Community-University Research for Recovery Alliance (CURRA) Report

The Nearshore Fish Fauna of Bonne Bay, a Fjord within Gros Morne National Park, Newfoundland

by

Jens J. Currie[1], Joseph S. Wroblewski[1,2], David A. Methven[1], and Robert G. Hooper[1]

[1]Department of Biology
[2]Ocean Sciences Centre
Memorial University of Newfoundland

September 2009

ABSTRACT

A standardized survey of the nearshore fish fauna of Bonne Bay, a fjord within Gros Morne National Park in western Newfoundland, was conducted using beach seines, gill-nets and bottom trawls during the month of June over a seven year period (2002-2008). The survey documents the presence of 31 fish species (in 17 taxonomic families). Sampling sites varied in benthic habitat and associated fish assemblages. Both juvenile and adult life history stages of Atlantic cod (*Gadus morhua*) were present in Bonne Bay, suggesting the presence of a local population or "bay cod stock". Acadian redfish (*Sebastes fasciatus*) live in the bay, and may be members of a genetically differentiable population of redfish. Striped wolfish (*Anarhichas lupus*), a fish species protected under Canada's Species at Risk Act (SARA), inhabits Bonne Bay. Surrounded by Gros Morne National Park, this bay with a diverse fish fauna is a focus of local stewardship and conservation efforts.

ACKNOWLEDGEMENTS

This research on the fishes in Bonne Bay is a contribution to the Community-University Research for Recovery Alliance (CURRA) project. CURRA is funded by the Social Sciences and Humanities Research Council (SSHRC) of Canada and Memorial University, with additional financial and in-kind support from numerous community partners and groups (www.curra.ca). The report draws heavily on the B. Sc. (Honours) thesis of Jens Currie (2009). The data presented here were collected by the students and instructors (Dr. Joe Wroblewski and Dr. David Methven) of the field course Biology 3714 (Estuarine Fish Ecology) taught at the Bonne Bay Marine Station in Norris Point, Newfoundland.

Special thanks are extended to the Biology 3714 students who collected fishes during the years 2002 to 2008 and to the teaching assistants, Liuming Hu and Shanshan Liu, who entered the data recorded in students' field books into Microsoft Excel files. We would like to thank Dr. David Schneider and Dr. Richard Haedrich for their advice on cluster analysis of the survey data. Our gratitude is expressed to Dennis Rumbolt, William Coffey and Fiona Cuthbert of the Bonne Bay Marine Station for logistical support. Finally, we thank Dr. Richard Haedrich for comments on the manuscript.

INTRODUCTION

Temperate coastal marine areas are among the most productive and biologically diverse ecosystems (Suchanek, 1994). The Convention on Biological Diversity established at the 1992 UN Conference on Environment and Development in Rio de Janeiro defined "biological diversity" as the variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. This includes diversity within species and ecosystems.

The most basic level of biological diversity is that found within a species and is referred to as "genetic diversity". Genetic diversity encompasses the variation among individuals within a population and the genetic variation among populations (Gray, 1997). A loss in genetic diversity weakens the ability of a species to adapt to environmental change. Studies carried out by Ward *et al.* (1994) showed that marine species have higher genetic diversity than freshwater and terrestrial species, indicating the importance of conservation of not only terrestrial and freshwater environments, but also marine environments. Commercial fisheries often target a specific size class of fish species (Pauly *et al.*, 2002) which can alter the genetic composition and decrease the genetic diversity of a fish population (Elliot and Ward, 1992).

The most common measure of biological diversity is the number of species found in a given area, referred to as "species richness" (Gray, 1997). Angel (1993) showed that most of the marine species diversity is benthic, rather than pelagic. It is estimated that there are approximately 1,200 oceanic fish species versus 13,000 coastal marine species (Angel, 1993), and thus a higher biodiversity of fishes within coastal habitats (Gray, 1994).

Each species plays a functional role within its ecosystem, referred to as its niche. High species richness results in high functional diversity (Gray, 1997). It has been shown that the higher the species richness in an ecosystem, the greater the efficiency of biogeochemical processes. (Naeem *et al.* 1994). However, habitat destruction, pollution and over-fishing can lead to the collapse of an aquatic ecosystem and its biodiversity (Suchanek, 1994).

Coastal habitats support economically important marine and estuarine species (Mateo and Tobias, 2004). Nearshore marine environments are nursery grounds for juvenile stages of fish species, as well as feeding areas for various migratory adults (Livingston, 1982; Russel and Garret, 1983; Riley and Parnell, 1984; Blaber *et al*., 1985). Nearshore habitats support coastal resident (non-migratory) fish species. Research on the use of coastal waters by juvenile and adult marine fish has intensified in the past two decades, after the collapse of numerous commercial fisheries (Simon and Campana, 1987).

General information on the Northwest Atlantic fish fauna is available (Scott and Crossman, 1973; Scott and Scott, 1988; Collette and Klein-MacPhee, 2002). Fish stock abundance surveys carried out by Fisheries and Oceans Canada (DFO) have provided information on the fish fauna of the Newfoundland and Labrador continental shelf (Gomes *et al*., 1995); but these bottom-trawl surveys do not sample the fauna in shallow coastal waters, largely due to vessel and gear size restrictions (Simon and Campana, 1987). As a result, there is inadequate knowledge of the fish fauna in nearshore areas of coastal Newfoundland and Labrador. Surveys by Methven *et al*. (2001) have focused on the shallow-water fish fauna of Trinity Bay on the east coast of Newfoundland.

Wroblewski *et al.* (2007) studied the fish fauna of Gilbert Bay on the southeast coast of Labrador. However, standardized survey information on the nearshore marine fish fauna along the west coast of Newfoundland is absent from the literature.

To predict changes in biodiversity, studies which assess areas at the ecosystem, landscape and local habitat levels are needed (Ray, 1991). Gros Morne National Park is located on the west coast of the island of Newfoundland, Canada. It was established in 1973 and encompasses 1,805 km^2 of land dominated by the Long Range Mountains and borders approximately 284 km of coastline (Dr. Tom Knight, personal communication, Gros Morne National Park, 2008). Bonne Bay is a fjord within the park boundaries. The bay has numerous underwater habitats, some with dense marine vegetation and others with very little vegetation. Bottom substrates range from sand, mud to rock. As a result, this bay can support a high diversity of fish fauna. Exploratory surveys of the marine life in Bonne Bay had previously been carried out (Hooper, 1975), but prior to our research there had been no standardized survey of the nearshore fish fauna of Bonne Bay.

A variety of sampling equipment must be used in order to accurately characterize a species community of benthic and pelagic fishes (Blaber *et al.*, 1985). Passive and active samplers (Hayes, 1989) are used based on bottom habitat type (Godo *et al.,* 1989), and sampling effort must be standardized (Ricker, 1975).

Biogeographic studies done by Dunbar (1968) and Steele (1983) identified the Strait of Belle Isle as an oceanographic boundary separating the cold-temperate waters of Newfoundland from the subarctic waters of Labrador. Given the location of Bonne Bay, it can be hypothesized that the fish fauna of Bonne Bay would be a combination of temperate fishes near their northern limit and subarctic fishes near their southern limit.

Environmental gradients are responsible for observed distribution patterns of marine species (Mills, 1969). However, interactions between species such as predator-prey, commensalism, symbiosis and competition can lead to co-occurrences of species under a given environmental condition (Gray, 1997). From this, it can be hypothesized that different nearshore habitats will have different fish species assemblages.

This study analyzed the fish collections made in Bonne Bay over a seven year period (2002-2008) during the month of June, by students enrolled in the field course Biology 3714 (Estuarine Fish Ecology) at Memorial University's Bonne Bay Marine Station in Norris Point. The objectives of this study were to (a) document the nearshore fish fauna within Bonne Bay; (b) characterize the variability in fish species assemblages associated with different bottom habitats; and (c) provide baseline information for conservation efforts (www. curra.ca).

MATERIALS AND METHODS

Study site

Bonne Bay consists of an outer bay and three arms: South Arm, Deer Arm and East Arm (Figure 1). East Arm and Deer Arm are partitioned from the outer bay by a sill (Figure 1). The sill, at its shallowest point, is approximately 14 m in depth. The deepest depth in East Arm is approximately 230 m (Richards and deYoung, 2004). The shoreline is composed of numerous rocky beaches at the base of steep cliffs. The tidal amplitude is

approximately 2 m. Deer Brook and Lomond River flow into Bonne Bay, the two main sources of freshwater draining into the bay.

Sampling strategy

The fish fauna of Bonne Bay were sampled during a two week period in the month of June from 2002 to 2008 at four main sites (Site 1, 2, 3 and 4 in Figure 1). Site 1 is closest in proximity to the Gulf of St. Lawrence. Site 2 is halfway into the East Arm. Site 3 and Site 4 are near Deer Brook and Lomond River respectively, in lower saline environments. Not all sites were sampled consistently throughout the seven years of data collection (Table 1). The bottom topography at some sites did not allow for sampling with all four fishing gear types (Table 1). Sites 2A, 3A and 4A were supplementary sampling sites, chosen to increase the probability that all fish species living in a particular habitat were documented.

Sampling sites

Site 1, Gadds Harbour

Beach substrate was observed at each of the sampling sites and classified according to the Wentworth scale of rock particle sizes (Shepard, 1963). The beach substrate at Site 1 consists of cobble and boulders. The area is semi-enclosed by cliffs and steep banks. There is one small brook which creates a localized lower saline environment. Most of the beach can be classified as a platform shore, with the slope of the bottom steepening with distance from shore. This site is known as Gadds Harbour.

Near the high tide mark, rough periwinkles and lichens are abundant. Approximately halfway between the high tide mark and the low tide mark, there are various seaweed species with barnacles, smooth periwinkles, and hydrozoans living as epiphytes on the seaweed. Just below the waterline, there are *Ulva lactuca,* as well as patches of *Polsiphonia* spp. and beds of blue mussels (*Mytilus edulis*). A list of the macro biota located at this site can be found in Appendix Table 1.

The presence of boulders prevented sampling with the 25 m beach seine. Sampling with the 10 m beach seine and the gill-nets was done in 2002, 2003, 2004, 2005, 2007 and 2008 (Table 1). The bottom trawl was only used in 2002.

Site 2, Norris Cove

The beach substrate at Site 2 consists of shale gravel. The slope is relatively steep and drops off rapidly with increasing distance from shore. Site 2 is also a platform beach, with beach surrounded by cliffs. The lithology between the high tide and the low tide marks consists largely of limestone rocks with numerous solution pools, the result of bioerosion. This site is called Norris Cove.

The substrate near the high tide mark is dominated by seaweed. Boulders found near the low tide line have holes created by sponges and small burrowing clams. A transition from burrowing species of clams and sponges to boring algae and polycheates was evident from the high tide line to the low tide line. A list of the macro biota located at this site can be found in Appendix Table 2.

Sampling with the 10 m beach seine took place closer to shore as a result of the steep bottom slope at this site. However, the near absence of boulders allowed sampling with the 25 m beach seine (Table 1).

Site 2A, Lord and Lady Cove

The beach substrate at Site 2A consists of mostly cobble with some pebbles. The slope is steep and drops off rapidly as it extends offshore. The shallow bottom was dominated by the kelp *Saccharina longicruris,* as well as stringy seaweeds such as *Ceramium, Polysiphonia,* and *Cystoclonium.* A list of the macro biota located at this site can be found in Appendix Table 3. This site is known as Lord and Lady Cove.

As a result of the steep slope gradient, samples obtained using the 10 m beach seine were close to shore in areas with very little vegetation, while those obtained with the 25m beach seine were hauled through areas with high concentrations of vegetation. Site 2A was only sampled in 2008 using the 10 m and 25 m beach seines and the gill-nets (Table 1).

Site 3, Deer Brook delta

The beach substrate at Site 3 consists of cobble and pebble. The beach has a relatively gentle slope which extends for several hundred metres, creating an area with low wave energy. This site is often strewed with receptacles (reproductive bodies) from numerous *Fucus* species. The site is influenced by Deer Brook, giving it a characteristic lower salinity when compared to the other sampling sites. The freshwater from the river is semi-partitioned from the bay by a shingle gravel bar, which juts out from the main land, approximately 20 metres. This low saline barachois is sample Site 3A. This site is called Deer Brook delta.

The exposed shore was relatively void of plant material; however, some of the limestone gravel/shingle was covered by endolithic algae, creating a food source for numerous snails and amphipods found near the low tide mark. Extensive beds of eelgrass

were observed from the shore near the river mouth. Directly at the river mouth in close proximity to the sampling site there were numerous beds of soft-shelled clams (*Mya*) as well as blue mussels (*Mytilus edulis*). A list of the macro biota located at this site can be found in Appendix Table 4.

The mixing of the river water with the more saline water of Bonne Bay at this site can create a convergence where fish often feed (Hooper, personal communication, Bonne Bay Marine Station, 2008).

