* had the highest percentage of occurrence of all stations sampled, and this species was predominantly found in the oceanic water mass. The relative abundance level was slightly less than that found in Paulić 2009, as that study found *B. saida* to have a relative abundance of 60 %, with an occurrence rate of 60 % at that station. These differences were expected, as the focus of this research was primarily to sample across the plume gradient. Overall, the highest densities of *B. saida* were found in the oceanic stations where salinity values were greater than 23 PSU; this finding

correlates with the finding in Hudson Bay, where *B. saida* was mostly found at a salinity value which exceeded 25 PSU (Ponton et al. 1993). Moreover, the few *B. saida* that were found in the diffuse and intense plume stations suggest that they can tolerate lower salinity values. However, it is not known how long they can withstand long periods of low salinity levels. Larval *B. saida* have been recorded occurring in lower salinity waters in Alaska Beaufort Sea (Craig et. 1982) and in Hudson Bay (Ponton et al. 1993). They are affected by light attenuation from the surface (Ponton and Fortier 1992).

Other species, such as *L. tunicatus*, *L. fabricii*, *L. gibbus*, *U. olrikii*, *Icelus* sp., *G. tricuspis*, *C. pallasii pallasii* were mostly observed at less than 5 m depth from the surface. Their overall dominance is found in the vicinity of the diffuse and intense plume water masses. *Clupea pallasii pallasii*, in contrast to *B. saida,* is the main target species for commercial fisheries, especially in the Pacific Ocean, Alaska Shelf, and other places around the world (Stewart 1993).

Eleginus gracilis is one of the uncommon species found in this study as compared to others findings (Chiperzak et al. 2003 a,b,c). Although the life history of *E. gracilis* is not known in the Beaufort Sea, they have been reported to exist in the coastal and offshore areas. The present study found a relatively small abundance of *E. gracilis* in its flexion stage in July and in its preflexion stage in August; and among those *E. gracilis* mostly found in the diffuse plume area. This suggests that *E. gracilis* may spawn close to the plume vicinity. However, further investigation is necessary to determine the specific key survival growth for the area and to elaborate on the ecology of this species.

Uniqueness is one criterion that has been identified as being potentially important in defining an EBSA when related to diversity (DFO 2004). If an area supports species diversity, it may represent a unique area requiring conservation and protection. In this study, the observation of diversity differences associated with the plume suggest that research is needed to determine if these differences are the result of rare species requiring protection or if the higher diversity of larval fish in the diffuse water mass influence the final recruitment of fish in the Beaufort Sea's ecosystem.

4.4 SECONDARY PRODUCTION AND GROWTH (GROWTH OF LARVAL FISH - ADVANTAGE OF THE PLUME)

Fish biomass provides useful information for evaluating fish population and fish habitat productivity (Randall and Minns 2000). It is also used as an ecological indicator to provide information on the trophic structure (Sosa-López et al. 2005). In this study, the total larvae biomass (mg 100 m^{-3}) was used to examine the productivity of the three water masses during the study period. The calculation of biomass may provide insight on larval fish aggregation based on their size differences rather than on the number of fish counts. Larval fish biomass in the oceanic water masses was consistently higher in both July and August than it was in the diffuse and intense plume water masses. Increase in the average weight of individual fish suggests fish growth is occurring in the water mass during the summer. In contrast, the diffuse plume water masses had a higher biomass than the intense plume, but these were observed only in July. This result is due to the fact that although *B. saida* was one of the two dominant species found in the study, it was found less frequently in the August diffuse plume station samples, thus affecting its contribution

to the total observed biomass. For the intense plume, there was no increase in biomass as summer progressed, thus indicating moderate production for larval fish, which thrived in this plume environment. This environment was therefore tolerated mostly by the dominant species *C. pallasii pallasii* and the sub-family Lumpeninae at a lower salinity level. Overall, the total larval fish biomass results revealed that there is no significant advantage in the diffuse and intense plumes; thus, higher larval fish production was not observed within these areas.

Moreover, large river plume studies in the southern climate regions have hypothesized and observed that the concentration of zooplankton abundances is consistently greater across the plume front than it is in the adjacent waters. In that case, it was used to account for the higher concentrations of fish larvae at the frontal zone due to the higher abundance of food and convergence (e.g., Govoni et al. 1989; Grimes and Finucane 1991; Kingsford and Suthers 1994), as previously described in the introduction. However, in the current study, no significant relationship was observed between zooplankton and the fish larvae biomass. Also, no relationship was found between the zooplankton abundance and the fish larvae density for any of the water masses. Zooplankton biomass was not significantly higher in the oceanic water mass, and was similar in all these water masses. This implies that the high concentration of zooplankton food supply for larval fish is not concentrated to any specific water mass, but varies in distribution. Although there is no aggregation at the plume frontal regions, it is important to recognize that there are three different zooplankton assemblages related to the water masses identified in this study region (Walkusz et al. 2010). Walkusz et al. (2010) indicated that at the frontal zone, a co-existence of freshwater and marine zooplankton

taxa were found, which included Copepoda nauplii, Polychaeta larvae, *Pseudocalanus* and *Limnocalanus macrurus*. Zooplankton at the intense plume grouping was composed of smaller copepods that were freshwater tolerant; they included *Podon leuckarti*, Copepoda nauplii and *Pseudocalanus* spp. Finally, zooplankton at the oceanic grouping was mainly marine taxa of *Calanus glacialis*, *C. hyperboreus*, *Triconia* (*Oncea*) *borealis* and *Microcalanus* spp.

The present study did not directly observe the food enhancement at the plume frontal areas; further data collection is necessary to verify this assessment. However, when the size differences for *B. saida* across the three water masses were observed, the intense plume stations contained the smallest amount of *B. saida* larvae, and were demonstrated to have the smallest standard length compared to the oceanic and diffuse plume water masses. This smaller size may suggest poor growth conditions, and it is likely due to the *B. saida* not adjusting to the low salinity and high freshwater tolerance. Ponton et al. 1993 found *B. saida* in higher numbers when salinity level exceeded 25 PSU Studies have indicated that larval fish may have selective behaviour for habitat preferences, and this behavior is intended to increase their chances of survival (Norcross and Shaw 1984). Ponton et al. (1993) reported that *B. saida* larvae dispersions were highest in salinities that exceeded 25 PSU. Craig et al. (1982) had reported that *B. saida* in the Simpson Lagoon (Alaska) can cope with a wide range of salinities, but concluded that *B. saida* abundance increased as salinities increased. Thus, the majority of *B. saida* that had the longest standard length were found in the oceanic water mass stations where the water depths were greater than 30 m and the salinity levels ranged between 23 to 32 PSU (Table 4). The larger size is not unexpected, as *B. saida* were found mostly during their

postflexion stage of development, which is the final phase before entering the juvenile stage. Food source depends on prey availability and size. Walkusz et al. (2011) revealed that postlarval *B. saida* fish feed mainly on copepoda nauplii and bivalvia veligers, but larger marine copepods such as *Pseudocalanus* spp. and *Calanus glacialis* are also their principle food source. Thus, this suggests that growth conditions were better in oceanic water masses for *B. saida,* as found within this study.

A steady progression of growth for *B. saida* was also revealed from July to August. The preflexion stage was mostly observed in the early part of July, while the postflexion stage was observed closer to August. This showed an increased size of fish recruiting into the adult populations. The development stages also correlate with the spawning time of *B. saida* in the Beaufort Sea, which is reported to take place from late November to early February (Craig et al. 1982).

No differences in the zooplankton biomass were observed in the different water masses. However, the water masses were observed to support different levels of growth for key species. The presence of different zooplankton assemblages, which were composed of different sizes, may explain some of the observed differences in growth and may explain why there was no observed relationship between the total zooplankton biomass and total larval fish biomass for the water masses.

4.5 EBSA EVALUATION

Canada's Ecologically and Biologically Significant Areas (EBSAs) under the Oceans Act provide guidelines to determine which areas in the Beaufort Sea should be carefully

managed. EBSA is not a legally binding management tool like the Marine Protected Area which Fisheries and Oceans use; instead, it is a useful tool to enhance protection and draw attention to an area that has significant importance (DFO 2004). The significant importance of an area is determined by evaluating how the area contributes to the ecological or biological functioning of the ecosystem. For example, a particular area of significance can be based on the fact that a fish species utilizes the area for part of its life history function (DFO 2004). If an area has been identified under EBSAs, appropriate ecosystem management would be warranted.

Under the management tool of EBSA, a physical boundary has to be drawn in order to provide enhanced protection. In 2007, DFO led the selection processes to identify EBSAs within the Beaufort Sea's Large Ocean Management Area (LOMA), which resulted in the Mackenzie Plume in the Kugmallit Corridor being one of the EBSA candidates. This identification was agreed upon by the scientific community and local stakeholders from the Inuvialuit Settlement Region Areas. Kugmallit Corridor is located north of Kittigazuit Bay to the Kugmallit Valley at a water depth of 50 m. Results from the present study suggest defining the boundary of such an EBSA would be difficult because of the lack of a clearly defined and consistent plume front. It is difficult to develop a conservation strategy for an area that keeps moving and changing, because the direction of the plume is reflected by the movement of the wind and current. The lack of a permanent plume structure would make defining a boundary for an EBSA on an Area bases challenging.

Although defining a boundary for a Mackenzie Plume would be a challenge, the question remains: Does this feature otherwise meet any of the dimensions identified by DFO for

an EBSA? This study assessed the DFO EBSA dimensions of aggregation, uniqueness, and fitness consequences in the context of larval fish ecology. This was done because many studies on the effects of large or small scale oceanographic plume features have indicated that these features are of importance in the ecology of larval fish. An initial analysis of ESBAs in the Beaufort Sea LOMA (Paulić et al. 2009) hypothesized that the Mackenzie Plume was an EBSA, based in part on the assumption the plume was associated with an aggregation of larval fish and was a larval fish nursery area. In the present study, data does not support that the Mackenzie River plume represents a high abundance of the total number of larval fish aggregating at the plume area or a high abundance for the total of individual species. Despite this, the highest diversity was in the diffuse water mass, which further supports the uniqueness of the Mackenzie River plume under the EBSA concept.

Uniqueness is another dimension under the EBSA concept for the integrated management approach to protect ocean areas. Physically, the Mackenzie River plume is a unique feature that adds complexity to the coastal dynamics by providing nutrients, sediments, organic matter, and phytoplankton to the Beaufort Sea shelf (Carmack and Macdonald 2002). In terms of uniqueness for larval fish species diversity, the Mackenzie River plume did demonstrate higher fish diversity compared to the oceanic water and intense plume water masses. The diversity included rare species such as Liparis species (i.e., *Liparis tunicatus*, *Liparis fabricii*, and *Liparis gibbus*) and *Ulcina olrikii*, which were mostly found within the oceanic and diffuse plume water masses. From the literature, it is reported that the adult Liparis species utilize bottom habitats: *Liparis tunicatus* inhabits in kelp areas and prefers rocky (e.g., pebbles, stones or boulders), muddy, and sandy

bottoms (Robins and Ray 1986); *Liparis fabricii* inhabits the muddy bottoms (Scott and Scott 1988) and *Liparis gibbus* prefers to inhabit seaweeds or rocky bottoms (Scott and Scott 1988). *Ulcina olrikii* and Liparis species share a common habitat, as they are benthic species (Coad and Reist 2004) that prefer to be in sandy and muddy bottoms. However, the present study was not able to determine how these rare species are utilizing the plume area, as they were found in the diffuse plume water mass areas. Thus, in future research, the life cycle for these species should be investigated in order to determine the recruitment role that the plume has on their life history.

Under the fitness consequences of the EBSA assumption, one would expect the Mackenzie Plume to provide conditions for increased growth or biomass. The Mackenzie River plume did not show a significant advantage for growth at the diffuse plume water mass and within the vicinity of the intense plume water mass compared to what the oceanic water mass showed.

In the present study, the Mackenzie River plume was not found to provide a high productive larval fish community, as described in the EBSA workshop in 2007; however, it did raise questions of the role of the plume. One question is to determine the larval fish recruitment to adult population. Thus, the role of fish ecology and the understanding of the fish life cycle are beyond the scope of this study. Further studies are needed to investigate the different fish species that utilize the plume environment.

CHAPTER 5: CONCLUSIONS

The observations from this study indicate that the Mackenzie River plume is a complex system in which a clear distinct diffuse plume water mass boundary (i.e., plume front) is difficult to detect. This is difficult because through wind mixing, along with upwelling and down welling events, the diffuse plume water mass becomes a flexible non-permanent boundary. For this reason, the simple concept of identifying the three water masses across the plume gradient is not easily defined for the Mackenzie River plume. However, one cannot argue the fact that the Mackenzie River plume creates a dynamic system on the coastal areas of the Beaufort Sea. The Mackenzie River runoff cycle affects the shelf oceanography (Carmack and Macdonald 2002), and the plume characteristic is dependent on the precondition set by the year before; that is, the amount of snow and the material elements of the Mackenzie River drainage system (Brunskill 1986). Therefore, in the summer, the Mackenzie River provides different amount of nutrients, sediments, and organic matter to the shelf. Every summer, anadromous fish, sea-birds, and marine mammals are known to utilize the coastal shelf area.

In general, the concept of the plume is important to the coastal area. However, the idea of delivering high density larval fish aggregation at the plume front does not always hold true, as is the case with the Mackenzie River plume. This study did not find direct evidence of marine larval fish benefiting from the plume environment during their early life cycle. The timeframe for the marine larval fish to enter the nearshore to feed and grow during the open water season is quite narrow. Therefore, if they were to benefit

from the plume by gaining survival advantage, there would be significant growth at the frontal zone.

Although this study does not answer all the questions about the biology and ecology of marine larval fish in the nearshore areas, it does add to the understanding of the habitat utilization and fish composition in the area. Geographically, this study has shown that the distribution of larval fish indicates that larval fish drift inshore and utilize the diffuse plume vicinity. This results in three assemblages that were identified in this study. The oceanic assemblage was dominated by Arctic cod (*Boreogadus saida*), the diffuse assemblage was dominated by the sub-family Lumpeninae, and the intense plume was dominated by the Pacific herring (*Clupea pallasii pallasii*).

Furthermore, this study prompts an open dialogue and encourages others to continuously look at the relationships of the physical, chemical, and biological components between fish and their habitats, and between fish and planktonic communities (e.g., meso-zooplankton species). Given the importance of the Mackenzie River Plume to the Beaufort Sea's nearshore environment, a greater understanding of the ecology of each individual fish is warranted. To fulfill this need, priority should be given to rare species that are important to the ecosystem, but about which we have no available information. Further research should be conducted in the following areas: (1) A study of how the behaviour of different fish responses differs within the plume, to provide further insight on different fish ecology. (2) A survey of the structure and role of rare species like Liparis and *Ulcina orlikii,* to provide knowledge of their ecology. (3) A study that looks at the plume conditions before spring break up, during break up and at freeze up for all

the marine larval fish species. This study is needed because fish aggregation and community might have changed, depending on the precondition of the plume the year before.

EBSA monitoring concept

One consequence that emerges from the study is the difficulty of defining the plume front. The concept of the three water masses is not as simple as it seems. Thus, the conservation strategy of EBSA based on defining a boundary can be difficult to monitor in the case of the plume, since quantitatively, the spread of the Mackenzie River plume can encompass a large area and also cover different ranges, depending on the wind movements. The identification of the Mackenzie River plume as a candidate for an EBSA in 2007 is a step in the right direction for monitoring critical habitats. However, the approach of site-specific management may be too early at this stage for larval fish monitoring. Current study results suggest that the Mackenzie River plume might be identified as an EBSA for larval fish based on uniqueness, but not on aggregation and ecological fitness, as previously thought.

Despite the complex nature of the habitat, three larval fish assemblages were identified across the plume area. Sufficient evidence was found to suggest that the plume system might support unique fish larval assemblage and may therefore be considered an EBSA. Prior to designating the plume as an EBSA, it will necessary to assess the degree to which larval fish from the plume assemblage are recruited into the adult population.

REFERENCES

Alaska Fisheries Science Center. 2010. Ichthyoplankton Information System. Resource Assessment and Conservation Engineering Division, 7600 Sand Point Way NE, Seattle, WA 98115. Web address: http:// access.afsc.noaa.gov/ichthyo/index.cfm. Access date: January 26, 2010.

Albaina, A. and Irigoien, X. 2004. Relationships between frontal structures and zooplankton communities along a cross-shelf transect in the Bay of Biscay (1995 to 2003). Mar. Ecol. Prog. Ser. 284: 65–75.

Anderson, P. J. and Piatt, J. F. 1999. Community Reorganization in the Gulf of Alaska following ocean climate regime shift. Mar. Ecol. Prog. Ser. 189: 117–123.

Andriyashev, A. P. 1954. Fishes of the northern seas of the U.S.S.R., Translated from the Russian edition of 1954. Jerusalem, Israel Program for Scientific Translations and the United States Department of Commerce, 617 p.

Aronovich, T. M., Doroshev, S. I., Spectorov, L. V., and Makhotin, V. M. 1975. Egg incubation and larval rearing of navaga (Eleginus navaga Pall.), polar cod (Boreogadus saida Lepechin) and arctic flounder (Liopsetta glacialis Pall.) in the laboratory. Aquaculture 6: 233–242.

Bagenal, T. B. and Braum, E. 1978. Eggs and early life history. *In* Bagenal, T. B. (ed.) Methods for assessment of fish production in fresh waters. Blackwell Scientific Publications, Oxford, 165–201 p.

Bailey, K. M., and Houde, E. D. 1989. Predation on Eggs and Larvae of Marine Fishes and the Recruitment Problem. Adv. Mar. Biol. 25: 1–83.

Beck, M. W., Heck Jr., K. L., Able, K. W., Childers, D. L., Eggleston, D. B., Gillanders, B. M., Halpern, B. S., Hays, C. G., Hoshino, K., Minello, T. J., Orth, R. J., Sheridan, P. F. and Weinstein, M. P. 2001. The Identification, Conservation, and Management of Estuarine and Marine Nurseries for Fish and Invertebrates. BioScience 51(8): 633–641.

Beck, M. W., Heck Jr., K. L, Able, K. W., Childers, D. L., Eggleston, D. B., Gillanders, B. M., Halpern, B. S., Hays, C. G., Hoshino, K., Minello, T. J., Orth, R. J.,Sheridan, P. F. and Weinstein, M. P. 2003. The Role of Nearshore Ecosystems as Fish and Shellfish Nurseries. Issues in Ecology No.11.

Belkin, I. M. and Cornillon, P. C. 2007. Fronts in the World Ocean's Large Marine Ecosystems. International council for the Exploration of the Sea (ICES).

Blaxter, J. H. S. and Hempel, G. 1963. The influence of egg size on herring larvae (*Clupea harengus L.*). J. Cons. Int. Explor. Mer. 28: 211–244.

Bond, W. A. 1982. A study of the fish resources of Tuktoyaktuk Harbour, southern Beaufort Sea coast, with special reference to life histories of anadromous coregonids. Can. Tech. Report. Fish. Aquat. Sci. 1119: vii+90.

Bouchard, C. and Fortier, L. 2008. Effects of polynyas on the hatching season, early growth and survival of polar cod Boreogadus saida in the Laptev Sea. Mar. Ecol. Prog. Ser. 355: 247–256.

Bowman, M. J. 1988. Estuarine fronts. *In* B. J. Kjerfve (ed.) Hydrodynamics of Estuaries. CRC Press, Boca Raton, FL, 85–132 p.

Bowman, M. J. and Iverson, R. I. 1978. Estuarine and plume fronts. *In* Bowman, M. J. and Esaias, W. F. (eds.) Oceanic fronts and coastal processes. Springer-Verlag, Berlin, 87–104 p.

Bradstreet, M. S. W., Finley, K. J., Sekerak, A. D., Griffiths, W. B., Evans, C. R., Faijan, M. F. and Stallard, H. E. 1986. Aspects of the biology of Arctic cod (*Boreogadus saida*) and its importance in Arctic marine food chains. Can. Tech. Report. Fish. Aquat. Sci. 1491: i–193.

Brodeur, R. D., Busby, M. S. and Wilson, M. T. 1995. Summer distribution of early life stages of walleye Pollock, *Theragra chalcogramma*, and associated species in the western Gulf of Alaska. Fish. B-NOAA. 93: 603–618.

Brunskill, G. J. 1986. Environmental features of the Mackenzie system. *In* Davis, B. R. and Walker, W. F. (eds.) The ecology of river systems. Dr. W. Junk Publications, Dordecht, The Netherlands, 435–471 p.

Carmack, E. C., Macdonald, R. W., and Papakis, J. E. 1989. Water mass structure and boundaries in the Mackenzie Shelf Estuary. J. Geophy. Res. 94: 18043–18055.

Carmack, E. C. and Macdonald, R. W. 2002. Oceanography of the Canadian Shelf of the Beaufort Sea: A Setting for Marine Life. Arctic 55(1): 29–45.

Carmack, E. C., Macdonald, R. W. and Jasper, S. 2004. Phytoplankton productivity on the Canadian Shelf of the Beaufort Sea. Mar. Ecol. Prog. Ser. 277: 37–50.

