Community-University Research for Recovery Alliance (CURRA) Report

The Habitats of 0-group Juvenile Atlantic Cod in Bonne Bay, a Fjord within Gros Morne National Park, Newfoundland

by

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ABSTRACT

A standardized survey of Bonne Bay, a fjord located within Gros Morne National Park, Newfoundland, was conducted in the month of June during the years 2002 – 2009 and in October 2009 to determine the fish species found in the nearshore waters of the bay. The survey was conducted using a 10 m beach seine, a 25 m beach seine, gillnets, and a bottom trawl to sample a variety of depths. The data for young-of-the-year (0-group) juvenile Atlantic cod (*Gadus morhua*) were analyzed using the general linear model approach to determine the effect of study site and year on the number of 0-group cod collected per tow of the 25 m beach seine. This study found that there was no trend in juvenile cod abundance over time. Although the statistical relationship between site and abundance was close to significant, there was no overall trend in the number of juvenile cod collected at each site. This implies that all of the sampling sites are suitable habitat for juvenile cod. The sites differ in macrophyte vegetation (seaweed) coverage, bottom substrate type, water depth, seawater temperature, and salinity. It can be concluded that the nearshore waters of Bonne Bay serve as a nursery ground for juvenile cod. Given the economic and cultural importance of Atlantic cod, Bonne Bay is a focus of local fisheries stewardship and habitat conservation efforts.

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INTRODUCTION

Standardized sampling within Bonne Bay, a fjord located in Gros Morne National Park, Newfoundland, conducted during 2002 - 2009 found both juvenile and adult Atlantic cod (*Gadus morhua*) in the nearshore waters of the bay (Appendix Figure 4a). The year class size of a cod stock is determined early in life (Methven & Schneider, 1998). The size of a year class is based upon the survival of cod larvae in the plankton (Fraser *et al.,* 1996), as well as the survival of young cod after settlement (Gotceitas *et al.,* 1997). The survival of these young cod depends on two key factors: the availability of food and shelter (Fraser *et al.,* 1996). This study is concerned with determining the habitat of the juvenile cod living in Bonne Bay. Fish habitat has been defined in a variety of ways. According to Orth & White (1993),

> habitat for a fish is a place…in which a fish, a fish population or a fish assemblage can find the physical and chemical features needed for life, such as suitable water quality, migration routes, spawning grounds, feeding sites, resting sites, and shelter from enemies and adverse weather. Although food, predators, and competitors are not habitat, proper places in which to seek food, escape predators, and contend with competitors are part of habitat, and a suitable ecosystem for fish includes habitat for these other organisms, as well.

The Atlantic cod is only one of many commercially important fish species experiencing global decline (Myers & Worm, 2003). In 2003 the Laurentian North population of Atlantic cod was designated “threatened” by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2003). Although the population met the criterion for the “endangered” status, COSEWIC determined that the population showed the potential for recovery. For this recovery to occur, however, conservation measures must be put into place and adhered to. While reducing fishing mortality will benefit the cod stock (i.e, those fish that have reached harvest size), it will not help protect the juvenile portion of the population. Recent literature has shown that juvenile cod represent a significant contribution to growth in a stock, despite the fact that small fish experience higher natural mortality rates than large fish. One theory holds that survival in the first year of life will impact the strength of a year-class; juvenile cod must survive a period of heightened mortality due to depletion of the larval yolk and the onset of starvation (Methven & Schneider, 1998). However, it is important to note that, unless a cod can also survive its second and third years of life, it will not be recruited into the stock.

While the eggs and larvae of Atlantic cod are pelagic (living within the water column), the juveniles and adults are demersal (living on or near the bottom of the water column) (Fraser *et al.,* 1996). The young-of-the-year, or 0-group fish, settle out of the water column into a variety of different bottom habitats (Gotceitas *et al.,* 1997). The characteristic that these habitats share is structural complexity (Sheppard 2005). There are a number of benefits to living in a complex environment, including increased feeding opportunities, less exposure to harsh environmental conditions, and increased opportunity for predator avoidance. The opportunity for predator avoidance appears to be one of the most important characteristics of a complex habitat. Fraser *et al*. (1996) showed that in the absence of predators, juvenile cod choose simple substrates, while in the presence of predators, they choose more complex substrates. If a complex habitat is not available, juvenile cod may exhibit behavioural changes as an effort to ward off predators – for example, increased aggression (Sheppard 2005). Interestingly, because of the benefits listed above, complex habitats tend to attract a high density of predators as well as prey species; despite this, the predation rate remains lower in these habitats (Gorman *et al.,* 2009).

It is important to consider the features of a habitat that contribute to complexity. Convolutions can be created by a mixture of substrate types (for example, a combination of gravel, cobble, and boulders), or by the presence of macrophyte vegetation. Since the mid-nineties, the relationship between juvenile cod and eelgrass (*Zostera marina*) has been studied closely; prior to this, focus was placed upon the role of macroalgae in juvenile cod habitat (Gotceitas *et al.,* 1997). More recent studies conducted in Newfoundland and Labrador have shown an apparent relationship between juvenile cod and eelgrass, although their association with macroalgae and rocky habitat is also acknowledged (Hu 2007; Sheppard 2005). Eelgrass beds have been shown to be important nursery grounds for Atlantic cod, based upon lower predation rates and higher prey densities therein, as well as their location in sheltered areas with low turbidity (Fisheries and Oceans Canada 2009). It has been shown that young-of-the-year cod are particularly associated with eelgrass, while age 1+ juveniles are associated with habitats characterized by macroalgae and rocky substrate (Gotceitas *et al.,* 1997). The association with habitat was found to be weak at the scale of 20 m or less for all habitat types, increasing in strength at larger scales for tall eelgrass, but not for other habitats (Schneider *et al.*, 2008).

On the east coast of Newfoundland, juvenile cod are found most commonly at depths between 4 and 7 m (Methven & Schneider, 1998), with similar patterns reported in England, Wales, Norway, and Scotland. Like many demersal fish species, there is a positive size – depth relationship seen in Atlantic cod (Macpherson & Duarte, 1991), where fish tend to move into deeper water as they grow bigger. The predators, including adult cod, live in deeper water (Methven & Schneider, 1998). As cod (and other fish species) grow larger, they rely less upon their habitat to provide protection (Sheppard 2005). The size-depth relationship separates juveniles from adult individuals; however, both age 0+ juveniles and age 1 juveniles share shallow waters. Age 1 cod are competitors and predators of 0-group cod (Fraser *et al.,* 1997). These two age classes select for very similar habitats in terms of substrate composition. However, it has been shown that age 0+ cod will avoid a suitable habitat if it is already occupied by age 1 cod (Gotceitas *et al.,* 1997); this means that age 0+ cod have a more restricted range than their older conspecifics (Sheppard 2005).

The hypothesis to be tested is that 0-group cod are found in a range of different habitats in Bonne Bay, characterized by different substrates and vegetation types. The prediction is that 0-group cod will not associate with any particular type of vegetation or substrate, but will be present in complex habitats. Should the hypotheses be correct, then conservation efforts in Bonne Bay should include the nearshore zone generally, not be focused only on eelgrass habitat.

MATERIALS AND METHODS

Study Area

Bonne Bay is a double-armed fjord surrounded by Gros Morne National Park on the west coast of Newfoundland (Figure 1). The bay is located at approximately 49°50'N, 57°80’W. The East Arm of Bonne Bay is particularly notable due to the presence of a moraine-sill at its opening. The water above the sill, at approximately 14 m depth, is much shallower than the rest of the East Arm, which has a maximum depth of approximately 230 m (Richards and deYoung, 2004). The sill limits the amount of seawater that can enter the East arm from the Gulf of St. Lawrence.

Sampling Sites

Site 1, Gadds Harbour

The bottom substrate at this site (Figures 1 and 2) is made up of cobble and boulders. This area is semi-enclosed by cliffs and steep banks, and has freshwater input from a single brook. Rough periwinkles (*Littorina saxatilis*) and lichens are abundant at the high tide mark of this site. Various seaweeds, barnacles, smooth periwinkles (*Littorina obtusata*), and hydrozoan colonies can be found between the high and low tide marks. The seaweeds *Ulva lactuca* and *Polysiphonia* spp., as well as beds of blue mussels (*Mytilus edulis*), can be found just below the waterline. The presence of boulders at this site prevents sampling with the 25 m beach seine (Currie 2009).

Site 2, Norris Cove

The beach substrate at this site (Figures 1 and 2) consists of shale gravel. Cliffs surround the beach, which has a relatively steep slope that drops off with increasing distance from the shore. This site experiences freshwater input from an underwater spring. Seaweeds dominate the substrate near the high tide mark. Burrowing species of clams and sponges characterize the high tide fauna, while boring algae and polychaetes are common at the low tide mark (Currie 2009).

Site 2A, Lord and Lady Cove

The beach substrate at this site (Figures 1 and 3) is composed of cobble with some pebbles. The beach slopes steeply and drops off rapidly with increasing distance from the shore. The shallows are dominated by the kelp *Saccharina longicruris*, along with the seaweeds *Ceramium*, *Polysiphonia*, and *Cystoclonium* (Currie 2009).

Site 3, Deer Brook delta

The beach substrate at this site (Figures 1 and 3) consists of cobble and pebbles. This beach slopes gently, extending for several hundred metres, resulting in an area with low wave energy. The receptacles or reproductive bodies of several *Fucus* species are commonly found here. This site has a characteristic lower salinity as a result of its proximity to Deer Brook. There is little vegetation on the exposed shore, although endolithic algae can be found near the low tide mark. Extensive eelgrass beds are found near the river mouth. Both soft-shelled clams (*Mya*) and blue mussels (*Mytilus*) are found directly at the river mouth (Currie 2009).

Site 3A, Deer Arm barachois

The substrate at this site (Figure 1) is dominated by sand, silt, and clay, as a result of sedimentation from Deer Brook. The water here is predominantly fresh, but there is still some input of water from the bay. There is a transition from sandy sediment to cobble, pebbles, and boulders towards the outer perimeter of the barachois that coincides with the transition from stagnant to moving water. Several species of the green alga *Enteromorpha* are present at this site; crustaceans such as *Mysis gaspensis* are also endemic. Due to the shallowness of this site, sampling is conducted using the 10 m seine only (Currie 2009).