Site 3 was sampled using the 10 m and 25 m beach seines throughout the seven year collection period. The gill-nets were only set in the years 2004, 2006, 2007 and 2008 and the bottom trawl was used from 2003 to 2007 (Table 1).

Site 3A, Deer Arm barachois

Site 3A consists of a barachois which has substrate dominated by sand, silt and clay. This was the result of sedimentation from Deer Brook. The barachois at its deepest point is 1.5 m. It has a dominant influx of freshwater from the river, but still receives some water from the bay and has a low salinity. The substrate contains a hypoxic upper grey layer and a lower anoxic black layer. Towards the outer perimeter of the barachois, there is a transition from the relatively stagnant water of the barachois to the faster moving water of the river. In association with this transition, there is a change from sandy sediment to cobble, pebble and boulders outside the barachois. This site is locally known as Deer Arm barachois.

Species of *Enteromorpha,* a tubular green alga, were identified at Site 3A. Crustaceans such as *Mysis gaspensis,* which are endemic to low saline waters, are present. A list of the macro biota located at this site can be found in Appendix Table 5.

Site 3A is suitable only for sampling using the 10 m beach seine (Table 1).

Site 4, Lomond Cove

The beach substrate at Site 4 consists of cobble with pebbles and scattered boulders. The slope is shallow and extends approximately 100 m before rapidly becoming deeper. The brackish water is attributed to the influx of freshwater from a small stream, which empties directly into this cove, as well as the Lomond River which is near this site. The nearshore shallow water is dominated by numerous kelps and seaweeds, which are scattered throughout the sampling area. A list of the macro biota located at this site can be found in Appendix Table 6. This site is called Lomond Cove.

Site 4A, Lomond River delta

The beach substrate at Site 4A is composed of pebbles and cobble, with a mixture of sand. Beyond the shore, in areas that are almost always submerged by water, there is a shift from pebble and cobble to finer sediments such as silt and clay with a small amount of sand. This provides an ideal habitat for eelgrass, which can be found in large beds throughout this sampling site. The cobble and pebble are coated by algae, which gives the shore a distinct green colour. A list of the macro biota located at this site can be found in Appendix Table 7

The bottom at this site is very shallow, so the sampling with the beach seines did not exceed 1 m in depth. In the middle of the delta, the river outflow has created a channel, which is approximately 5 m in depth and becomes wider and deeper with increasing distance into the bay. This site is called Lomond River delta.

Due to the shallow nature of this site, sampling was restricted to the 10 m and 25 m beach seines. The gill-nets were not set (Table 1).

Methods of collecting fishes

A variety of collection equipment is needed to determine the fish fauna present in nearshore environments (Methven *et al.,* 2001). Therefore, a small beach seine (10 m in panel net length), a large beach seine (25 m in net mouth width), gill-nets with various mesh sizes, and a semi-balloon bottom trawl (4.9 m in net mouth width) were used to collect fishes within Bonne Bay. These four types of collection gear were used during a two week period in the month of June for seven years (2002 to 2008). The different types of equipment were deployed according to the bottom depth being sampled. It should be noted that the bottom substrate at some sites did not permit sampling with all types of gear (Table 1).

For all fish collected, the species name and standard length (SL) to the nearest millimetre were recorded. Fish removed from the sampling gear were held in a tub filled with sea water until measured. If a fish was not identifiable in the field, it was taken back to the Bonne Bay Marine Station for later identification. Latin and common names of fishes follow those presented in Scott and Scott (1988) or Collette and Klein-MacPhee (2002). In 2002, no length data was recorded for any of the fishes collected. In 2003, length data was recorded only for the fishes caught with the 10 m beach seine and in 2005 there was no length data recorded for the fish caught with the bottom trawl.

By-catch of flora and fauna other than fish were often recorded to help characterize the types of vegetation and invertebrates that may be associated with each sampling site. Sea state, precipitation, water temperature, depth and salinity were recorded at each site at the time of sampling.

Equipment used to collect fishes

10 m beach seine

A 10 m by 1.5 m panel (10mm stretch mesh) beach seine was used to sample waters along the shoreline at each sampling site. The net was hauled parallel to the shoreline by two people wearing chest waders in water no deeper than 1 m. The beach was sectioned in a manner to avoid large rock obstacles but still maintain a standardized hauling length. This was done multiple times in different areas within the sampling site until all desirable habitats were sampled, which ranged on average from two to six tows/sampling site. All seven sites were sampled at least one time by the 10 m beach seine (Table 1).

25 m beach seine

A larger beach seine measuring 25 m by 1.5 m in the wing, with 10 mm stretch mesh netting (5 mm stretch mesh in the cod end) was hauled perpendicular towards the shoreline to sample waters approximately 0-15 m in depth (depending on the bottom slope). The seine was deployed out from shore (approx. 20-30 m) using a boat and then hauled in along the bottom by people on the shore pulling on the ropes attached to the bridles of the seine. This procedure was repeated with the total number of tows ranging from three to six tows, depending on the length of the beach shoreline. Sampling with the 25 m beach seine was restricted to Site 2, Site 2A, Site 3, and Site 4, Site 4A. Site 1 contained too many submerged boulders, which would become entangled in the net and thus prevented sampling, while Site 3A was too shallow to access with a boat (Table 1).

All sampling done with the 10 m and 25 m beach seines was restricted to daytime tows, with the exception of the collections done in 2006 at Site 2, which involved several

hours of night-time sampling. The area seined with the 10 m and 25 m beach seines were standardized in order to allow for comparison among catch data. A distance of 25 m along the shoreline was measured before each 10 m beach seine tow. A distance of 30 m along the shoreline was measured before each 25 m beach seine tow.

Gill-nets

Sites were sampled with both single panel and multi-panel gill-nets. Three-panel gill-nets had stretch mesh sizes of 1 inch, 1.5 inch and 2 inches. Sampling from 2002 to 2004 was done using only multi-panel netting. Sampling from 2005 to 2006 used both single panel and multi-panel netting. Sampling from 2007 to 2008 used only single panel netting with a stretch mesh size of three inches. At least three gill-nets were deployed each year at the site sampled; typically two gill-nets in shallow water and one gill-net in deeper water, never exceeding a depth of 100 m. Gill-nets were usually set overnight for a 12 to 24 hour period. Sampling with the gill-nets took place at Site 1, Site 2, Site 2A, Site 3, and Site 4 (Table 1). Sites 3A and 4A were too shallow to sample with gill-nets.

Bottom trawl

A 4.9 m semi-balloon bottom trawl (5.1 m head rope and 6.4 m footrope) made of nylon netting (38mm stretched mesh, with a 9 mm stretched mesh in the cod end) was used to sample Site 1 in 2002 and Site 3 from 2003 to 2007. Of the seven study sites, these two were the only sites which had a bottom suitable for trawling. The duration of the trawl tows was 10 minutes.

Oceanographic data collection

Salinity, temperature and bottom depth were recorded at each site. Salinity and temperature were measured using a YSI Model 30M-100FT handheld salinometer. Depth was measured using a Piranha Max 15 dual beam depth sounder. These data were useful in characterizing the habitat at each sampling site. An oceanographic survey carried out by Richards and deYoung (2004) provides conductivity (salinity), temperature, depth data for the deeper waters of the East Arm and outer Bonne Bay.

Analysis of faunal collections

The Jaccard similarity coefficient (Omori and Ikeda, 1984) was used to determine the similarity among collections made at each site with the 10 m and 25 m beach seines. The Jaccard similarity coefficient (S_J) is based on presence and absence of species in a sample pair:

$$Sj = \frac{a}{a+b+c}$$

where *a* is the number of species present in sample X and in Sample Y (joint occurrences), *b* is the number of species in sample X but not in sample Y, and *c* is number of species in sample Y but not in sample X. S_J ranges from 0 (no similarity) to 1 (samples identical).

Computer packages Microsoft (MS) Excel and the Numerical Taxonomy System of Multivariate Programs (NTSys) version 2.2 were used to analyze faunal data. MS Excel was used to organize and format the data for use in NTSys (Powell *et al*., 2003). Dendrograms formed by cluster analyses produced in NTSys (Rohlf, 2005) were examined to determine relationships in faunal composition over a spatial scale when

fishing with the 10 m and 25 m beach seines. A similar analysis could not be done for the bottom trawl collections due to the infrequency of sampling, nor for the gill-net collections due to inconsistency in mesh sizes.

The catches for the 10 m and 25 m beach seines and the gill-nets were expressed as catch per unit effort (CPUE). For the 10 m beach seine this was determined by calculating the total number of fish caught per 100 m of shoreline. For the 25 m beach seine, this was determined by calculating the total number of fish caught per tow. CPUE for the gill-nets was determined by calculating the total number of a fish species caught in the gill-net per total hours fished.

RESULTS

Thirty-one species in 17 taxonomic families were collected in Bonne Bay from 2002 to 2008. Ten species accounted for 97 % of the total number of fishes collected: *Gasterosteus aculeatus* (31%), *Tautogolabrus adspersus* (26%), *Gasterosteus wheatlandi* (15%), *Pseudopleuronectes americanus* (10%), *Apeltes quadracus* (4%), *Gadus morhua* (4%), *Myoxocephalus scorpius* (2%), *Myoxocephalus octodecemspinosus* (2%), *Osmerus mordax* (2%) and *Salmo salar* (1%). Twenty-one additional species accounted for the remainder (Table 2).

The number of fish species (richness, S) recorded in the annual survey ranged from 18 to 23. Some species were only caught once during the seven surveys: *Microgadus tomcod, Mallotus villosus, Raja erinacea,* and *Merluccius bilinearis*. One

species, *Aspidophoroides monopterygius,* was only caught using the bottom trawl (Table 3). The life history stage of species captured in Bonne Bay based on standard length at reproductive maturity is presented in Table 8.

In addition to the 31 species reported here, 15 other fish species have been observed within Bonne Bay by Hooper (1975), and one additional species by J. Currie (reported in Table 9); but these specimens were not all collected and measured.

Spatial variation in occurrence of fish species

The fish fauna present in the nearshore waters of Bonne Bay varied with location. Of the 31 species of fishes collected during the seven surveys, two species were present at all seven sites and caught with one or more of the four sampling methods (Table 2). These ubiquitous species were: *Pseudopleuronectes americanus* and *Gasterosteus aculeatus*. Two of the remaining 29 species were found in six of the seven sampling sites: *Osmerus mordax* and *Salmo salar*, both of which were absent from Site 2A (Table 2). Six of the remaining 27 species were present in five of the seven locations: *Clupea harengus, Gadus morhua, Gadus ogac, Gasterosteus wheatlandi, Tautogolabrus adspersus* and *Myoxocephalus octodecemspinosus* (Table 2). The remaining 21 species were found in four or less of the seven sampling sites, and eight species were found exclusively at only one of the seven sampling sites. These eight species were: *Raja erinacea, Mallotus villosus, Merluccius bilinearis, Microgadus tomcod, Ulvaria subbifurcata, Anarhichas lupus, Aspidophproides monopterygius* and *Scophthalmus aquosus.* There were no species found only at Sites 2A, 3A, 4 and 4A (Table 2).

Species richness (S) was highest at Site 1 (S=23) and Site 3 (S=25). Species richness was lower at the remaining sites, Site 2 (S=20), Site 4 (S=14), Site 4A (S=8), Site 3A (S=7) and Site 2A (S=6) (Table 4).

Collections at Site 1 (Gadds Harbour)

A total of 1,327 specimens representing 23 fish species were collected at Site 1 during the seven surveys using the 10 m beach seine and the gill-nets. An additional 15 specimens (three species) were caught at Site 1 using the bottom trawl. This brings the total number of specimens collected at Site 1 to 1,342. When considering all the fish caught at Site 1, 68% were *T. adspersus.* Of the 31 fish species captured in Bonne Bay, only eight species were not found at this site: *R. erinacea, R. ocellata, M, bilinearis, M. tomcod, A. quadracus, U. subbifurcata, A. monopterygius* and *S. aquosus.* The species *M. villosus* and *A. lupus* were collected exclusively at Site 1 (Table 2).

Collections at Site 2 (Norris Cove)

A total of 1,224 specimens representing 20 fish species were collected at Site 2 using the 10 m and 25 m beach seines and the gill-nets during the seven years sampling. *P. americanus* (33%) and *T. adspersus* (27%) together were 60 % of the total specimens caught at Site 2. *G. morhua* and *M. scorpius* accounted for 13% and 9%, respectively, of the total fish count caught at Site 2. Species not caught at Site 2 were: *R. erinacea, R. radiate, M. villosus, M. bilinearis, M. tomcod, A. quadracus, A. lupus, M. aenaeus, A. monopterygius, S. aquosus* and *L. ferruginea.* One species, *U. subbifurcata* was collected only at Site 2 (Table 2).