Chant, R. J., Wilkin, J., Zhang, W., Choi, B. J., Hunter, E., Castelao, R., Glenn, S., Jurisa, J., Shofield, O., Houghston, R., Kohut, J., Frazer, T. K. and Moline, A. M. Dispersal of the Hudson River plume in the New York Bight. The Oceanography Society 21(4).

Chiperzak, D. B., Hopky, G. E., Lawrence, M. J., Schmid, D. F. and Reist, J. D. 2003a. Larval and Post-Larval Fish Data from the Canadian Beaufort Sea shelf, July to September, 1985. Can. Data. Rep. Fish. Aquat. Sci. 1119: iv +116p.

Chiperzak, D. B., Hopky, G. E., Lawrence, M. J., Schmid, D. F. and Reist, J. D. 2003b. Larval and post-larval fish data from the Canadian Beaufort Sea shelf, July to September, 1986. Can. Data. Rep. Fish. Aquat. Sci. 1120: iv +153p.

Chiperzak, D. B., Hopky, G. E., Lawrence, M. J, Schmid, D. F. and Reist, J. D. 2003c. Larval and post-larval fish data from the Canadian Beaufort Sea shelf, July to September, 1987. Can. Data. Rep. Fish. Aquat. Sci. 1121: iv + 84pp.

Clarke, K. R. and Warwick, R. M. 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation, 2nd Edition. PRIMER-E Ltd., Phymouth, U.K.

Coad, B. W. and Reist, J. D. 2004. Annotated list of the Arctic Marine Fishes of Canada. Can. Manuscr. Rep. Fish. Aquat. Sci. 2674: iv +112 p.

Cobb, D., Fast, H., Papst, M. H., Rosenberg, D., Rutherford, R. and Sareault, J. E. 2008. Beaufort Sea Large Ocean Management Area: Ecosystem Overview and Assessment report. Can. Tech. Rep. Fish. Aquat. Sci. 2780.

Cowen, R. K., Hare, J. A. and Fahay, F. P. 1993. Beyond hydrography: Can physical processes explain larval fish assemblages within the middle Atlantic Bight? B. Mar. Sci. 53(2): 567–587.

Craig, P. C. 1984. Fish use of coastal waters of the Alaskan Beaufort Sea: A Review. Trans. Am. Fish. Soc. 113: 265–282.

Craig, P. C., Griffiths, W. B., Haldorson, L. and McElderry, H. 1982. Ecological Studies of Arctic Cod (*Boreogadus saida*) in Beaufort Sea coastal waters, Alaska. Can. J. Fish. Aquat. Sci. 39: 395–406.

Cushing, D. H. 1972. The production cycle and the number of marine fish. Sym. Zool. Soc. London 29: 213–232.

Cushing, D. H. 1975. Marine Ecology and Fisheries. Cambridge University Press, New York, 278 p.

Cushing, D. H. 1990. Plankton production and year-class strength in fish populations: an update of the match/mismatch hypothesis. Adv. Mar. Biol. 26: 249–293.

Dagg, M., Benner, R., Lohrenz, S. and Lawrence, D. 2004. Transformation of dissolved and particulate materials on continental shelves influenced by large rivers: plume processes. Cont. Shelf Res. 24: 833–858.

Dayton, P. K., Mordida, B. J. and Bacon, F. 1994. Polar Marine Communities. Amer. Zool. 34: 90–99.

De Robertis, A., Morgan, C. A., Schabetsberger, R. A., Zabel, R. W., Brodeur, R. D., Emmett, R. L., Knight, C. M., Krutzikowsky, G. K. and Casillas, E. 2005. Columbia River plume fronts. II. Distribution, abundance, and feeding ecology of juvenile salmon. Mar. Ecol. Prog. Ser. 299: 33–44.

DFO 2004. Identification of Ecologically and Biologically Significant Areas. DFO Can. Sci. Advis. Sec. Ecosystem Status Rep. 2004/006.

Dickson, D. L. and Gilchrist, H. G. 2002. Status of marine birds of the southeastern Beaufort Sea. Arctic 55 (Supp. 1): 46–58.

Dittmar, T. and Kattner, G. 2003. The biogeochemistry of the river and shelf ecosystem of the Arctic Ocean: a review. Mar. Chem. Chemistry 83: 103–450.

Doyle, M. J. Morse, W. W. and Kendall Jr., A. W. 1993. A Comparison of Larval Fish Assemblages in the Temperate Zone of the Northeast Pacific and Northwest Atlantic Oceans. Bulletin of Marine Science 53(2): 588–644.

Doyle, M. J., Rugen, W. C. and Brodeur, R. D. 1995. Neustonic ichthyoplankton in the western Gulf of Alaska during spring. Fish. B-NOAA. 93: 231–253.

Dunn, J. R. and Matarese, A. C. 1984. Gadidae: Development and Relationships. *In* Moser, H. G., Richards, W. J., Cohen, D. M., Fahay, M. P., Kendall Jr, A. W. and Richardson, S. L. (eds.) Ontogeny and systematics of fishes. Spec. Publ. 1, Am. Soc. Ichthyol. Herpetol., p. 283-299. Allen Press, Lawrence, KS, 760 p.

Dunton, K. H., Weingarter, T., Carmack, E. C. 2006. The nearshore western Beaufort Sea ecosystem: Circulation and importance of terrestrial carbon in arctic coastal food webs. Prog. Oceanogr. 71: 362–378.

Epifanio, C. E. and Garvine, R. W. 2001. Larval Transport on the Atlantic Continental Shelf of North America: a Review. Estuar. Coast. Shelf. S. 52: 51–77.

Faber, D. J. 1976. Identification of Four Northern Blennioid Fish Larvae in the Canadian Atlantic Ocean (Stichaeidae, Lumenidae). J. Fish. Res. Board Can. 33: 1798–1802.

Fager, E. W. 1957. Determination and Analysis of recurrent groups. Ecology 38(4): 586–595.

Fahay, M. P. 2007a. Early stages of fishes in the Western North Atlantic Ocean, Northwest Atlantic Fisheries Organization, Dartmouth, Nova Scotia, Canada, Vol I, 935 p.

Fahay, M. P. 2007b. Early stages of fishes in the Western North Atlantic Ocean, Northwest Atlantic Fisheries Organization, Dartmouth, Nova Scotia, Canada, Vol II, 1696 p.

Fahay, M. P., and Markle, D. F. 1984. Gadiformes: Development and relationships. *In* Moser, H. G., Richards, W. J., Cohen, D. M., Fahay, M. P., Kendall Jr, A. W. and Richardson, S. L. (eds.) Ontogeny and systematics of fishes. Spec. Publ. 1, Am. Soc. Ichthyol. Herpetol., p. 265–283. Allen Press, Lawrence, KS, 760 p.

Filippino, K. C., Bernhardt, P. W., and Mulholland, M. R. 2009. Chesapeake Bay Plume Morphology and the Effects on Nutrient Dynamics and Primary Productivity in the Coastal Zone. Estuar. Coast 32: 410–424.

Fissel, D. B., Bradstreet, M. S. W. and Moen, J. 1987. Water Mass Distributions in the Canadian Beaufort Sea. The Ocean - An International Workplace, Halifax, NS, 910–916 p.

Foreman, M. G. G., Lee, D. K., Morrison, J., Macdonald, S., Barnes, D. and Williams, I. V. 2001. Simulations and retrospective analyses of Fraser watershed flows and temperatures. Atmos. Ocean. 39(2): 89–105. DOI: 10.1080/07055900.2001.9649668.

Fortier, L., Sirois, P., Michaud, J., and Barber, D. 2006. Survival of Arctic cod larvae (*Boreogadus saida*) in relation to sea ice and temperature in the Northeast Water Polynya (Greenland Sea). Can. J. Fish. Aquat. Sci. 63: 1608–1616.

Frank, K. T., and Leggett, W. C. 1982. Environmental regulation of growth rate, efficiency, and swimming performance in larval capelin (Mallotus villosus), and its application to the match/mismatch hypothesis. Can. J. Fish. Aquat. Sci. 39: 691–699.

Franks, P. J. S. 1992. Sink or swim: accumulation of biomass at fronts. Mar. Ecol. Prog. Ser. 82: 1–12.

Frost, K. J. and Lowry, L. F. 1984. Trophic relationships of vertebrate consumers in the Alaskan Beaufort Sea. *In* Barnes, P. W. et al. (eds.) The Alaskan Beaufort Sea: ecosystems and environments. Academic Press, Orlando, FL, 381–401 p.

Fukuwaka, M. and Suzuki, T. 1998. Role of a riverine plume as a nursery area for chum salmon Oncorhynchus keta. Mar. Ecol. Prog. Ser. 173: 289–297.

Garvine, R. W. 1977. River Plumes and Estuary Fronts. *In* Estuaries, Geophysics and the Environment. National Academy of Sciences, Washington, DC, 30–35 p.

Garvine, R. W. 1987. Estuary Plumes and Fronts in Shelf Waters: A Layer Model. J. Phys. Oceanogr. 17: 1877–1896.

Garvine, R. W., and Monk, J. D. 1974. Frontal Structure of a River Plume. J. Geophys. Res. 79(15): 2251–2259.

Gilbert, M., Fortier, L., Ponton, D., and Drolet, R. 1992. Feeding ecology of marine fish larvae across the Great Whale River plume in seasonally ice-covered southeastern Hudson Bay. Mar. Ecol. Prog. Ser. 84: 19–30.

Gillman, D. V. and Kristofferson, A. H. 1984. Biological data on Pacific herring (*Clupea harengus pallasi*) from Tuktoyaktuk Harbour and the Liverpool Bay area, Northwest Territories, 1981 to 1983. Can. Data Rep. Fish. Aquat. Sci. 485: iv+22p.

Gjøsæter, H. and Ajiad, M. A. 1993. Growth of polar cod, *Boregadus siada* (Lepechin), in the Barents Sea. ICES J. Mar. Sci. 51(1): 115–120.

Govoni, J. J. 2005. Fisheries oceanography and the ecology of early life histories of fishes: a perspective over fifty years. Sci. Mar. 69 (Suppl. 1): 125–137.

Govoni, J. J. and Grimes, C. B. 1992. The surface accumulation of larval fishes by hydrodynamic convergence within the Mississippi River plume front. Cont. Shelf Res. 12: 1265–1276.

Govoni, J. J., Hoss, D. E., and Colby, D. R. 1989. The spatial distribution of larval fishes about the Mississippi River plume. Limnol. Oceanogra. 34(1): 178–187.

Grigor'yev, S. S. 1992. Larvae of Three Species of Lumpenids (*Anisarchus medius, Lumpenus fabricii, Leptoclinus maculatus*) from Kamchatka. Voprosy iktiologii. 32(2): 172–176.

Grimes, C. B. and Finucane, J. H. 1991. Spatial distribution and abundance of larval and juvenile fish chlorophyll and macrozooplankton around the Mississippi River discharge plume and the role of the plume in fish recruitment. Mar. Ecol. Prog. Ser. 75: 109–119.

Grimes, C. B. and Kingsford, M. J. 1996. How do Riverine Plumes of Different Sizes Influence Fish Larvae: do they Enhance Recruitment? Mar. Freshwater Res. 47: 191–208.

Grothues, T. M. and Cowen, R. K. 1999. Larval fish assemblages and water mass history in a major faunal transition zone. Cont. Shelf Res. 19: 1171–1198.

Harwood, L. A. and Smith, T. G. 2002. Whales of the Inuvialuit Settlement Region in Canada's Western Arctic: An Overview and Outlook. Arctic 55 (Supp. 1): 77–93.

Hill, M. O. 1973. Diversity and Evenness: A Unifying Notation and Its Consequences. Ecology 54: 427–432.

Hopky, G. E. 1990. Chapter 5: Seasonal Salinity, Temperature and Density Data for the Canadian Beaufort Sea Shelf. *In* Meyer, R.M. and Johnson, T.M. Fisheries Oceanography A comprehensive Formulation of Technical Objectives for Offshore Application in the Arctic, Workshop Proceedings April 5-6, 1988, Sheraton Anchorage Hotel, Anchorage, Alaska. Anchorage, Alaska : Alaska OCS Region, Minerals Management Service, U.S. Dept. of the Interior. OCS Study MMS 88-0042. 25–29 p.

Hopky, G. E. and Ratynski, R. A. 1983. Relative Abundance, spatial and temporal distribution, age and growth of fishes in Tuktoyaktuk Harbour, N.W.T., 28 June to 5 September, 1981. Can. Data. Rep. Fish. Aquat. Sci. 1713: v +70 p.

Hopky, G. E., Chiperzak, D. B. and Lawrence, M. J. 1994. NOGAP B2; Zooplankton, and Larval and Post Larval Fish Data from Tuktoyaktuk Harbour, N.W.T., 1984–1987. Can. Data. Rep. Fish. Aquat. Sci. 945: v +117 p.

Ingram, R. G. 1981. Characteristics of the Great Whale River Plume. J. Geophy. Res. 86(C3): 2017–2023.

Kendall Jr., A. W., Ahlstrom, E. H. and Moser, H. G. 1984: Early life history stages of fishes and their characters. *In* Moser, H. G., Richards, W. J., Cohen, D. M., Fahay, M. P., Kendall Jr., A. W. and Richardson, S. L. (eds.) Ontogeny and systematics of fishes. Spec. Publ. 1, Am. Soc. Ichthyol. Herpetol. 11–22 p.

Kendall Jr., A. W. and Dunn, J. R. 1985. Ichthyoplankton of the Continental Shelf Near Kodiak Island, Alaska. NOAA Techincal Report NMFS 20. U.S. Department of Commerce: National Oceanic and Atmospheric Adminstration.

Kingsford, M. J. and Suthers, I. M.1996. The influence of Tidal Phase on Patterns of ichthyoplankton Abundance in the Vicinity of an Estuarine Front, Botany Bay, Australia. Estuarine, Coastal and Shelf Science 43: 33–54.

Krebs, C. J. 1998. Ecological methodology, Second Edition. Benjamin /Cummings Menlo Park, California, 620 p.

Lande, R. 1996. Statistics and Partitioning of Species Diversity and Similarity among Multiple Communities. Oikos. 76: 5–13.

Lara-Lopez, A. and Neira, F. J. 2008. Synchronicity between zooplankton biomass and larval fish concentrations along a highly flushed Tasmanian estuary: assessment using net and acoustic methods. J. Plankton Res. 30(9): 1061–1073.

Largier, J. L. 1993. Estuarine fronts: How important are they? *In* Largier, J. L. (ed.) Estuarine Fronts – Hydrodynamics, Sediment Dynamics and Ecology. Estuaries 16(1): 1–11.

Leenheer, J. 1982. United States Geological Survey data information service. *In* Degens, E. T. (ed.) Transport of Carbon and Minerals in Major World Rivers, Pt. 1. Mitt. Geol.-Palaont. Inst. Univ. Hamburg, SCOPE/UNEP Sonderbd. 52: 355–356.

Le Fèvre, J. 1986. Aspects of the biology of the frontal systems. Adv. Mar. Biol. 23: 164–281.

Lobel, P.S. and Robinson, A. R. 1986. Transport and entrapment of fish larvae by ocean mesoscale eddies and currents in Hawaiian waters. Deep Sea Research A: Oceanographic Research Papers 33: 483–500.

Lohrenz, S. E., Dagg, M. J., Whitledge, T. E. 1990. Enhanced primary production at the plume/oceanic interface of the Mississippi River. Cont. Shelf. Res. 10: 639–664.

Lohrenz, S. E., Fahnenstiel, G. L., Redalje, D. G., Lang, G. A., Chen, X., Dagg, M. J. 1997. Variations in primary production of northern Gulf of Mexico continental shelf waters linked to nutrient inputs from the Mississippi River. Mar. Ecol. Prog. Ser. 155: 435–454.

Lønne, O. J. and Gulliksen, B. 1989. Size, Age and Diet of Polar Cod, *Boregadus saida* (Lepechin 1773), in Ice Covered Waters. Polar Biol. 9: 187–191.

Macdonald, R. W. 2000. Arctic estuaries and ice: a positive-negative estuarine couple. *In* Lewis, E.L. (ed.) The Freshwater Budget of the Arctic Ocean. Kluwer Academic Publishers, Dordrecht, MA, 383–407 p.

Macdonald, R. W., Wong, C. S. and Erickson, P. E. 1987. The Distribution of Nutrients in the Southeastern Beaufort Sea: Implications for Water Circulation and Primary Production. J. Geophys. Res. 92(C3): 2939–2952.

Macdonald, R. W., Carmack, E. C., McLaughlin, F. A., Iseki, K., Macdonald, D. M. and O'Brien, M. O. 1989. Composition and modification of water masses in the Mackenzie Shelf Estuary. J. Geophys. Res. 94 (C12): 18057–18070.

Macdonald, R. W., Solomon, S. M., Cranston, R. E., Welch, H. E., Yunker, M. B. and Gobeil, C. 1998: A sediment and organic carbon budget for the Canadian Beaufort Shelf. Mar. Geol. 144: 255–273.

Macdonald, R. W., Naidu, A. S., Yunker, M. B. and Gobeil, C. 2004. The Beaufort Sea: Distribution, Sources, Fluxes and Burial of Organic Carbon. *In* Stein, R. and Macdonald, R. W. (eds) The Organic carbon cycle in the Arctic Ocean. Springer, 177–192 p.

Majewski, A. R., Reist, J. D., Sareault, J. E., Park, B. J. and Lowdon, M. K. 2009. Fish Catch Data from Offshore Sites in the Mackenzie River Estuary and Beaufort Sea

During the Open Water Season, July and August 2005 Aboard the CCGS Nahidik. Can. Data. Rep. Fish. Aquat. Sci. 1204: vii +53p.

Marancik, K. E., Clough, L. M., and Hare, J. A. 2005. Cross-shelf and seasonal variation in larval fish aseemblages on the southeast United States continental shelf off the coast of Georgia. Fish. B-NOAA 103: 108–129.

Matarese, A. C., Kendall Jr., A. W., Blood, D. M. and Vinter, B. M. 1989. Laboratory guide to the early life history stages of Northeast Pacific fishes. U.S. Dep. Commer., NOAA Tech. Rep., NMFS 80, 652 p.

McAllister, D. E. 1975. Ecology of the marine fishes of Arctic Canada. Proceedings of Circumpolar conference on northern Ecology II. National Museum of Natural Sciences, Ottawa, 49–65 p.

McAllister, D.E. 1990. A list of the fishes in Canada. Syllogues 64, National Museum of Natural Sciences. Ottawa, Ontario.

McAllister, D. E., Anderson, M. E. and Hunter, J. G. 1981. Deep-water eelpouts, Zoarcidae, from Arctic Canada and Alaska. Canadian Journal of Aquatic Science 38: 821–839.

Meade, R. H. 1996. River-sediment inputs to major deltas. *In* Milliman, J., Haq, B. (eds.) Sea-Level Rise and Coastal Subsidence. Kluwer, London, 63–85 p.

Moser, H. G. and Smith, P. E. 1993. Larval Fish Assemblages of the California Current Region and Their Horizontal and Vertical Distributions Across A Front. B. Mar. Sci. 53(2): 645–691.

Moser, H. G., Richards, W. J., Cohen, D. M., Fahay, M. P., Kendall Jr., A. W. and Richardson, S. L. (ed.). 1984. Ontogeny and systematics of fishes. Am. Soc. Ichthyol. Herpetol. Spec. Publ. I. 760 p.

Moser, H. G., Smith, P. E. and Eber, L. E. 1987. Larval fish in California current region, 1954-1960, a period of dynamic environmental change. CalCOFI Rep., Vol. XXVIII.

Munk, P., Hansen, B. W., Nielsen, T. G., and Thomsen, H. A. 2003. Changes in plankton and fish larvae communities across hydrographic fronts off West Greenland. J Plankton Res. 25(7): 815–830.

Mulligan, R. P., Perrie, W., and Solomon, S. 2010. Dynamics of the Mackenzie River plume on the inner Beaufort shelf during an open water period in summer. Estuarine, Coastal and Shelf Science 89: 214–220.

Nahrgang, J., Camus, L., Gonzalez, P., Goksøyr, A., Chistiansen, J. S. and Hop, H. 2009. PAH biomarker responses in polar cod (*Boreogadus saida*) exposed to benzo(a)pyrene. Aquat Toxicol. 94(4): 309–319.

Naidina, O. D. and Bauch, H. A. 2001. A Holocene pollen record from the Laptev Sea shelf, northern Yakutia. Global Planet. Change. 31 (1-4): 141–153.

Nash, J. D. and Moum, J. N. 2005. River plumes as a source of large amplitude internal waves in the ocean, in press, Nature.

Newton, G.M. 1996. Estuarine ichthyoplankton ecology in relation to hydrology and zooplankton dynamics in a salt-wedge estuary. Mar. Freshwater Res. 47:99–111.

Norcross, B. L. and Shaw, R. F. 1984. Oceanic and Estuarine Transport of Fish Eggs and Larvae: A Review. T. Am. Fish. Soc. 113: 153–165.

O'Brien, M., Macdonald R. W., Melling, H., Iseki, K. 2006. Particle Xuxes and geochemistry on the Canadian Beaufort Sea: implications for sediment transport and deposition. Cont. Shelf Res. 26:41–81.

O'Donnell, J. 1993. Surface Fronts in Estuaries: A Review. Estuaries 16(1): 12–39.