Site 4, Lomond Cove

The beach substrate at this site (Figures 1 and 4) is composed of cobble, pebbles, and scattered boulders. The beach has a shallow slope that extends approximately 100 m offshore, before becoming deeper. This site experiences freshwater input from both a small stream emptying directly onto the beach, as well as the Lomond River located nearby. As a result, the water at this site can be characterized as brackish. The nearshore is dominated by various kelps and seaweeds (Currie 2009).

Site 4A, Lomond River delta

The beach substrate at this site (Figures 1 and 4) consists of a mixture of pebbles, cobble, and sand. Further from shore, the substrate transitions to finer sediments such as silt and clay, creating an ideal habitat for eelgrass, of which there are large beds in this area. This site is very shallow, rarely exceeding a depth of one metre. The exception is the channel located in the middle of the delta, which is approximately five metres deep. Gillnets were not used at this site because it is too shallow for the gear to be properly deployed (Currie 2009).

Fish sampling procedure

Students enrolled in the field course Biology 3714 (Estuarine Fish Ecology) at Memorial University's Bonne Bay Marine Station made the June collections during 2002-2009. Arnault LeBris and Dr. David Methven conducted the sampling in October of 2009. A 10 m beach seine, 25 m beach seine, gillnets of various mesh sizes, and bottom trawl were used to collect fish in Bonne Bay. Fish caught by all sampling gears were identified to species and measured for standard length to the nearest millimeter. Any fish that could not be identified in the field were brought back to the Bonne Bay Marine Station for identification based on Scott and Scott (1988). Fish were removed from the sampling gear and placed in a bucket filled with seawater until they were identified and measured; they were then released alive. Depth, salinity, and water temperatures were also recorded at each sample site. All of the data collected for this study were obtained during the daylight hours (approximately 6 a.m. to 10 p.m.).

Equipment used to collect fishes

The 10 m beach seine had a panel net length of 10 m and a stretch mesh size of 10 mm. This net was deployed by two people walking parallel to the shore, with one person wearing chest waders in water < 1 m depth and the other person walking along the waterline. The distance between the start and the finish of the tow was paced off as 25 long strides, approximately 25 m. Multiple hauls done at each site were spaced out so the same area was not re-sampled; i.e., the start point of one tow was not within the 25 m sampled in any previous tows on that sampling day.

The 25 m beach seine had a panel net length of 25 m, with a stretch mesh of 10 mm in the wings and 5 mm in the cod end. This net was hauled perpendicular to the shoreline. The net was deployed out from the shore approximately 50 m using a boat. The end of the rope attached to one of the seine's bridles was held at shore at the start of the boat run. The rope attached to the other seine bridle was 16 paces away from the start point at the end of the boat run. The net was then hauled onto the shore along the bottom by pulling the two ropes. This seine sampled waters over a range of depths, from 1 m to 20 m (see Figures 2, 3 and 4). As with the 10 m seine, multiple hauls were spaced out to avoid sampling the same area more than once. The 25 m seine could not be used at Gadds Harbour due to the rough bottom.

Both single panel and multi-panel gillnets were set at various depths at each site, never exceeding 50 m. The single panel, twine gillnets had a stretch mesh size of three inches (78 mm). The three-panel, monofilament gillnets had stretch mesh sizes of one inch (26 mm), 1.5 inch (39 mm), and two inches (52 mm). The nets were always deployed in water at least 10 m shallower than the buoy line length; this was done to allow the gillnets to deploy without submerging the float at the end of the line. Gillnet sampling was typically done overnight, with the nets being deployed in the late afternoon or early evening and collected the following morning. Gillnets were not used at Site 3A or 4A due to the shallow depth of the water (< 1 m).

The bottom trawl was a 4.9 m semi-balloon style with a 5.1 m head rope and 6.4 m footrope. This trawl was made of nylon netting, with an overall stretched mesh of 38 mm and a 9 mm stretched mesh liner in the cod end. The trawl was used at Site 1 in 2002, and at Site 3 from 2003-2007; these two sites were the only sites with bottom suitable for trawling. Each tow was 10 minutes in duration.

Oceanographic data collection

Seawater salinity and temperature profiles, and bottom depth with distance from the shoreline were recorded for each site. The depth profile was obtained using a rope marked off in 1 m intervals and a Humminbird Piranha depth sounder. The boat traveled out perpendicular to the shore; at each 10 m interval, a depth sounding was taken. At 100 m from shore, the temperature/conductivity probe on a cabled YSI handheld meter was lowered to the bottom. The cable of the YSI handheld meter was marked at 1 m intervals. Salinity and temperature readings were taken at 10 m intervals from the sea bottom until the sensor was raised to 10 m depth, after which readings were taken every meter up to the surface.

Statistical analysis of juvenile cod abundance data

The subset of data pertaining to Atlantic cod was the focus of this study. Length was used as the criterion to estimate the age of each individual cod collected. The lengths for each age class were based upon those used in previous studies conducted on juvenile cod in Newfoundland (Methven & Schneider, 1998). Young-of-the-year, or 0-group cod, were those measuring 96 mm or less in standard length (SL), while age 1 cod were those measuring between 97 – 192 mm SL (Methven & Schneider, 1998). The 25 m beach seine was the gear type catching 0-group cod most often. Because of this, the data used for statistical analysis are from the collections made using the 25 m seine only.

The effect of location (Site 2, 2A, 3, 4, or 4A) and the effect of year (2002 through 2009) on the number of 0-group cod caught in each tow were analyzed using a two-way Analysis of Variance (ANOVA) with the general linear model (GLM) approach (Schneider 2009). The statistical computations were untaken with the computer software Minitab 15. The first model constructed incorporates sample site and year of collection as explanatory variables, with the number of juveniles collected per tow as the response variable. It also takes into account possible interactions between the explanatory variables. The first formal model tested was:

$$N = \beta_O + \beta_S S + \beta_Y Y + \beta_{SY} S \bullet Y + E$$

where N is the number of 0-group cod collected per tow, S represents the sample site, Y represents the year of collection, and E represents the residual error. In this case, the year variable was considered categorical; whereby each year is considered a separate category (just as each site represents a category). Setting year as a categorical variable allows testing for habitat effects controlled for year. As we are most interested in the effect of site on abundance, we are controlling for the effect of the year. The interaction term tests whether habitat effects depend on year.

The second formal model tested was:

$$N = \beta_O + \beta_S S + \beta_Y Y + E$$

where each symbol is the same as defined above. This model also tests the effect of site on abundance while controlling for the year effect; the interaction term has been eliminated in this model.

A third model was run to test for temporal trends:

$$N = \beta_O + \beta_S S + \beta_Y Y + \beta_{SY} S \bullet Y + E$$

where each of the symbols is defined the same as above, but year is a continuous variable instead of a categorical variable. This means that the entire sampling period (2002-2009) was considered as whole, rather than each year being considered separately. This model controls for year as a trend, rather than within years.

For all models, the residuals were examined for normality, independence, and homogeneity (Sokal & Rohlf 1995) to determine if the data set met the assumptions made when using the GLM. Because the assumptions were not met for these tests, if a p-value close to 5% was obtained, a randomization procedure was used to calculate a more statistically accurate p-value by randomizing the F-ratio 1000 times. The F-ratio is the ratio of variances; specifically, it is equal to the variance of the model divided by the variance of the residuals (Sokal & Rohlf 1995). The new p-value was computed by determining the proportion of F-ratios that were greater than or equal to the original observed F-ratio. The criterion for significance (alpha value) for this ANOVA test was set at 0.05; alpha represents the probability of Type I error that the study will tolerate (Peterman 1989).

RESULTS

Analysis of the 0-group cod data set using the first formal model was not possible. There was an uneven number of tows at each site in each year (Tables 1 and 2), with no data at some sites in some years; this creates empty cells in the Minitab spreadsheet. The second model, using the same explanatory variables but without an interaction term, was then successfully tested using a two-way ANOVA. The effect of year on the catch per tow was found to be insignificant ($F_{7,82} = 1.40$, $p = 0.217$, Table 3). The effect of site on the catch per tow was found to be close to the critical value of 5% ($F_{4,82} = 2.44$, $p = 0.053$, Table 3), so a randomization test was run for this model because the assumption of homogeneous error was strongly violated. The results of this randomization show that, of 1000 randomized F values, 851 of them were greater than or equal to the original F value (2.44). As such, the newly calculated p-value was approximately 0.851, which indicates that the effect of site on the abundance of juvenile cod per tow is insignificant. The third model shows that there are no significant overall trends in either site ($F_{4,84} = 1.58$, $p = 0.188$, Table 4) or year ($F_{1,84} = 0.53$, $p = 0.467$, Table 4).

DISCUSSION

The results of this study show no significant trend in the abundance of juvenile 0-group cod in the East Arm of Bonne Bay over the years 2002-2009. That is to say, the abundance from year to year has neither increased nor decreased. The observed fluctuations in the abundance of juveniles over time might reflect a proportional fluctuation in the abundance of spawning cod, either in Bonne Bay or in the northern Gulf of St. Lawrence. Had there been a decline or increase in the abundance of spawning adult cod, we likely would have seen that trend reflected in the abundance of 0-group cod collected in Bonne Bay. The observed lack of trend is encouraging because it suggests that the biomass of the spawning cod has been relatively stable over the eight years. It is important to note, however, that the standing stock biomass of cod in the northern Gulf of St. Lawrence is significantly reduced from the historical abundance and has yet to show any signs of recovery (Dutil & Brander, 2003; DFO, 2010).