Collections at Site 2A (Lord and Lady Cove)

During the 2008 survey, 751 specimens representing six fish species were caught at Site 2A, using the 10 and 25 m beach seines and the gill-nets. Ninety percent of the fish caught at Site 2A consisted of a single species, *T. adspersus*. No fish species was found to be exclusive to Site 2A. The six species collected at this site were: *C. harengus, G. ogac, G. aculeatus, T. adspersus, Sebastes sp.,* and *P. americanus* (Table 2).

Collections at Site 3 (Deer Brook delta)

A total of 1,910 specimens representing 22 species were caught at Site 3 during the seven surveys using the 10 and 25 m beach seines and the gill-nets. An additional 632 fishes (14 species), where caught using the bottom trawl. This brings the total number of specimens collected at Site 3 to 2,542 representing 25 species. Twenty-eight percent of the total were *T. adspersus,* with *P. americanus* and *G. aculeatus* at 22% and 21% respectively. Five species were collected only at Site 3 (Table 2). These species were: *M. tomcod, M. bilinearis, R. erinacea, A. monopterygius,* and *S. aquosus.* Six species present in Bonne Bay were not collected at Site 3: *M. villosus, A. quadracus, U. subbifurcata, A. lupus, A. americanus* and *S. fasciatus* (Table 2).

Collections at Site 3A (Deer Arm barachois)

A total of 3,907 fish representing seven species were caught at Site 3A during the surveys using only the 10 m beach seine. The bottom topography of this site prevented additional sampling with the other fishing equipment. Interestingly, three species of stickleback accounted for 99.6% of the total specimens collected at Site 3A. *G. aculeatus* made up 66% of the entire collection at Site 3A. No fish species was found only at this site. The seven fish species found at this site were: *C. harengus, S. salar, O. mordax, G. aculeatus, G. wheatlandi, P. americanus* and *A. quadracus* (Table 2).

Collections at Site 4 (Lomond Cove)

A total of 457 specimens representing 15 species were collected at Site 4 using the 10 m and 25 m beach seines and the gill-nets during the seven surveys. *T. adspersus* made up 60% of the total specimens collected within this site. No species was found only at this site (Table 2). The 15 species found at this site were: *R. ocellata, R. radiate, S. salar, S. fontinalis, O. mordax, G. morhua, G. ogac, G. aculeatus, T. adspersus, P. gunnellus, S. fasciatus, H. americanus, M. octodecemspinosus P. americanus* and *M. scorpius* (Table 2).

Collections at Site 4A (Lomond River delta)

A total of 1,127 specimens representing nine fish species were caught at Site 4A using the 10 m and 25 m beach seines during the seven surveys. Similar to Site 3A, sticklebacks accounted for 90% of the fish collected within Site 4A. The species *G. wheatlandi* accounted for 61% of the total specimens caught at Site 4A, which contrasts with the results for Site 3A where the species *G. aculeatus* accounted for a largest percentage of the total specimens caught. No species was found only at Site 4A. The nine species collected at Site 4A were: *G. morhua, O. mordax, S. salar, G. aculeatus, G. wheatlandi, A. quadracus, A. americanus, P. americanus* and *M. octodecemspinosus* (Table 2).

Cluster analysis of species assemblages sampled with the 10 m beach seine

Cluster analysis based on the Jaccard similarity coefficient (presence-absence) for the 10 m beach seine collections (Table 5) shows the highest similarity (71%) among the

sites to be between Site 3A and 4A (Figure 2). High similarities also occur between Site 2 and Site 3 (69%) as well as Site 1 with Site 2 and 3 (67%). Sites 1, 2, and 3 differ from sites 3A and 4A having a similarity of only 29%, while Site 4 is least similar to all the other sites having a low similarity of 23% (Figure 2).

Site 3A and 4A were found to be most similar since all five species found at Site 4A were also present at Site 3A. Two additional species found at Site 3A were not found within Site 4A. The five species in common were *G. aculeatus, G. wheatlandi, P. americanus, A. quadracus,* and *O. mordax* (Table 5).

Site 2 and Site 3 were similar since nine of the 13 species found at Sites 2 and 3 were at both sites: *G. aculeatus, G. wheatlandi, P. americanus, T. adspersus, P. gunnellus, S. fontinalis, M. octodecemspinosus, M. scorpius* and *U. tenuis* (Table 5). The similarity observed among Site 1 and Sites 2 and Site 3 was the result of eight species present at all three of the sampling sites: *S. fontinalis U. tenuis, G. aculeatus, G. wheatlandi, T. adspersus, P. gunnellus, M. scorpius* and *P. americanus* (Table 5). Site 4 differs from the other five sites due to low species richness, (S=3): *P. americanus, S. fontinalis* and *S. salar* (Table 5). It should be noted that Site 2A was sampled with the 10 m beach seine in 2008 but collected no fish, and therefore was not included in the dendrogram.

Cluster analysis of species assemblages sampled with the 25 m beach seine

Cluster analysis based on the Jaccard similarity coefficient for the 25 m beach seine collection (Table 6) shows the highest similarity (60%) is between Site 2 and Site 4 (Figure 3). Similarity occurs also between Site 3 with Sites 2 and Site 4 (55%). Little

similarity was observed between Site 4A and Site 2; Site 3 and Site 4 having a similarity of only 33%. Site 2A was the most distinct of all five sites having a low similarity of 23% (Figure 3).

Site 2 and Site 4 appeared most similar as a result of sharing nine species. These species were: *G. aculeatus, P. americanus, T. adspersus, P. gunnellus, S. fontinalis, O. mordax, M. octodecemspinosus, M. scorpius* and *G. morhua* (Table 6). Site 3 shares nine of its 18 species with Sites 2 and Site 4, which explains the moderate similarity shown in Figure 3. The nine species in common at all three sites were: *S. fontinalis, O. mordax, G. morhua, G. aculeatus, T. adspersus, P. gunnellus, M. octodecemspinosus, M. scorpius,* and *P. americanus* (Table 6). Four of the eight species found at Site 4A were also present at Site 2, Site 3 and Site 4: *S. fontinalis, O. mordax, G. aculeatus* and *P. americanus*. Finally, Site 2A was observed to be the most dissimilar as a result of low faunal diversity, having a total of only three species present: *T. adspersus, P. americanus,* and *G. aculeatus.*

Analysis of species assemblages sampled with the gill-nets

Six species were found only at Site 1: *S. fontinalis, M. villosus, U. tenuis, Z. americanus, A. lupus* and *L. ferruginea* (Table 7). *R. radiata* and *R. ocellata* were species restricted to only one sample site (Table 7). The highest species richness occurs at Site 1 (S=18) while Site 4A has the lowest (S=4) (Table 7).

DISCUSSION

The results summarized in Table 3 confirm the importance of using various gear types at all locations sampled, in order to increase the probability of capturing all the species inhabiting Bonne Bay. For example, the species composition obtained using the 10 m beach seine differed from that obtained with the 25 m beach seine, the bottom trawl and the gill-nets. This is in accordance with Allen (1982), as well as Methven and Schneider (1998) who suggest the type of sampling gear has a bias in the fish species caught.

Bonne Bay fish fauna in comparison to Trinity Bay and Gilbert Bay

Comparison of the Bonne Bay fish fauna with the study by Methven *et al.* (2001) in Trinity Bay on the east coast of Newfoundland finds 20 species in common. The fish species present in both bays are: *Gasterosteus aculeatus, G. wheatlandi, Pseudopleuronectes americanus, Limanda ferruginea, Mallotus villosus, Osmerus mordax, Urophycis tenuis, Gadus morhua, G. ogac, Myoxocephalus scorpius, M. octodecemspinosus, M. aenaeus, Raja erinacea, Raja radiata, Salvelinus fontinalis, Clupea harengus, Pholis gunnellus, Ulvaria subbifurcata, Zoarces americanus* and *Tautogolabrus adspersus.*

Eleven species present in Bonne Bay were not collected in Trinity Bay by Methven *et al.* (2001): *Raja ocellata, Salmo salar, Merluccius bilinearis, Microgadus tomcod, Apeltes quadracus, Anarhichas lupus, Ammodytes americanus, Sebastes fasciatus, Hemitripterus americanus, Scopththalmus aquosus* and *Aspidophoroides monopterygius.* However, Methven *et al.* (2001) collected fishes only using a 10 m beach

seine. Fishes living further from the shoreline in Trinity Bay would not have been collected.

The fish fauna survey of Gilbert Bay, Labrador carried out by Wroblewski *et al.* (2007) used the same 10 m and 25 m beach seines and gill-nets used in this study of Bonne Bay. Comparison of the Gilbert Bay fish fauna with that of Bonne Bay finds 18 species in common: *C. harengus, S. salar, S. fontinalis, M. villosus, O. mordax, G. morhua, G. ogac, U. tenuis, G. aculeatus, G. wheatlandi, A. quadracus, Z. americanus, P. gunnellus, A. americanus, H. americanus, M. scorpius, A. monopterygius, P. americanus.*

Thirteen species collected in Bonne Bay were not collected in Gilbert Bay by Wroblewski *et al*. (2007). These species are: *R. erinacea, R. ocellata, R. radiata, M. bilinearis, M. tomcod, T. adspersus, U. subbifurcata, A. lupus, Sebastes fasciatus, M. aenaeus M. octodecemspinosus, S. aquosus and L. ferruginea*.

Spatial patterns in the Bonne Bay fish assemblages

The fish assemblages within Bonne Bay appear to be habitat specific. Species richness was highest at Sites 1 and Site 3, where S = 23 and S = 25 respectively (all seven surveys). The high species richness at Site 1 (compared to the rest of the bay) may be attributable to migrating fish from the Gulf of St. Lawrence. An example is *Z. americanus,* which is found off the coast but migrates into nearshore waters during the spring (Scott and Scott, 1988).

The high species richness at Site 3 is consistent with Dando (1984), who suggests that estuarine locations have a high species richness when compared to other nearshore

locations. Estuarine water provides habitat suitable for spawning and feeding fish. An example is *O. mordax* which occurred at a relatively high abundance within Site 3 (Table 3) *O. mordax* aggregate in estuaries and enter rivers in the spring, where they deposit adhesive eggs on bottom substrate (Scott and Scott 1988).

Similarity of species composition in the Bonne Bay collections

The composition of fish assemblages is thought to be in response to environmental gradients, such as seawater salinity, temperature and depth (Scott and Scott, 1988). The varying environmental gradients at each of the seven sampling locations can drive the association of individual species. One way to examine the similarity of species composition between collections is by cluster analysis using Jaccard's coefficient of similarity (Omori and Ikeda, 1984). The Jaccard index is based on presence or absence of a species at a particular site. The value ranges from zero when there is no similarity in fish assemblages between sites, to unity when the fish assemblages are identical.

Similarity of collections with the 10 m beach seine

Analysis of fish collections with the 10 m beach seine produced three main clusters, indicating a distinction between the low salinity locations and the rest of the bay (Figure 2). This distinction can be attributed to five species, four of which inhabit low salinity environments: *G. aculeatus, G. wheatlandi, A. quadracus,* and *P. americanus.* The fourth species is known to use estuaries to spawn: *O. mordax* (Scott and Scott, 1988; Collette and Klein-MacPhee, 2002).

Cluster analysis also showed the fauna composition of the inner and middle of the bay to be more similar compared to Site 1 (Figure 2). This distinction was the result of two species: *M. octodecemspinosus* and *M. aenaeus.* The longhorn sculpin *M. octodecemspinosus* was absent from Site 1 (Table 5). This is consistent with Collette and Klein-Macphee (2002), who state that *M. octodecemspinosus* are abundant in many harbours and bays and enter estuaries, salt creeks and river mouths. *M. aenaeus* was present only at Site 1 (Table 5). This is in accordance with Scott and Scott (1988), who found *M. aenaeus* to be more common in the open coast, rather than in estuaries.

The relatively low species richness at Site 4 contributed to its offset from the other sites (Table 5). The three species collected at this site (*Salmo salar, Salvelinus fontinalis* and *P. americanus*) comprise a faunal composition that is only 23% similar to the rest of the sites. The low species richness may be a result of the lower sampling effort when compared to other sites within the bay (Table 1).

Similarity of collections with the 25 m beach seine

Cluster analysis of fish assemblages sampled with the 25 m beach seine again indicated a distinction between the lowest salinity sites and the other sites (Figure 3). This distinction can be attributed to the presence of species such as *O. mordax, A. americanus* and *A. quadracus* which use the low salinity areas at various life history stages (Scott and Scott, 1988).

It is interesting to note that once again, the inner and middle parts of the bay formed one of the three clusters, with a similarity of more than 60% (Figure 3). The presence of nine species, all of which may have resident populations within Bonne Bay, contribute to the similarity among these parts of the bay.

Site 2A is offset from the rest of the sites as a result of its low species richness (Table 6). The presence of only *G. aculeatus, P. americanus* and *T. adspersus* create a faunal composition which is only 23% similar to the rest of the sites in the bay.