O'Donnell, J. and Garvine, R. W. 1983. A time dependent, two-layer frontal model of buoyant plume dynamics. Tellus 35A: 73–80.

Olson, D. B., Hitchcock, G. L., Mariano, A. J., Ashjian, C. J., Peng, G., Nero, R. W., Podestá, G. P. 1994. Life on the edge: marine life and fronts. Oceanography 7: 52–60.

Omori, M., and Ikeda, T. 1984. Methods in Marine Zooplankton Ecology. John Wiley & Sons, Inc., New York, 332 p.

Parsons, T. R., Webb, D. G., Dovey, H., Haigh, R., Lawrence, M. and Hopky, G. 1988. Production studies in the Mackenzie River-Beaufort Sea estuary. Polar Biol. 8: 235–239.

Parsons, T. R., Webb, D. G., Rokeby, B. E., Lawrence, M., Hopky, G. E. and Chiperzak, D. B. 1989. Autotrophic and heterotrophic production in the Mackenzie River/Beaufort Sea estuary. Polar Biol. 9: 261–266.

Paulić, J. E. 2009. Marine larval fish assemblages in the nearshore Canadian Beaufort Sea during July and August. M.Sc. Dissertation, University of Manitoba.

Paulić, J. E., Papst, M. H., and Cobb, D. G. 2009. Proceedings for the identification of ecologically and biologically significant areas in the Beaufort Sea Large Ocean Area. Can. Manuscr. Rep. Fish. Aquat. Sci. 46 p.

Percy, R. 1975. Fishes of the outer Mackenzie Delta. Beaufort Sea Project Technical Report No. 8., 50 p.

Percy, R., Eddy, W., and Munro, D. 1974. Anadromous and Freshwater fish of the outer Mackenzie Delta. Interim report of the Beaufort Sea Project Study, 51 p.

Peterson, J. O. and Peterson, W. T. 2008. Influence of the Columbia River plume (USA) on the vertical and horizontal distribution of mesozooplankton over the Washington and Oregon shelf. ICES J. Mar. Sci. 65: 477–483.

Ponton, D. and Fortier, L. 1992. Vertical distribution and foraging of marine fish larvae under the ice cover of southeastern Hudson Bay. Mar. Ecol. Prog. Ser. 81:215–227.

Ponton, D., Gagné, J. A. and Fortier, L. 1993. Production and dispersion of freshwater, anadromous, and marine fish larvae in and around a river plume in subarctic Hudson Bay, Canada. Polar Biol. 13: 321–331.

Randall, R.G. and Minns, C. K. 2000. Use of fish production per unit biomass ratios for measuring the productive capacity of fish habitats. Can. J. Fish. Aquat. Sci. 57: 1657–1667.

Reichert, J. M., Fryer, B. J., Pangle, K. L., Johnson, T. B., Tyson, J. T. Drelich, A. B., and Ludsin, S. A. 2010. Can. J. Fish. Aquat. Sci. 67: 987–1004.

Retamal, L., Bonilla, S. and Warwick, F. V. 2008. Optical gradients and phytoplankton production in the Mackenzie River and the coastal Beaufort Sea. Polar Biol. 31: 363–379. Doi:10.1007/s00300-007-0365-0.

Rissik, D. and Suthers, I. M. 1996. Feeding in a larval fish assemblage: the nutritional significance of an estuarine plume front. Mar. Biol. 125: 233–240.

Robins, C. R. and Ray, G. C. 1986. A field guide to Atlantic coast fishes of North America. Houghton Mifflin Company, Boston, U.S.A. 354 p.

Schlitzer, R. 2009. Ocean Data View. Version 3.4.4. http://odv.awi.de/

Scott, W. B. and Scott, M.G. 1988. Atlantic fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219, 731 p.

Sherman, K., Smith, W., Morse, W., Berman, M., Green, J. and Ejsymount L. 1984. Spawning strategies of fishes in relation to circulation, phytoplankton production, and pulses in zooplankton off the northeastern United States. Mar. Ecol. Prog. Ser. 18: 1–19.

Smetacek, V. S. 1986. Impact of freshwater discharge on production and transfer of materials in the marine environment. *In* Skeslet, S. (ed) The Role of Freshwater Outflow in Coastal Marine Ecosystemspp. Springer: Berlin, 85–106 p.

Sosa-Lopez, A., Mouillo, D., Chi, T. D., and Ramos-Miranda, J. 2005. Ecological indicators based on fish biomass distribution along trophic levels: an application to the Terminos coastal lagoon, Mexico. ICES J. Mar. Sci. 62: 453–458. Doi:10.1016/j.icesjms.2004.12.004.

Spielhagen, R. F., Erlenkheuser, H. and Siegert, C. 2005. History of freshwater runoff across the Laptev Sea (Arctic) during the last deglaciation. Global Planet. Change. 48: 187–207.

StatSoft, Inc. (2011). Electronic Statistics Textbook. Tulsa, OK: StatSoft. Web address: http://www.statsoft.com/textbook/

Stewart, D. B., Ratynski, R. A., Bernier, L. M. J. and Ramsey, D. J. 1993. A Fishery Development Strategy for the Canadian Beaufort Sea-Amundsen Gulf Area. Can. Tech. Report. Fish. Aquat. Sci. 1910.

Süfke, L., Piepenburg, D. and von Dorrien, C. F. 1998. Body size, sex ratio and diet composition of *Arctogadus glacialis* (Peters, 1874) (Pisces: Gadidae) in the Northeast Water Polynya (Greenland). Biomedical and Life Sciences 20(5): 357–363. Doi:10.1007/s003000050314.

Sutherland, I. 1982. A collection of zooplankton from Tuktoyaktuk Harbour, Northwest Territories. Can. J. Zool. 60: 477–480.

Telang, S. A., Packlington, R., Naidu, A. S, Romankevich, E. A, Gitelzon II, Galdshev MI. 1991. Carbon and mineral transport in major North American, Russian Arctic, and Siberian rivers: the St. Lawrence, the Mackenzie, the Yukon, the Arctic Alaskan rivers, the Arctic Basin rivers in the Soviet Union, and the Yenisei. *In* Degens, E., Kempe, S., Richey, J. (eds.) SCOPE 42 biogeochemistry of major world rivers. Wiley, London, 75–104 p.

Thorrold, S. R. and McKinnon, A. D. 1995. Response of larval fish assemblages to a riverine plume in coastal waters of the central Great Barrier Reef lagoon. Limnol. Oceanogr. 40(1): 177–181.

UNESCO. 1968. Zooplankton sampling: monographs on oceanographic methodology 2. Imprimerie Rolland, Paris, 174 p.

Van Guelpen, L. 1989. Guide to Spiny-Cheeked Fishes of the Canadian Atlantic: Scorpaenidae, Triglidae, Cottidae and Psychroloutidae and Agonidae. ARC Species ID Leaflet. #89-01-F

von Dorrien, C.F., Piepenburg, D. and Schmid, M. K. 1991. On the abundance of Arctic cod *Arctogadus glacialis* in Northeast Water. Polar Record 27: 362–364. Doi:10.1017/S0032247400013140.

Walkusz, W., Paulić, J. E., Kwasniewski, S., William, W. J., Wong, S., and Papst, M. H. 2010. Distribution, diversity and biomass of summer zooplankton from the coastal Canadian Beaufort Sea. Polar Biol. 33: 321–335. Doi:10.1007/s00300-009-0708-0.

Walkusz, W., Paulic, J. E., Williams, W. J., Kwasniewski, S., and Papst, M. H. 2011. Distribution and diet of larval and juvenile Arctic cod (Boreogadus saida) in the shallow Canadian Beaufort Sea. J. Mar. Syst. Doi:10.1016/j.jmarsys.2010.09.001.

Welch, H. E., Crawford, R. E. and Hop, H. 1993. Occurrence of Arctic Cod (*Boreogadus saida*) schools and their vulnerability to predation in the Canadian High Actic. Arctic 46(4): 331–339.

Williams, W. et al. 2007. CCGS Nahidik, 20th July – 20th August, 2007. Northern Coastal Marine Studies on the Canadian Beaufort Shelf. Cruise report.

Wolanski, E. and Jones, M. 1981. Physical Properties of Great Barrier Reef Lagoon Waters near Townsville. I Effects of Burdekin River Floods. Aust. J. Mar. Freshwater Res. 32: 305–319.

Yamamoto-Kawai, M., McLaughlin, F. A., Carmack, E. C., Nishino, S., Shimada, K. and Kurita, N. 2009. Surface freshening of the Canada Basin, 2003–2007: River runoff versus sea ice meltwater, J. Geophys. Res. 114: C00A05. Doi:10.1029/2008JC005000.

Yin, K., Harrison, P. J. and Beamish, R.J. 1997. Effects of a fluctuation in Fraser River discharge on primary production in the central Strait of Georgia, British Columbia, Canada. Can. J. Fish. Aquat. Sci. 54: 1015–1024.

APPENDICES

Appendix 1. Primary and secondary station names during the Mackenzie River Plume Study (2007). Primary station names were used for the Northern Coastal Marine Study Program and secondary station names were used for the larval fish & zooplankton research team. The final secondary station names were used throughout this thesis, as an explanation was provided in the Method section for removing stations Plume 4 and Plume 7.

Date (local NWT time)	Primary Station Name	CTD Cast No.	Secondary Station Names	Final Secondary Station Names	Latitude (N)	Longitude (W)
24-07-2007	P6	6	Plume 1	PL1	70° 05.038'	133° 44.238'
24-07-2007	P4	7	Plume 2	PL2	69° 54.760'	133° 35.718'
24-07-2007	P1	8	Plume 3	PL3	69° 39.287'	133° 22.489'
25-07-2007	P2.5	9	Plume 4	Removed	69° 39.287'	133° 27.806'
25-07-2007	P12	10	Plume 5	PL6	69° 54.040'	134° 13.349'
25-07-2007	P12.5	14	Plume 6	PL5	69° 55.745'	134° 14.675'
26-07-2007	None	None	Plume 7	Removed	69° 58.956'	134° 17.003'
27-07-2007	P16.5	16	Plume 8	PL4	70° 08.750'	134° 25.946'
27-07-2007	P26	26	Plume 9	PL9	69° 53.830'	134° 53.467'
27-07-2007	P30	27	Plume 10	PL8	70° 06.270'	135° 04.538'
27-07-2007	P33	28	Plume 11	PL7	70° 15.489'	135° 12.397'
16-08-2007	P30R	212	P30_r	PL10	70° 06.173'	135° 04.128'
16-08-2007	P26R	220	P26_r	PL11	69° 53.711'	134° 53.169'
16-08-2007	P24R	221	P24_r	PL12	69° 47.554'	134° 47.756'
18-08-2007	P6R	229	P6_r	PL13	70° 05.036'	133° 44.300'
18-08-2007	P1.5R	234	P1.5_r	PL14	69° 41.821'	133° 24.667'
18-08-2007	P0.5	236	P0.5_r	PL15	69° 33.834'	133° 17.014'

Appendix 2. Station information for oblique and target tows during the Mackenzie River Plume Study (2007).

Transect	Date	Station	Latitude (N)	Longitude (W)	Station Depth (m)	Tow No.	Time (local NWT MTN time) Start	Time (local NWT MTN time) End	Avg. Vol. Filtered (m^3)	No. of larval fish	Density ind/100 m^3 per tow
1	Jul. 24	PL1	70° 05.038'	133° 44.238'	33	Tow 1	10:53 AM	11:11AM	508.29	19	1.87
						Tow 2	11:19 AM	11:34 AM	247.21	17	3.44
						Tow 3*	11:41AM	11:55 AM	393.26	1	0.13
						Tow 4*	12:02 PM	12:28 PM	215.27	12	2.79
	Jul. 24	PL2	69° 54.760'	133° 35.718'	16	Tow 1	2:57 PM	3:07 PM	197.73	18	9.10
						Tow 2	4:00 PM	4:13 PM	263.84	30	5.69
						Tow 3*	4:22 PM	4:37 PM	136.39	63	23.1
	Jul. 24	PL3	69° 39.287'	133° 22.489'	6	Tow 1	9:41 PM	9:56 PM	275.02	10	1.82
2	Jul. 27	PL4	70° 08.750'	134° 25.946'	33	Tow 1	12:13 AM	12:31 AM	359.31	32	4.45
						Tow 2	12:43 AM	1:00 AM	312.91	27	4.31
						Tow 3*	1:12 AM	1:35 AM	553.02	75	6.78
	Jul. 25	PL5	69° 55.745'	134° 14.675'	11	Tow 1	10:19 A.M.	10:35 A.M.	366.33	7	0.96
						Tow 2	10:42 A.M.	10:57 A.M.	339.18	5	0.74
	Jul. 25	PL6	69° 54.040'	134° 13.349'	11	Tow 1	8:10 A.M.	8:36 A.M.	378.33	9	1.19
3	Jul. 28	PL7	70° 15.489'	135° 12.397'	53	Tow 1	10:46 PM	11:02 PM	203.93	14	3.43
						Tow 2	11:12 PM	11:29 PM	283.63	21	3.70
						Tow 3*	11:41 PM	11:56 PM	227.76	22	4.83
	Jul. 28	PL8	70° 06.270'	135° 04.538'	39	Tow 1	6:12 PM	6:29 PM	356.46	34	4.77
						Tow 2	6:43 PM	6:58 PM	285.06	27	4.74
						Tow 3*	7:10 PM	7:25 PM	284.80	74	12.99
	Jul. 28	PL9	69° 53.830'	134° 53.467'	13	Tow 1	12:21 PM	12:40 PM	296.65	10	1.69
						Tow 2	12:54 PM	1:09 PM	241.62	62	12.83

*Target tow at specific depth

Appendix 2 Continued. Station information for oblique and target tows during the Mackenzie River Plume Study (2007).

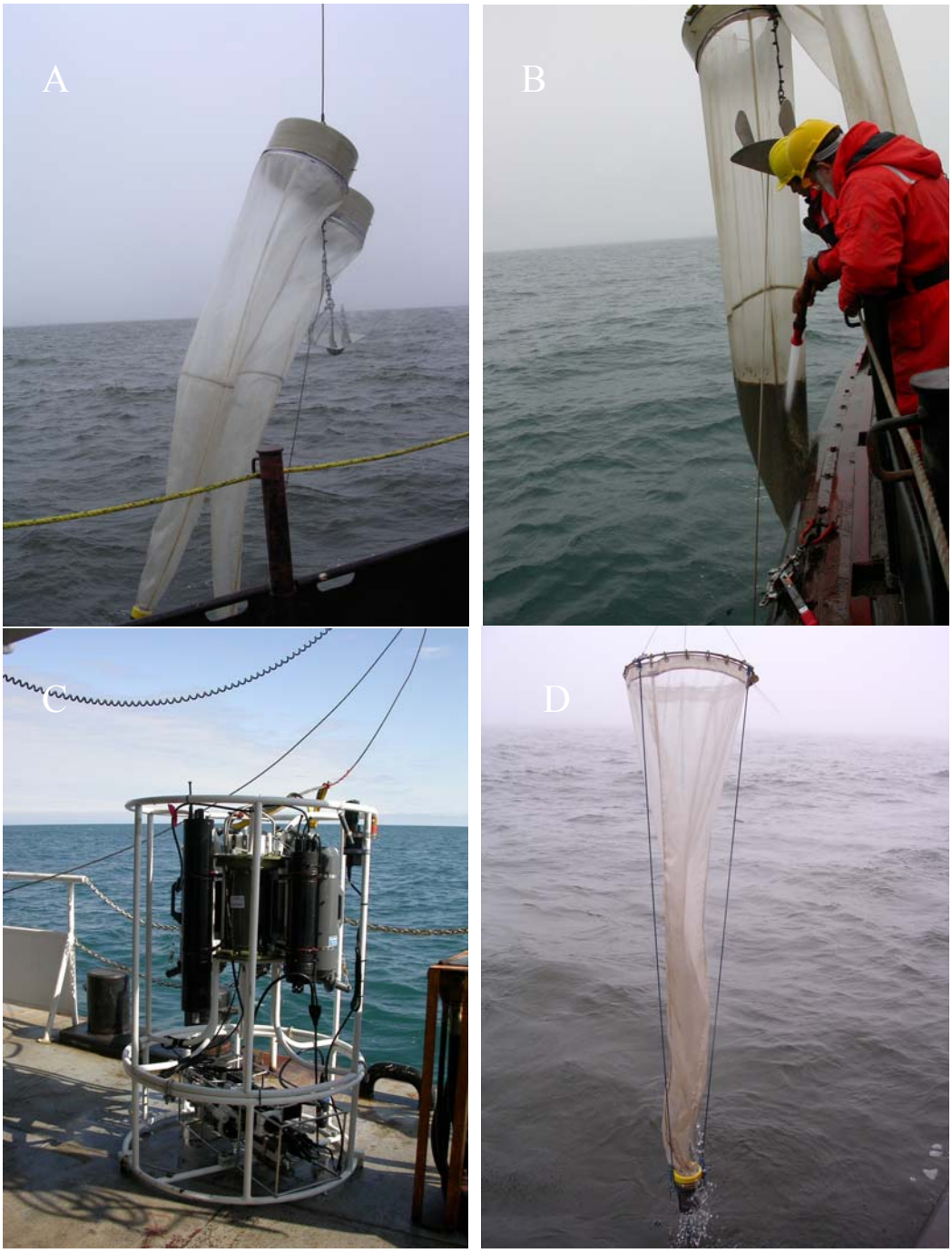
							Time (local NWT time)				
Transect	**Date**	**Station**	**Latitude (N)**	**Longitude (W)**	**Station Depth (m)**	**Tow No.**	**Start**	**End**	**Avg. Vol. Filtered (m^3)**	**Total No. of larval fish**	**Density ind/100 m^3 per tow**
Transect 4	Aug. 17	PL10	70° 06.173'	135° 04.128'	38	Tow 1	8:16 AM	8:31 AM	288.52	17	2.95
						Tow 2	8:38 AM	8:54 AM	285.30	14	2.45
						Tow 3*	9:03 AM	9:18 AM	273.48	4	0.73
	Aug. 17	PL11	69° 53.711'	134° 53' 10"	14	Tow 1	12:32 PM	12:48 PM	287.29	19	3.31
						Tow 2	12:55 PM	1:10 PM	267.79	14	2.61
	Aug. 18	PL12	69° 47.554'	134° 47.756'	8	Tow 1	3:20 PM	3:36 PM	305.60	34	5.56
						Tow 2	3:41 PM	3:55 PM	251.23	28	5.57
						Tow 3	4:01 PM	4:16 PM	281.68	18	3.20
Transect 5	Aug. 18	PL13	70° 05.036'	133° 44.300'	32	Tow 1	8:12 AM	8:28 AM	318.48	12	1.88
						Tow 2	9:02 AM	9:18 AM	296.78	9	1.52
						Tow 3*	9:27 AM	9:43 AM	284.93	12	2.11
	Aug. 18	PL14	69° 41.821'	133° 24.667'	7	Tow 1	2:55 PM	3:10 PM	281.82	11	1.95
						Tow 2	3:44 PM	3:59 PM	272.31	8	1.47
	Aug. 18	PL15	69° 33.834'	133° 17.014'	4	Tow 1	5:47 PM	6:02 PM	287.45	21	3.65
						Tow 2	6:08 PM	6:22 PM	701.08	38	2.71

*Target tow at specific depth

Appendix 3. Information for oblique tows for stations Plume 4 and Plume 7, which were removed from the analyses (2007).