Although the initial p-value obtained suggested that the effect of sampling site on the abundance of cod per tow might be significant, further analysis by way of a randomization test, free of the statistical assumptions, showed that the relationship between site and abundance was not significant. This means that there was no single site (and therefore no one particular habitat) that supported a significantly greater abundance of 0-group cod. As predicted, 0-group cod in the East Arm of Bonne Bay are associated with a variety of habitat types. Currie (2009) characterized each sampling site used in this study. It is known that all of the sites have vegetation and substrate that create some degree of complexity. Our results show that 0-group cod can live in very different habitats in Bonne Bay. Juvenile cod can use a multitude of cover types as protection from predators. For example, juvenile cod found at Norris Cove can hide amongst gravel and seaweeds, while those found at Deer Brook delta may use eelgrass as their primary source of cover. The sites also differ in terms of salinity and depth, indicating that juvenile cod can live within a range of nearshore depths, temperatures, and salinities. As data collection continues, more tows per sample site may reveal that 0-group cod are especially abundant at sites with particular salinity and temperature range, a particular bottom substrate type, or a particular type of macrophyte vegetation, such as eelgrass.

Bonne Bay as a nursery ground for juvenile cod

Although the focus of this study was the 0-group cod in Bonne Bay, the data set as a whole revealed an interesting distribution of the lengths of fishes inhabiting Bonne Bay (Appendix). Juvenile cod were chosen for this study based on the importance of their survival, and therefore recruitment, to the commercial cod stock. As one can see in Appendix Fig. 4a, the 0-group cod represent the most abundant age class of Atlantic cod collected in Bonne Bay. In comparing the length distribution of Atlantic cod to those for other species collected in the bay, we can see that the Atlantic cod does not exhibit the continuous distribution of lengths that characterizes a bay-resident species. Rather, the distribution of Atlantic cod in Bonne Bay clusters around juvenile age classes, particularly the 0-group and the age 3 group. This suggests that the East Arm serves as a nursery ground for juvenile cod; the bay does not appear to support an abundance of large, adult cod. If Bonne Bay is, in fact, a nursery ground for Atlantic cod, then local stewardship efforts to protect the cod in the bay should be focused on preserving the habitats used by the juveniles. The juvenile cod found in Bonne Bay may be the progeny of adult cod spawning in the Gulf of St. Lawrence, and it is likely to the Gulf that the juvenile cod will migrate when they reach a certain size (ICES 2005).

The length distributions of species presented in the Appendix suggest that the fish species found in Bonne Bay occupy a variety of ecological guilds (Wroblewski *et al.,* 2007). Winter flounder (*Pseudopleuronectes americanus*) (Appendix Fig. 7c), for example, is likely a resident species in Bonne Bay. In Newfoundland waters, winter flounder spawn in the spring. Metamorphosis and the associated settlement begin five or six weeks after hatching. At the time of settlement from the plankton, juvenile winter flounder are typically between 9-13 mm in standard length (Pereira *et al.,* 1999). Spawning is thought to begin between the ages of six and seven, when a standard length of 250 mm (for females) and 210 mm (for males) has been reached (Kennedy & Steele, 1971). Appendix Fig. 7c shows that winter flounder as small as 20 mm SL, representing the post-settlement young-of-the-year, and as large as 280 mm SL, representing fully mature adults, were collected.

In comparison, female Atlantic cod in the Northern Gulf of St. Lawrence begin to spawn at a mean standard length of 470 mm, although this length at maturity has fluctuated over the past two decades (Fréchet *et al.*, 2003). Although Appendix Fig. 4a shows individuals of this size, indicating the presence of young adult fish in Bonne Bay, there were few individuals larger than 470 mm SL collected. Large adult cod are rarely caught in this summertime survey. Fréchet *et al.* (2003) report that Atlantic cod in the Gulf reach an average length of 340 mm by age 3, 420 mm by age 4, 500 mm by age 5, 540 mm by age 6, and 640 mm by age 10. Based on these values, one can see that 3-year-old cod represent an abundant age class in the East Arm of Bonne Bay, while the subsequent age classes become less and less abundant. It is unknown, however, whether these 3-year-old cod are the progeny of local spawning in the East Arm, or whether they are migrating into Bonne Bay from the Gulf to feed in the summer.

Limitations of the study

The standardized sampling of Bonne Bay is ongoing, with new data being added every year. These surveys are conducted not only to gather information on the fish fauna of Bonne Bay, but also to allow university students the opportunity to learn sampling techniques and learn how to identify fish species. As such, the nature of the survey has varied from year to year; i.e., the number of tows conducted at each site and the sites sampled has not been consistent through time. As the data set grows, there will be opportunity for further research on cod in Bonne Bay. The results presented here show that the relationship between site and abundance of 0-group cod was not significant. With further sampling it is possible that the power to detect change may increase, resulting in a significant relation. However, the large variance in the data, which can also be expected to increase with more sampling, may well cancel out any gains in power due to increased sample size. Because the association of juvenile cod with habitat is generally weak at scales of less than 20 m (Schneider *et al.,* 2008), we expect that further sampling will not produce a strong association unless the area sampled is increased at each site. The results of this study suggest that a range of habitat types suitable for juvenile cod should be protected; further research may show that protection should be focused on several particularly suitable habitats.

This study incorporated a temporal element by comparing the abundance of 0-group cod collected in each sampling year. Another opportunity for temporal study would be comparing the abundance of 0-group cod at each site from season to season. For the first time in 2009, the sites were sampled with the 25 m seine in both the summer and the autumn. If the autumn survey were to continue (and if a winter and/or spring survey were to be initiated), then season could be introduced into the models analyzed in this study as an additional explanatory variable. This variable could reveal information about the movement of 0-group cod during the first year of their life; one may find, for example, that one particular habitat is the most populated during the summer, while a completely different habitat supports the highest abundances in the winter. Results such as these would require a careful characterization of the vegetation and substrate at each site in an effort to determine what makes that habitat more beneficial for juvenile cod at a particular time of year.

Further temporal study should include both daytime and nighttime surveys. The juvenile cod data considered here were collected in the daytime; however, other studies have shown that juvenile cod are more active at night, when it is safer to move into shallower, inshore waters to feed (Methven & Bajdik, 1994; Gregory *et al.,* 1997). If time of day were to be incorporated into a statistical model as an explanatory variable, then one must become concerned with details such as the distance from shore and the depth at which the fish were collected.

This study could be expanded further still by incorporating multiple age classes of cod. In this study, the focus was on the 0-group cod. This was because few age-1 cod have been collected over the years. As more data are collected, there may be adequate information about age-1 (or age-2, or age-3) cod to include them in analysis. A significant effect of age on juvenile cod abundance at a given site would imply that, as expected, there is change in the habitat use as cod become larger and begin undertaking extensive seasonal movements.

SUMMARY

Using data obtained from standardized sampling surveys of the fish fauna of Bonne Bay conducted during 2002-2009, this study found no statistically significant relationship between the year of collection and the abundance of young-of-the-year (0-group) juvenile Atlantic cod. Nor was there a statistically significant relationship between the sampling site location and the abundance of 0-group juvenile cod. The study was limited by a data set where the sites were sampled inconsistently and the number of samples per site varied each year. Thus the data set does not give a complete assessment of the abundance of 0-group cod at each of the sampling locations over time. However, based on the available data, one can conclude that 0-group juvenile cod are not abundant at any one particular site in Bonne Bay, but rather are found at all sites sampled. These results imply that juvenile cod occupy a range of habitats in Bonne Bay, i.e. nearshore waters with different seaweeds, bottom substrate type, bottom depth and ranges of seawater salinity and temperature. The nearshore waters of Bonne Bay serve as a nursery ground for juvenile cod. Therefore, the entire shoreline of Bonne Bay should be protected from human-induced disturbance and pollution, rather than concentrating conservation efforts on a single marine habitat type (for example, eelgrass beds) known to support juvenile cod.

The length distribution of Atlantic cod collected during the surveys also indicates that the Atlantic cod species (*Gadus morhua*) use Bonne Bay as a nursery ground, with the young-of-the-year (0-group) being the most abundant age class. Although the length distribution of Atlantic cod collected in Bonne Bay does not resemble that of a bay-resident species (e.g. winter flounder, *Pseudopleuronectes americanus*), one cannot

dismiss the possibility that Bonne Bay has a bay cod stock, similar to the bay cod stocks in Trinity Bay, Placentia Bay and Gilbert Bay (Wroblewski *et al.,* 2005; 2007). This study has provided only a first look at the distribution and abundance of Atlantic cod within the East Arm of Bonne Bay. As the yearly fish fauna survey of Bonne Bay continues, there will be opportunity to continue this research using an expanded data set, allowing the incorporation of additional spatial and temporal variables into the analysis of cod abundance and habitat use.