The annual surveys were conducted during the month of June. High latitude temperate fishes, such as those found in Bonne Bay, experience large seasonal variations in temperature and day-length and these environmental factors may impart a natural seasonality to a fish assemblage (Nash, 1988). Other studies of temperate fish assemblages have found a decrease in catch size between spring and fall peaks (Allen, 1982; Methven and Bajdik, 1994). The data presented here are for fish species found in Bonne Bay in early summer. Sampling on a seasonal basis is needed to fully establish the faunal composition within Bonne Bay.

The different habitats that comprise Bonne Bay provide heterogeneity in structure that may affect biological interactions such as competition and predation and may promote enhanced survival of juvenile fish species (Shulman, 1984). The variability in fish species assemblages throughout the sampling locations within Bonne Bay suggests different habitats contain different fish species assemblages, and therefore supports our original hypothesis.

Components of the Fish Fauna of Bonne Bay

To describe the fish fauna of Bonne Bay, it may be advantageous to consider the five "ecological guilds" proposed by Wroblewski *et al*. (2007) for Gilbert Bay fishes. These are: (1) fish resident in the bay year-round (these species would be common in annual surveys); (2) anadromous species transiting the bay (these species would appear

depending on the timing of the annual survey); (3) marine species which migrate into the bay to spawn (these species would also appear depending on timing of the survey); (4) offshore-spawning marine fish for which the bay is a nursery area (juvenile stages of these species would be common in annual surveys); (5) marine species which migrate into the bay to feed (these species would appear occasionally in surveys).

Bonne Bay resident species

Several species collected within Bonne Bay were captured as both juveniles and adults (Table 8), which is suggestive of a local population (Wroblewski *et al.,* 2005). The topographic features of Bonne Bay promote the retention of planktonic fish eggs and larvae and the settlement of juveniles within the bay. The sill located near the mouth of East Arm (Figure 1) hinders the movement of water into and out of the bay. Of the 32 fish species collected, 19 species may have a resident population in Bonne Bay.

G. morhua is likely a resident of Bonne Bay. Adult and juvenile stages were collected at five of the seven locations (Table 2 and 8). These results indicate the possibility of a self-sustaining, local population of *G. morhua,* which is important since this species is threatened with extinction (COSEWIC, 2003).

G. ogac may be a resident fish species of Bonne Bay. Adults and juveniles were collected at five of the seven sampling locations (Table 2 and 8). This catch data is consistent with the statement by Backus (1957) that *G. ogac* is a nearshore species which frequents harbors and fjords, and occurs less commonly offshore.

A single adult *M. tomcod* was collected from Site 3, within Bonne Bay (Table 2 and 8). This species regularly enters brackish or freshwaters during spawning migrations

(Scott and Scott, 1988), but spends the majority of its life history within an estuarine habitat, which is consistent with its collection from Site 3.

G. aculeatus, G. wheatlandi and A. quadracus are thought to be resident species within Bonne Bay. Sampling found that these species are common at Site 3A and Site 4A (Table 3). *A. quadracus* exhibits the largest range in salinity tolerance of the three stickleback species (Scott and Scott, 1988) and was only found at Site 3A and 4A (Table 2). *A. quadracus* at these low saline sites may experience reduced competition and predation by other sticklebacks (Blouw and Hagen, 1981) as well as other predatory fish unable to tolerate low salinity.

T. adspersus is very likely a resident species within Bonne Bay, since numerous adults and juveniles were collected at five of the seven sampling locations (Table 2 and 8). Green (1975) found that *T. adspersus* occupy small home ranges for long periods of time, and will even return to their home ranges if displaced. Green (1974) has reported mass mortalities in *T. adspersus,* possibly as a result of their inability to withstand cold temperatures. This is important to note, since this species is approaching its northern limit of distribution. *T. adspersus* serves as an indicator species for the division between the cold temperate climate of Newfoundland and the subarctic climate of Labrador.

Adult and juvenile *P. gunnellus* and *U. subbifurcata* were collected within Bonne Bay (Table 2 and 8) and may be resident species. Collette and Klein-MacPhee (2002), report that *P. gunnellus* avoids muddy bottoms as well as eelgrass, which is consistent with our catch data which shows its absence from Sites 3A and 4A, both of which have mud bottoms and eelgrass beds. *U. subbifurcata* occurred at much lower abundances than the closely related *P. gunnellus* (Table 3). A possible explanation is provided by LeDrew

and Green (1975), who showed that both species rely on similar food sources and exhibit resource partitioning. *U. subbifurcata* remains inactive during the daylight hours, hiding under rocks or within crevices, while *P. gunnellus* forages for food during the daylight hours. Our sampling, which took place mostly during daylight, could have captured *P. gunnellus* that were foraging for food in the water column. Additional nighttime sampling may reveal more occurrences of *U. subbifurcata* in Bonne Bay.

H. americanus, *M. octodecemspinosus, M. scorpius* and *M. aenaeus* may have resident populations within Bonne Bay, since adults and juveniles of each species were collected (Table 2 and 8). *H. americanus* and *M. aenaeus* occurred at low abundances when compared to *M. octodecemspinosus* and *M. scorpius* (Table 2). Scott and Scott (19880) state that *H. americanus* and *M. aenaeus* not common in estuaries. *M. octodecemspinosus* and *M. scorpius* are described as sedentary fish species which undergo only local seasonal migrations from shallow to deep water (Scott and Scott, 1988).

P. americanus and *S. aquosus* may be residents of Bonne Bay, since both adults and juveniles were collected (Table 2 and 8). *S. aquosus* is a shallow-water benthic species, which lives on sandy bottoms (Scott and Scott, 1988). This is in accordance with our results which found *S. aquosus* only at Site 3, which has sand substrate. It is interesting to note that Scott and Scott (1988) reported Port-au-Port Bay as the most northerly record of *S. aquosus* on the west coast of Newfoundland. Port-au-Port Bay is further south than Bonne Bay. Our results show that *S. aquosus* has a more northerly range than originally proposed in 1988.

R. erinacea and *R. ocellata* may be residents of Bonne Bay. This is in accordance with McEachran and Musick (1975) and Scott and Scott (1988) who suggest these species inhabit shallow coastal waters, from the shore to depths of approximately 100 m.

Sebastes fasciatus is found within Bonne Bay (Valentin, 2006) and *Sebastes sp.* specimens were collected from four of the seven sampling locations (Table 2). *Sebastes fasciatus* collected from Bonne Bay by Valentin (2006) were genetically distinguishable from other *S. fasciatus* populations (DFO, 2008). As the *Sebastes fasciatus* population in Bonne Bay is genetically distinctive, it would be interesting to see if other fish populations in Bonne Bay are also genetically distinguishable.

A. monopterygius was collected at Site 3 within Bonne Bay (Table 2) and may be a resident of the bay. Collections made by Backus (1957) along the Labrador coast found specimens over muddy and sandy substrate, which is consistent with our data. There is little information available for this species and its presence within Bonne Bay prompts further research.

Bonne Bay anadromous species

Salmo salar, Salvelinus fontinalis and *Osmerus mordax* are anadromous species. *Salmo salar* were collected at six of the seven sites within Bonne Bay (Table 2). Most specimens were juveniles moving seaward from freshwater rivers. The *S. salar* populations spawning in the rivers of Newfoundland are among the few wild populations in North America that have not been impacted genetically by hatchery escapes (Zyll de Jong *et al.,* 2004).

O. mordax were collected at six of the seven sampling locations within Bonne Bay (Table 2). Studies carried out by Clayton (1976) and Hulbert (1974) found that *O.*

mordax spawn in estuarine locations characterized by rock, sand and gravel substrates as well as fast-flowing freshwater conditions, which are typical of the brackish locations within Bonne Bay.

Migratory marine species which spawn in Bonne Bay

The fish assemblages of the inner and middle bay regions differ somewhat in their composition from Site 1, which is closest to the Gulf of St. Lawrence (Figure 2). This faunal component includes continental shelf species which migrate considerable distances to spawn nearshore (e.g. *M. villosus* and *A. americanus*).

M. villosus are smelt-like fish inhabiting the Newfoundland and Labrador continental shelf that migrate inshore to spawn at various sub-tidal depths (Templeman, 1984; Nakashima and Taggart, 2002). During the seven surveys only one specimen at Site 1 was collected (Table 2). This specimen could have been a juvenile undergoing a trial migration before reaching maturity. The near absence of *M. villosus* in our collections is a result of the timing of the surveys. Sampling in Bonne Bay later in the summer would likely find abundant capelin.

There is little information in the literature about the spawning of *A. americanus* (Collette and Klein-MacPhee, 2002). With both adults and juveniles collected in June throughout the seven years of sampling (Table 8), our data suggest that *A. americanus* reproduce within Bonne Bay, This is in accordance with a survey of Gilbert Bay by Wroblewski *et al.* (2007), who also suggest *A. americanus* undergo spawning within the bay.

There has been debate in the literature concerning the inshore migration of *A. lupus* into shallow waters to spawn (Collette and Klein-MacPhee, 2002). Keats *et al.*

(1985) reported an inshore movement of *A. lupus* during spring in Newfoundland waters, presumably in preparation for August spawning. Two adult specimens collected at Site 1 (Table 2 and 8), may either be resident in Bonne Bay, or may have migrated inshore in preparation for spawning.

Z. americanus is a shelf species, which migrates into shallow waters during the spring to spawn (Keats, *et al.*, 1985). The specimens collected from Bonne Bay (Table 2) include both adults and juveniles (Table 8).

L. ferruginea is a continental shelf species common in the shallow waters of the Grand Banks (Scott and Scott, 1988). Seasonal movements are limited; however, some reports have shown a movement into shallower coastal waters during the spring and movement back into deeper water in the fall and early winter (Scott and Scott, 1988). Both juvenile and adult specimens of *L. ferruginea* were collected in Bonne Bay (Table 2 and Table 8)

Shelf-spawning species for which Bonne Bay is a nursery

This category includes marine fish species which spawn on the continental shelf, but whose planktonic eggs and larvae drift towards the coastline, where pelagic juveniles settle onto inshore nursery grounds. *U. tenuis* were collected in shallow waters at Site 1 and Site 2 (Table 2). Collette and Klein-MacPhee (2002) suggest that *U. tenuis* is a shelf-spawning species which uses the coastal zone as a nursery ground throughout much of Atlantic Canada.

A single specimen of *M. bilinearis* was collected at Site 3 and is thought to be a juvenile which settled on an inshore nursery ground. *M. bilinearis* is known to spawn over a wide area of the continental shelf (Scott, 1983). Scott and Scott (1988) have

reported the northern range of *M. bilinearis* to be the southern coast of Newfoundland, suggesting that this specimen was at the northern limit of its range.

Marine species which migrate into Bonne Bay to feed

C. harengus were collected at five of the seven sampling locations with no juveniles present at any of the sites (Table 2 and 8). This is in accordance with results presented by Scott and Scott (1988), who suggest that *C. harengus* undergo annual migratory movements to feeding areas. All but one of the specimens in the surveys was captured in the gill-nets. The single specimen caught with the small beach seine may have been preparing to spawn, or may have followed prey into shallow water.

R. radiata lives offshore at depths down to 1000 m (McEachran and Musick, 1975). Little information is available on the migrations of *R. radiata.* However, prey of *R radiata* include sculpins and sand lance (Scott and Scott, 1988), both of which are found within Bonne Bay.

The presence of both temperate and subarctic species in Bonne Bay supports the premise that the faunal composition would consist of fish species at various ranges of climatic tolerances.

Diversity of the Fish Fauna of Bonne Bay

A total of 47 fish species are now documented as inhabiting Bonne Bay. Bell and Pollard (1989) and Ferrel and Bell (1991) emphasized the important role of nearshore habitats in sustaining the biodiversity of fish assemblages and stressed the need for their careful management. Shallow, vegetated habitats play a vital role as fish spawning and

nursery areas. Shallow, non-vegetated habitats serve as feeding areas for fish (West and King, 1996).

In the present study, several fish species exhibited specific habitat association, while other species were found in more than one habitat. It is worth stressing that more than one habitat can be suitable for a particular species, and what constitutes a suitable habitat changes with life history stage (Francour, 1997). An example is the Atlantic salmon (*Salmo salar*), which exhibits shifts in habitat use during its feeding and spawning seasons.

This study presents the first data on the nearshore fish assemblages at different habitats within Bonne Bay. Our findings emphasize the need to protect Bonne Bay's varied nearshore habitats, in order to maintain the diverse fish assemblages.

Future research

The topography of Bonne Bay, especially the shallow sill near Norris Point, suggests the possibility that some fish species may be confined within the bay. There has only been one study done to identify any genotypic variation of the fish populations within Bonne Bay, i.e. the research by Valentin (2006) on Acadian redfish, *Sebastes fasciatus*. Additional genetic studies could clarify the population structure of species commonly found in the bay.

A survey carried out within the deeper waters of Bonne Bay would provide additional information on the fish fauna. Bonne Bay has become a focus for local

conservation efforts, because it is located within Gros Morne National Park and supports several local fisheries (Hooper, 1975).

