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**Demersal Juvenile Atlantic Cod (*Gadus morhua*) Survey of the Northeast Coast of
Newfoundland: 2020 Fleming Survey**

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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TABLE OF CONTENTS

ABSTRACT	iv
1. INTRODUCTION	1
2. METHODS	2
2.1. GEAR	2
2.2. SAMPLING.....	2
2.3. LOCATIONS.....	3
2.4. TIMELINE.....	3
2.5. ANALYSIS.....	4
3. RESULTS	4
3.1. SITE VISITS	4
3.2. HABITAT	4
3.3. CATCH.....	4
3.3.1. Species	4
3.3.2. Juvenile Atlantic Cod.....	4
4. DISCUSSION.....	6
5. SUMMARY.....	6
6. ACKNOWLEDGEMENTS	7
7. REFERENCES CITED.....	8
8. APPENDIX I - TABLES.....	10
9. APPENDIX II - FIGURES.....	16
10. APPENDIX III - GENERAL SITE SUMMARIES.....	22

ABSTRACT

A survey of demersal juvenile Atlantic cod (*Gadus morhua*) was conducted along the Northeast Coast of Newfoundland in nearshore waters (<10 m deep) from 1959–64 by Government of Canada Departments (now represented by the Department of Fisheries and Oceans [DFO]). This survey (which became known as the Fleming survey, after originator Alistair Fleming) aimed to characterize the distribution and abundance of juvenile Atlantic cod and was based upon Norway's Flødevigen sampling program which has been conducted continuously since 1919. A 25 m seine was used to sample juvenile Atlantic cod nursery locations on the Avalon Peninsula and Northeast Coast of Newfoundland in September and October. The survey was discontinued in 1964 but was reinstated by Memorial University of Newfoundland from 1992–97. Multiple tows were conducted at a subset of the original 55 Fleming sites located in St. Mary's Bay, Trepassey Bay, the Southern Shore, Conception Bay, Trinity Bay, Bonavista Bay, Gander Bay, New World Island, Fortune Harbour, Badger Bay, Halls Bay and Green Bay. A full version of the survey (40 sites) was executed in 2001 and select sites were surveyed in 2017 and 2018.

The Fleming survey program was reestablished by DFO in 2020. A total of 42 of the modern subset of 45 sites were visited resulting in 40 sites being sampled successfully in 2020. Direct comparison of Atlantic cod catch (count, lengths and rate) is possible across the time series because of consistency with survey methods. The primary objective was to collect data to determine abundance of age 0-, 1-, and 2- group cod to compare with previous surveys and reestablish a network of inshore harvesters (active and retired) to participate in the survey.

A total of 665 juvenile cod (615 0-group; 47 1-group, 3 2-group) were collected at 40 sites between St. Mary's Bay and western Notre Dame Bay. The catch of 0-group cod dominates the overall catch (mean=15.38 cod/tow). In general, the mean juvenile cod catch for each group is similar to the mean catches from the 1990s and latter part of the 1959–64 time series. During the 2020 survey, only one tow was made per site to measure juvenile cod density due to logistical constraints. In earlier Fleming survey programs, multiple tows were conducted (minimum two) at a survey site in an attempt to develop a density index. In 2020, the average catch rate for 0-, 1-, and 2-groups was 15.38, 1.18, and 0.08 cod per haul respectively. These rates are generally consistent with the average cod per tow (first tow only) reported from the Fleming survey in the post collapse era (1992–97, and 2001): 13.35, 5.90, and 0.56 cod per tow for 0-, 1- and 2- groups. Densities of juvenile cod have not recovered since the stock collapse in the early-1990s, despite some improvements in adult population size.

1. INTRODUCTION

Long-term monitoring of juvenile fish in demersal habitats has revealed that both physical and biological processes can regulate populations of Atlantic cod (Fromentin et al. 2001). Mortality in juvenile cod is density dependent (Sundby et al. 1989, Bjørnstad et al. 1999) and mortality rates of ages 0 to 3 fish may be high enough to modify year-class strength (Fromentin et al. 2001). Therefore, a recruitment signal may be expected to be observed most frequently when later versus earlier pre-recruit stages are monitored. Along the coast of Newfoundland, monitoring of demersal juveniles of the Northern cod stock has detected a recruitment signal (Schneider et al. 1997b). However, the signal was weak, detected best on a rank scale in a coast-wide study (Ings et al. 1997) and only observed between age 0 cod inshore and age three fish of the same cohort offshore when a smaller coastal area was sampled (Lunzmann-Cooke et al. 2021). Long-term monitoring of multiple pre-recruit age classes may be required to more fully understand the recruitment dynamics of Northern cod.