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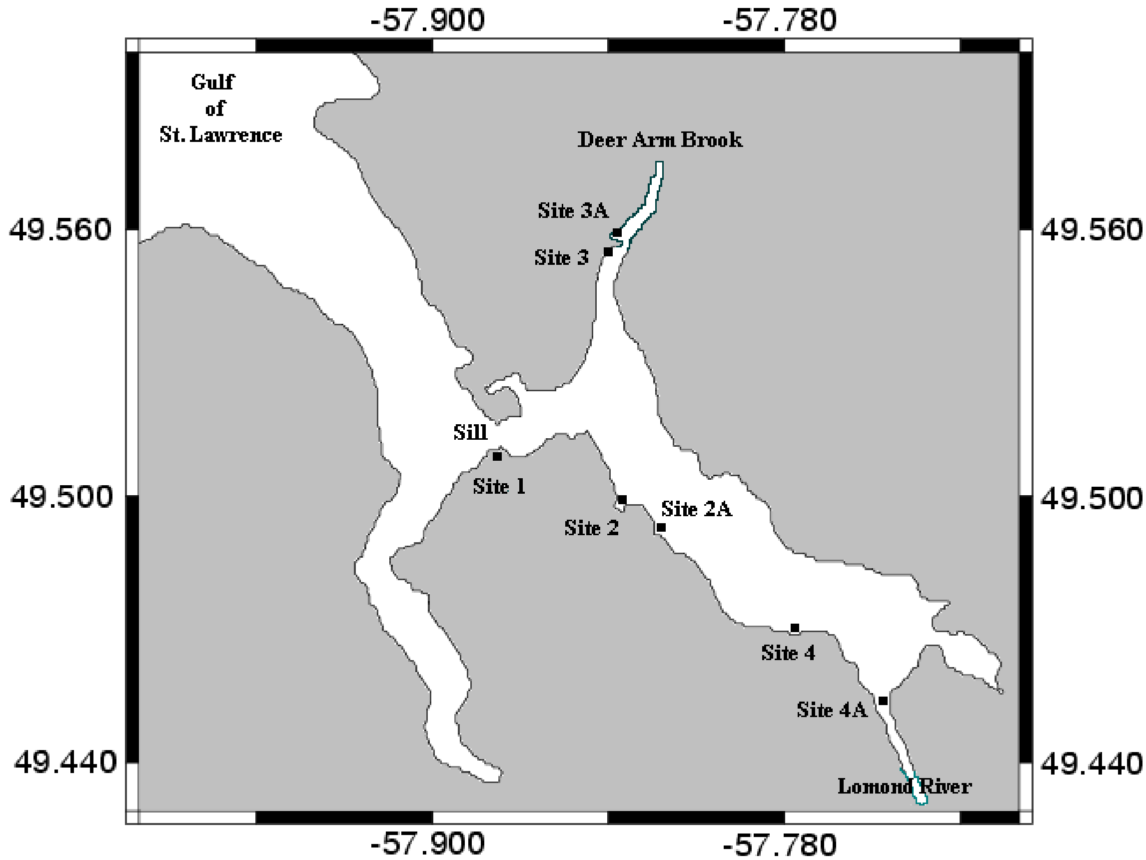
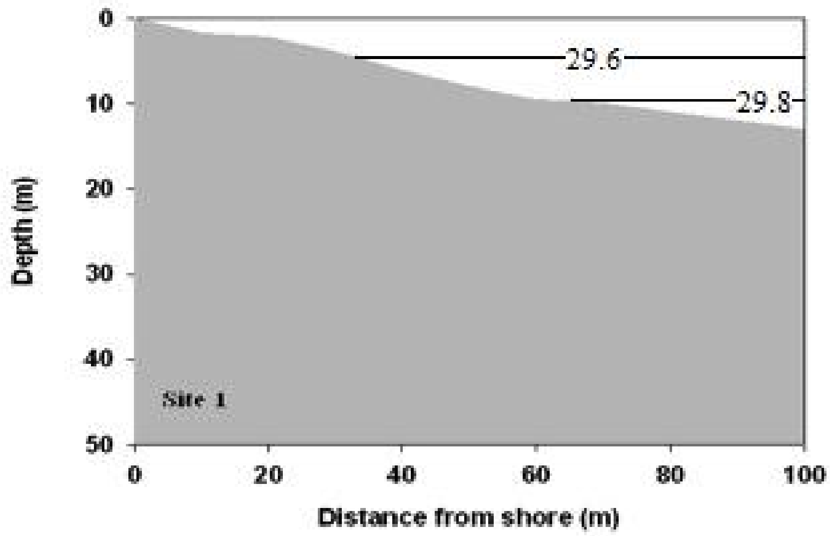


Figure 1. Map of Bonne Bay, Newfoundland, showing locations of sampling sites 1, 2, 2A, 3, 3A, 4, and 4A. Site 1 is Gadds Harbour; Site 2 is Norris Cove; Site 2A is Lord and Lady Cove; Site 3 is Deer Brook delta; Site 3A is Deer Arm barachois; Site 4 is Lomond Cove; and Site 4A is Lomond River delta.



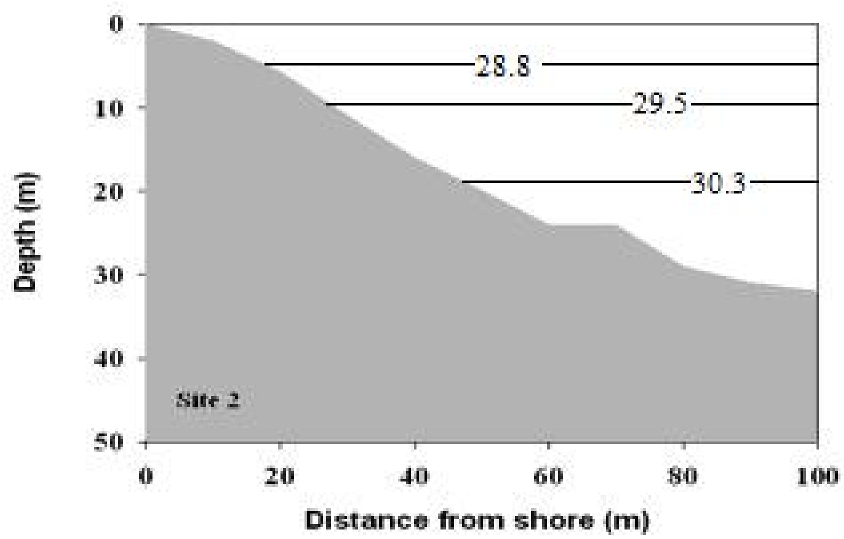
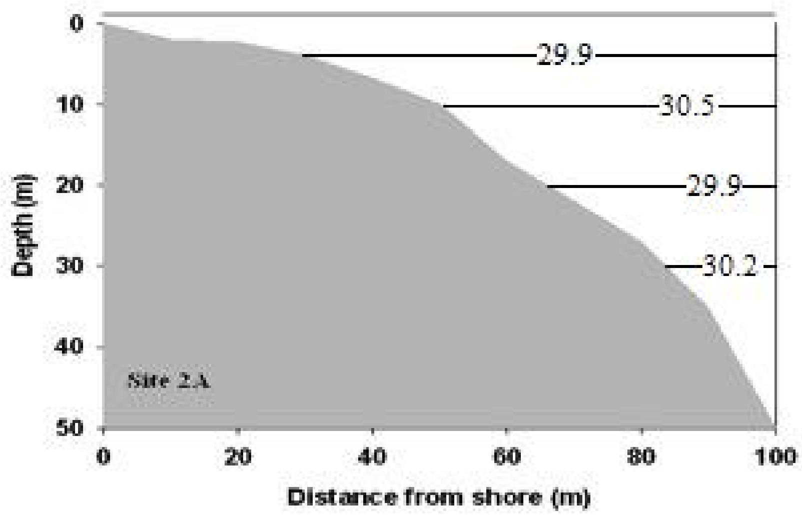


Figure 2. Depth (m) and salinity (parts per thousand or ppt) profiles of Site 1 (Gadds Harbour) and Site 2 (Norris Cove). Gadds Harbour water temperature was 16.5 °C at the surface, 7.5 °C at 10 m. Norris Cove water temperature was 16.4 °C at the surface, 7.7 °C at 10 m, and 5.0 °C at 20 m. Depth, temperature, and salinity data were collected on June 25, 2009.



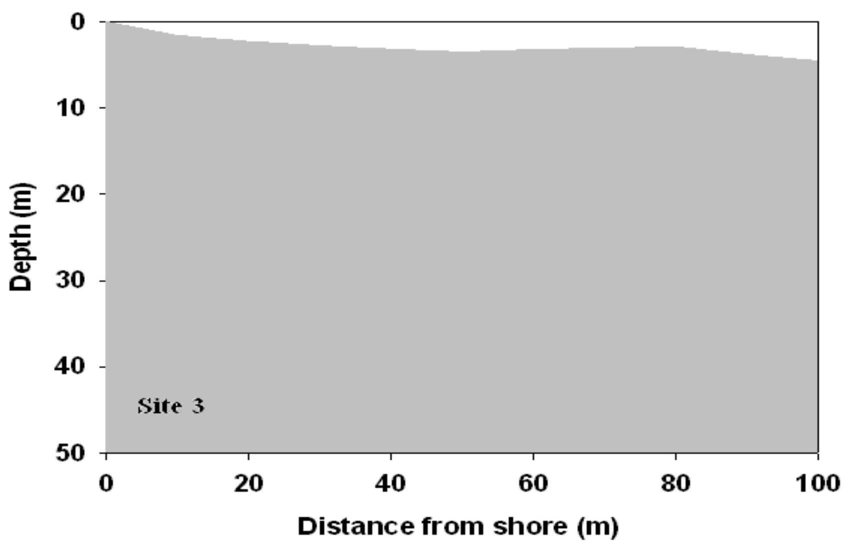
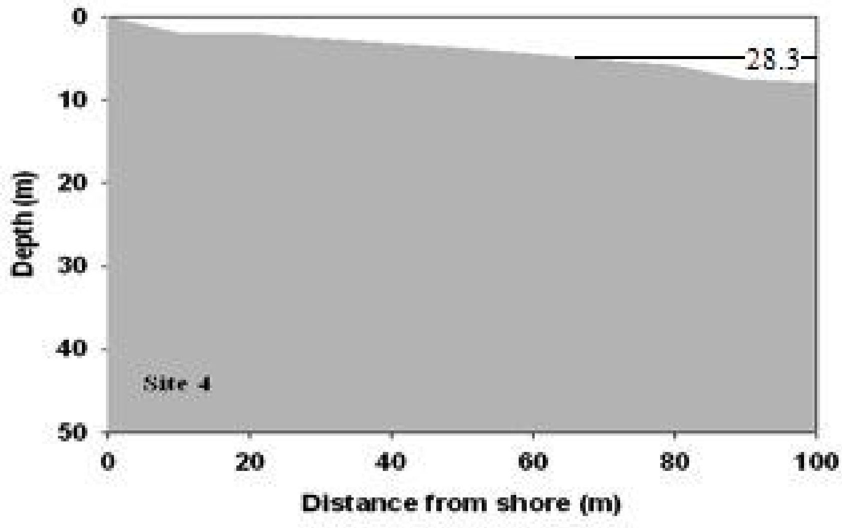


Figure 3. Depth (m) and salinity (ppt) profiles for Site 2A (Lord and Lady Cove) and Site 3 (Deer Brook delta). Lord and Lady Cove water temperature was 11.7 °C at the surface, 7.8 °C at 10 m, and 5.4 °C at 20 m. Deer Brook delta water temperature was 15.0 °C at the surface, 10.1 °C at 5 m. Deer Brook delta salinity at 5 m was 28.4 ppt (not depicted). Depth, temperature, and salinity data collected on June 25 (Deer Brook delta) and June 30 (Lord and Lady Cove) in 2009.