SUMMARY

We conducted annual, standardized surveys of the nearshore fish fauna of Bonne Bay, Newfoundland. The study documented the presence in the bay of 31 species representing 17 taxonomic families of coastal marine and estuarine fishes. Along with the species identified by Hooper (1975), a total of 47 fish species are now documented for Bonne Bay. Limitations in sampling protocol increase the likelihood that not all fish species present in Bonne Bay have been recorded. Such limitations include: lack of sampling throughout the year (i.e., the annual survey was conducted during the month of June), fish size selectivity of fishing gear type, and restricted water depths and bottom substrates where sampling equipment could be deployed.

Analysis of the data suggests that some fish species are residents of Bonne Bay, some species are anadromous transients, some species migrate into the bay to spawn, some species use Bonne Bay as a nursery ground, and other species migrate into the bay to feed. Sampling suggests that these resident species are found throughout the bay. The faunal composition of Bonne Bay includes the Laurentian North population of Atlantic cod (*Gadus morhua*) designated by COSEWIC as "threatened", as well as striped wolfish (*Anarhichas lupus*) which is protected under Canada's Species at Risk Act (SARA). The genetically distinctive population of Acadian redfish (*Sebastes fasciatus*) living in Bonne

Bay is being considered for listing by COSEWIC. This study provides baseline information for further research on the Bonne Bay ecosystem.

REFERENCES

Allen, L. 1982. Seasonal abundance, composition, and productivity of the littoral fish assemblage in upper Newport Bay, California. Fish. Bulletin U.S. 80: 769-790.

Angel, M.V. 1993. Biodiversity of the pelagic ocean. Conser. Biol. 7: 760-772.

Backus R. H. 1957. The fishes of Labrador. Bulletin Am. Mus. Natur. Hist. 113: 273-338.

Bell, J.D. and Pollard, D.A. 1989. Ecology of fish assemblages and fisheries associated with seagrasses. *In*: The Biology of Seagrasses: An Australian Perspective Larkum, A. W. D.

Blaber, S.J.M.,Young, J.W. and Dunning, M.C. 1985. Community structure and zoogeographic affinities of the coastal fishes of the Dampier Region of Northwestern Australia. Aust. J. Mar. Freshwater Res. 36: 247-266.

Blouw, D.M. and Hagen, D.W. 1981. Ecology of the fourspine stickleback, *Apeltes quadracus,* with respect to a polymorphism from dorsal spine number. Can. J. Zoology 59: 1677-1692.

Clayton, G.R. 1976. Reproduction, first year growth, and distribution of anadromous rainbow smelt. *Osmerus mordax*, in the Parker River and Plum Island Sound estuary, Massachusetts. M. S. thesis, University of Massachusetts, Amherst, pp. 105.

Collette, B. B. and Klein-MacPhee, G. 2002. Bigelow and Schroeder's Fishes of the Gulf of Maine, 3rd edition. Washington: Smithsonian Institution Press.

COSEWIC. 2003. COSEWIC assessment and update status report on the Atlantic cod *Gadus morhua* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 76p.

Currie, J. 2009. The nearshore fish fauna of Bonne Bay, a fjord within Gros Morne National Park. B. Sc. Honours Thesis. Dept. Biology, Memorial Univ. 64p.

Dando, P.R. 1984. Reproduction in estuarine fish. pp. 155-170. In G. W. Potts and R.J. Wootton (eds.), Fish Reproduction Strategies and Tactics. Academic Press, London.

DFO. 2008. Advice on the stock definition of redfish (*Sebastes fasciatus* and *S. mentella*) in Units 1 and 2. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/026.

Dunbar, M. J., 1968. Ecological Development in Polar Regions. Prentice-Hall, Englewood Cliff, N.J. 119 pp.

Elliot, N.G., and Ward, R.D. 1992. Enzyme variation in orange roughy, *Hoplestethus atlanticus* (Teleastei: Trachichthyidae), from southern Australia and New Zealand waters. Aust. J. Mar. Freshwat. Res. 43: 1561-1571.

Ferrell, D.J. and Bell, J.D. 1991. Differences among assemblages of fish associated with *Zostera capricorna* and bare sand over a large spatial scale. Mar. Ecol. Progr. Series 72: 15-24.

Francour, P. 1997. Fish assemblages of *Posidonia oceanic* beds at Port-Cros (France NW Mediterranean): assessment of composition and long term fluctuations by visual census. Marine Ecology 18: 157-173.

Godo, O.R., Gjosaeter, J., Sunnana, K. and Dagesund, O. 1989. Spatial distribution of 0-group gadoids of Min-Norway. Rapp. P.-v. Reun. Cons. Int. Explor. Mer. 191: 273-280.

Gomes, M. C., Haedrich, R. L. and Villagarcia, M. G. 1995. Spatial and temporal changes in the groundfish assemblage on the Northeast Newfoundland/Labrador shelf, Northwest Atlantic, 1978-1991. Fish. Oceanogr. 4: 85-101.

Gray, J.S. 1994. Is the deep-sea really so diverse? Species diversity from the Norwegian continental shelf. Mar. Ecol. Prog. Ser. 112: 205-209.

Gray, J.S. 1997. Marine biodiversity: patterns, threats, and conservation needs. Biodiversity and Conservation 6: 153-175.

Green, J.M. 1974. A localized mass winter kill of cunners in Newfoundland. Can. Field-Natur. 88: 96-97.

Green, J.M. 1975, Restricted movements and homing of the cunner, *Tautogolabrus adspersus* (Walbaum) (Pisces: Labridae). Can. J. of Zoology 53: 1427-1431.

Gunnarsson, A. and Gunnarsson, K. 2002. Temperature effects on growth and maturity of butterfish (*Pholis gunnellus*) in Iceland. J. Mar. Biol. Ass. U.K., 82: 903-906.

Hayes, M.L. 1989. Active fish capture methods, *In* Fisheries Techniques. Edited by L. A. Nielsen and D. L. Johnson. American Fisheries Society, Bethesda, Md. 123-145.

Hooper, R. 1975. Bonne Bay Marine Resources: An Ecological and Biological Assesment. Parks Canada. pp. 267.

Hulbert, P.J. 1974. Factors affecting spawning site selection and hatching success of anadromous rainbow smelt, *Osmerus mordax*. M. S. thesis, University of Maine, Orno. 43p.

Keats, D.W., South, G.R. and D.H. Steele. 1985. Reproduction and egg guarding by Atlantic wolffish (*Anarchichas lupus*: Anarhichidae) and ocean pout (*Macrozoarces americanus:* Zoarcidae) in Newfoundland waters. Can. J. Zool. 63: 2565-2568.

LeDrew, B.R. and J.M. Green. 1974, Biology of the radiated shanny *Ulvaria subbifurcata* Storer in Newfoundland (Pisces: Stichaeidae). J. Fish Biol. 7: 485-495.

Livingston, R.J. 1982. Trophic organization of fishes in a coastal seagrass system. Mar. Ecol. Prog. Ser. 7: 1-12.

Mateo, I. and Tobias, W.J. 2004. Survey of nearshore communities on the tropical backreef lagoons on the southeastern coast of St. Croix. Caribbean Journal of Science 40: 327-342.

McComb, A.J. and Shepherd, S.A., eds) . Elsevier, Amsterdam, pp. 565-609.

McEachran, J. D., and J. A. Musick. 1975. Distribution and relative abundance of seven species of skates (Pisces: Rajidae) which occur between Nova Scotia and Cape Hatteras. Fish. Bull., U. S. 73: 110-136.

Methven, D.A. and Bajdik, C. 1994. Temporal variation in size and abundance of juvenile Atlantic Cod (*Gadus morhua*) at an inshore site off eastern Newfoundland. Canadian Journal of Fishes and Aquatic Sciences 51: 78-90.

Methven, D.A. and Schneider, D.C. 1998. Gear-independent patterns of variation in catch of juvenile Atlantic cod (*Gadus morhua*) in coastal habitats. Can. J. Fish. Aquat. Sci. 55: 1430-1442.

Methven, D.A., Haedrich, R.L. and Rose, G.A. 2001. The fish assemblage of a Newfoundland estuary: diel, monthly, and annual variation. Estuarine, Coastal and Shelf Science 52: 669-687.

Mills, E.L. 1969. The community concept in marine zoology, with comments on the continua and instability in some marine communities: a review. J Fish. Res. Bd. Canada. 26: 1415-1428.

Naeem, S., Thompson, L.J., Lawler, S.P., Lawton, J.H. and Woodfin, R.M. 1994. Declining biodiversity can alter the performance of ecosystems. Nature. 368: 734-737.

Nakashima, B.S. and Taggart, C.T. 2002. Is beach-spawning success for capelin, *Mallotus villosus* (Muller), a function of the beach? ICES Journal of Marine Science 59: 897-908.

Nash, R.D.M. and Gibson, R.N. 1982. Seasonal fluctuations and compositions of two populations of small demersal fishes on the west coast of Scotland. Estuarine Coastal and Shelf Science 15: 485-495.

O'Brien, L., J. Burnett and R.K. Mayo. 1993. Maturation of nineteen species of finfish off the northeast coast of the United States, 1985-1990. NOAA Tech. Rep. NMFS 113, pp. 66.

Omori, M. and Ikeda, T., 1984. Methods in Marine Zooplankton Ecology. New York: Wiley-Interscience. John Wiley & Sons.

Pauley, D., Christensen, V., Guenette, S., Pitcher, T.J., Sumalia, U.R., Walters, C.J., Watson, R. and Zeller, D. 2002. Towards sustainability in world fisheries. Nature, London, 418: 689-695.

Powell, S. M., Haedrich, R. L. and McEachran, J. D. 2003. The deep-sea demersal fish fauna of the northern Gulf of Mexico. J. Northwest Atl. Fish. Sci. 31: 19-33.

Ray, G.C. 1991. Coastal-zone biodiversity patterns. Bioscience 41: 490-498.

Richards, C. and deYoung, B. 2004. Analysis of Physical Oceanographic Data from Bonne Bay, September 2002 – September 2004. Physics and Physical Oceanography Data Report 2004-1.Department of Physics and Physical Oceanography, Memorial University of Newfoundland. St. John's, NL. 41 pp.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. No. 191.

Riley, J.D. and Parnell, W.G. 1984. The distribution of young cod. The propagation of cod *Gadus morhua* L. Flodevigen rapportser 1: 563-580.

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.

Roseman, E.F., Tomichek, C.A., Maynard, T. and Burton, J.A. 2005. Relative abundance, age, growth, and fecundity of grubby *Myoxocephalus aenaeus* in Niantic River and Niantic Bay, Long Island Sound. Journal of Sea Research, 53(4): 309-318.

Rohlf, F. J. 2005. NTSYS-pc. Numerical taxonomy and multivariate analysis system. Version 2.2. Getting started Guide. Exeter Software, Setauket N. Y.

Russel D. J. and Garrett, R.N. 1983. Use by juvenile barramundi *Lates calcarifer* (Bloch), and other fishes of temporary supralittoral habitats in a tropical estuary in northern Australia. Aust. J. Mar. Freshwater Res. 34: 805-811.

Scott, W.B. 1983. Fishes, p 156-175. *In* M. L. H. Thomas (ed.), Marine and coastal systems of the Quoddy region, New Brunswick. Can. Spec. Publ. Fish. Aquatic. Sci. 64: 306 p.

Scott, W. B. and Crossman, E. J. 1973. Freshwater Fishes of Canada. Fisheries Research Board of Canada , Bulletin 184. Ottowa, O. N.

Scott, W. B. and Scott, M. B., 1988. Atlantic Fishes of Canada. Toronto: University of Toronto Press.

Shepard, 1963. Submarine Geology. 2nd edition. Harper and Row, New York, N. Y.

Shulman, M.J. 1984. Resource limitation and recruitment patterns in a coral reef fish assemblage. J. Exp. Mar. Biology. Ecol. 74: 198-215.

Simon, J.E., and Campana, S.E. 1987. Species composition and distribution in inshore waters of southern Nova Scotia: results of exploratory trawl surveys. Can. Tech. Rep. Fish. Aquat. Sci. 1582: 53.

Steele, D.H. 1983. Marine ecology and zoogeography. *In* Biogeography and Ecology of the Island of Newfoundland, *Edited by* G. R. South. The Hague: Dr W. Junk Publishers. pp. 421-465.

Suchanek, T.H. 1994.Temperate coastal marine communities: biodiversity and threats. Am. Zool. 34: 100-114.

Templeman, W. 1984. The life history of the capelin (*Mallotus villosus* O. F. Muller) in Newfoundland waters. Newfoundland Department of Natural Resources. Research Bulletin (Fisheries) 17: 1-151.

Valentin, A. 2006. Structure des populations de sébaste de l'Atlantique du nord-ouest dans un contexte de gestion des stocks et d'évolution. Thèse de Doctorat Université du Québec à Rimouski. 212p.