In the late-1950s, a survey program was developed with the Department of Fisheries (now DFO) to further the understanding of the distribution and abundance of juvenile Atlantic cod. This survey is based on the Norwegian Flødevigen sampling program (1919–present), which employed beach seines for survey water depths approximately 3–10 m during September to October along the Norwegian coastline (Tveite 1971). Analyses of data from this time-series showed that both density dependent and stochastic processes are important in regulating juvenile cod populations (Fromentin et al. 2001).

From 1959–64 a survey was conducted regularly from the R/V Parr along the coast of eastern Newfoundland from St. Mary's Bay to western Notre Dame Bay during September and October. Multiple tows of a beach seine deployed from a small dory were conducted at a set of approximately 55 beaches located in St. Mary's Bay, Trepassey Bay, the Southern Shore, Conception Bay, Trinity Bay, Bonavista Bay, Gander Bay, New World Island, Fortune Harbour, Badger Bay, Halls Bay and Green Bay. The original intent of this survey work was to generate indices of the abundance of juvenile cod for these inshore area (Lear et al. 1980).

The survey was reestablished in the 1990s with the main proponent being Ocean Sciences Centre (Memorial University of Newfoundland). The rationale for reinstating the survey was based on new oceanographic modeling at the time that supported the hypothesis that eggs and larvae produced offshore could be transported to coastal areas. Significant efforts were made to ensure the consistency of data collected from the earlier survey campaigns with the data collected from 1992–97. This was achieved by personnel from the original campaign observing the survey methods employed at the start of the 1992 survey effort (Schneider et al. 1997a). In 1996 and again in 1997, inshore harvesters with an interest in juvenile cod were identified and invited to participate with the Fleming survey. There is a major emphasis on monitoring the abundance of juvenile Atlantic cod identifiable length groups (corresponding to ages 0+, 1+ and age 2+). The survey was conducted in 2001 and a small subset of Fleming sites were surveyed in 2017 and 2018 (Gregory et al. in prep¹).

¹ Gregory, R.S, Geissinger, E., Newton, B., Lancaster, D., and MacRobert, E. in prep. Strength of three cohorts (2018-20) of Atlantic cod, from nearshore surveys of demersal age 0 and 1 juveniles in Newman Sound, Bonavista Bay relative to the 2J3KL stock. DFO Can. Sci. Advis. Sec. Res. Doc.

As with previous versions of the survey, particular effort was directed toward ensuring the 2020 survey was consistent with historical surveys. This included consistency with gear specifications; deployment methods; site location; and time of sampling.

The minor differences between the original Fleming Survey in 1959 and the recent campaigns relate more to modernization and updated technology than changes in methods and procedure:

- A motorized vessel was used in the 1990s compared to a rowboat in the 1960s;
- Oak sticks that were used as spreaders for the original seine were replaced with aluminum rods; and
- Nylon mesh replaced the cotton mesh of the 50s and 60s.

The overall goal of this project is to provide a better understanding of the recruitment dynamics of Northern cod by reinstating a survey of juvenile cod abundance along the Northeast Coast of Newfoundland. This paper describes the spatial and temporal details of the Fleming survey including general details from previous Fleming surveys. The catch and mean catch per tow for 2020 are analyzed and compared with previous data.

2. METHODS

2.1. GEAR

A small bar seine with weighted footrope was used to collect demersal juvenile Atlantic cod. The dimensions of the seine used in the 2020 Fleming survey are consistent throughout the Fleming program. The headrope is 24.4 m and the footrope is 26.2 m. The nylon netting consists of 19 mm mesh in the wings and belly and the 9 mm mesh in the codend. In the 1990s, a 12.7 mm stretch mesh was used in the codend and lined with a knotless nylon 9 mm stretch mesh. The footrope is weighted and the headrope has floats to keep separation between headrope and footrope. An aluminum bar is attached to the outer edge of each wing of the seine to act as a spreader and keep the seine open (i.e. separation between headrope and footrope). The seine is connected to two warp lines (~55 m) for pulling the seine toward the shore. Increments of approximately 10 m each are marked on each warp to use as an aid during the pulling process and ensure that each warp is being pulled towards the shore at the same rate.