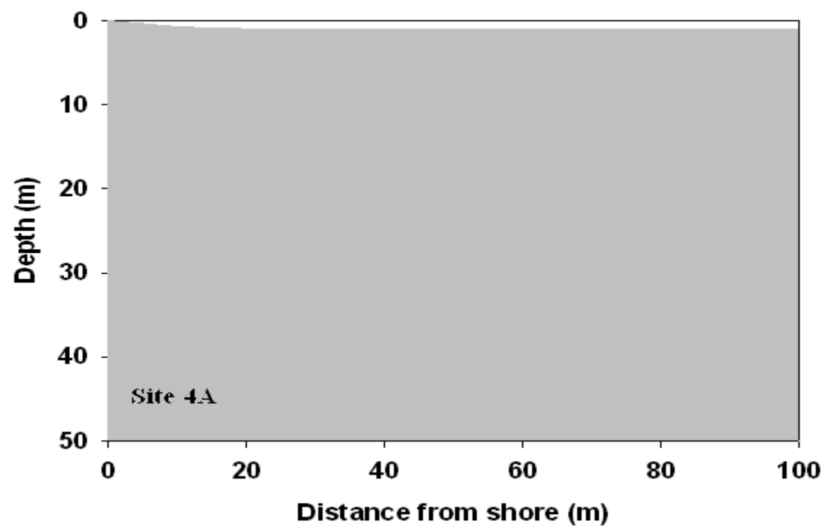


Figure 4. Depth (m) and salinity (ppt) profiles for Site 4 (Lomond Cove) and Site 4A (Lomond River delta). Lomond Cove water temperature was 13.8 °C at the surface, 9.4 °C at 5 m. Lomond River delta water temperature was 13.8 °C at the surface. Lomond River delta salinity at 0.8 m was 26.7 ppt (not depicted). Depth, temperature, and salinity data were collected on June 29, 2009.

Table 1. Frequency of sampling carried out within Bonne Bay from 2002 to 2009 for the seven sites using the 25 m beach seine.

Number of sampling sets using the 25 m beach seine at each site									
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**Summer 2009**	**Fall 2009**
Site 1									
Site 2		4	4	8	20	4	4	5	6
Site 2A							3	3	6
Site 3	4	1	2	5	3	3	4	5	6
Site 3A									
Site 4						2	2	4	6
Site 4A						2	2	1	

Table 2. Number of 0-group Atlantic cod caught in tows of the 25 m beach seine at sites over time. 0-group cod are those that measure ≤ 96 mm standard length.

Year	Site	Tow #	# 0-group cod
2002	3	1	2
		2	0
		3	2
		4	3
2003	3	1	0
	2	1	0
		2	0
		3	0
		4	0
2004	3	1	0
		2	0
	2	1	1
		2	0
		3	0
		4	0
2005	3	1	0
		2	0
		3	0
		4	0
		5	2
	2	1	0
		2	0
		3	0
		4	1
		5	0
		6	0
		7	1
		8	2
2006	3	1	0
		2	0
		3	2
	2	1	0
		2	0
		3	0
		4	1
		5	2
		6	0
		7	1
		8	0
		9	0
		10	0
		11	0
		12	1
		13	0
		14	0
		15	0

Table 2. continued

Year	Site	Tow #	# 0-group cod
		16	9
		17	1
		18	2
		19	0
		20	0
2007	3	1	0
		2	0
		3	3
	2	1	2
		2	13
		3	0
		4	0
	4	1	5
		2	3
	4A	1	0
		2	0
2008	3	1	0
		2	1
		3	6
		4	0
	2	1	0
		2	5
		3	3
		4	14
	4	1	0

Year	Site	Tow #	# 0-group cod
		2	64
		3	19
	4A	1	0
	2A	1	8
		2	0
		3	0
2009	3	1	0
		2	0
		3	1
		4	0
		5	0
	2	1	1
		2	0
		3	1
		4	8
		5	32
	4	1	0
		2	0
		3	0
		4	0
	4A	1	0
	2A	1	1
		2	0
		3	0

Table 2. continued

Year	Site	Tow #	# 0-group cod
Oct. 2009	3	1	0
		2	0
		3	0
		4	0
		5	0
		6	0
	2	1	1
		2	0
		3	0
		4	1
		5	0
		6	3

Year	Site	Tow #	# 0-group cod
	4	1	0
		2	3
		3	0
		4	0
		5	0
		6	0
	2A	1	2
		2	1
		3	2
		4	0
		5	0
		6	1

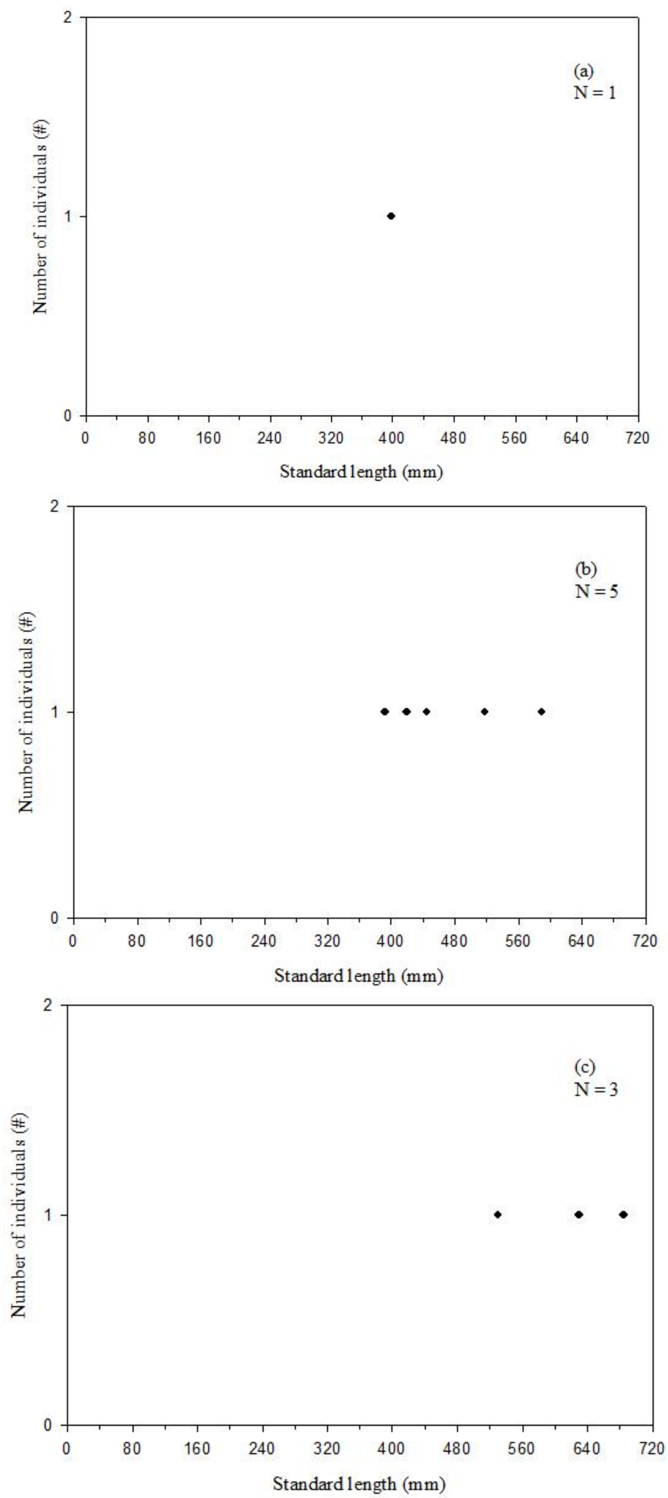
Table 3. Probability values for N (the number of 0-group cod per tow) using a two-way ANOVA with site (categorical) and year (categorical) as factors within the general linear model.

Source	DF	Seq SS	Adj SS	Adj MS	F	p
Site	4	635.57	538.99	134.75	2.44	0.053
Year	7	539.56	539.56	77.08	1.40	0.217
Error	82	4520.57	4520.57	55.13		
Total	93	5695.70				

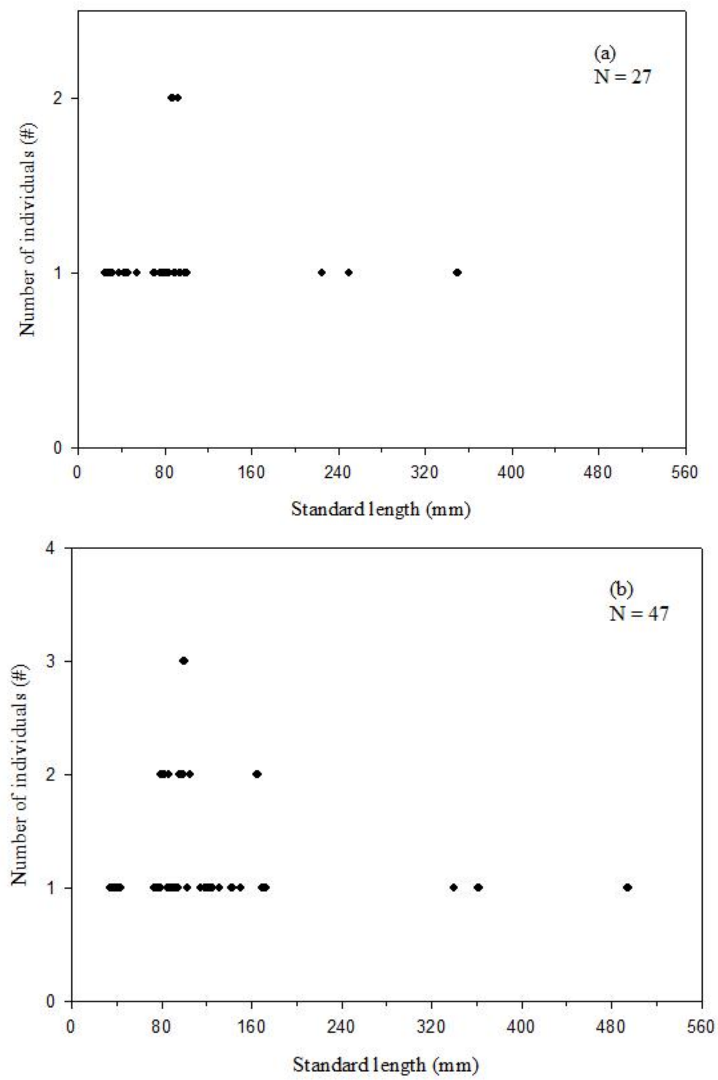
Table 4. Probability values for N using a two-way ANOVA with site (categorical), year (continuous), and an interaction term as factors within the general linear model.