Ward, R.D., Woodwark, M. and Skibinski, D.O.F. 1994. A comparison of genetic diversity levels in marine, freshwater and anadromous fishes. J. Fish Biol. 44: 213-132.

West, R.J. and King, R.J. 1996. Marine brackish, and freshwater fish communities in the vegetated and bare shallows of an Australian river. Estuaries 19: 31-41.

Williams, D.D., and Delbeek, J.C. 1989, Biology of threespine stickleback, *Gasterosteus aculeatus,* and the blackspotted stickleback, *G. wheatlandi,* during their marine pelagic phase in the Bay of Fundy, Canada. Environ. Biol. Fish, 24: 33-41.

Wroblewski, J.S., Kryger, L.K., Methven, D.A. and Haedrich, R.L. 2007. The fish fauna of Gilbert Bay, Labrador: a marine protected area in the Canadian subarctic coastal zone. J, Marine Biology Ass. U.K. 87: 575-587.

Wroblewski, J., B. Neis and K. Gosse. 2005. Inshore stocks of Atlantic cod are important for rebuilding the East Coast fishery. Coastal Management 33: 411-432.

Zyll de Jong, M.C. van, Gibson, R.J. and Cowx, I. G. 2004. Impacts of stocking and introductions on freshwater fisheries of Newfoundland and Labrador, Canada. Fisheries Management and Ecology 11: 183-193.

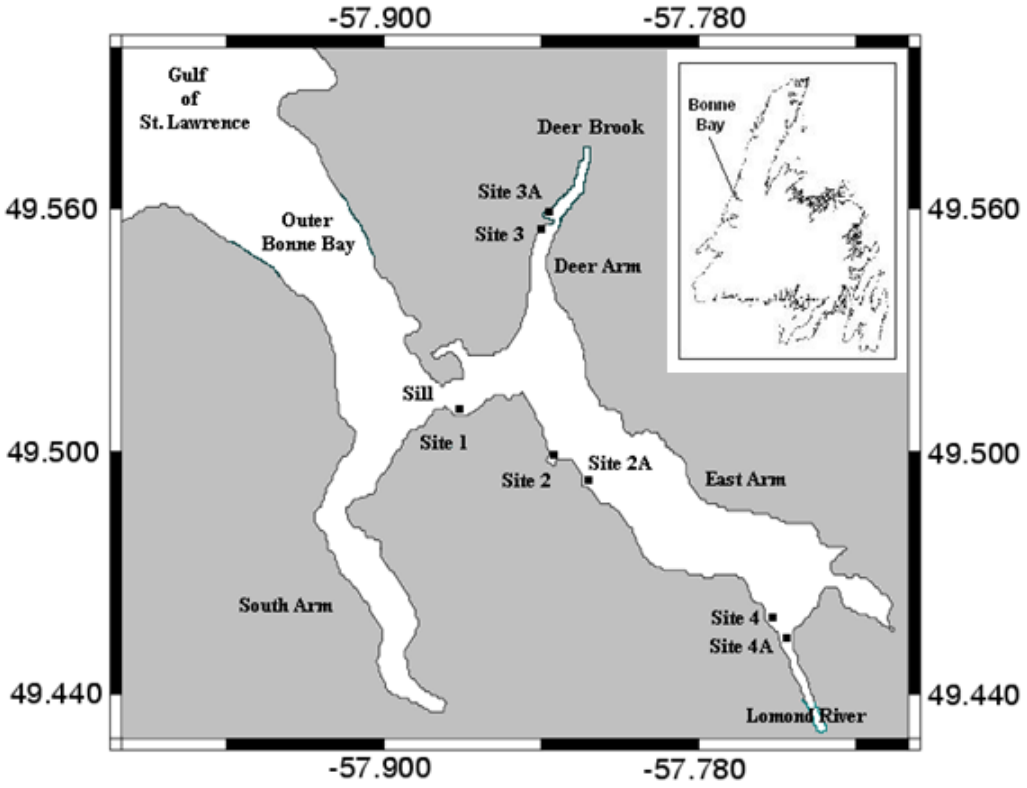
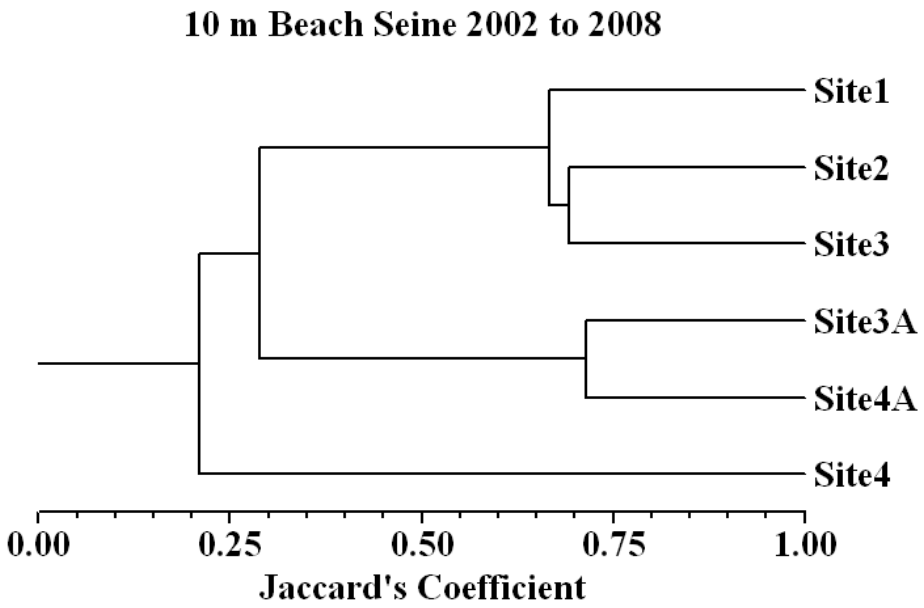
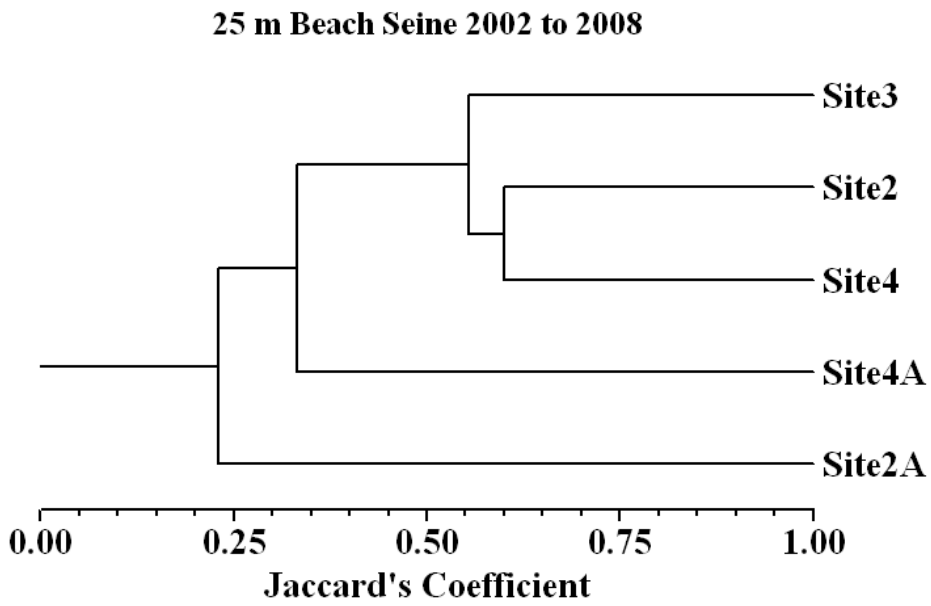


Figure 1. Map of Bonne Bay, island of Newfoundland showing place names mentioned in text and locations of standard sampling sites 1, 2, 2A, 3, 3A, 4, and 4A. Site 1 is Gadds Harbour; Site 2 is Norris Cove; Site 2A is Lord and Lady Cove; Site 3 is Deer Brook delta; Site 3A is Deer Arm barachois (sheltered sand flat formed by a sandbar at the mouth of Deer Brook); Site 4 is Lomond Cove; Site is 4A Lomond River delta.



10 m beach seine						
	Site 1	Site 2	Site 3	Site 3A	Site 4	Site 4A
Site 1	1.0000					
Site 2	0.6667	1.0000				
Site 3	0.6667	0.6923	1.0000			
Site 3A	0.3125	0.2000	0.3846	1.0000		
Site 4	0.2143	0.1667	0.2727	0.2500	1.0000	
Site 4A	0.2667	0.2308	0.3333	0.7143	0.1429	1.0000

Figure 2. Dendrogram and matrix of Jaccard's similarity coefficient values calculated for the fish collections made with the 10 m seine from 2002 to 2008 at Sites 1, 2, 3, 3A, and 4A.



25 m beach seine					
	Site 3	Site 2	Site 4	Site 4A	Site 2A
Site 3	1.000				
Site 2	0.5789	1.000			
Site 4	0.5294	0.6000	1.000		
Site 4A	0.3333	0.3750	0.2857	1.000	
Site 2A	0.1875	0.2143	0.3000	0.2222	1.000

Figure 3. Dendrogram and matrix of Jaccard's similarity coefficient values calculated for the fish collections made with the 25 m seine from 2002 to 2008 at Sites 2, 2A, 3, 4 and 4A

Table 1. Frequency of sampling carried out within Bonne Bay from 2002 to 2008 for each of the seven sites for each sampling gear type.

Number of sampling sets using the 10 m beach seine at each site							
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Site 1	2	10	10	19		6	6
Site 2		24	11	7	27	4	6
Site 2A							3
Site 3	4	4	9	19	3	3	4
Site 3A	2	2	15	5	3	1	5
Site 4						3	3
Site 4A						3	4
Number of sampling sets using the 25 m beach seine at each site							
Site 1							
Site 2		4	4	8	20	4	4
Site 2A							3
Site 3	4	1	2	5	3	3	4
Site 4						2	2
Site 4A						2	2
Number of sampling sets using the gill-nets							
Site 1	5	11	14	9		3	4
Site 2		2	2	1	8	3	6
Site 2A							3
Site 3			2		2	4	6
Site 4						6	3
Number of sampling sets using the bottom trawl							
Site 1	1						
Site 3		2	9	1	4	4	

Table 2: Fish collected by standardized sampling methods in Bonne Bay from 2002 to 2008. N = total number of individuals of a species collected.

			Standard length (mm)		Present at sites
Species	Common name	N	Range	Mean	
Family Rajidae					
Raja erinacea	little skate	1	-	398	3
Raja ocellata	winter skate	5	392-590	480	2, 3, 4
Raja radiata	thorny skate	8	530-685	615.0	1, 3, 4
Family Clupeidae					
Clupea harengus	Atlantic herring	69	198-532	309.2	1, 2, 2A, 3, 3A
Family Salmonidae					
Salmo salar	Atlantic salmon	115	25-370	124.4	1, 2, 3, 3A, 4, 4A
Salvelinus fontinalis	brook trout	51	36-495	96.2	1, 2, 3, 4
Family Osmeridae					
Mallotus villosus	capelin	1	-	105	1
Osmerus mordax	rainbow smelt	212	38-205	126.9	1, 2, 3, 3A, 4, 4A
Family Gadidae					
Gadus morhua	Atlantic cod	405	23-800	192.6	1, 2, 3, 4, 4A
Gadus ogac	Greenland cod	72	103-490	281.3	1, 2, 2A, 3, 4
Merluccius bilinearis	silver hake	1	-	215	3
Microgadus tomcod	Atlantic tomcod	1	-	200	3
Urophycis tenuis	white hake	14	59-511	162.1	1, 2, 3
Family Gasterosteidae					
Gasterosteus aculeatus	threespine stickleback	3515	12-79	48.5	1, 2, 2A, 3, 3A, 4, 4A
Gasterosteus wheatlandi	blackspotted stickleback	1741	20-71	35.9	1, 2, 3, 3A, 4A
Apeltes quadracus	fourspine stickleback	444	21-79	38.6	3A, 4A
Family Labridae					
Tautogolabrus adspersus	cunner	2899	10-267	89.4	1, 2, 2A, 3, 4
Family Zoarcidae					
Zoarces americanus	ocean pout	11	78-290	134.2	1, 2, 3
Family Stichaeidae					
Ulvaria subbifurcata	radiated shanny	5	70-120	92.7	2
Family Pholidae					
Pholis gunnellus	rock gunnel	66	30-188	128.3	1, 2, 3, 4
Family Anarhichadidae					
Anarhichas lupus	wolffish	2	550-600	575	1

Table 2: Continued

Family Ammodytidae					
Ammodytes americanus	American sand lance	13	86-131	105.0	1, 2, 4A
Family Scorpaenidae					
Sebastes spp.	redfish	41	205-335	267.7	1, 2, 2A, 4
Family Cottidae					
Hemitripterus americanus	sea raven	15	70-460	334.3	1, 2, 3, 4
Myoxocephalus aenaeus	grubby	11	81-158	124.5	1, 3
Myoxocephalus octodecemspinosus	longhorn sculpin	215	52-305	176.6	1, 2, 3, 4, 4A
Myoxocephalus scorpius	shorthorn sculpin	240	10-420	87.9	1, 2, 3, 4
Family Agonidae					
Aspidophoroides monopterygius	alligator fish	7	80-115	85	3
Family Bothidae					
Scophthalmus aquosus	windowpane flounder	4	87-265	191	3
Family Pleuronectidae					
Limanda ferruginea	yellowtail flounder	20	146-223	177.2	1, 3
Pseudopleuronectes americanus	winter flounder	1146	35-277	116.9	1, 2, 2A, 3, 3A, 4, 4A

Table 3. Counts of all fish species collected at all sites, using all sampling gears, from 2002 to 2008.