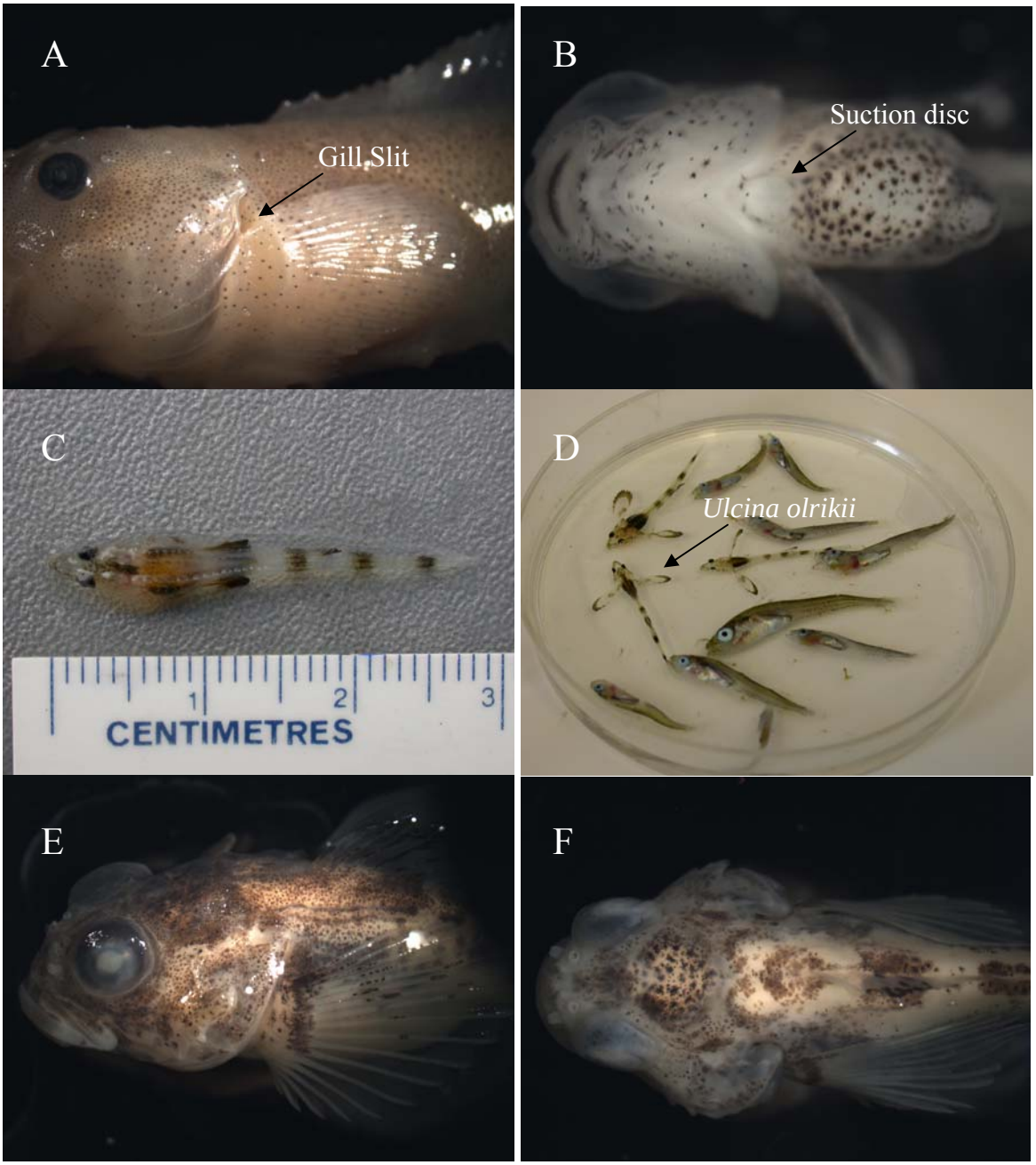
Date	Station	Latitude (N)	Longitude (W)	Station Depth (m)	Tow No.	Time (local NWT MTN time) Start	End	Avg. Vol. Filtered (m^3)	Total No. of larval fish	Density ind/100 m^3 per tow
Jul. 25	Plume 4	69° 39.287'	133° 27.806'	10	Tow 1	12:04 AM	12:19 AM	319.08	4	0.63
					Tow 2	12:27 AM	12:42 AM	352.68	1	0.14
Jul. 25	Plume 7	69° 58.956'	134° 17.003'	14	Tow 1	8:18 PM	8:33 PM	235.76	51	10.82
					Tow 2	8:42 PM	8:57 PM	259.64	11	2.12

Appendix 4. (A) Bongo nets with a mesh size of 500 µm were used to sample larval fish in this study. (B) The flow meter in the middle of the net was used to determine the volume of water filtered. (C) An inclinometer was used to measure the angle of the wire in relation to the horizon/waterline. (D) Bongo nets being rinsed with a deck hose so that organisms will fall into the cod end (E and F) Sample collected in a collecting bucket after a tow.

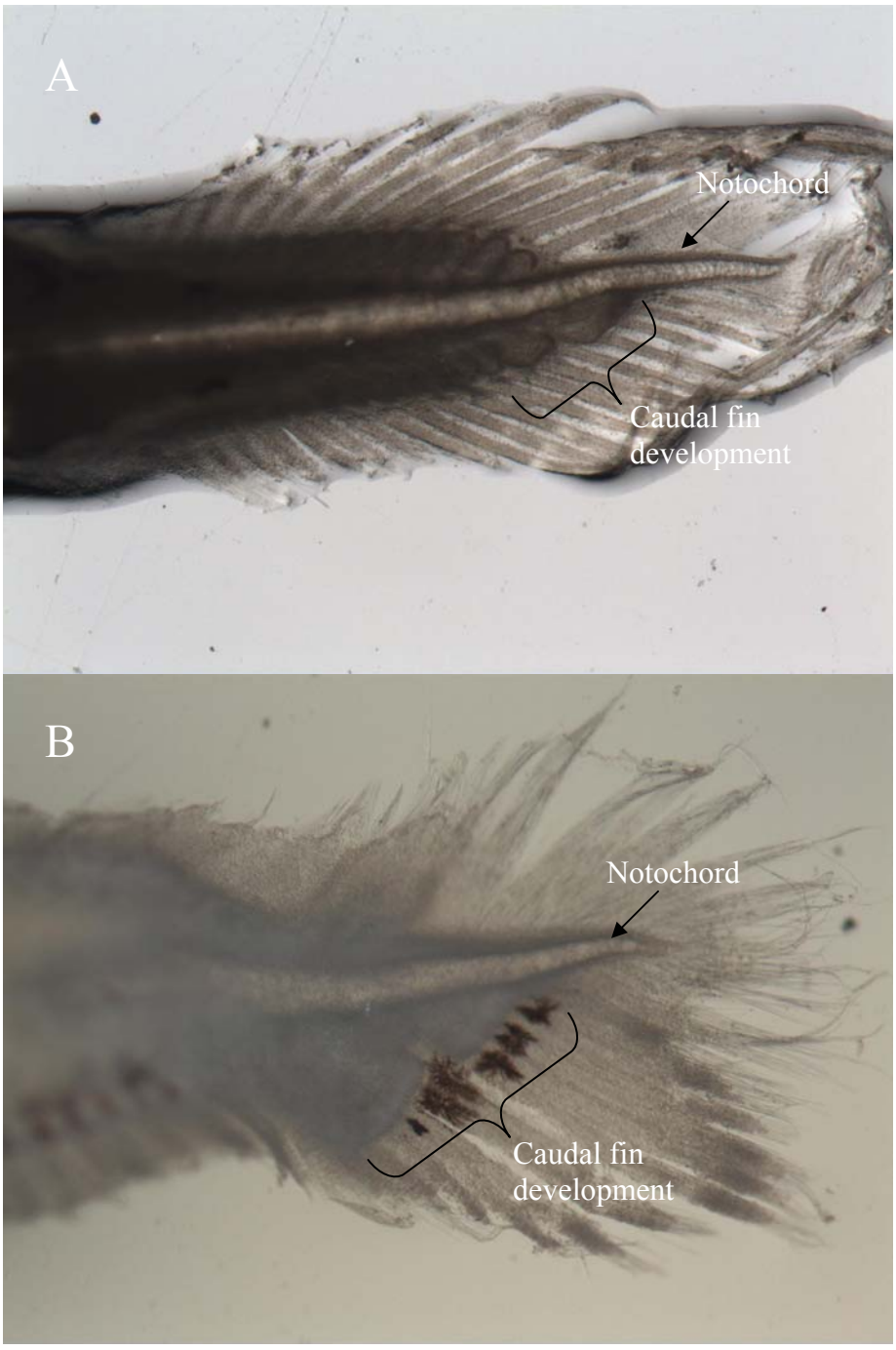


Appendix 5. (A) Bongo nets with a depressor (in the middle) to stabilize the net and create a horizontal orientation when towing. (B) Bongo net accidentally caught in mud at a shallow station. (C) CTD/Rosette used to measure the physical and chemical parameters of the water. (D) Vertical net with mesh size of 153 µm.

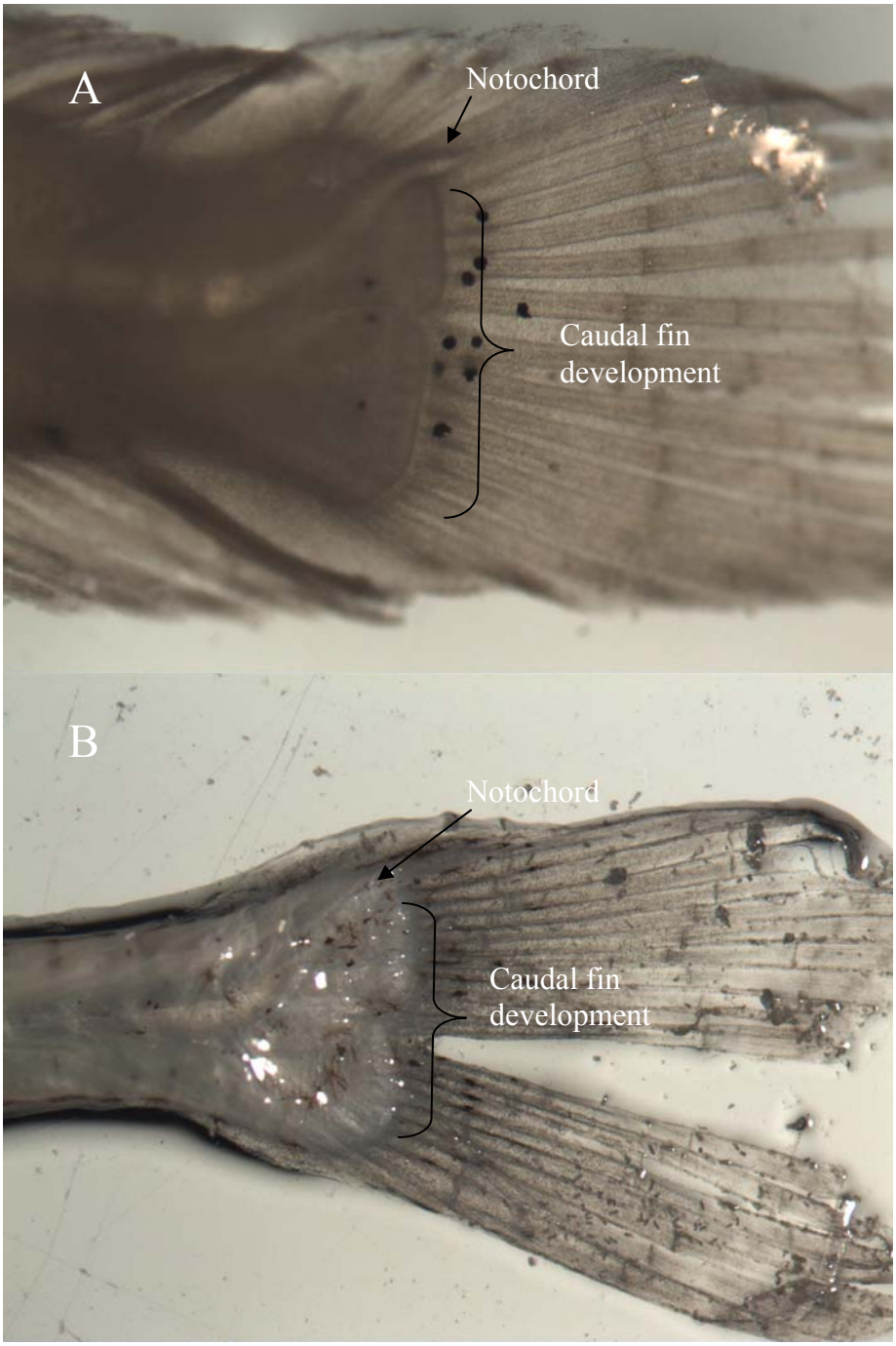
Appendix 6. (A) A metal tray used to sort a plankton sample in the lab immediately after the sample was taken. (B) Nalgene® bottles for storage of larval fish and zooplankton. (C) A petri dish filled with larval fish that were picked out before being preserved in bottles. (D) Lumpeninae. (E) Photo of *Boreogadus saida*. (F) Liparis species.



Appendix 7. (A) A small gill slit of *Liparis tunicatus*. (B) An example of a suction disc for *Liparis fabricii*. (C) *Ulcina olrikii*. (D) Dorsal view of *U. olrikii*. (E) Side view of *Gymnocanthus tricuspis*. (F) Dorsal view of *G. tricuspis*.



Appendix 8. (A) A notochord flexion in the flexion stage of *Boreogadus saida*. (B) A notochord in the flexion stage of Lumpeninae.



Appendix 9. (A) Completed notochord flexion in the postflexion stage of Lumpeninae. (B) Completed notochord flexion in the postflexion stage of *Clupea pallasii pallasii*.

Appendix 10. Depth Determination for Horizontal Sampling.

	Cosine Angle [°C]											
Depth[m]	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**70**
1	1	1	1	1	1	1	1	1	1	2	2	3
2	2	2	2	2	2	2	3	3	3	3	4	6
3	3	3	3	3	3	4	4	4	5	5	6	9
4	4	4	4	4	5	5	5	6	6	7	8	12
5	5	5	5	6	6	6	7	7	8	9	10	15
6	6	6	6	7	7	7	8	8	9	10	12	18
7	7	7	7	8	8	9	9	10	11	12	14	20
8	8	8	9	9	9	10	10	11	12	14	16	23
9	9	9	10	10	10	11	12	13	14	16	18	26
10	10	10	11	11	12	12	13	14	16	17	20	29
15	15	16	16	17	17	18	20	21	23	26	30	32
20	20	21	21	22	23	24	26	28	31	35	40	58
25	25	26	27	28	29	31	33	35	39	44	50	73
30	30	31	32	33	35	37	39	42	47	52	60	88
35	36	36	37	39	40	43	46	49	54	61	70	102
40	41	41	43	44	46	49	52	57	62	70	80	117
45	46	47	48	50	52	55	59	64	70	78	90	132
50	51	52	53	55	58	61	65	71	78	87	100	146
55	56	57	59	61	64	67	72	78	86	96	110	161
60	61	62	64	66	69	73	78	85	93	105	120	175
65	66	67	69	72	75	79	85	92	101	113	130	190
70	71	72	74	77	81	85	91	99	109	122	140	205
75	76	78	80	83	87	92	98	106	117	131	150	219
80	81	83	85	88	92	98	104	113	124	139	160	234
85	86	88	90	94	98	104	111	120	132	148	170	249
90	91	93	96	99	104	110	117	127	140	157	180	263
95	96	98	101	105	110	116	124	134	148	166	190	278
100	102	104	106	110	115	122	131	141	156	174	200	292

The cosine angle and depth determines the amount of cable out needed for desired depth. The equation that was used to calculate the depth at predetermined cosine angles (found in the Wildco Clinometer Manual):

$D = L \cdot \cos \cdot a$

where, D = Depth of the Bongo net;
L = Length of two cables from surface of water to Bongo net
cos.a = Cosine of cable angle

Appendix 11. Larval fish biological data for the oblique and target tows during the Mackenzie River Plume Study (2007). Developmental stages include: Preflexion, Flexion, Postflexion, and Early Juvenile.

Station Name	Plankton Sample Number	Vial No. ID	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL1	BN-07-01-01	1	*Boreogadus saida*	7.93	0.0082	Preflexion
PL1	BN-07-01-01	2	*Boreogadus saida*	13.24	0.0288	Flexion
PL1	BN-07-01-01	3	*Boreogadus saida*	14.08	0.0283	Flexion
PL1	BN-07-01-01	4	*Boreogadus saida*	14.99	0.0388	Flexion
PL1	BN-07-01-01	5	*Boreogadus saida*	21.47	0.0684	Postflexion
PL1	BN-07-01-01	6	*Boreogadus saida*	12.00	0.0181	Flexion
PL1	BN-07-01-01	7	*Boreogadus saida*	15.40	0.0288	Flexion
PL1	BN-07-01-01	8	*Boreogadus saida*	17.62	0.0481	Flexion
PL1	BN-07-01-01	9	Lumpeninae	21.87	0.0288	Postflexion
PL1	BN-07-01-01	10	*Liparis gibbus*	15.64	0.0682	Flexion
PL1	BN-07-01-02	11	*Gymnocanthus tricuspis*	18.53	0.0785	Postflexion
PL1	BN-07-01-02	12	*Boreogadus saida*	22.00	0.0881	Postflexion
PL1	BN-07-01-02	13	*Liparis gibbus*	17.82	0.1085	Flexion
PL1	BN-07-01-02	14	*Boreogadus saida*	22.20	0.0886	Postflexion
PL1	BN-07-01-02	15	*Boreogadus saida*	19.46	0.0580	Postflexion
PL1	BN-07-01-02	16	*Boreogadus saida*	21.00	0.0784	Postflexion
PL1	BN-07-01-02	17	*Liparis gibbus*	17.65	0.0787	Flexion
PL1	BN-07-01-02	18	*Boreogadus saida*	12.00	0.0186	Preflexion
PL1	BN-07-01-02	19	*Boreogadus saida*	16.00	0.0289	Flexion
PL1	BN-07-01-03	20	*Boreogadus saida*	21.00	0.0881	Postflexion
PL1	BN-07-01-03	21	*Boreogadus saida*	13.00	0.0100	Flexion
PL1	BN-07-01-03	22	*Boreogadus saida*	14.00	0.0280	Flexion
PL1	BN-07-01-03	23	*Boreogadus saida*	16.00	0.0382	Flexion
PL1	BN-07-01-03	24	*Boreogadus saida*	13.00	0.0183	Flexion
PL1	BN-07-01-03	25	*Boreogadus saida*	19.00	0.0486	Postflexion
PL1	BN-07-01-03	26	*Boreogadus saida*	15.50	0.0386	Flexion
PL1	BN-07-01-03	27	Lumpeninae	23.46	0.0389	Postflexion
PL1	BN-07-01-03	28	Lumpeninae	23.06	0.0387	Postflexion
PL1	BN-07-01-03	29	*Liparis tunicatus*	20.93	0.1887	Postflexion
PL1	BN-07-01-04	30	*Boreogadus saida*	15.00	0.0385	Flexion
PL1	BN-07-01-04	31	*Boreogadus saida*	14.00	0.0288	Flexion
PL1	BN-07-01-04	32	*Boreogadus saida*	17.00	0.0384	Flexion
PL1	BN-07-01-04	33	*Boreogadus saida*	10.00	0.0087	Preflexion

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial No. ID	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL1	BN-07-01-04	34	*Ulcina olrikii*	14.87	0.0187	Postflexion
PL1	BN-07-01-04	35	Lumpeninae	24.83	0.0487	Postflexion
PL1	BN-07-01-04	36	Lumpeninae	20.61	0.0289	Postflexion
PL1	BN-07-01-05*	37	*Boreogadus saida*	8.00	0.0085	Flexion
PL1	BN-07-01-06*			No fish was caught		
PL1	BN-07-01-07*	38	*Boreogadus saida*	21.00	0.0685	Postflexion
PL1	BN-07-01-07*	39	*Boreogadus saida*	20.50	0.0687	Postflexion
PL1	BN-07-01-07*	40	*Triglops nybelini*	22.84	0.098	Postflexion
PL1	BN-07-01-07*	41	*Boreogadus saida*	16.00	0.0185	Flexion
PL1	BN-07-01-07*	42	*Liparis tunicatus*	20.08	0.1583	Postflexion
PL1	BN-07-01-07*	43	*Liparis gibbus*	13.16	0.0381	Flexion
PL1	BN-07-01-07*	44	*Liparis tunicatus*	21.22	0.1986	Postflexion
PL1	BN-07-01-07*	45	*Liparis gibbus*	14.70	0.0484	Flexion
PL1	BN-07-01-07*	46	*Liparis tunicatus*	13.22		Flexion
PL1	BN-07-01-08*	47	*Boreogadus saida*	14.00	0.0187	Flexion
PL1	BN-07-01-08*	48	*Boreogadus saida*	16.00	0.0289	Flexion
PL1	BN-07-01-08*	49	*Liparis gibbus*	13.22	0.0388	Flexion
PL2	BN-07-02-01	50	*Boreogadus saida*	15.00	0.0286	Flexion
PL2	BN-07-02-01	51	*Boreogadus saida*	9.00	0.0089	Preflexion
PL2	BN-07-02-01	52	*Boreogadus saida*	10.50	0.0089	Preflexion
PL2	BN-07-02-01	53	*Boreogadus saida*	14.00	0.0181	Flexion
PL2	BN-07-02-01	54	*Boreogadus saida*	16.00	0.0281	Flexion
PL2	BN-07-02-01	55	*Boreogadus saida*	11.00	0.0085	Flexion
PL2	BN-07-02-01	56	*Liparis tunicatus*	18.52	0.1080	Flexion
PL2	BN-07-02-01	57	Lumpeninae	17.39	0.0181	Postflexion
PL2	BN-07-02-01	58	Lumpeninae	26.43	0.0484	Postflexion
PL2	BN-07-02-01	59	Lumpeninae	20.68	0.0285	Postflexion
PL2	BN-07-02-01	60	Lumpeninae	24.72	0.0489	Postflexion
PL2	BN-07-02-01	61	Lumpeninae	21.00	0.0380	Postflexion
PL2	BN-07-02-01	62	Lumpeninae	28.64	0.0585	Postflexion
PL2	BN-07-02-01	63	Lumpeninae	20.00	0.0282	Postflexion
PL2	BN-07-02-01	64	Lumpeninae	25.75	0.0483	Postflexion
PL2	BN-07-02-01	65	Lumpeninae	23.81	0.0384	Postflexion
PL2	BN-07-02-01	66	Lumpeninae	24.61	0.0480	Postflexion
PL2	BN-07-02-01	67	Lumpeninae	24.62	0.0480	Postflexion