Source	DF	Seq SS	Adj SS	Adj MS	F	p
Site	4	635.57	348.47	87.12	1.58	0.188
Year	1	71.83	29.43	29.43	0.53	0.467
Site*Year	4	348.37	348.37	87.09	1.58	0.188
Error	84	4639.93	4639.93	55.24		
Total	93	5695.70				

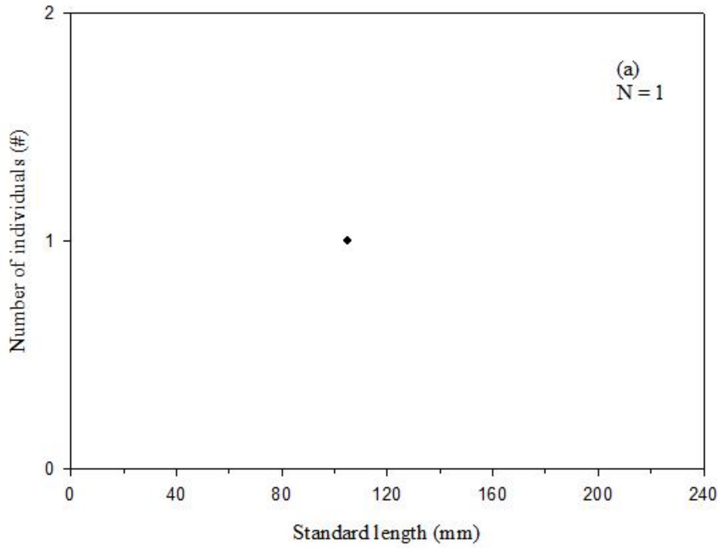
APPENDIX

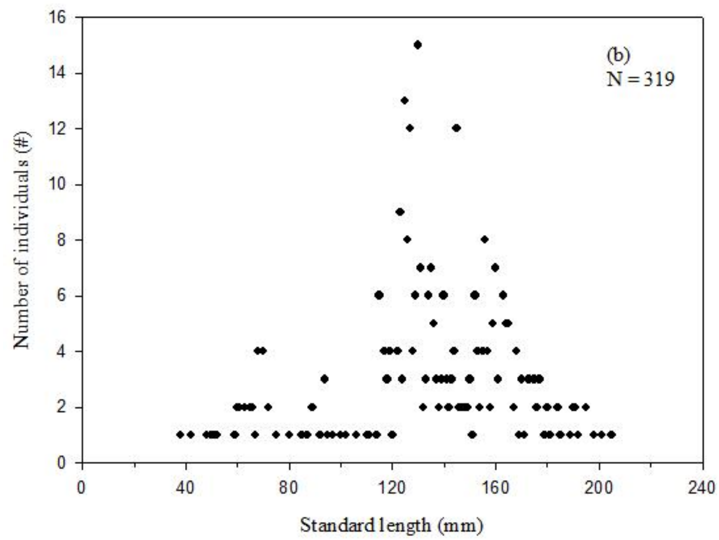


Appendix Fig 1. Length distributions of members of the family Rajidae collected in Bonne Bay between 2002 and 2009 using all gear types. N = total number of individuals collected and measured. (a) *Raja erinacea*, little skate; (b) *R. ocellata*, winter skate; (c) *R. radiata*, thorny skate.

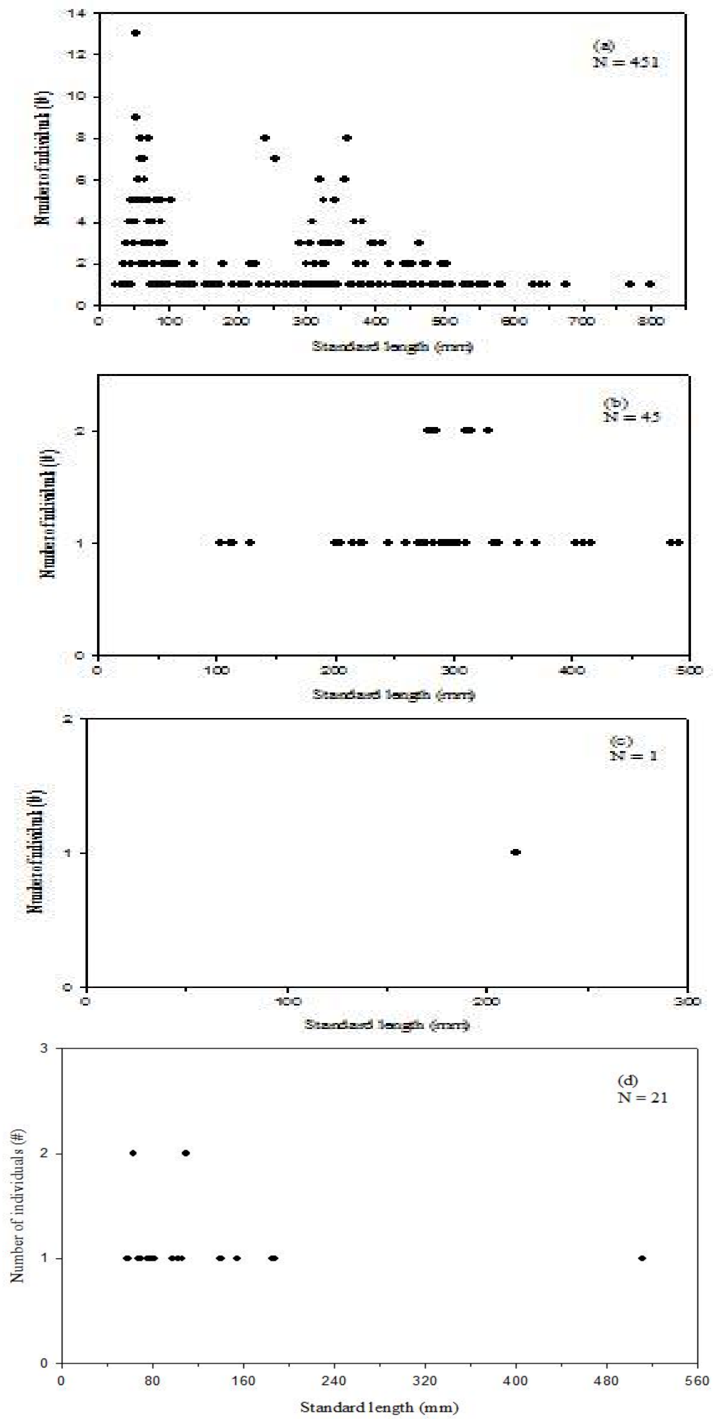


Appendix Fig 2. Length distributions of members of the family Salmonidae collected in Bonne Bay between 2002 and 2009 using all gear types. N = total number of individuals collected and measured. (a) *Salmo salar*, Atlantic salmon; (b) *Salvelinus fontinalis*, brook trout.