	10 m beach seine						25 m beach seine					Gill-net (various mesh sizes)					Bottom trawl		Total
Species	Site 1	Site 2	Site 3	Site 3A	Site 4	Site 4A	Site 2	Site 2A	Site 3	Site 4	Site 4A	Site 1	Site 2	Site 2A	Site 3	Site 4	Site 1	Site 3	
Family Rajidae																			
Raja erinacea									1										**1**
Raja ocellata										2			1					2	**5**
Raja radiata												3				1		4	**8**
Family Clupeidae																			
Clupea harengus				1								12	2	53	1				**69**
Family Salmonidae																			
Salmo salar	9		74	7	3				15		1	2	2		2				**115**
Salvelinus fontinalis	6	7	8		4		1		17	3	1	3						1	**51**
Family Osmeridae																			
Mallotus villosus												1							**1**
Osmerus mordax	7		1	2		1	1		182	1	2	14			1				**212**
Family Gadidae																			
Gadus morhua	2	1					88		20	92		93	80	15	10	4			**405**
Gadus ogac	5											56	2	2	4	1		2	**72**
Merluccius bilinearis									1										**1**
Microgadus tomcod															1				**1**
Urophycis tenuis	1	4	1				3		2			1						2	**14**
Family Gasterosteidae																			
Gasterosteus aculeatus	53	22	224	2566		48	1	3	317	4	277								**3515**
Gasterosteus wheatlandi	5	7	125	905		124	1		9		565								**1741**
Apeltes quadracus				420		7					17								**444**
Family Labridae																			
Tautogolabrus adspersus	99	26	21				302	674	605	272		806	4		5		13	72	**2899**

Table 3. Continued.

Family Zoarcidae																			
Zoarces americanus							8					1						2	**11**
Family Stichaeidae																			
Ulvaria subbifurcata							5												**5**
Family Pholidae																			
Pholis gunnellus	9	11	3				36		2	5									**66**
Family Anarhichadidae																			
Anarhichas lupus												2							**2**
Family Ammodytidae																			
Ammodytes americanus	8	3					1				1								**13**
Family Scorpaenidae																			
Sebastes spp.												6	7	2		26			**41**
Family Cottidae																			
Hemitripterus americanus	1								1			7	2		2			2	**15**
Myoxocephalus aenaeus	7								4										**11**
Myoxocephalus octodecemspinosus		7	1				74		37	3		6	1		8	2		76	**215**
Myoxocephalus scorpius	10	39	44				76		18	15		15			2		1	20	**240**
Family Agonidae																			
Aspidophoroides monopterygius																		7	**7**
Family Bothidae																			
Scophthalmus aquosus									3									1	**4**
Family Pleuronectidae																			
Limanda ferruginea									4			1						15	**20**
Pseudopleuronectes americanus	65	31	6	6	2	2	368	2	121	16	81	11			7	1	1	426	**1146**
Species richness	**15**	**11**	**11**	**7**	**3**	**5**	**14**	**3**	**18**	**10**	**8**	**18**	**9**	**4**	**11**	**6**	**3**	**14**	
Total Fish caught at each site	**287**	**158**	**508**	**3907**	**9**	**182**	**965**	**679**	**1359**	**413**	**945**	**1040**	**101**	**72**	**43**	**35**	**15**	**632**	**11350**

Table 4. Species richness at the seven sampling locations within Bonne Bay.

Sampling locations	Species richness (S)
Site 1	23
Site 2	20
Site 2A	6
Site 3	25
Site 3A	7
Site 4	14
Site 4A	8

Table 5. Catch per unit effort (number caught/100 m of shoreline < 1m deep) for each species using a 10 m x 1.5 m beach seine within Bonne Bay from 2002 to 2008.

	N	Site 1	Site 2	Site 3	Site 3A	Site 4	Site 4A
Species							
Family Clupeidae							
Clupea harengus	1	0	0	0	0.121	0	0
Family Salmonidae							
Salmo salar	93	0.679	0	6.435	0.848	2.000	0
Salvelinus fontinalis	25	0.453	0.354	0.696	0	2.667	0
Family Osmeridae							
Osmerus mordax	11	0.528	0	0.087	0.242	0	0.571
Family Gadidae							
Gadus morhua	3	0.151	0.051	0	0	0	0
Gadus ogac	5	0.377	0	0	0	0	0
Urophycis tenuis	6	0.075	0.203	0.087	0	0	0
Family Gasterosteidae							
Gasterosteus aculeatus	2913	4.000	1.114	19.478	311.030	0	27.429
Gasterosteus wheatlandi	1166	0.377	0.354	10.870	78.696	0	70.857
Apeltes quadracus	427	0	0	0	50.909	0	4.000
Family Labridae							
Tautogolabrus adspersus	146	7.472	1.316	1.826	0	0	0
Family Pholidae							
Pholis gunnellus	23	0.679	0.557	0.261	0	0	0
Family Ammodytidae							
Ammodytes americanus	11	0.604	0.152	0	0	0	0
Family Cottidae							
Hemitripterus americanus	1	0.075					
Myoxocephalus aenaeus	7	0.528	0	0	0	0	0
Myoxocephalus octodecemspinosus	8	0	0.354	0.087	0	0	0
Myoxocephalus scorpius	93	0.755	1.975	3.826	0	0	0
Family Pleuronectidae							
Pseudopleuronectes americanus	112	4.906	1.570	0.522	0.727	1.333	1.143
Total number collected	5051	287	158	508	3907	9	182
Species richness		15	11	11	7	3	5
Total number of meters towed		1325	1975	1150	825	150	175
Total CPUE		21.584	8.00	43.567	442.573	6.00	104.00

Table 6. Catch per unit effort (number caught/total number of hauls at that site) for each species using a 25 m x 1.5 m beach seine within Bonne Bay from 2002 to 2008.
Site 1 could not be seined with the 25 m seine due to bottom roughness.

	N	Site 2	Site 2A	Site 3	Site 4	Site 4A
Species						
Family Rajidae						
Raja erinacea	1	0	0	0.045	0	0
Raja ocellata	2	0	0	0	0.500	0
Family Salmonidae						
Salmo salar	16	0	0	0.682	0	0.250
Salvelinus fontinalis	22	0.023	0	0.773	0.750	0.250
Family Osmeridae						
Osmerus mordax	186	0.023	0	8.273	0.250	0.500
Family Gadidae						
Gadus morhua	200	2.000	0	0.909	23.000	0
Merluccius bilinearis	1	0	0	0.045	0	0
Urophycis tenuis	5	0.068	0	0.091	0	0
Family Gasterosteidae						
Gasterosteus aculeatus	602	0.023	1.000	14.409	1.000	69.250
Gasterosteus wheatlandi	575	0.023	0	0.409	0	141.250
Apeltes quadracus	17	0	0	0	0	4.250
Family Labridae						
Tautogolabrus adspersus	1853	6.864	224.667	27.500	68.000	0
Family Zoarcidae						
Zoarces americanus	8	0.182	0	0	0	0
Family Stichaeidae						
Ulvaria subbifurcata	5	0.114	0	0	0	0
Family Pholidae						
Pholis gunnellus	43	0.818	0	0.091	1.250	0
Family Ammodytidae						
Ammodytes americanus	2	0.023	0	0	0	0.250
Family Cottidae						
Hemitripterus americanus	1	0	0	0.045	0	0
Myoxocephalus aenaeus	4	0	0	0.182	0	0
Myoxocephalus octodecemspinosus	114	1.682	0	1.682	0.750	0
Myoxocephalus scorpius	109	1.727	0	0.818	3.750	0
Family Bothidae						
Scophthalmus aquosus	3	0	0	0.136	0	0
Family Pleuronectidae						
Limanda ferruginea	4	0	0	0.182	0	0
Pseudopleuronectes americanus	588	8.364	0.667	5.500	4.000	20.250
Total number collected	4361	965	679	1359	413	945
Species richness		14	3	18	10	8
Total number of hauls		44	3	22	4	4
Total CPUE		21.934	226.334	61.772	103.25	236.25

Table 7. Catch per unit effort (number caught/total hours set) for each species using the gill-nets (various mesh sizes) within Bonne Bay from 2002 to 2008.

	N	Site 1	Site 2	Site 2A	Site 3	Site 4
Species						
Family Rajidae						
Raja ocellata	1	0	0.003	0	0	0
Raja radiata	4	0.001	0	0	0	0.011
Family Clupeidae						
Clupea harengus	68	0.017	0.007	0.768	0.005	0
Family Salmonidae						
Salmo salar	6	0.003	0.007	0	0.011	0
Salvelinus fontinalis	3	0.004	0	0	0	0
Family Osmeridae						
Mallotus villosus	1	0.001	0	0	0	0
Osmerus mordax	15	0.020	0	0	0.005	0
Family Gadidae						
Gadus morhua	202	0.133	0.273	0.217	0.055	0.046
Gadus ogac	65	0.080	0.007	0.029	0.022	0.011
Microgadus tomcod	1	0	0	0	0.005	0
Urophycis tenuis	1	0.001	0	0	0	0
Family Labridae						
Tautogolabrus adspersus	815	1.156	0.014	0	0.027	0
Family Zoarcidae						
Zoarces americanus	1	0.001	0	0	0	0
Family Anarhichadidae						
Anarhichas lupus	2	0.003	0	0	0	0
Family Scorpaenidae						
Sebastes spp.	41	0.009	0.024	0.029	0	0.299
Family Cottidae						
Hemitripterus americanus	11	0.010	0.007	0	0.011	0
Myoxocephalus octodecemspinosus	17	0.009	0.003	0	0.044	0.023
Myoxocephalus scorpius	17	0.022	0	0	0.011	0
Family Pleuronectidae						
Limanda ferruginea	1	0.001	0	0	0	0
Pseudopleuronectes americanus	19	0.016	0	0	0.038	0.011
Total number collected	1291	1040	101	72	43	35
Species richness		18	9	4	11	6
Total hours net was fished		697	298	69	183	87
Total CPUE		1.488	0.345	1.043	0.235	0.427

Table 8. Percent of specimens of each species collected estimated to be sexually mature, based on the size at first spawning as reported in the literature.

Species	N (caught)	N (measured)	Percent mature	Reference
Raja erinacea	1	1	0.0	Scott and Scott (1988)
Raja ocellata	5	4	0.0	Scott and Scott (1988)
Raja radiata	8	3	100.0	Scott and Scott (1988)
Clupea harengus	69	67	100.0	Scott and Scott (1988)
Salmo salar	115	25	44.0	Scott and Scott (1988)
Salvelinus fontinalis	51	42	4.8	Scott and Scott (1988)
Mallotus villosus	1	1	0.0	Scott and Scott (1988)
Osmerus mordax	212	186	58.6	Scott and Scott (1988)
Gadus morhua	405	335	9.6	Collette and Klein-MacPhee
Gadus ogac	72	36	5.6	Scott and Scott (1988)
Merluccius bilinearis	1	1	0.0	Scott and Scott (1988)
Microgadus tomcod	1	1	100.0	Scott and Scott (1988)
Urophycis tenuis	14	8	12.5	Scott and Scott (1988)
Gasterosteus aculeatus	3515	766	99.6	Scott and Scott (1988)
Gasterosteus wheatlandi	1741	890	88.3	Williams and Delbeek (1989)
Apeltes quadracus	444	81	79.0	Scott and Scott (1988)
Tautogolabrus adspersus	2899	2265	61.3	Scott and Scott (1988)
Zoarces americanus	11	6	16.7	O'Brien *et al.* (1993)
Ulvaria subbifurcata	5	3	33.3	LeDrew and Green (1974)
Pholis gunnellus	66	53	86.8	Gunnarsson and Gunnarsson (2002)
Anarhichas lupus	2	2	100.0	Scott and Scott (1988)
Ammodytes americanus	13	11	63.6	Collette and Klein-MacPhee (2002)
Sebastes spp.	41	40	100	Scott and Scott (1988)
Hemitripterus americanus	15	9	88.9	Robins and Ray (1986)
Myoxocephalus aenaeus	11	6	100.0	Roseman *et al.* (2005)
M. octodecemspinosus	215	100	34.0	Scott and Scott (1988)
M. scorpius	240	126	3.2	Scott and Scott (1988)
Scophthalmus aquosus	4	3	66.7	Scott and Scott (1988)
Limanda ferruginea	20	5	20.0	Collette and Klein-MacPhee (2002)
Pseudopleuronectes americanus	1146	794	7.8	Scott and Scott (1988)

Table 9. Fish species observed by Hooper (1975) within Bonne Bay, but not collected by any of the four standard sampling methods used in this study.