* Target Tows

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL2	BN-07-02-02	68	*Boreogadus saida*	10.00	0.0082	Flexion
PL2	BN-07-02-02	69	*Gymnocanthus tricuspis*	21.90	0.0985	Postflexion
PL2	BN-07-02-02	70	*Liparis fabricii*	12.24	0.0284	Flexion
PL2	BN-07-02-02	71	*Liparis tunicatus*	21.32	0.1514	Flexion
PL2	BN-07-02-02	72	Lumpeninae	27.64	0.0488	Postflexion
PL2	BN-07-02-02	73	Lumpeninae	21.82	0.0281	Postflexion
PL2	BN-07-02-02	74	Lumpeninae	21.72	0.0285	Postflexion
PL2	BN-07-02-02	75	Lumpeninae	29.02	0.0487	Postflexion
PL2	BN-07-02-02	76	Lumpeninae	25.24	0.0381	Postflexion
PL2	BN-07-02-02	77	Lumpeninae	20.69	0.0281	Postflexion
PL2	BN-07-02-03	78	*Boreogadus saida*	10.00	0.0087	Flexion
PL2	BN-07-02-03	79	*Liparis gibbus*	10.18	0.0288	Preflexion
PL2	BN-07-02-03	80	*Liparis gibbus*	10.79	0.0282	Flexion
PL2	BN-07-02-03	81	*Liparis gibbus*	16.69	0.0985	Flexion
PL2	BN-07-02-03	82	*Liparis gibbus*	19.52	0.1284	Flexion
PL2	BN-07-02-03	83	*Liparis tunicatus*	17.70	0.0884	Flexion
PL2	BN-07-02-03	85	Lumpeninae	27.08	0.0381	Postflexion
PL2	BN-07-02-03	86	Lumpeninae	23.66	0.0485	Postflexion
PL2	BN-07-02-03	87	Lumpeninae	27.52	0.0685	Postflexion
PL2	BN-07-02-03	88	Lumpeninae	23.43	0.0381	Postflexion
PL2	BN-07-02-03	89	Lumpeninae	23.83	0.0482	Postflexion
PL2	BN-07-02-03	90	Lumpeninae	25.08	0.0481	Postflexion
PL2	BN-07-02-03	91	Lumpeninae	21.48	0.0289	Postflexion
PL2	BN-07-02-03	92	Lumpeninae	21.79	0.0283	Postflexion
PL2	BN-07-02-03	93	Lumpeninae	22.86	0.0382	Postflexion
PL2	BN-07-02-03	94	Lumpeninae	23.15	0.0384	Postflexion
PL2	BN-07-02-03	95	Lumpeninae	17.46	0.0181	Postflexion
PL2	BN-07-02-03	96	Lumpeninae	25.55	0.0482	Postflexion
PL2	BN-07-02-03	97	Lumpeninae	17.66	0.0587	Postflexion
PL2	BN-07-02-03	98	*Liparis fabricii*	14.29	0.0389	Flexion
PL2	BN-07-02-04*	99	*Boreogadus saida*	14.29	0.0288	Flexion
PL2	BN-07-02-04*	100	*Liparis gibbus*	11.62	0.0282	Flexion
PL2	BN-07-02-04*	101	*Liparis gibbus*	15.11	0.0686	Flexion
PL2	BN-07-02-04*	102	*Liparis fabricii*	14.00	0.0381	Flexion
PL2	BN-07-02-04*	103	*Liparis gibbus*	11.15	0.0284	Flexion

* Target Tows

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL2	BN-07-02-04*	104	*Liparis gibbus*	10.73	0.0284	Flexion
PL2	BN-07-02-04*	105	Lumpeninae	23.03	0.038	Postflexion
PL2	BN-07-02-04*	106	Lumpeninae	25.33	0.0487	Postflexion
PL2	BN-07-02-04*	107	Lumpeninae	24.36	0.0482	Postflexion
PL2	BN-07-02-04*	108	Lumpeninae	19.81	0.0289	Postflexion
PL2	BN-07-02-04*	109	Lumpeninae	24.14	0.0385	Postflexion
PL2	BN-07-02-04	110	Lumpeninae	21.53	0.0284	Postflexion
PL2	BN-07-02-04*	111	Lumpeninae	23.69	0.0385	Postflexion
PL2	BN-07-02-04*	112	Lumpeninae	27.88	0.0589	Postflexion
PL2	BN-07-02-04*	113	Lumpeninae	20.33	0.038	Postflexion
PL2	BN-07-02-04*	114	Lumpeninae	22.56	0.0381	Postflexion
PL2	BN-07-02-04*	115	Lumpeninae	22.49	0.0281	Postflexion
PL2	BN-07-02-04*	116	Lumpeninae	23.6	0.0384	Postflexion
PL2	BN-07-02-04*	117	Lumpeninae	25.44	0.0385	Postflexion
PL2	BN-07-02-04*	118	Lumpeninae	20.00	0.0184	Postflexion
PL2	BN-07-02-04*	119	Lumpeninae	28.43	0.0487	Postflexion
PL2	BN-07-02-04*	120	Lumpeninae	19.89	0.0182	Postflexion
PL2	BN-07-02-04*	121	Lumpeninae	25.76	0.0486	Postflexion
PL2	BN-07-02-04*	122	Lumpeninae	22.12	0.0389	Postflexion
PL2	BN-07-02-04*	123	Lumpeninae	17.77	0.0181	Postflexion
PL2	BN-07-02-04*	124	Lumpeninae	25.71	0.0487	Postflexion
PL2	BN-07-02-04*	125	Lumpeninae	17.95	0.0182	Postflexion
PL2	BN-07-02-04*	126	Lumpeninae	26.09	0.0487	Postflexion
PL2	BN-07-02-04*	127	Lumpeninae	22.66	0.0282	Postflexion
PL2	BN-07-02-04*	128	Lumpeninae	22.65	0.0283	Postflexion
PL2	BN-07-02-04*	129	Lumpeninae	23.76	0.0484	Postflexion
PL2	BN-07-02-04*	130	Lumpeninae	24.40	0.0346	Postflexion
PL2	BN-07-02-04*	131	Lumpeninae	13.09	0.0086	Flexion
PL2	BN-07-02-05*	132	*Liparis gibbus*	10.07	0.0284	Flexion
PL2	BN-07-02-05*	133	*Liparis tunicatus*	20.57	0.1789	Flexion
PL2	BN-07-02-05*	134	*Liparis gibbus*	12.07	0.0384	Flexion
PL2	BN-07-02-05*	135	Lumpeninae	23.40	0.0383	Postflexion
PL2	BN-07-02-05*	136	Lumpeninae	23.94	0.0486	Postflexion
PL2	BN-07-02-05*	137	Lumpeninae	25.20	0.0485	Postflexion
PL2	BN-07-02-05*	138	Lumpeninae	16.57	0.0189	Postflexion

* Target Tows

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL2	BN-07-02-05*	139	Lumpeninae	18.69	0.0286	Postflexion
PL2	BN-07-02-05*	140	Lumpeninae	22.99	0.0386	Postflexion
PL2	BN-07-02-05*	141	Lumpeninae	25.40	0.0489	Postflexion
PL2	BN-07-02-05*	142	Lumpeninae	23.53	0.0387	Postflexion
PL2	BN-07-02-05*	143	Lumpeninae	23.16	0.0384	Postflexion
PL2	BN-07-02-05*	144	Lumpeninae	24.84	0.0389	Postflexion
PL2	BN-07-02-05*	145	Lumpeninae	31.50	0.0786	Postflexion
PL2	BN-07-02-05*	146	Lumpeninae	21.74	0.0385	Postflexion
PL2	BN-07-02-05*	147	Lumpeninae	27.06	0.0484	Postflexion
PL2	BN-07-02-05*	148	Lumpeninae	27.34	0.0588	Postflexion
PL2	BN-07-02-05*	149	Lumpeninae	23.56	0.0383	Postflexion
PL2	BN-07-02-05*	150	Lumpeninae	26.86	0.0589	Postflexion
PL2	BN-07-02-05*	151	Lumpeninae	27.45	0.058	Postflexion
PL2	BN-07-02-05*	152	Lumpeninae	27.80	0.0583	Postflexion
PL2	BN-07-02-05*	153	Lumpeninae	29.67	0.0682	Postflexion
PL2	BN-07-02-05*	154	Lumpeninae	24.10	0.0382	Postflexion
PL2	BN-07-02-05*	155	Lumpeninae	28.81	0.0589	Postflexion
PL2	BN-07-02-05*	156	Lumpeninae	22.69	0.0387	Postflexion
PL2	BN-07-02-05*	157	Lumpeninae	22.23	0.0288	Postflexion
PL2	BN-07-02-05*	158	Lumpeninae	18.62	0.0283	Postflexion
PL2	BN-07-02-05*	159	Lumpeninae	22.50	0.0389	Postflexion
PL2	BN-07-02-05*	160	Lumpeninae	18.66	0.0285	Postflexion
PL2	BN-07-02-05*	161	*Dried up*			
PL2	BN-07-02-05*	162	*Lumpeninae*	26.11	0.0487	Postflexion
PL3	BN-07-03-01	527	*Lumpeninae*	26.64	0.0386	Postflexion
PL3	BN-07-03-01	528	*Lumpeninae*	14.38	0.0084	Flexion
PL3	BN-07-03-02	479	*Eleginus gracilis*	5.91	0.0084	Preflexion
PL3	BN-07-03-02	480	*Eleginus gracilis*	5.25	0.0082	Preflexion
PL3	BN-07-03-02	481	Lumpeninae	8.50	0.0001	Preflexion
PL3	BN-07-03-02	482	Lumpeninae	14.19	0.0080	Flexion
PL3	BN-07-03-02	483	Lumpeninae	30.84	0.0483	Postflexion
PL3	BN-07-03-02	484	*Clupea pallasii pallasii*	12.93	0.0089	Flexion
PL3	BN-07-03-02	529	Lumpeninae	25.40	0.0384	Postflexion
PL3	BN-07-03-02	530	Lumpeninae	26.86	0.0384	Postflexion
PL6	BN-07-05-01	163	*Boreogadus saida*	11.79	0.0082	Preflexion

* Target Tows

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL6	BN-07-05-01	485	*Boreogadus saida*	5.05	0.0083	Preflexion
PL6	BN-07-05-01	486	*Boreogadus saida*	6.00	0.0084	Preflexion
PL6	BN-07-05-01	487	*Boreogadus saida*	5.84	0.0008	Preflexion
PL6	BN-07-05-01	488	*Boreogadus saida*	5.82	0.0084	Preflexion
PL6	BN-07-05-01	489	*Clupea pallasii pallasii*	11.51	0.0890	Preflexion
PL6	BN-07-05-01	490	*Boreogadus saida*	3.88	0.0010	Preflexion
PL6	BN-07-05-01	491	*Boreogadus saida*	3.72	0.0010	Preflexion
PL6	BN-07-05-02	164	*Eleginus gracilis*	8.00	0.0084	Preflexion
PL5	BN-07-06-01	165	*Eleginus gracilis*	7.91	0.0088	Preflexion
PL5	BN-07-06-01	166	*Eleginus gracilis*	12.53	0.0184	Flexion
PL5	BN-07-06-01	167	*Eleginus gracilis*	13.35	0.0284	Flexion
PL5	BN-07-06-01	536	*Clupea pallasii pallasii*	13.38	0.0089	Flexion
PL5	BN-07-06-01	537	*Clupea pallasii pallasii*	12.03	0.0089	Flexion
PL5	BN-07-06-02	492	*Boreogadus saida*	7.04	0.0084	Preflexion
PL5	BN-07-06-02	493	*Boreogadus saida*	5.08	0.0083	Preflexion
PL5	BN-07-06-04	168	*Eleginus gracilis*	11.00	0.0133	Preflexion
PL5	BN-07-06-04	169	*Eleginus gracilis*	8.00	0.0080	Preflexion
PL5	BN-07-06-04	170	*Eleginus gracilis*	9.50	0.0086	Preflexion
PL5	BN-07-06-04	171	*Eleginus gracilis*	11.00	0.0089	Preflexion
PL5	BN-07-06-04	172	*Boreogadus saida*	11.00	0.0188	Flexion
PL4	BN-07-08-01	175	*Boreogadus saida*	20.11	0.0687	Postflexion
PL4	BN-07-08-01	176	*Boreogadus saida*	12.73	0.0182	Preflexion
PL4	BN-07-08-01	177	*Boreogadus saida*	18.24	0.0689	Postflexion
PL4	BN-07-08-01	178	*Boreogadus saida*	20.00	0.0582	Postflexion
PL4	BN-07-08-01	179	*Boreogadus saida*	17.00	0.0288	Postflexion
PL4	BN-07-08-01	180	*Boreogadus saida*	20.19	0.0689	Postflexion
PL4	BN-07-08-01	181	*Boreogadus saida*	26.51	0.1487	Postflexion
PL4	BN-07-08-01	182	*Boreogadus saida*	21.29	0.0686	Postflexion
PL4	BN-07-08-01	183	*Boreogadus saida*	16.86	0.0381	Postflexion
PL4	BN-07-08-01	184	*Boreogadus saida*	17.00	0.0383	Flexion
PL4	BN-07-08-01	185	*Boreogadus saida*	15.00	0.0287	Flexion
PL4	BN-07-08-01	186	*Boreogadus saida*	15.51	0.0280	Flexion
PL4	BN-07-08-01	188	*Boreogadus saida*	19.65	0.0589	Postflexion
PL4	BN-07-08-01	189	*Liparis tunicatus*	22.49	0.0208	Flexion
PL4	BN-07-08-01	190	*Gymnocanthus tricuspis*	21.29	0.0988	Postflexion
PL4	BN-07-08-01	191	*Gymnocanthus tricuspis*	20.99	0.0986	Postflexion

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL4	BN-07-08-02	192	*Boreogadus saida*	13.40	0.0285	Flexion
PL4	BN-07-08-02	193	*Boreogadus saida*	19.00	0.0389	Postflexion
PL4	BN-07-08-02	194	*Boreogadus saida*	20.00	0.0584	Postflexion
PL4	BN-07-08-02	195	*Boreogadus saida*	18.45	0.0486	Postflexion
PL4	BN-07-08-02	196	*Boreogadus saida*	19.00	0.0785	Postflexion
PL4	BN-07-08-02	197	*Boreogadus saida*	18.74	0.0482	Postflexion
PL4	BN-07-08-02	198	*Boreogadus saida*	21.85	0.0684	Postflexion
PL4	BN-07-08-02	199	*Boreogadus saida*	18.42	0.0487	Postflexion
PL4	BN-07-08-02	560	*Liparis gibbus*	18.36	0.0785	Flexion
PL4	BN-07-08-02	561	*Liparis gibbus*	20.61	0.1384	Flexion
PL4	BN-07-08-02	562	*Liparis gibbus*	17.64	0.0881	Flexion
PL4	BN-07-08-02	563	*Liparis gibbus*	19.23	0.0981	Flexion
PL4	BN-07-08-02	564	*Gymnocanthus tricuspis*	23.51	0.1489	Postflexion
PL4	BN-07-08-02	565	*Icelus sp.*	20.78	0.0986	Postflexion
PL4	BN-07-08-02	566	*Gymnocanthus tricuspis*	23.92	0.1680	Postflexion
PL4	BN-07-08-03	200	*Boreogadus saida*	25.23	0.1080	Postflexion
PL4	BN-07-08-03	201	*Boreogadus saida*	22.61	0.0688	Postflexion
PL4	BN-07-08-03	202	*Boreogadus saida*	18.83	0.0485	Postflexion
PL4	BN-07-08-03	203	*Boreogadus saida*	15.50	0.0289	Flexion
PL4	BN-07-08-03	204	*Boreogadus saida*	12.74	0.0181	Flexion
PL4	BN-07-08-03	205	*Boreogadus saida*	14.00	0.0184	Flexion
PL4	BN-07-08-03	206	*Boreogadus saida*	14.22	0.0280	Flexion
PL4	BN-07-08-03	207	*Boreogadus saida*	20.64	0.0788	Postflexion
PL4	BN-07-08-03	208	*Boreogadus saida*	23.81	0.0982	Postflexion
PL4	BN-07-08-03	209	*Boreogadus saida*	24.10	0.0884	Postflexion
PL4	BN-07-08-03	567	*Liparis gibbus*	14.35	0.0589	Flexion
PL4	BN-07-08-03	568	*Liparis tunicatus*	19.24	0.1085	Flexion
PL4	BN-07-08-03	569	*Liparis tunicatus*	23.00	0.2287	Flexion
PL4	BN-07-08-03	570	*Liparis tunicatus*	24.23	0.3082	Postflexion
PL4	BN-07-08-04	210	*Boreogadus saida*	11.00	0.0088	Flexion
PL4	BN-07-08-04	211	*Boreogadus saida*	19.86	0.0488	Postflexion
PL4	BN-07-08-04	212	*Boreogadus saida*	18.46	0.0386	Postflexion
PL4	BN-07-08-04	213	*Boreogadus saida*	16.00	0.0289	Postflexion
PL4	BN-07-08-04	214	*Boreogadus saida*	9.00	0.0182	Flexion
PL4	BN-07-08-04	215	*Boreogadus saida*	21.83	0.0782	Postflexion
PL4	BN-07-08-04	216	*Boreogadus saida*	19.48	0.0584	Postflexion

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL4	BN-07-08-04	217	*Boreogadus saida*	14.60	0.0283	Flexion
PL4	BN-07-08-04	218	*Boreogadus saida*	22.09	0.0786	Postflexion
PL4	BN-07-08-04	571	*Liparis gibbus*	18.09	0.0684	Flexion
PL4	BN-07-08-04	572	*Liparis tunicatus*	23.32	0.1583	Postflexion
PL4	BN-07-08-04	573	*Liparis gibbus*	18.58	0.1083	Flexion
PL4	BN-07-08-04	574	*Liparis gibbus*	20.22	0.1000	Flexion
PL4	BN-07-08-05*	219	*Boreogadus saida*	25.57	0.1287	Postflexion
PL4	BN-07-08-05*	220	*Boreogadus saida*	22.53	0.0886	Postflexion
PL4	BN-07-08-05*	221	*Boreogadus saida*	16.00	0.0281	Flexion
PL4	BN-07-08-05*	222	*Boreogadus saida*	14.00	0.028	Flexion
PL4	BN-07-08-05*	223	*Boreogadus saida*	18.00	0.0386	Postflexion
PL4	BN-07-08-05*	224	*Boreogadus saida*	24.08	0.0884	Postflexion
PL4	BN-07-08-05*	225	*Boreogadus saida*	16.00	0.0287	Flexion
PL4	BN-07-08-05*	226	*Boreogadus saida*	19.00	0.0486	Postflexion
PL4	BN-07-08-05*	227	*Boreogadus saida*	18.00	0.0388	Postflexion
PL4	BN-07-08-05*	228	*Boreogadus saida*	15.10	0.0289	Postflexion
PL4	BN-07-08-05*	229	*Gymnocanthus tricuspis*	17.82	0.0283	Postflexion
PL4	BN-07-08-05*	230	*Boreogadus saida*	20.63	0.0587	Postflexion
PL4	BN-07-08-05*	231	*Boreogadus saida*	17.59	0.0387	Postflexion
PL4	BN-07-08-05*	232	*Boreogadus saida*	17.00	0.0389	Postflexion
PL4	BN-07-08-05*	233	*Boreogadus saida*	17.00	0.0289	Postflexion
PL4	BN-07-08-05*	234	*Boreogadus saida*	24.05	0.0986	Postflexion
PL4	BN-07-08-05*	235	*Boreogadus saida*	19.00	0.0489	Postflexion
PL4	BN-07-08-05*	236	*Boreogadus saida*	12.00	0.0187	Flexion
PL4	BN-07-08-05*	237	*Boreogadus saida*	13.32	0.0188	Flexion
PL4	BN-07-08-05*	238	*Boreogadus saida*	23.90	0.0986	Postflexion
PL4	BN-07-08-05*	239	*Boreogadus saida*	19.08	0.0585	Postflexion
PL4	BN-07-08-05*	240	*Boreogadus saida*	15.00	0.0283	Flexion
PL4	BN-07-08-05*	241	*Boreogadus saida*	12.00	0.0185	Flexion
PL4	BN-07-08-05*	242	*Boreogadus saida*	20.05	0.0588	Postflexion
PL4	BN-07-08-05*	575	*Liparis* sp.	16.11	0.0685	Flexion
PL4	BN-07-08-05*	576	*Liparis* sp.	19.30	0.1183	Flexion
PL4	BN-07-08-05*	577	*Liparis* sp.	18.95	0.098	Flexion
PL4	BN-07-08-05*	578	*Liparis tunicatus*	24.14	0.218	Postflexion
PL4	BN-07-08-05*	579	*Liparis gibbus*	17.88	0.0689	Flexion