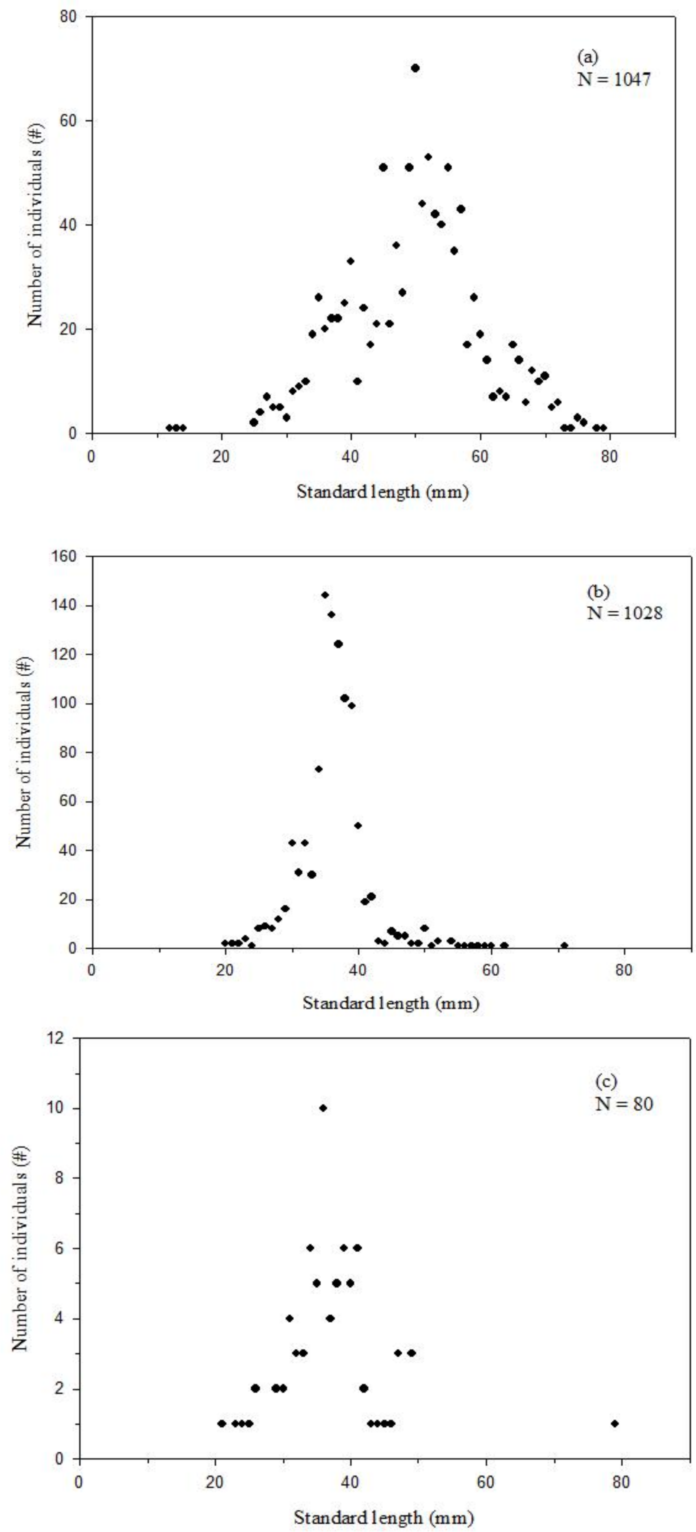




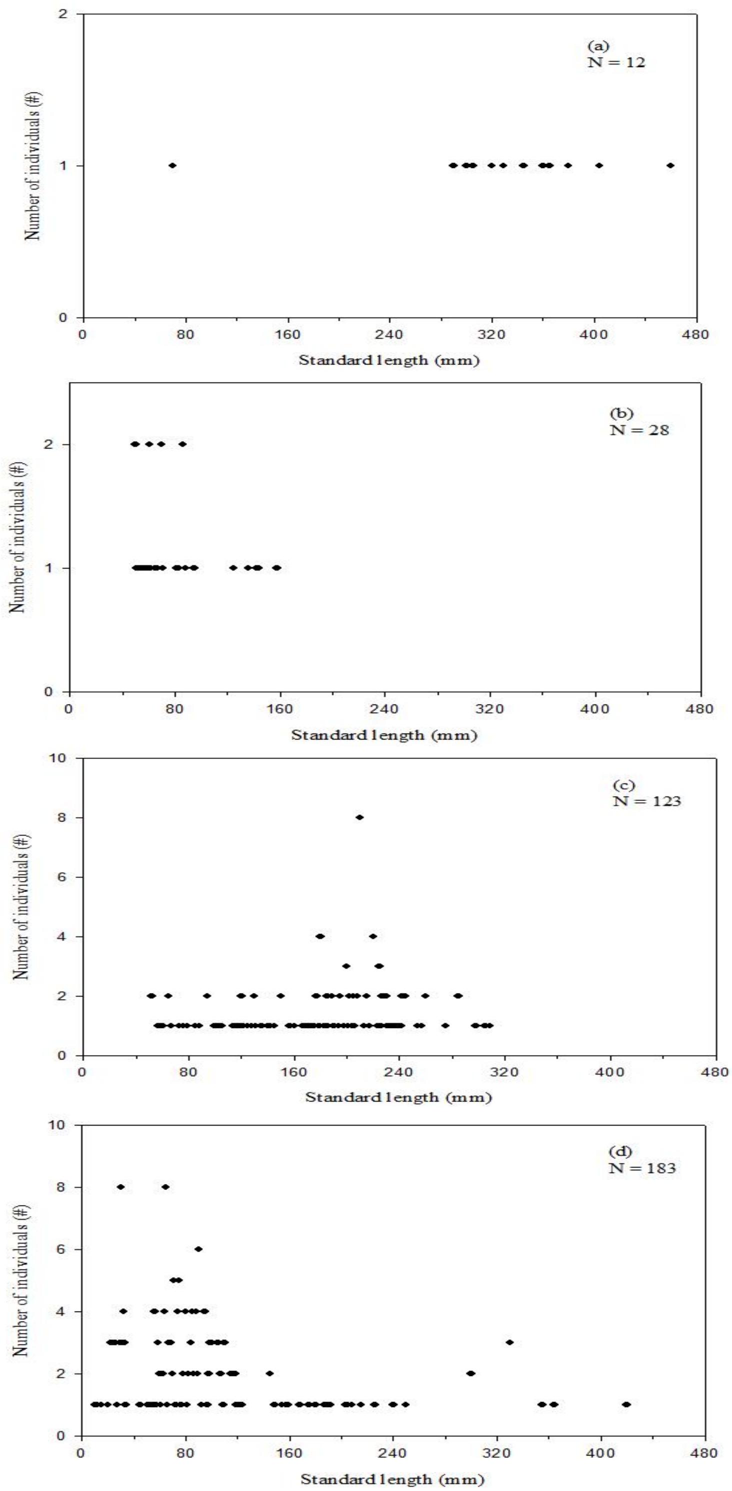
Appendix Fig 3. Length distributions of members of the family Osmeridae collected in Bonne Bay between 2002 and 2009 using all gear types. N = total number of individuals collected and measured. (a) *Mallotus villosus*, capelin; (b) *Osmerus mordax*, rainbow smelt.



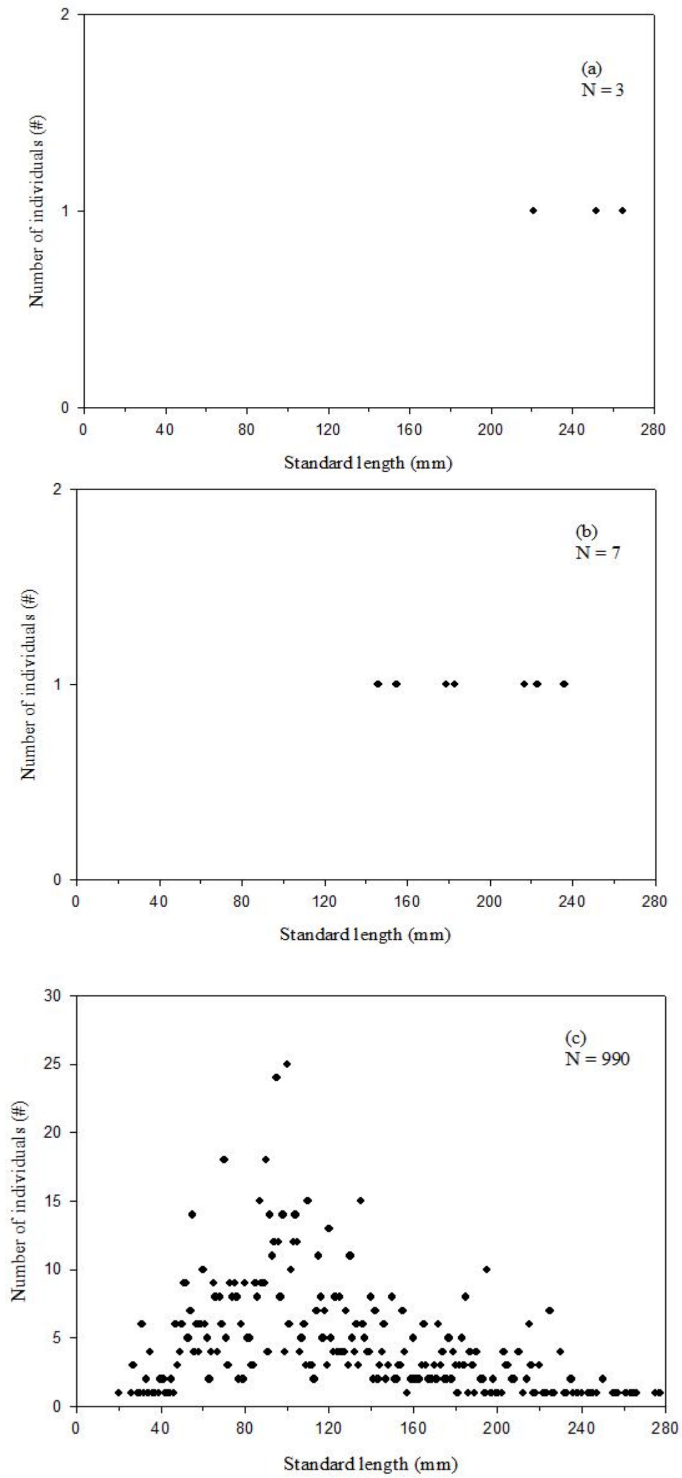
Appendix Fig 4. Length distributions of members of the family Gadidae collected in Bonne Bay between 2002 and 2009 using all gear types. N = total number of individuals collected and measured. (a) *Gadus morhua*, Atlantic cod; (b) *G. ogac*, Greenland cod; (c) *Merluccius bilinearis*, silver hake; (d) *Urophycis tenuis*, white hake.