Species	Common name	Location
Family Squalidae		
Squalus acanthias	spiny dogfish	
Family Anguillidae		
Anguilla rostrata	American eel	Site 1, 2, 3, 3A, 4, 4A
Family Gadidae		
Melanogrammus aeglefinus	haddock	
Pollachius virens	pollack	
Urophycis chuss	red hake	
Family Syngnathidae		
*Syngnathus fuscus**	northern pipefish	Site 3
Family Zoarcidae		
Lycodes lavalaei	Newfoundland eelpout	
Family Stichaeidae		
Lumpenus maculatus	daubed shanny	Site 1, 2
Stichaeus punctatus	Arctic shanny	
Family Scombridae		
Scomber scombrus	mackerel	Site 1
Thunnus thynnus	bluefin tuna	South arm of Bonne Bay
Family Anarhichadidae		
Anarhichas minor	spotted wolffish	Site 1, 2, 4
Family Xiphiidae		
Xiphias gladius	swordfish	
Family Cyclopteridae		
Cyclopterus lumpus	lumpfish	Site 1
\Liparis atlanticus	Atlantic snailfish	Site1, 2
Family Molidae		
Mola mola	ocean sunfish	

* Observed by J. Currie during August of 2008 using the 10 m beach seine

APPENDIX

Appendix Table 1. Macro biota present at Site 1, Gadds Harbour (Hooper, 1975; personal observations by J. Currie).

Present at site 1	Common name	Also present at sites
Species		
Phylum Phaeophyta	brown seaweeds	
Acrothrix novaeangliae	black whip weed	2,2A
Ascophyllum nodosum	knotted wrack	2,2A,4
Chorda filum	smooth cord weed	2,2A,3,4,4A
Fucus spiralis	rockweed (jelly bags)	
Halopteris scoparia	-	
Laminaria longicruris	hollow stemmed kelp	2,2A
Laminaria solidungula	-	
Papenfussiella collitricha	-	
Punctaria plantaginea	ribbon weed	2A,4
Saccorhiza dermatodea	-	
Sphaerotrichia divariata	slippery tangle weed	2
Phylum Chlorophyta	green seaweeds	
Enteromorpha intestinalis	hollow green weeds (gut weed)	2,3,3A,4
Ulva lactuca	sea lettuce	2A,4
Clodophera sericea	filamentous seaweeds	2,2A,3,4,4A
Clodophera rupestris	filamentous seaweeds	2,3,4
Phylum Rhodophyta	red seaweeds	
Ahnfeltia plicata	wire weed	2A,3,4,4A
Audouinella purpurea	-	2,2A,4
Callophyllis cristata	-	4
Chondrus crispus	Irish moss	2,2A,3,4,4A
Choreocolax polysiphoniae	-	
Harveyella mirabilis	-	
Leptophytum leave	-	
Lithothamnium glaciale	crustose algae	2A,3,4
Lithothamnium lemoineae	crustose algae	2A
Pantoneura baerii	-	
Phyllophora truncata	leaf weed	
Phymatolithon laevigatum	crustose algae	2,2A,4
Phymatolithon lenormandi	crustose algae	2,2A,4
Polyides rotundus	twig weed	
Polysiphonia nigrescens	tubed weed	2,2A,3,3A,4,4A
Polysiphonia nigra	tubed weed	
Rhodophyllis dichotoma	frayed weed	
Other biota		
Entophysalis spp.	-	
Spirulina subsalsa spp.	-	
Polymastia spp.	sponge	
Subertechinus spp.	sponge	
Ptychogastria spp.	hydrozoa	
Cnidaria	polyps and medusae	
Cerianthus spp.	sea anemone	2,2A
Stomphia spp.	Anthozoa	2
Mollusca	mollusks	
Littorina littorea	common periwinkle	2,2A
Mya arenaria	soft shelled clam	3,4A
Cystisella spp.	Bryozoa	

Appendix Table 2. Macro biota present at Site 2, Norris Cove (Hooper, 1975; personal observations by J. Currie).

Present at site 2	Common name	Also present at sites
Species		
Phylum Phaeophyta	brown seaweeds	
Acrothrix novaeangliae	black whip weed	1,2A
Ascophyllum nodosum	knotted wrack	1,2A,4
Chorda filum	smooth cord weed	1,2A,3,4,4A
Laminaria longicruris	hollow stemmed kelp	1,2A
Sphaerotrichia divaricata	slippery tangle weed	1
Phylum Rhodophyta	red seaweeds	
Audouinella purpurea	-	1,2A,4
Callithamnion corymbosun	tubed weed	5
Chondrus crispus	Irish moss	1,2A,3,4,4A
Dilsea integra	-	
Phymatolithon laevigatum	crustose algae	1,2A,4
Phymatolithon lenormandi	crustose algae	1,2A,4
Polysiphonia nigrescens	tubed weed	1,2A,3,3A,4,4A
Phylum Chlorophyta	green seaweeds	
Enteromorpha intestinalis	hollow green weeds (gut weed)	1,3,3A,4
Clodophera sericea	filamentous seaweeds	1,2A,3,4,4A
Clodophera rupestris	filamentous seaweeds	1,3,4
Cnidaria	polyps and medusae	
Cerianthus spp.	sea anemone	1,2A
Stomphia spp.	-	1
Mollusca	mollusks	
Littorina littorea	common periwinkle	1,2A

Appendix Table 3. Macro biota present at Site 2A, Lord and Lady Cove (Hooper, 1975; personal observations by J. Currie).

Present at site 2A	Common name	Also present at sites
Species		
Phylum Phaeophyta	brown seaweeds	
Laminaria longicruris	hollow stemmed kelp	1,2
Acrothrix novaeangliae	black whip weed	1,2
Ascophyllum nodosum	knotted wrack	1,2,4
Chorda filum	smooth cord weed	1,2,3,4,4A
Fucus vasiculosus	rockweed (bladder wrack)	3,4,4A
Punctaria plantaginea	ribbon weed	1,4
Phylum Chlorophyta	green seaweeds	
Ulva Lactuca	sea lettuce	1,4
Phylum Rhodophyta	red seaweeds	
Clodophera sericea	-	1,2,3,4,4A
Clodophera rupestris	-	1,2,3,4
Ahnfeltia plicata	wire weed	1,3,4,4A
Audouinella purpurea	-	1,2,4
Callithamnion corymbosun	tubed weed	2,4
Chondrus crispus	Irish moss	1,2,3,4,4A
Clathromorphum circumscriptum	-	3,4,4A
Dumontia incrassata	Dumont's red weed	3,4,4A
Lithothamnium glaciale	crustose algae	1,3,4
Lithothamnium lemoineae	crustose algae	1
Phymatolithon laevigatum	crustose algae	1,2,4
Phymatolithon lenormandi	crustose algae	1,2,4
Polysiphonia nigrescens	tubed weed	1,23,3A,4,4A
Other biota		
Cerianthus spp.	Anthozoa	1,2
Electra pilosa	Bryozoa	4
Mollusca	mollusks	
Littorina littorea	common periwinkle	1,2

Appendix Table 4. Macro biota present at Site 3, Deer Brook delta (Hooper, 1975; personal observations by J. Currie).

Present at site 3	Common name	Also present at sites
Phylum		
Species		
Phaeophyta	brown seaweeds	
Chorda filum	smooth cord weed	1,2,2A,4,4A
Fucus vesiculosus	rockweed (bladder wrack)	2A,4,4A
Ralfsia fungiformis	crustose algae (isogawara)	3A
Scytosiphon lomentaria	sausage weed	4
Rhodophyta	red seaweeds	
Ahnfeltia plicata	wire weed	1,2A,4,4A
Chondrus crispus	Irish moss	1,2,2A,4,4A
Clathromorphum circumscriptum	-	2A,4,4A
Dumontia incrassate	Dumont's red weed	2A,4,4A
Lithothamnium glaciale	crustose algae	1,2A,4
Polysiphonia nigrescens	tubed weed	1,2,2A,3A,4,4A
Rhodophysema georgii		4A
H. lejolisii	-	4A
Chlorophyta	green seaweeds	
Enteromorpha intestinalis	hollow green weeds (gut weed)	1,2,3A,4
Clodophera sericea	filamentous seaweed	1,2,2A,4,4A
Clodophera rupestris	filamentous seaweed	1,2,4
Cyanobacteria	blue-green algae	
Rivularia atra	blue-green algae	3A,4A
Spirulina subsalsa	blue-green algae	
Spermatophyta	seed plants	
Zostera marina	eelgrass	4A
Mollusca	mollusks	
Mya arenaria	soft shelled clam	1,4A

Appendix Table 5. Macro biota present at Site 3A, Deer Arm barachois (Hooper, 1975; personal observations by J. Currie).

Present at site 3A	Common name	Also present at sites
Species		
Phylum Phaeophyta	brown seaweeds	
Ralfsia fungiformis	crustose algae (isogawara)	3
Phylum Rhodophyta	red seaweeds	
Polysiphonia nigrescens	tubed weed	1,2,2A,3,4,4A
Phylum Chlorophyta	green seaweeds	
Enteromorpha intestinalis	hollow green weeds (gut weed)	1,2,3,4
Capsosiphon spp.	-	
Percursaria spp.	-	4A
Cyanobacteria	blue-green algae	
Rivularia atra	blue-green algae	3,4A
Annelida	segmented worms	
Arenicola spp.	lugworm	4

Appendix Table 6. Macro biota present at Site 4, Lomond Cove (Hooper, 1975; personal observations by J. Currie).

Present at site 4	Common name	Also present at sites
Species		
Phylum Phaeophyta	brown seaweeds	
Punctaria plantaginea	ribbon weed	1,2A
Scytosiphon lomentaria	sausage weed	3
Fucus vasiculosus	rockweed (bladder wrack)	2A,3,4A
Chorda filum	smooth cord weed	1,2,2A,3,4A
Phylum Chlorophyta	green seaweeds	
Ulva Lactuca	sea lettuce	1,2A
Enteromorpha intestinalis	hollow green weeds (gut weed)	1,2,3,3A
Clodophera sericea	filamentous seaweed	1,2,2A,3,4A
Clodophera rupestris	filamentous seaweed	1,2,3
Ascophyllum nodosum	knotted wrack	1,2,2A
Phylum Rhodophyta	red seaweeds	
Audouinella purpurea	-	1,2,2A
Ahnfeltia plicata	wire weed	1,2A,3,4A
Clathromorphum circumscriptum	-	2A,3,4A
Chondrus crispus	Irish moss	1,2,2A,3,4A
Callophyllis cristata	-	1
L. tophiforme	-	
Phymatolithon laevigatum	crustose algae	1,2,2A
Phymatolithon lenormandi	crustose algae	1,2,2A
Dumontia incrassate	Dumont's red weed	2A,3,4A
Callithamnion corymbosum	-	2,2A
Lithothamnium glaciale	crustose algae	1,2A,3
Polysiphonia nigrescens	tubed weed	1,2,2A,3,3A,4A
Other biota		
Electra pilosa	Bryozoa	2A

Appendix Table 7. Macro biota present at Site 4A, Lomond River delta (Hooper, 1975; personal observations by J. Currie).

Present at site 4A	Common name	Also present at sites
Species		
Phylum Phaeophyta	brown seaweeds	
Fucus vasiculosus	rockweed (bladder wrack)	2A,3,4
Chorda filum	smooth cord weed	1,2,2A,3,4
Phylum Chlorophyta	green seaweeds	
Percursaria	-	3A
Clodophera sericea	filamentous seaweed	1,2,2A,3,4
Phylum Rhodophyta	red seaweeds	
Ahnfeltia plicata	wire weed	1,2A,3,4
Clathromorphum circumscriptum	-	2A,3,4
Chondrus crispus	Irish moss	1,2,2A,3,4
Dumontia incrassate	Dumont's red weed	2A,3,4
H. lejolisii	-	3
Polysiphonia nigrescens	tubed weed	1,2,2A,3,3A,4
Rhodophysema georgii	-	3
Cyanobacteria	blue-green algae	
Rivularia atra	blue-green algae	3,3A
Other biota		
Salicornia spp.	-	
Spermatophyta	seed plants	
Zostera marina	eelgrass	3
Annelida	segmented worms	
Arinicola spp.	lugworm	3A
Mollusca	mollusks	
Mya arenaria	soft shelled clam	1,3