* Target Tows

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL4	BN-07-08-05*	580	*Ulcina olrikii*	18.60	0.0283	Postflexion
PL4	BN-07-08-05*	581	*Ulcina olrikii*	21.86	0.0486	Postflexion
PL4	BN-07-08-05*	582	*Ulcina olrikii*	19.15	0.0384	Postflexion
PL4	BN-07-08-05*	583	*Gymnocanthus tricuspis*	22.66	0.1487	Postflexion
PL4	BN-07-08-06*	243	*Boreogadus saida*	20.83	0.068	Postflexion
PL4	BN-07-08-06*	244	*Boreogadus saida*	20.00	0.0584	Postflexion
PL4	BN-07-08-06*	245	*Boreogadus saida*	20.00	0.0487	Postflexion
PL4	BN-07-08-06*	246	*Boreogadus saida*	16.00	0.0286	Flexion
PL4	BN-07-08-06*	247	*Boreogadus saida*	14.00	0.0185	Flexion
PL4	BN-07-08-06*	248	*Boreogadus saida*	12.19	0.0188	Flexion
PL4	BN-07-08-06*	249	*Boreogadus saida*	24.00	0.0784	Postflexion
PL4	BN-07-08-06*	250	*Boreogadus saida*	24.36	0.1084	Postflexion
PL4	BN-07-08-06*	251	*Boreogadus saida*	23.40	0.0886	Postflexion
PL4	BN-07-08-06*	252	*Boreogadus saida*	25.17	0.1082	Postflexion
PL4	BN-07-08-06*	253	*Boreogadus saida*	12.00	0.0189	Flexion
PL4	BN-07-08-06*	254	*Boreogadus saida*	21.00	0.0587	Postflexion
PL4	BN-07-08-06*	255	*Boreogadus saida*	19.00	0.0483	Postflexion
PL4	BN-07-08-06*	256	*Boreogadus saida*	18.35	0.0482	Postflexion
PL4	BN-07-08-06*	257	*Boreogadus saida*	22.37	0.0788	Postflexion
PL4	BN-07-08-06*	258	*Boreogadus saida*	12.17	0.0189	Postflexion
PL4	BN-07-08-06*	259	*Boreogadus saida*	18.55	0.0485	Postflexion
PL4	BN-07-08-06*	260	*Boreogadus saida*	12.00	0.0185	Flexion
PL4	BN-07-08-06*	261	*Boreogadus saida*	24.19	0.1088	Postflexion
PL4	BN-07-08-06*	262	*Boreogadus saida*	15.86	0.0288	Postflexion
PL4	BN-07-08-06*	263	*Boreogadus saida*	24.47	0.1111	Postflexion
PL4	BN-07-08-06*	264	*Boreogadus saida*	25.00	0.1089	Postflexion
PL4	BN-07-08-06*	265	*Boreogadus saida*	25.51	0.1186	Postflexion
PL4	BN-07-08-06*	266	*Boreogadus saida*	18.00	0.0388	Postflexion
PL4	BN-07-08-06*	267	*Boreogadus saida*	20.39	0.0588	Postflexion
PL4	BN-07-08-06*	584	*Liparis tunicatus*	23.41	0.2184	Postflexion
PL4	BN-07-08-06*	585	*Liparis gibbus*	17.39	0.098	Flexion
PL4	BN-07-08-06*	586	*Liparis gibbus*	19.28	0.1188	Flexion
PL4	BN-07-08-06*	587	*Liparis gibbus*	19.67	0.1085	Flexion
PL4	BN-07-08-06*	588	*Liparis gibbus*	19.58	0.0981	Flexion
PL4	BN-07-08-06*	589	*Liparis tunicatus*	24.83	0.3081	Postflexion

* Target Tows

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL4	BN-07-08-06*	590	*Liparis gibbus*	20.79	0.168	Postflexion
PL4	BN-07-08-06*	591	*Liparis* sp.	19.81	0.1186	Flexion
PL4	BN-07-08-06*	592	*Liparis gibbus*	20.02	0.1283	Postflexion
PL4	BN-07-08-06*	593	*Liparis tunicatus*	22.74	0.1986	Postflexion
PL4	BN-07-08-06*	594	*Liparis tunicatus*	19.07	0.1182	Flexion
PL4	BN-07-08-06*	595	*Ulcina olrikii*	21.57	0.0487	Postflexion
PL4	BN-07-08-06*	596	*Ulcina olrikii*	21.53	0.0487	Postflexion
PL4	BN-07-08-06*	597	*Gymnocanthus tricuspis*	20.26	0.0983	Postflexion
PL4	BN-07-08-06*	598	*Gymnocanthus tricuspis*	22.71	0.1389	Postflexion
PL4	BN-07-08-06*	599	*Icelus sp.*	15.31	0.0386	Flexion
PL4	BN-07-08-06*	600	*Lumpeninae*	26.78	0.0381	Postflexion
PL9	BN-07-09-01	601	*Lumpeninae*	28.66	0.0587	Postflexion
PL9	BN-07-09-01	602	*Lumpeninae*	29.22	0.0482	Postflexion
PL9	BN-07-09-01	603	*Lumpeninae*	33.18	0.0681	Postflexion
PL9	BN-07-09-01	604	*Lumpeninae*	26.92	0.0388	Postflexion
PL9	BN-07-09-01	605	*Lumpeninae*	28.16	0.0480	Postflexion
PL9	BN-07-09-02	606	*Lumpeninae*	25.60	0.0288	Postflexion
PL9	BN-07-09-02	607	*Lumpeninae*	32.53	0.0481	Postflexion
PL9	BN-07-09-02	608	*Lumpeninae*	32.83	0.0582	Postflexion
PL9	BN-07-09-02	609	*Lumpeninae*	31.95	0.0485	Postflexion
PL9	BN-07-09-02	610	*Lumpeninae*	30.67	0.0380	Postflexion
PL9	BN-07-09-03	268	*Gymnocanthus tricuspis*	15.84	0.0483	Flexion
PL9	BN-07-09-03	269	*Boreogadus saida*	22.00	0.0483	Postflexion
PL9	BN-07-09-03	270	*Boreogadus saida*	15.50	0.0182	Flexion
PL9	BN-07-09-03	271	*Boreogadus saida*	15.00	0.0184	Flexion
PL9	BN-07-09-03	272	*Boreogadus saida*	14.00	0.0186	Flexion
PL9	BN-07-09-03	611	Lumpeninae	30.60	0.0585	Postflexion
PL9	BN-07-09-03	612	Lumpeninae	33.97	0.0707	Postflexion
PL9	BN-07-09-03	613	Lumpeninae	26.83	0.0382	Postflexion
PL9	BN-07-09-03	614	Lumpeninae	31.50	0.0580	Postflexion
PL9	BN-07-09-03	615	Lumpeninae	31.25	0.0586	Postflexion
PL9	BN-07-09-03	616	Lumpeninae	32.03	0.0589	Postflexion
PL9	BN-07-09-03	617	Lumpeninae	28.69	0.0484	Postflexion
PL9	BN-07-09-03	618	Lumpeninae	32.05	0.0584	Postflexion
PL9	BN-07-09-03	619	Lumpeninae	30.27	0.0484	Postflexion

* Target Tows

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL9	BN-07-09-03	620	Lumpeninae	27.07	0.0385	Postflexion
PL9	BN-07-09-03	621	Lumpeninae	31.13	0.0485	Postflexion
PL9	BN-07-09-03	622	Lumpeninae	34.12	0.0682	Postflexion
PL9	BN-07-09-03	623	Lumpeninae	29.30	0.0488	Postflexion
PL9	BN-07-09-03	624	Lumpeninae	20.02	0.0184	Flexion
PL9	BN-07-09-03	625	Lumpeninae	32.78	0.0681	Postflexion
PL9	BN-07-09-03	626	Lumpeninae	26.56	0.0389	Postflexion
PL9	BN-07-09-03	627	Lumpeninae	29.75	0.0489	Postflexion
PL9	BN-07-09-03	628	Lumpeninae	29.04	0.0484	Postflexion
PL9	BN-07-09-03	629	Lumpeninae	33.92	0.0680	Postflexion
PL9	BN-07-09-03	630	Lumpeninae	29.81	0.0583	Postflexion
PL9	BN-07-09-03	631	Lumpeninae	30.70	0.0584	Postflexion
PL9	BN-07-09-03	632	Lumpeninae	26.98	0.0483	Postflexion
PL9	BN-07-09-03	633	Lumpeninae	28.29	0.0484	Postflexion
PL9	BN-07-09-03	634	Lumpeninae	25.84	0.0386	Postflexion
PL9	BN-07-09-03	635	Lumpeninae	30.52	0.0581	Postflexion
PL9	BN-07-09-03	636	Lumpeninae	33.80	0.0789	Postflexion
PL9	BN-07-09-03	637	Lumpeninae	28.23	0.0380	Postflexion
PL9	BN-07-09-03	638	Lumpeninae	30.36	0.0480	Postflexion
PL9	BN-07-09-03	639	Lumpeninae	31.58	0.0583	Postflexion
PL9	BN-07-09-04	273	*Icelus* sp.	31.39	0.0186	Postflexion
PL9	BN-07-09-04	274	*Boreogadus saida*	12.00	0.0183	Flexion
PL9	BN-07-09-04	275	*Boreogadus saida*	11.00	0.0070	Flexion
PL9	BN-07-09-04	276	*Boreogadus saida*	17.00	0.0281	Postflexion
PL9	BN-07-09-04	277	*Boreogadus saida*	14.00	0.0082	Flexion
PL9	BN-07-09-04	640	Lumpeninae	30.24	0.0582	Postflexion
PL9	BN-07-09-04	641	Lumpeninae	30.23	0.0486	Postflexion
PL9	BN-07-09-04	642	Lumpeninae	24.49	0.0285	Postflexion
PL9	BN-07-09-04	643	Lumpeninae	29.17	0.0485	Postflexion
PL9	BN-07-09-04	644	Lumpeninae	30.73	0.0580	Postflexion
PL9	BN-07-09-04	645	Lumpeninae	25.79	0.0380	Postflexion
PL9	BN-07-09-04	646	Lumpeninae	28.57	0.0486	Postflexion
PL9	BN-07-09-04	647	Lumpeninae	31.81	0.0682	Postflexion
PL9	BN-07-09-04	648	Lumpeninae	29.37	0.0480	Postflexion
PL9	BN-07-09-04	649	Lumpeninae	32.04	0.0582	Postflexion
PL9	BN-07-09-04	650	Lumpeninae	31.40	0.0582	Postflexion

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL9	BN-07-09-04	651	Lumpeninae	30.58	0.0581	Postflexion
PL9	BN-07-09-04	652	Lumpeninae	27.12	0.0384	Postflexion
PL9	BN-07-09-04	653	Lumpeninae	30.75	0.0588	Postflexion
PL9	BN-07-09-04	654	Lumpeninae	27.99	0.0386	Postflexion
PL9	BN-07-09-04	655	Lumpeninae	27.48	0.0483	Postflexion
PL9	BN-07-09-04	656	Lumpeninae	24.91	0.0382	Postflexion
PL9	BN-07-09-04	657	Lumpeninae	26.96	0.0384	Postflexion
PL9	BN-07-09-04	658	Lumpeninae	33.80	0.0685	Postflexion
PL9	BN-07-09-04	659	Lumpeninae	29.45	0.0482	Postflexion
PL9	BN-07-09-04	660	Lumpeninae	27.83	0.0382	Postflexion
PL9	BN-07-09-04	661	Lumpeninae	26.70	0.0389	Postflexion
PL9	BN-07-09-04	662	Lumpeninae	30.37	0.0589	Postflexion
PL8	BN-07-10-01	278	*Boreogadus saida*	20.73	0.0688	Postflexion
PL8	BN-07-10-01	279	*Boreogadus saida*	20.07	0.0682	Postflexion
PL8	BN-07-10-01	280	*Boreogadus saida*	18.40	0.0487	Postflexion
PL8	BN-07-10-01	281	*Boreogadus saida*	20.00	0.0482	Postflexion
PL8	BN-07-10-01	282	*Boreogadus saida*	20.88	0.0687	Postflexion
PL8	BN-07-10-01	283	*Boreogadus saida*	22.11	0.0788	Postflexion
PL8	BN-07-10-01	284	*Boreogadus saida*	18.95	0.0483	Postflexion
PL8	BN-07-10-01	285	*Boreogadus saida*	17.32	0.0385	Postflexion
PL8	BN-07-10-01	286	*Boreogadus saida*	27.00	0.1387	Postflexion
PL8	BN-07-10-01	287	*Boreogadus saida*	18.95	0.0480	Postflexion
PL8	BN-07-10-01	288	*Boreogadus saida*	18.00	0.0285	Postflexion
PL8	BN-07-10-01	289	*Boreogadus saida*	20.46	0.0786	Postflexion
PL8	BN-07-10-01	290	*Boreogadus saida*	22.00	0.0480	Postflexion
PL8	BN-07-10-01	663	Lumpeninae	31.83	0.0684	Postflexion
PL8	BN-07-10-01	913	Lumpeninae	27.76	0.0382	Postflexion
PL8	BN-07-10-02	291	*Boreogadus saida*	21.00	0.0583	Postflexion
PL8	BN-07-10-02	292	*Boreogadus saida*	12.53	0.0184	Flexion
PL8	BN-07-10-02	293	*Boreogadus saida*	24.28	0.1082	Postflexion
PL8	BN-07-10-02	294	*Boreogadus saida*	17.00	0.0387	Postflexion
PL8	BN-07-10-02	295	*Boreogadus saida*	24.50	0.1083	Postflexion
PL8	BN-07-10-02	296	*Boreogadus saida*	23.73	0.0807	Postflexion
PL8	BN-07-10-02	297	*Boreogadus saida*	17.00	0.0285	Postflexion
PL8	BN-07-10-02	298	*Boreogadus saida*	13.28	0.0186	Flexion
PL8	BN-07-10-02	299	*Boreogadus saida*	22.69	0.0982	Postflexion

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL8	BN-07-10-02	300	*Boreogadus saida*	24.47	0.0987	Postflexion
PL8	BN-07-10-02	301	*Boreogadus saida*	23.23	0.0882	Postflexion
PL8	BN-07-10-02	302	*Boreogadus saida*	22.00	0.0682	Postflexion
PL8	BN-07-10-02	303	*Boreogadus saida*	18.25	0.0487	Postflexion
PL8	BN-07-10-02	664	Lumpeninae	29.15	0.0584	Postflexion
PL8	BN-07-10-02	665	Lumpeninae	25.64	0.0100	Postflexion
PL8	BN-07-10-02	666	*Ulcina olrikii*	21.73	0.0486	Postflexion
PL8	BN-07-10-02	667	*Ulcina olrikii*	19.46	0.0387	Postflexion
PL8	BN-07-10-02	668	*Liparis gibbus*	19.06	0.0987	Flexion
PL8	BN-07-10-02	669	*Icelus sp.*	19.79	0.0687	Postflexion
PL8	BN-07-10-03	304	*Boreogadus saida*	18.55	0.0386	Postflexion
PL8	BN-07-10-03	305	*Boreogadus saida*	18.14	0.0387	Postflexion
PL8	BN-07-10-03	306	*Boreogadus saida*	18.81	0.0384	Postflexion
PL8	BN-07-10-03	307	*Boreogadus saida*	24.12	0.1084	Postflexion
PL8	BN-07-10-03	308	*Boreogadus saida*	18.64	0.0484	Postflexion
PL8	BN-07-10-03	309	*Boreogadus saida*	12.00	0.0186	Flexion
PL8	BN-07-10-03	310	*Boreogadus saida*	18.80	0.0483	Postflexion
PL8	BN-07-10-03	311	*Boreogadus saida*	22.27	0.0885	Postflexion
PL8	BN-07-10-03	312	*Boreogadus saida*	22.01	0.0682	Postflexion
PL8	BN-07-10-03	313	*Boreogadus saida*	16.42	0.0287	Postflexion
PL8	BN-07-10-04	314	*Boreogadus saida*	20.80	0.0886	Postflexion
PL8	BN-07-10-04	315	*Boreogadus saida*	16.38	0.0389	Postflexion
PL8	BN-07-10-04	316	*Gymnocanthus tricuspis*	20.65	0.0588	Postflexion
PL8	BN-07-10-04	317	*Boreogadus saida*	19.00	0.0389	Postflexion
PL8	BN-07-10-04	318	*Boreogadus saida*	20.51	0.0683	Postflexion
PL8	BN-07-10-04	319	*Boreogadus saida*	22.69	0.0989	Postflexion
PL8	BN-07-10-04	320	*Boreogadus saida*	21.80	0.0682	Postflexion
PL8	BN-07-10-04	321	*Boreogadus saida*	13.19	0.0188	Flexion
PL8	BN-07-10-04	322	*Boreogadus saida*	15.57	0.0287	Flexion
PL8	BN-07-10-04	323	*Boreogadus saida*	19.93	0.0486	Postflexion
PL8	BN-07-10-04	670	*Liparis fabricii*	21.49	0.1084	Flexion
PL8	BN-07-10-04	671	*Liparis tunicatus*	20.42	0.1482	Flexion
PL8	BN-07-10-04	672	*Liparis tunicatus*	22.98	0.2083	Flexion
PL8	BN-07-10-04	673	*Liparis tunicatus*	24.95	0.3286	Postflexion
PL8	BN-07-10-04	674	*Liparis fabricii*	12.13	0.0182	Flexion
PL8	BN-07-10-04	675	*Liparis fabricii*	18.09	0.0385	Postflexion

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL8	BN-07-10-05*	324	*Boreogadus saida*	22.44	0.0782	Postflexion
PL8	BN-07-10-05*	325	*Boreogadus saida*	18.03	0.0481	Postflexion
PL8	BN-07-10-05*	326	*Boreogadus saida*	18.29	0.0283	Postflexion
PL8	BN-07-10-05*	327	*Boreogadus saida*	25.22	0.1186	Postflexion
PL8	BN-07-10-05*	328	*Boreogadus saida*	17.74	0.0389	Postflexion
PL8	BN-07-10-05*	329	*Boreogadus saida*	18.64	0.0588	Postflexion
PL8	BN-07-10-05*	330	*Boreogadus saida*	13.00	0.0183	Postflexion
PL8	BN-07-10-05*	331	*Boreogadus saida*	19.00	0.0382	Postflexion
PL8	BN-07-10-05*	332	*Boreogadus saida*	26.00	0.1188	Postflexion
PL8	BN-07-10-05*	333	*Boreogadus saida*	18.71	0.0388	Postflexion
PL8	BN-07-10-05*	334	*Boreogadus saida*	18.78	0.0381	Postflexion
PL8	BN-07-10-05*	335	*Boreogadus saida*	17.00	0.0284	Postflexion
PL8	BN-07-10-05*	336	*Boreogadus saida*	19.00	0.0388	Postflexion
PL8	BN-07-10-05*	337	*Boreogadus saida*	21.00	0.0584	Postflexion
PL8	BN-07-10-05*	338	*Boreogadus saida*	23.93	0.0889	Postflexion
PL8	BN-07-10-05*	339	*Boreogadus saida*	18.68	0.0388	Postflexion
PL8	BN-07-10-05*	340	*Boreogadus saida*	16.74	0.0382	Postflexion
PL8	BN-07-10-05*	341	*Boreogadus saida*	21.52	0.0582	Postflexion
PL8	BN-07-10-05*	342	*Boreogadus saida*	19.21	0.0388	Postflexion
PL8	BN-07-10-05*	343	*Boreogadus saida*	22.00	0.0687	Postflexion
PL8	BN-07-10-05*	344	*Boreogadus saida*	21.00	0.0681	Postflexion
PL8	BN-07-10-05*	345	*Boreogadus saida*	29.50	0.1789	Postflexion
PL8	BN-07-10-05*	346	*Boreogadus saida*	18.00	0.0287	Postflexion
PL8	BN-07-10-05*	347	*Boreogadus saida*	25.00	0.0884	Postflexion
PL8	BN-07-10-05*	348	*Boreogadus saida*	22.00	0.0682	Postflexion
PL8	BN-07-10-05*	349	*Boreogadus saida*	18.46	0.0184	Flexion
PL8	BN-07-10-05*	350	*Boreogadus saida*	21.18	0.0489	Postflexion
PL8	BN-07-10-05*	676	*Liparis tunicatus*	18.60	0.1284	Flexion
PL8	BN-07-10-05*	677	*Liparis gibbus*	24.54	0.4388	Postflexion
PL8	BN-07-10-05*	678	*Liparis gibbus*	17.59	0.1187	Flexion
PL8	BN-07-10-05*	679	*Liparis tunicatus*	20.14	0.1684	Flexion
PL8	BN-07-10-05*	680	*Ulcina olrikii*	20.45	0.048	Postflexion
PL8	BN-07-10-05*	681	*Ulcina olrikii*	22.23	0.0581	Postflexion
PL8	BN-07-10-06*	351	*Boreogadus saida*	21.85	0.0683	Postflexion
PL8	BN-07-10-06*	352	*Boreogadus saida*	19.00	0.0383	Postflexion