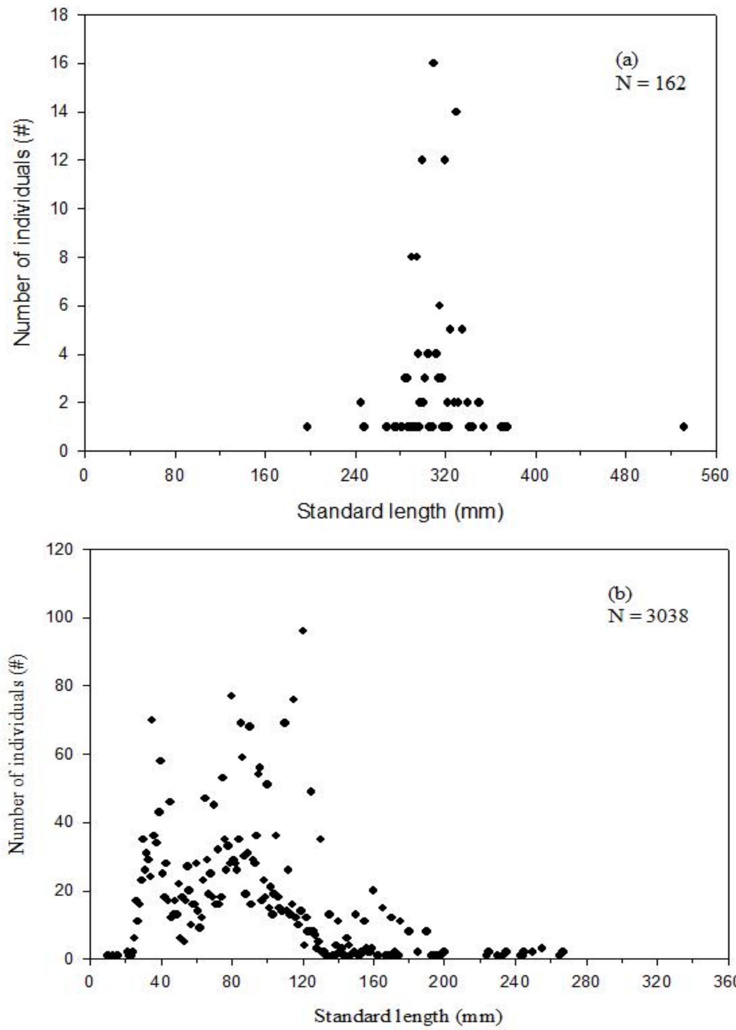
Appendix Fig 5. Length distributions of members of the family Gasterosteidae collected in Bonne Bay between 2002 and 2009 using all gear types. N = total number of individuals collected and measured. (a) *Gasterosteus aculeatus*, threespine stickleback; (b) *G. wheatlandi*, blackspotted stickleback; (c) *Apeltes quadracus*, fourspine stickleback.



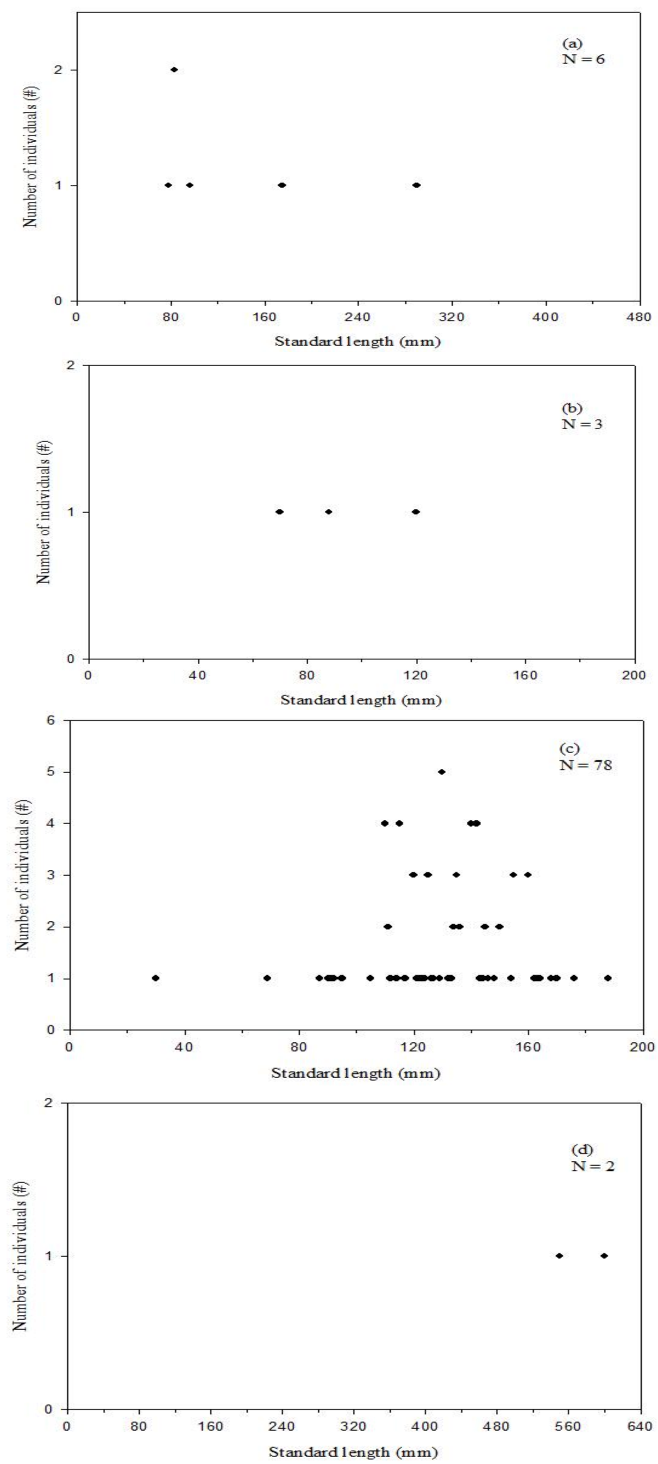
Appendix Fig 6. Length distributions of members of the family Cottidae collected in Bonne Bay between 2002 and 2009 using all gear types. N = total number of individuals collected and measured. (a) *Hemitripterus americanus*, sea raven; (b) *Myoxocephalus aenaeus*, grubby sculpin; (c) *M. octodecemspinosus*, longhorn sculpin; (d) *M. scorpius*, shorthorn sculpin.



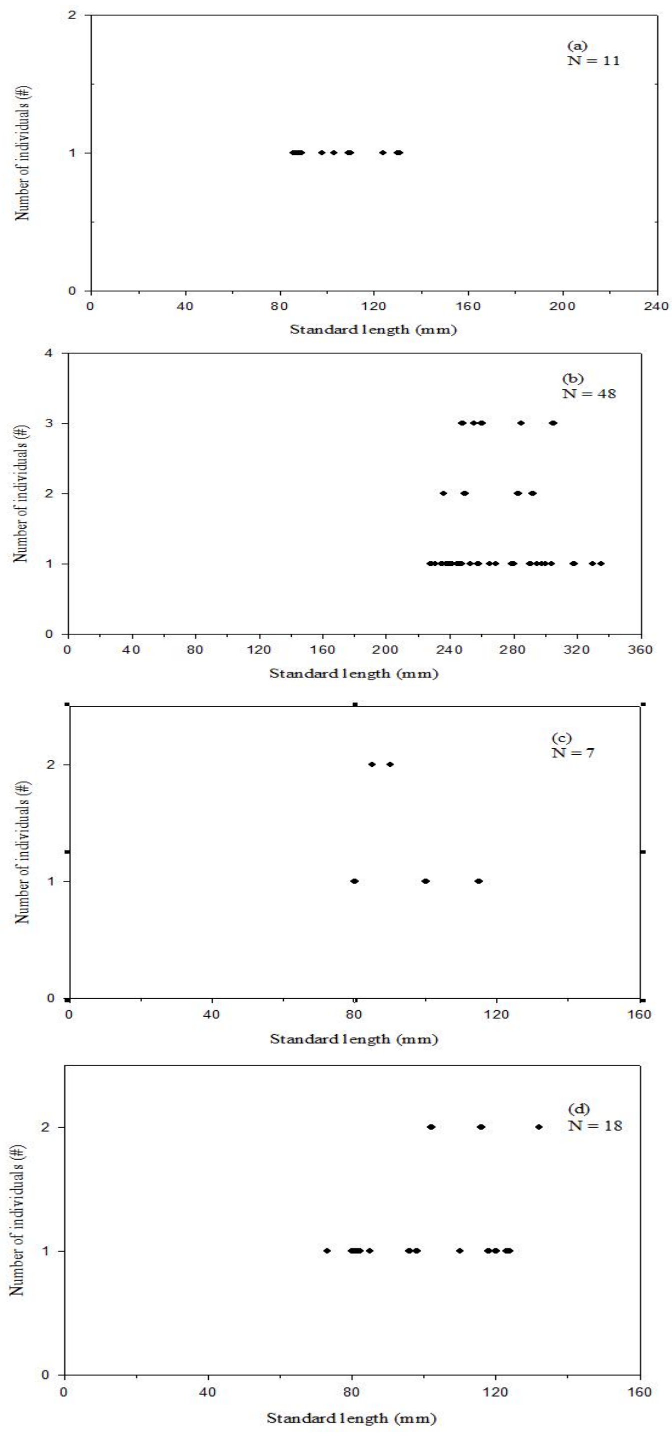
Appendix Fig 7. Length distributions of members of the families Bothidae and Pleuronectidae collected in Bonne Bay between 2002 and 2009 using all gear types. N = total number of individuals collected and measured. (a) *Scopthalmus aquosus*, windowpane flounder (family Bothidae); (b) *Limanda ferruginea*, yellowtail flounder (family Pleuronectidae); (c) *Pseudopleuronectes americanus*, winter flounder (family Pleuronectidae).



Appendix Fig 8. Length distributions of members of the families Clupeidae and Labridae collected in Bonne Bay between 2002 and 2009 using all gear types. N = total number of individuals collected and measured. (a) *Clupea harengus*, Atlantic herring (family Clupeidae); (b) *Tautogolabrus adspersus*, cunner (family Labridae).



Appendix Fig 9. Length distributions of members of the families Zoarcidae, Stichaeidae, Pholidae, and Anarhichadidae collected in Bonne Bay between 2002 and 2009 using all gear types. N = total number of individuals collected and measured. (a) *Zoarces americanus*, ocean pout (family Zoarcidae); (b) *Ulvaria subbifurcata*, radiated shanny (family Stichaeidae); (c) *Pholis gunnellus*, rock gunnel (family Pholidae); (d) *Anarhichas lupus*, striped wolfish (family Anarhichadidae).



Appendix Fig 10. Length distributions of members of the families Ammodytidae, Scorpaenidae, Agonidae, and Syngnathidae collected in Bonne Bay between 2002 and 2009 using all gear types. N = total number of individuals collected and measured. (a) *Ammodytes americanus*, American sandlance (family Ammodytidae); (b) *Sebastes spp*., redfish (family Scorpaenidae); (c) *Aspidophoroides monopterygius*, alligator fish (family Agonidae); (d) *Syngnathus fuscus*, Northern pipefish (family Syngnathidae).