* Target Tows

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL8	BN-07-10-06*	353	*Boreogadus saida*	30.00	0.1688	Early Juvenile
PL8	BN-07-10-06*	354	*Boreogadus saida*	25.57	0.1089	Postflexion
PL8	BN-07-10-06*	355	*Boreogadus saida*	31.00	0.2286	Early Juvenile
PL8	BN-07-10-06*	356	*Boreogadus saida*	24.06	0.0989	Postflexion
PL8	BN-07-10-06*	357	*Boreogadus saida*	13.00	0.0183	Flexion
PL8	BN-07-10-06*	358	*Boreogadus saida*	19.00	0.0485	Postflexion
PL8	BN-07-10-06*	359	*Boreogadus saida*	17.00	0.038	Postflexion
PL8	BN-07-10-06*	360	*Boreogadus saida*	21.00	0.0581	Postflexion
PL8	BN-07-10-06*	361	*Boreogadus saida*	17.00	0.0281	Postflexion
PL8	BN-07-10-06*	362	*Boreogadus saida*	25.00	0.108	Postflexion
PL8	BN-07-10-06*	363	*Boreogadus saida*	22.00	0.0588	Postflexion
PL8	BN-07-10-06*	364	*Boreogadus saida*	21.00	0.0482	Postflexion
PL8	BN-07-10-06*	365	*Boreogadus saida*	26.00	0.1285	Postflexion
PL8	BN-07-10-06*	366	*Boreogadus saida*	19.87	0.0486	Postflexion
PL8	BN-07-10-06*	367	*Boreogadus saida*	28.41	0.1688	Early Juvenile
PL8	BN-07-10-06*	368	*Boreogadus saida*	15.00	0.0181	Postflexion
PL8	BN-07-10-06*	369	*Boreogadus saida*	24.00	0.0986	Postflexion
PL8	BN-07-10-06*	370	*Boreogadus saida*	20.83	0.0689	Postflexion
PL8	BN-07-10-06*	371	*Boreogadus saida*	16.73	0.0289	late flexion
PL8	BN-07-10-06*	372	*Boreogadus saida*	25.61	0.1087	Postflexion
PL8	BN-07-10-06*	373	*Boreogadus saida*	23.04	0.0707	Postflexion
PL8	BN-07-10-06*	374	*Boreogadus saida*	17.00	0.0388	Postflexion
PL8	BN-07-10-06*	375	*Boreogadus saida*	18.00	0.0383	Postflexion
PL8	BN-07-10-06*	376	*Boreogadus saida*	19.00	0.0383	Postflexion
PL8	BN-07-10-06*	377	*Boreogadus saida*	17.00	0.0284	Postflexion
PL8	BN-07-10-06*	378	*Boreogadus saida*	18.23	0.0385	Postflexion
PL8	BN-07-10-06*	379	*Boreogadus saida*	22.00	0.0688	Postflexion
PL8	BN-07-10-06*	380	*Boreogadus saida*	18.00	0.038	Postflexion
PL8	BN-07-10-06*	381	*Boreogadus saida*	19.83	0.0488	Postflexion
PL8	BN-07-10-06*	382	*Boreogadus saida*	26.00	0.1186	Postflexion
PL8	BN-07-10-06*	383	*Boreogadus saida*	24.74	0.1081	Postflexion
PL8	BN-07-10-06*	384	*Boreogadus saida*	16.73	0.0383	Flexion
PL8	BN-07-10-06*	385	*Boreogadus saida*	27.76	0.1283	Postflexion
PL8	BN-07-10-06*	386	*Boreogadus saida*	16.08	0.0289	Postflexion
PL8	BN-07-10-06*	387	*Boreogadus saida*	25.21	0.1088	Postflexion

* Target Tows

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL8	BN-07-10-06*	388	*Boreogadus saida*	24.11	0.1083	Postflexion
PL8	BN-07-10-06*	682	*Liparis tunicatus*	22.69	0.1487	Flexion
PL8	BN-07-10-06*	683	*Liparis tunicatus*	20.84	0.1485	Flexion
PL8	BN-07-10-06*	684	*Liparis fabricii*	22.90	0.0983	Flexion
PL7	BN-07-11-01	389	*Triglops nybelini*	23.01	0.0781	Postflexion
PL7	BN-07-11-01	390	*Boreogadus saida*	19.00	0.0380	Postflexion
PL7	BN-07-11-01	391	*Boreogadus saida*	20.33	0.0580	Postflexion
PL7	BN-07-11-01	392	*Boreogadus saida*	22.85	0.0785	Postflexion
PL7	BN-07-11-01	685	*Ulcina olrikii*	18.62	0.0380	Postflexion
PL7	BN-07-11-01	686	*Ulcina olrikii*	23.25	0.0686	Postflexion
PL7	BN-07-11-02	393	*Boreogadus saida*	18.54	0.0487	Postflexion
PL7	BN-07-11-02	394	*Boreogadus saida*	16.78	0.0285	Postflexion
PL7	BN-07-11-02	395	*Boreogadus saida*	18.80	0.0380	Postflexion
PL7	BN-07-11-02	396	*Boreogadus saida*	18.46	0.0480	Postflexion
PL7	BN-07-11-02	397	*Boreogadus saida*	14.97	0.0283	Flexion
PL7	BN-07-11-02	398	*Boreogadus saida*	19.92	0.0588	Postflexion
PL7	BN-07-11-02	687	*Ulcina olrikii*	20.36	0.0387	Postflexion
PL7	BN-07-11-02	688	*Gymnocanthus tricuspis*	22.51	0.1286	Postflexion
PL7	BN-07-11-03	399	*Boreogadus saida*	21.25	0.0682	Postflexion
PL7	BN-07-11-03	400	*Boreogadus saida*	17.75	0.0384	Postflexion
PL7	BN-07-11-03	401	*Boreogadus saida*	24.29	0.1084	Postflexion
PL7	BN-07-11-03	402	*Boreogadus saida*	17.41	0.0380	Postflexion
PL7	BN-07-11-03	403	*Boreogadus saida*	20.18	0.0687	Postflexion
PL7	BN-07-11-03	404	*Boreogadus saida*	22.10	0.0688	Postflexion
PL7	BN-07-11-03	405	*Boreogadus saida*	24.12	0.0980	Postflexion
PL7	BN-07-11-03	406	*Boreogadus saida*	15.59	0.0384	Flexion
PL7	BN-07-11-03	689	*Ulcina olrikii*	19.55	0.0381	Postflexion
PL7	BN-07-11-03	690	*Ulcina olrikii*	14.89	0.0107	Postflexion
PL7	BN-07-11-03	691	*Liparis fabricii*	18.42	0.0482	Postflexion
PL7	BN-07-11-03	692	*Liparis fabricii*	27.32	0.2289	Postflexion
PL7	BN-07-11-03	693	*Gymnocanthus tricuspis*	20.41	0.0986	Postflexion
PL7	BN-07-11-03	694	*Icelus* sp.	19.55	0.0689	Postflexion
PL7	BN-07-11-03	695	*Triglops Nybelini*	23.94	0.1089	Postflexion
PL7	BN-07-11-03	914	*Liparis fabricii*	10.00	0.0089	Preflexion
PL7	BN-07-11-04	407	*Boreogadus saida*	18.29	0.0482	Postflexion

* Target Tows

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL7	BN-07-11-04	408	*Boreogadus saida*	18.68	0.0482	Postflexion
PL7	BN-07-11-04	409	*Boreogadus saida*	16.21	0.0289	Flexion
PL7	BN-07-11-04	410	*Boreogadus saida*	21.21	0.0587	Postflexion
PL7	BN-07-11-04	696	*Liparis fabricii*	18.85	0.0486	Postflexion
PL7	BN-07-11-05*	411	*Boreogadus saida*	16.00	0.0386	Postflexion
PL7	BN-07-11-05*	412	*Boreogadus saida*	23.87	0.0988	Postflexion
PL7	BN-07-11-05*	413	*Boreogadus saida*	23.29	0.0844	Postflexion
PL7	BN-07-11-05*	414	*Boreogadus saida*	13.5	0.0187	Flexion
PL7	BN-07-11-05*	415	*Boreogadus saida*	18.00	0.0387	Postflexion
PL7	BN-07-11-05*	416	*Boreogadus saida*	15.00	0.0187	Flexion
PL7	BN-07-11-05*	417	*Boreogadus saida*	15.00	0.0183	Flexion
PL7	BN-07-11-05*	418	*Boreogadus saida*	15.00	0.0286	Flexion
PL7	BN-07-11-05*	419	*Boreogadus saida*	17.89	0.048	Postflexion
PL7	BN-07-11-05*	697	*Ulcina olrikii*	19.37	0.0389	Postflexion
PL7	BN-07-11-05*	698	*Ulcina olrikii*	21.16	0.0588	Postflexion
PL7	BN-07-11-05*	699	*Ulcina olrikii*	21.46	0.0483	Postflexion
PL7	BN-07-11-05*	700	*Ulcina olrikii*	21.32	0.0484	Postflexion
PL7	BN-07-11-05*	701	*Liparis tunicatus*	20.17	0.1782	Flexion
PL7	BN-07-11-05*	702	*Liparis tunicatus*	18.32	0.1286	Postflexion
PL7	BN-07-11-06*	420	*Boreogadus saida*	23.00	0.0686	Postflexion
PL7	BN-07-11-06*	421	*Boreogadus saida*	19.99	0.0585	Postflexion
PL7	BN-07-11-06*	422	*Boreogadus saida*	16.00	0.0782	Postflexion
PL7	BN-07-11-06*	423	*Boreogadus saida*	23.99	0.0888	Postflexion
PL7	BN-07-11-06*	424	*Boreogadus saida*	16.88	0.0038	Flexion
PL7	BN-07-11-06*	425	*Boreogadus saida*	28.77	0.1584	Early Juvenile
PL7	BN-07-11-06*	703	*Liparis tunicatus*	18.64	0.1083	Flexion
PL10	BN-07-37-01	426	*Boreogadus saida*	35.78	0.2785	Early Juvenile
PL10	BN-07-37-01	427	*Boreogadus saida*	27.65	0.1385	Postflexion
PL10	BN-07-37-01	428	*Boreogadus saida*	33.63	0.2681	Early Juvenile
PL10	BN-07-37-01	429	*Boreogadus saida*	26.36	0.1384	Postflexion
PL10	BN-07-37-01	430	*Boreogadus saida*	26.96	0.1384	Postflexion
PL10	BN-07-37-01	431	*Boreogadus saida*	31.07	0.2581	Early Juvenile
PL10	BN-07-37-01	432	*Boreogadus saida*	24.72	0.0887	Postflexion
PL10	BN-07-37-01	433	*Boreogadus saida*	20.76	0.0584	Postflexion
PL10	BN-07-37-01	434	*Boreogadus saida*	26.99	0.1187	Postflexion

* Target Tows

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL10	BN-07-37-01	704	Lumpeninae	39.51	0.1088	Postflexion
PL10	BN-07-37-01	705	*Liparis fabricii*	28.22	0.2089	Postflexion
PL10	BN-07-37-02	435	*Boreogadus saida*	23.82	0.0883	Postflexion
PL10	BN-07-37-02	436	*Boreogadus saida*	30.79	0.1780	Early Juvenile
PL10	BN-07-37-02	437	*Boreogadus saida*	29.02	0.1683	Postflexion
PL10	BN-07-37-02	438	*Boreogadus saida*	22.51	0.0682	Postflexion
PL10	BN-07-37-02	706	*Liparis tunicatus*	33.72	0.6185	Postflexion
PL10	BN-07-37-02	707	*Ulcina olrikii*	26.58	0.0984	Postflexion
PL10	BN-07-37-03	439	*Boreogadus saida*	21.40	0.0587	Postflexion
PL10	BN-07-37-03	440	*Boreogadus saida*	35.51	0.2780	Early Juvenile
PL10	BN-07-37-03	441	*Boreogadus saida*	41.45	0.4782	Early Juvenile
PL10	BN-07-37-03	442	*Boreogadus saida*	20.37	0.0487	Postflexion
PL10	BN-07-37-03	443	*Boreogadus saida*	28.53	0.1382	Postflexion
PL10	BN-07-37-03	444	*Boreogadus saida*	38.27	0.3486	Early Juvenile
PL10	BN-07-37-03	445	*Boreogadus saida*	36.04	0.2885	Early Juvenile
PL10	BN-07-37-04	446	*Boreogadus saida*	30.05	0.1985	Postflexion
PL10	BN-07-37-04	447	*Boreogadus saida*	29.01	0.1286	Postflexion
PL10	BN-07-37-04	448	*Boreogadus saida*	40.90	0.4388	Postflexion
PL10	BN-07-37-04	449	*Boreogadus saida*	35.78	0.2581	Postflexion
PL10	BN-07-37-04	450	*Boreogadus saida*	28.94	0.1582	Postflexion
PL10	BN-07-37-04	451	*Boreogadus saida*	26.20	0.0983	Postflexion
PL10	BN-07-37-04	452	*Boreogadus saida*	32.14	0.1882	Early Juvenile
PL10	BN-07-37-05		No fish caught			
PL10	BN-07-37-06	453	*Boreogadus saida*	22.45	0.0583	Postflexion
PL10	BN-07-37-06	454	*Boreogadus saida*	35.69	0.2787	Early Juvenile
PL10	BN-07-37-06	708	*Gymnocanthus tricuspis*	28.81	0.2888	Early Juvenile
PL10	BN-07-37-06	709	*Liparis tunicatus*	25.80	0.198	Post flexion
PL11	BN-07-38-01	455	*Boreogadus saida*	23.29	0.0686	Postflexion
PL11	BN-07-38-01	456	*Boreogadus saida*	34.75	0.2386	Early Juvenile
PL11	BN-07-38-01	710	Lumpeninae	31.72	0.0481	Postflexion
PL11	BN-07-38-01	711	Lumpeninae	36.17	0.0683	Postflexion
PL11	BN-07-38-01	712	Lumpeninae	35.76	0.0682	Postflexion
PL11	BN-07-38-01	713	Lumpeninae	41.97	0.1289	Postflexion
PL11	BN-07-38-01	714	Lumpeninae	33.11	0.0489	Postflexion
PL11	BN-07-38-01	715	Lumpeninae	36.13	0.0581	Postflexion
PL11	BN-07-38-01	716	Lumpeninae	34.21	0.0484	Postflexion

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL11	BN-07-38-02	457	*Eleginus gracilis*	8.50	0.0880	Flexion
PL11	BN-07-38-02	717	Lumpeninae	38.32	0.0787	Postflexion
PL11	BN-07-38-02	718	Lumpeninae	33.66	0.0584	Postflexion
PL11	BN-07-38-02	719	Lumpeninae	36.83	0.0786	Postflexion
PL11	BN-07-38-02	720	Lumpeninae	39.45	0.0885	Postflexion
PL11	BN-07-38-02	721	Lumpeninae	38.48	0.0887	Postflexion
PL11	BN-07-38-02	722	Lumpeninae	35.59	0.0686	Postflexion
PL11	BN-07-38-02	723	Lumpeninae	37.09	0.0788	Postflexion
PL11	BN-07-38-02	724	Lumpeninae	30.29	0.0485	Postflexion
PL11	BN-07-38-02	725	*Liparis tunicatus*	27.20	0.4185	Postflexion
PL11	BN-07-38-03	726	*Liparis sp.*	13.61	0.0289	Preflexion
PL11	BN-07-38-03	727	*Clupea pallasii pallasii*	13.69	0.0087	Postflexion
PL11	BN-07-38-03	728	Lumpeninae	40.81	0.0980	Postflexion
PL11	BN-07-38-03	729	Lumpeninae	35.72	0.0687	Postflexion
PL11	BN-07-38-03	730	Lumpeninae	34.62	0.0687	Postflexion
PL11	BN-07-38-03	731	Lumpeninae	37.11	0.0785	Postflexion
PL11	BN-07-38-04	732	*Liparis tunicatus*	28.14	0.3982	Postflexion
PL11	BN-07-38-04	733	Lumpeninae	33.94	0.0782	Postflexion
PL11	BN-07-38-04	734	Lumpeninae	28.06	0.0484	Postflexion
PL11	BN-07-38-04	735	Lumpeninae	25.83	0.0489	Postflexion
PL11	BN-07-38-04	736	Lumpeninae	38.94	0.1085	Postflexion
PL11	BN-07-38-04	737	Lumpeninae	30.64	0.0586	Postflexion
PL11	BN-07-38-04	738	Lumpeninae	32.04	0.0584	Postflexion
PL11	BN-07-38-04	739	Lumpeninae	30.94	0.0686	Postflexion
PL12	BN-07-39-01	740	Lumpeninae	36.82	0.0782	Postflexion
PL12	BN-07-39-01	741	Lumpeninae	36.33	0.0686	Postflexion
PL12	BN-07-39-01	742	Lumpeninae	38.76	0.0880	Postflexion
PL12	BN-07-39-01	743	Lumpeninae	34.95	0.0683	Postflexion
PL12	BN-07-39-01	744	Lumpeninae	35.89	0.0881	Postflexion
PL12	BN-07-39-01	745	Lumpeninae	30.25	0.0388	Postflexion
PL12	BN-07-39-01	746	Lumpeninae	40.84	0.1084	Postflexion
PL12	BN-07-39-01	747	Lumpeninae	33.98	0.0585	Postflexion
PL12	BN-07-39-01	748	Lumpeninae	33.92	0.0587	Postflexion
PL12	BN-07-39-01	749	Lumpeninae	36.14	0.0584	Postflexion
PL12	BN-07-39-01	915	Lumpeninae	33.73	0.0581	Postflexion
PL12	BN-07-39-01	916	*Clupea pallasii pallasii*	17.30	0.0080	Postflexion

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL12	BN-07-39-01	917	*Clupea pallasii pallasii*	16.10	0.0084	Flexion
PL12	BN-07-39-02	750	Lumpeninae	38.03	0.0788	Postflexion
PL12	BN-07-39-02	751	Lumpeninae	34.76	0.0589	Postflexion
PL12	BN-07-39-02	752	Lumpeninae	38.14	0.0887	Postflexion
PL12	BN-07-39-02	753	Lumpeninae	36.70	0.0784	Postflexion
PL12	BN-07-39-02	754	Lumpeninae	34.71	0.0683	Postflexion
PL12	BN-07-39-02	755	Lumpeninae	37.97	0.0784	Postflexion
PL12	BN-07-39-02	756	Lumpeninae	33.76	0.0583	Postflexion
PL12	BN-07-39-02	757	Lumpeninae	39.78	0.0988	Postflexion
PL12	BN-07-39-02	758	Lumpeninae	35.26	0.0687	Postflexion
PL12	BN-07-39-02	759	Lumpeninae	33.60	0.0580	Postflexion
PL12	BN-07-39-02	760	Lumpeninae	34.00	0.0583	Postflexion
PL12	BN-07-39-02	761	Lumpeninae	34.87	0.0587	Postflexion
PL12	BN-07-39-02	762	Lumpeninae	32.67	0.0581	Postflexion
PL12	BN-07-39-02	763	Lumpeninae	35.47	0.0588	Postflexion
PL12	BN-07-39-02	764	Lumpeninae	31.86	0.0482	Postflexion
PL12	BN-07-39-02	765	Lumpeninae	36.29	0.0781	Postflexion
PL12	BN-07-39-02	766	Lumpeninae	34.08	0.0684	Postflexion
PL12	BN-07-39-02	767	Lumpeninae	37.07	0.0780	Postflexion
PL12	BN-07-39-02	768	Lumpeninae	35.20	0.0689	Postflexion
PL12	BN-07-39-02	918	*Clupea pallasii pallasii*	11.10	0.0089	Flexion
PL12	BN-07-39-02	919	*Clupea pallasii pallasii*	13.44	0.0084	Flexion
PL12	BN-07-39-03	770	Lumpeninae	37.41	0.0701	Postflexion
PL12	BN-07-39-03	771	Lumpeninae	28.92	0.0387	Postflexion
PL12	BN-07-39-03	772	Lumpeninae	37.38	0.0788	Postflexion
PL12	BN-07-39-03	773	Lumpeninae	36.44	0.0683	Postflexion
PL12	BN-07-39-03	774	Lumpeninae	33.75	0.0684	Postflexion
PL12	BN-07-39-03	775	Lumpeninae	33.98	0.0489	Postflexion
PL12	BN-07-39-03	776	Lumpeninae	35.80	0.0783	Postflexion
PL12	BN-07-39-03	777	Lumpeninae	34.57	0.0580	Postflexion
PL12	BN-07-39-03	778	Lumpeninae	36.31	0.0780	Postflexion
PL12	BN-07-39-03	779	Lumpeninae	29.94	0.0483	Postflexion
PL12	BN-07-39-03	780	Lumpeninae	37.64	0.0782	Postflexion
PL12	BN-07-39-03	781	Lumpeninae	40.49	0.0182	Postflexion
PL12	BN-07-39-03	782	Lumpeninae	34.74	0.0589	Postflexion
PL12	BN-07-39-03	783	Lumpeninae	37.46	0.0786	Postflexion

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL12	BN-07-39-03	784	Lumpeninae	36.27	0.0784	Postflexion
PL12	BN-07-39-04	785	Lumpeninae	38.60	0.0787	Postflexion
PL12	BN-07-39-04	786	Lumpeninae	35.62	0.0684	Postflexion
PL12	BN-07-39-04	787	Lumpeninae	39.72	0.1087	Postflexion
PL12	BN-07-39-04	788	Lumpeninae	35.21	0.0686	Postflexion
PL12	BN-07-39-04	789	Lumpeninae	34.33	0.0583	Postflexion
PL12	BN-07-39-04	790	Lumpeninae	40.58	0.1000	Postflexion
PL12	BN-07-39-04	791	Lumpeninae	35.76	0.0689	Postflexion
PL12	BN-07-39-04	792	Lumpeninae	33.55	0.0488	Postflexion
PL12	BN-07-39-04	793	Lumpeninae	31.18	0.0387	Postflexion
PL12	BN-07-39-04	794	Lumpeninae	37.00	0.0788	Postflexion
PL12	BN-07-39-04	795	Lumpeninae	39.55	0.0988	Postflexion
PL12	BN-07-39-04	796	Lumpeninae	33.48	0.0487	Postflexion
PL12	BN-07-39-04	797	Lumpeninae	38.63	0.0985	Postflexion
PL12	BN-07-39-05	458	*Boreogadus saida*	19.06	0.0388	Postflexion
PL12	BN-07-39-05	798	Lumpeninae	33.08	0.0581	Postflexion
PL12	BN-07-39-05	799	Lumpeninae	36.60	0.0888	Postflexion
PL12	BN-07-39-05	800	Lumpeninae	36.95	0.0881	Postflexion
PL12	BN-07-39-05	801	Lumpeninae	35.02	0.0701	Postflexion
PL12	BN-07-39-05	802	Lumpeninae	39.56	0.1085	Postflexion
PL12	BN-07-39-05	803	Lumpeninae	37.43	0.0788	Postflexion
PL12	BN-07-39-05	804	Lumpeninae	35.39	0.0787	Postflexion
PL12	BN-07-39-05	805	Lumpeninae	40.36	0.0108	Postflexion
PL12	BN-07-39-05	806	Lumpeninae	38.57	0.0783	Postflexion
PL12	BN-07-39-05	807	Lumpeninae	37.44	0.0982	Postflexion
PL12	BN-07-39-05	808	Lumpeninae	38.34	0.0789	Postflexion
PL12	BN-07-39-05	809	Lumpeninae	35.69	0.0687	Postflexion
PL12	BN-07-39-05	810	Lumpeninae	36.57	0.0889	Postflexion
PL12	BN-07-39-06	811	Lumpeninae	43.71	0.1781	Postflexion
PL12	BN-07-39-06	812	Lumpeninae	37.29	0.0889	Postflexion
PL12	BN-07-39-06	813	*Clupea pallasii pallasii*	13.47	0.0084	Flexion
PL12	BN-07-39-06	814	*Clupea pallasii pallasii*	12.53	0.0083	Flexion
PL13	BN-07-40-01	459	*Boreogadus saida*	30.27	0.1888	Postflexion
PL13	BN-07-40-01	460	*Boreogadus saida*	30.16	0.1781	Postflexion
PL13	BN-07-40-01	461	*Boreogadus saida*	29.62	0.1885	Postflexion
PL13	BN-07-40-01	889	*Liparis tunicatus*	25.74	0.2382	Postflexion

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL13	BN-07-40-01	890	*Liparis tunicatus*	22.69	0.1887	Postflexion
PL13	BN-07-40-01	887	*Ulcina olrikii*	30.82	0.1688	Postflexion
PL13	BN-07-40-01	888	*Ulcina olrikii*	25.91	0.0986	Postflexion
PL13	BN-07-40-01	891	*Icelus sp.*	21.39	0.0981	Postflexion
PL13	BN-07-40-02	462	*Boreogadus saida*	27.64	0.1386	Postflexion
PL13	BN-07-40-02	463	*Boreogadus saida*	34.48	0.2483	Early Juvenile
PL13	BN-07-40-02	892	*Liparis tunicatus*	31.20	0.5283	Postflexion
PL13	BN-07-40-02	893	*Liparis tunicatus*	31.74	0.5180	Postflexion
PL13	BN-07-40-03	815	*Boreogadus saida*	33.42	0.1782	Early Juvenile
PL13	BN-07-40-03	816	*Liparis tunicatus*	30.75	0.4780	Postflexion
PL13	BN-07-40-04	464	*Boreogadus saida*	28.91	0.1588	Postflexion
PL13	BN-07-40-04	465	*Boreogadus saida*	33.15	0.2183	Early Juvenile
PL13	BN-07-40-04	894	*Liparis tunicatus*	25.21	0.1984	Postflexion
PL13	BN-07-40-04	895	*Liparis tunicatus*	26.71	0.3481	Postflexion
PL13	BN-07-40-04	896	*Liparis tunicatus*	27.80	0.3488	Postflexion
PL13	BN-07-40-04	897	*Ulcina olrikii*	26.04	0.0888	Postflexion
PL13	BN-07-40-04	898	*Icelus* sp.	21.45	0.1188	Postflexion
PL13	BN-07-40-05*	466	*Boreogadus saida*	28.24	0.1282	Early Juvenile
PL13	BN-07-40-05*	899	*Liparis tunicatus*	24.71	0.2185	Postflexion
PL13	BN-07-40-05*	900	*Liparis tunicatus*	29.29	0.3786	Early Juvenile
PL13	BN-07-40-05*	901	*Liparis tunicatus*	28.43	0.4681	Early Juvenile
PL13	BN-07-40-05*	902	*Liparis tunicatus*	27.41	0.2786	Early Juvenile
PL13	BN-07-40-05*	903	*Liparis tunicatus*	25.52	0.2987	Postflexion
PL13	BN-07-40-06*	467	*Boreogadus saida*	33.34	0.2188	Early Juvenile
PL13	BN-07-40-06*	468	*Boreogadus saida*	27.92	0.1383	Early Juvenile
PL13	BN-07-40-06*	469	*Boreogadus saida*	30.65	0.1886	Early Juvenile
PL13	BN-07-40-06*	904	*Liparis tunicatus*	21.04	0.1783	Postflexion
PL13	BN-07-40-06*	905	*Liparis tunicatus*	25.08	0.2088	Postflexion
PL13	BN-07-40-06*	906	*Ulcina olrikii*	26.86	0.1083	Early Juvenile
PL14	BN-07-41-01	470	*Eleginus gracilis*	6.00	0.0080	Preflexion
PL14	BN-07-41-01	471	*Eleginus gracilis*	13.90	0.0189	Flexion
PL14	BN-07-41-01	817	*Clupea pallasii pallasii*	9.61	0.0084	Flexion
PL14	BN-07-41-01	818	*Clupea pallasii pallasii*	13.48	0.0089	Flexion
PL14	BN-07-41-01	819	*Clupea pallasii pallasii*	14.21	0.0085	Flexion
PL14	BN-07-41-01	820	*Clupea pallasii pallasii*	15.89	0.0084	Flexion

* Target Tows

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL14	BN-07-41-01	821	*Clupea pallasii pallasii*	14.57	0.0083	Flexion
PL14	BN-07-41-02	472	*Eleginus gracilis*	13.45	0.0185	Flexion
PL14	BN-07-41-02	472	*Eleginus gracilis*	9.53	0.0089	Preflexion
PL14	BN-07-41-02	474	*Eleginus gracilis*	8.35	0.0088	Preflexion
PL14	BN-07-41-02	827	*Clupea pallasii pallasii*	14.21	0.0080	Flexion
PL14	BN-7-41-03	475	*Eleginus gracilis*	8.54	0.0086	Preflexion
PL14	BN-7-41-03	822	*Clupea pallasii pallasii*	12.90	0.0082	Flexion
PL14	BN-7-41-03	823	*Clupea pallasii pallasii*	12.05	0.0085	Flexion
PL14	BN-7-41-03	825	*Clupea pallasii pallasii*	17.50	0.0185	Postflexion
PL14	BN-7-41-03	826	*Clupea pallasii pallasii*	8.93	0.0084	Flexion
PL14	BN-07-41-04	476	*Eleginus gracilis*	8.00	0.0083	Preflexion
PL14	BN-07-41-04	477	*Eleginus gracilis*	10.42	0.0084	Flexion
PL14	BN-07-41-04	478	*Eleginus gracilis*	11.28	0.0089	Flexion
PL15	BN-07-42-01	828	*Clupea pallasii pallasii*	18.27	0.0086	Postflexion
PL15	BN-07-42-01	829	*Clupea pallasii pallasii*	16.04	0.0086	Postflexion
PL15	BN-07-42-01	830	*Clupea pallasii pallasii*	17.79	0.0089	Postflexion
PL15	BN-07-42-01	831	*Clupea pallasii pallasii*	17.46	0.0086	Postflexion
PL15	BN-07-42-01	832	*Clupea pallasii pallasii*	15.42	0.0080	Flexion
PL15	BN-07-42-01	833	*Clupea pallasii pallasii*	17.80	0.0083	Postflexion
PL15	BN-07-42-01	834	*Clupea pallasii pallasii*	20.53	0.0282	Postflexion
PL15	BN-07-42-01	835	*Clupea pallasii pallasii*	15.56	0.0086	Flexion
PL15	BN-07-42-02	836	*Clupea pallasii pallasii*	15.17	0.0084	Flexion
PL15	BN-07-42-02	837	*Clupea pallasii pallasii*	12.61	0.0083	Flexion
PL15	BN-07-42-02	838	*Clupea pallasii pallasii*	13.04	0.0086	Flexion
PL15	BN-07-42-02	839	*Clupea pallasii pallasii*	17.24	0.0183	Postflexion
PL15	BN-07-42-02	840	*Clupea pallasii pallasii*	14.31	0.0087	Flexion
PL15	BN-07-42-02	841	*Clupea pallasii pallasii*	15.64	0.0085	Flexion
PL15	BN-07-42-02	842	*Clupea pallasii pallasii*	13.75	0.0089	Flexion
PL15	BN-07-42-02	843	*Clupea pallasii pallasii*	12.91	0.0082	Flexion
PL15	BN-07-42-02	844	*Clupea pallasii pallasii*	14.69	0.0089	Flexion
PL15	BN-07-42-02	845	*Clupea pallasii pallasii*	15.91	0.0086	Flexion
PL15	BN-07-42-02	846	*Clupea pallasii pallasii*	14.18	0.0085	Flexion
PL15	BN-07-42-02	847	*Clupea pallasii pallasii*	21.90	0.0282	Postflexion
PL15	BN-07-42-02	848	*Clupea pallasii pallasii*	17.19	0.0084	Postflexion
PL15	BN-07-42-03	849	*Clupea pallasii pallasii*	15.36	0.0082	Flexion
PL15	BN-07-42-03	850	*Clupea pallasii pallasii*	12.74	0.0085	Flexion

Appendix 11. Continued

Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
PL15	BN-07-42-03	851	*Clupea pallasii pallasii*	14.92	0.0084	Flexion
PL15	BN-07-42-03	852	*Clupea pallasii pallasii*	16.78	0.0089	Flexion
PL15	BN-07-42-03	853	*Clupea pallasii pallasii*	14.97	0.0085	Flexion
PL15	BN-07-42-03	854	*Clupea pallasii pallasii*	15.89	0.0087	Flexion
PL15	BN-07-42-03	855	*Clupea pallasii pallasii*	14.40	0.0081	Flexion
PL15	BN-07-42-03	856	*Clupea pallasii pallasii*	16.93	0.0086	Flexion
PL15	BN-07-42-03	857	*Clupea pallasii pallasii*	10.77	0.0082	Flexion
PL15	BN-07-42-03	858	*Clupea pallasii pallasii*	10.39	0.0088	Flexion
PL15	BN-07-42-03	859	*Clupea pallasii pallasii*	12.85	0.0083	Flexion
PL15	BN-07-42-03	860	*Clupea pallasii pallasii*	14.75	0.0083	Flexion
PL15	BN-07-42-03	861	*Clupea pallasii pallasii*	16.34	0.0085	Flexion
PL15	BN-07-42-03	862	*Clupea pallasii pallasii*	20.79	0.0088	Postflexion
PL15	BN-07-42-03	863	*Clupea pallasii pallasii*	13.62	0.0082	Flexion
PL15	BN-07-42-03	864	*Clupea pallasii pallasii*	14.10	0.0082	Flexion
PL15	BN-07-42-04	865	*Clupea pallasii pallasii*	17.18	0.0083	Postflexion
PL15	BN-07-42-04	866	*Clupea pallasii pallasii*	14.39	0.0081	Flexion
PL15	BN-07-42-04	867	*Clupea pallasii pallasii*	16.73	0.0082	Flexion
PL15	BN-07-42-04	868	Lumpeninae	36.00	0.0787	Postflexion
PL15	BN-07-42-04	869	*Clupea pallasii pallasii*	13.33	0.0081	Flexion
PL15	BN-07-42-04	870	*Clupea pallasii pallasii*	12.85	0.0080	Flexion
PL15	BN-07-42-04	871	*Clupea pallasii pallasii*	26.10	0.0589	Postflexion
PL15	BN-07-42-04	872	*Clupea pallasii pallasii*	14.41	0.0081	Flexion
PL15	BN-07-42-04	873	*Clupea pallasii pallasii*	14.64	0.0084	Flexion
PL15	BN-07-42-04	874	*Clupea pallasii pallasii*	17.61	0.0087	Postflexion
PL15	BN-07-42-04	875	*Clupea pallasii pallasii*	18.13	0.0087	Postflexion
PL15	BN-07-42-04	876	*Clupea pallasii pallasii*	18.38	0.0085	Postflexion
PL15	BN-07-42-04	877	*Clupea pallasii pallasii*	16.38	0.0089	Flexion
PL15	BN-07-42-04	878	*Clupea pallasii pallasii*	13.17	0.0082	Flexion
PL15	BN-07-42-04	879	*Clupea pallasii pallasii*	16.22	0.0088	Flexion
PL15	BN-07-42-04	880	*Clupea pallasii pallasii*	21.02	0.0289	Postflexion
PL15	BN-07-42-04	881	*Clupea pallasii pallasii*	10.27	0.0089	Flexion
PL15	BN-07-42-04	882	*Clupea pallasii pallasii*	18.71	0.0186	Postflexion
PL15	BN-07-42-04	883	*Clupea pallasii pallasii*	15.39	0.0087	Flexion
PL15	BN-07-42-04	884	*Clupea pallasii pallasii*	17.37	0.0082	Postflexion
PL15	BN-07-42-04	885	*Clupea pallasii pallasii*	18.22	0.0100	Postflexion
PL15	BN-07-42-04	886	*Clupea pallasii pallasii*	13.11	0.0089	Flexion

Appendix 12. Larval fish biological data for the two original stations Plume 4 and Plume 7, which were removed from the analyses. Station information provided on Appendix 3.

Original Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
Plume 4	BN-07-04-01	531	*Lumpeninae*	26.3	0.0384	Postflexion
Plume 4	BN-07-04-01	532	*Lumpeninae*	34.11	0.058	Postflexion
Plume 4	BN-07-04-01	533	*Lumpeninae*	24.53	0.0281	Postflexion
Plume 4	BN-07-04-02	534	*Lumpeninae*	21.78	0.0281	Postflexion
Plume 4	BN-07-04-03		No fish was caught			
Plume 4	BN-07-04-04	535	*Lumpeninae*	26.38	0.0281	Postflexion
Plume 7	BN-07-07-01	544	*Lumpeninae*	30.48	0.0387	Postflexion
Plume 7	BN-07-07-01	545	*Lumpeninae*	28.11	0.0382	Postflexion
Plume 7	BN-07-07-01	546	*Lumpeninae*	26.98	0.0382	Postflexion
Plume 7	BN-07-07-01	547	*Lumpeninae*	32.47	0.0485	Postflexion
Plume 7	BN-07-07-01	548	*Lumpeninae*	28.97	0.0381	Postflexion
Plume 7	BN-07-07-01	549	*Lumpeninae*	32.2	0.0584	Postflexion
Plume 7	BN-07-07-01	550	*Lumpeninae*	30.81	0.0381	Postflexion
Plume 7	BN-07-07-01	551	*Lumpeninae*	29.81	0.0387	Postflexion
Plume 7	BN-07-07-01	552	*Lumpeninae*	27.8	0.0386	Postflexion
Plume 7	BN-07-07-01	553	*Lumpeninae*	31.7	0.0486	Postflexion
Plume 7	BN-07-07-01	554	*Lumpeninae*	29.2	0.0481	Postflexion
Plume 7	BN-07-07-01	555	*Lumpeninae*	29.27	0.0386	Postflexion
Plume 7	BN-07-07-01	556	*Lumpeninae*	33.44	0.0287	Postflexion
Plume 7	BN-07-07-01	557	*Lumpeninae*	26.59	0.058	Postflexion
Plume 7	BN-07-07-01	558	*Lumpeninae*	26.49	0.0289	Postflexion
Plume 7	BN-07-07-01	559	*Lumpeninae*	28.38	0.0387	Postflexion
Plume 7	BN-07-07-02	498	*Eleginus gracilis*	9.78	0.0089	Preflexion
Plume 7	BN-07-07-02	499	*Liparis fabricii*	14.15	0.0186	Preflexion
Plume 7	BN-07-07-02	500	*Liparis gibbus*	15.11	0.0381	Flexion
Plume 7	BN-07-07-02	501	*Lumpeninae*	31.57	0.0386	Postflexion
Plume 7	BN-07-07-02	502	*Lumpeninae*	33.8	0.0582	Postflexion
Plume 7	BN-07-07-02	503	*Lumpeninae*	32.27	0.0584	Postflexion
Plume 7	BN-07-07-02	504	*Lumpeninae*	32.93	0.0586	Postflexion
Plume 7	BN-07-07-02	505	*Lumpeninae*	33.56	0.0685	Postflexion
Plume 7	BN-07-07-02	506	*Lumpeninae*	30.46	0.0484	Postflexion
Plume 7	BN-07-07-02	507	*Lumpeninae*	33.79	0.0689	Postflexion
Plume 7	BN-07-07-02	508	*Lumpeninae*	38.36	0.1082	Early Juvenile

Appendix 12. Continued

Original Station Name	Plankton Sample Number	Vial ID (#)	Species	Standard Length (mm)	Weight (g)	Developmental Stages
Plume 7	BN-07-07-02	509	*Lumpeninae*	3.8	0.0585	Postflexion
Plume 7	BN-07-07-02	510	*Lumpeninae*	28.4	0.0386	Postflexion
Plume 7	BN-07-07-02	511	*Lumpeninae*	28.32	0.0385	Postflexion
Plume 7	BN-07-07-02	512	*Lumpeninae*	30.24	0.0485	Postflexion
Plume 7	BN-07-07-02	513	*Lumpeninae*	30.16	0.0481	Postflexion
Plume 7	BN-07-07-02	514	*Lumpeninae*	29.19	0.0482	Postflexion
Plume 7	BN-07-07-02	515	*Lumpeninae*	32.5	0.0587	Postflexion
Plume 7	BN-07-07-02	516	*Lumpeninae*	27.8	0.0386	Postflexion
Plume 7	BN-07-07-02	517	*Lumpeninae*	28.28	0.0384	Postflexion
Plume 7	BN-07-07-02	518	*Lumpeninae*	31.44	0.0481	Postflexion
Plume 7	BN-07-07-02	519	*Lumpeninae*	28.73	0.0384	Postflexion
Plume 7	BN-07-07-02	520	*Lumpeninae*	29.33	0.0382	Postflexion
Plume 7	BN-07-07-02	521	*Lumpeninae*	27.5	0.0385	Postflexion
Plume 7	BN-07-07-02	522	*Lumpeninae*	28.89	0.0387	Postflexion
Plume 7	BN-07-07-02	523	*Lumpeninae*	32.12	0.0587	Postflexion
Plume 7	BN-07-07-02	524	*Lumpeninae*	30.33	0.0681	Postflexion
Plume 7	BN-07-07-02	525	*Liparis gibbus*	18.48	0.0681	Flexion
Plume 7	BN-07-07-02	526	*Liparis tunicatus*	26.49	0.6385	Postflexion
Plume 7	BN-07-07-02	907	*Liparis gibbus*	16.52	0.0481	Flexion
Plume 7	BN-07-07-02	908	*Icelus sp.*	18.1	0.0488	Flexion
Plume 7	BN-07-07-02	909	*Lumpeninae*	29.42	0.0384	Postflexion
Plume 7	BN-07-07-02	910	*Lumpeninae*	30.53	0.0483	Postflexion
Plume 7	BN-07-07-02	911	*Lumpeninae*	28.39	0.0381	Postflexion
Plume 7	BN-07-07-02	912	*Lumpeninae*	26.74	0.0284	Postflexion
Plume 7	BN-07-07-03	495	*Eleginus gracilis*	8.64	0.0088	Preflexion
Plume 7	BN-07-07-03	496	*Eleginus gracilis*	11.93	0.0081	Flexion
Plume 7	BN-07-07-03	497	*Clupea pallasii pallasii*	12.47	0.0082	Flexion
Plume 7	BN-07-07-03	541	*Liparis* sp.	11.91	0.0101	Preflexion
Plume 7	BN-07-07-03	542	*Lumpeninae*	27.88	0.0381	Postflexion
Plume 7	BN-07-07-03	543	*Lumpeninae*	30.05	0.048	Postflexion
Plume 7	BN-07-07-04	173	*Eleginus gracilis*	11	0.0089	Preflexion
Plume 7	BN-07-07-04	174	*Boreogadus saida*	22	0.0082	Postflexion
Plume 7	BN-07-07-04	538	*Lumpeninae*	28.48	0.0387	Postflexion
Plume 7	BN-07-07-04	539	*Liparis gibbus*	16.55	0.0483	Flexion
Plume 7	BN-07-07-04	540	*Liparis* sp.	11.94	0.0185	Preflexion