2.2. SAMPLING

A typical deployment involved landing one individual on the beach to layout the survey area. The survey area is demarcated by the two individuals placing two markers 16 m apart, along the beach. Two plastic fish boxes, filled with seawater, were staged in the centre of the survey area. One individual is stationed with a warp line at one of the survey markers, then the other individual with the seine backs away from shore in a small motorized boat to a distance of about 55 m. Then the seine is deployed along a parallel track to the survey area (~25 m). After the seine is completely submerged, then the boat cuts back toward the shore, heading directly for the other marker. The individual in the boat jumps ashore with the other end of the warp line. Both individuals then begin to tow the seine ashore while pulling at an equal, constant and slow rate to herd any fish toward the shore and into the codend. Further details can be found in Lear et al. (1980) including images of the seine and diagram of the seine towing process.

Once the seine is landed, then the catch is deposited into one of the fish boxes. The catch is identified to species and measured (standard length) before being released at the site of capture. Once the catch is completely sampled, i.e. the collection fish box is empty, then the sampled fish box is filled with water, carried several metres out into the water and allowed to

sink so that the catch is safely returned to its habitat. Sampling is not limited to specific time of day or tide level. The former protocol was to execute two sets at precisely the same location and then conduct a third set immediately adjacent to that location. Due to time and logistical constraints, one tow was conducted per site in 2020. One tow is sufficient to determine a measure of density; the seine is a highly efficient and few fish escape catch (Schneider et al. 1997b).

2.3. LOCATIONS

The geographic extent of the Fleming survey spans approximately 1,500 kms (as measured with 5 km increments) (Schneider et al. 1997b). The 2020 Fleming survey of demersal juvenile cod was conducted at a subset of 40 out of a possible 45 locations around the Avalon Peninsula and Northeast Coast of the Island of Newfoundland. The list of 45 locations was carried forward from the recent survey efforts in 1997 and 2001 (Table 7.1).

The list of all sites surveyed is in Table 7.2. In general, a core subset of survey sites persists through the years, although some historical sites were bypassed in various years due to logistics, weather, and sea conditions that made beach access and/or seining impractical or hazardous. Other sites, in the vicinity of Terra Nova Nation Park, were subsumed into a comprehensive beach seine survey program monitoring juvenile cod and cod nursery habitat in that general area (Gregory et al. 2004).

2.4. TIMELINE

The 2020 survey commenced in St. Mary's Bay and proceeded in a generally counterclockwise direction around the Northeast Coast of Newfoundland. It was conducted between September 30th and October 29th, a period when juvenile cod abundance in nearshore waters was known to be high seasonally and annual recruitment of length group 0 cod was well underway. It started at the two sites on Grand Colinet Island in St. Mary's Bay and concluded in Middle Arm (Green Bay) in the western extent of Notre Dame Bay. The historical survey dates for the survey are in Table 7.3. They are grouped by general area:

- **St. Mary's Bay (SMB):** Harricot Beach, Half Island, Mother Hicks Cove, Mosquito Cove, North Harbour (bottom) and Trepassey;
- **Conception Bay (CB):** Davies Head (North; South), Crockers Cove, Bryants Cove and Bristols Hope Cove;
- **Trinity Bay (TB):** Masters Head, Little Mosquito Cove, Bald Point Beach, Long Beach (East; West), Middle Lance Cove, Burgoynes Cove, Lockston's Arm and Cap Cove;
- **Bonavista Bay (BB):** Cannings Cove, Man Point and Indian Bay;
- **Notre Dame Bay (NDB):** Rubens Cove, Grassy Island, Seal Island, Fox Island, Bridgeport, Luke's Arm, Fortune Harbour (NW, bottom; Fox Cove 1; Fox Cove 2; SW bottom; SE bottom), Wild Bight, Julies Harbour, Tommy's Arm, Woodfords Arm (outcrops; middle; bottom), Lower Wolfe Cove, Green Island, Halls Bay, Beachy Cove, Shimmey Cove, Little Bay Arm and Middle Arm (Green Bay).

Table 7.4 provides a timeline for 2020 iteration of the Fleming survey in greater detail. The sites are listed on the date they are surveyed and in the order that they were surveyed. Strong winds delayed the start of the survey by approximately a week and delayed the start of the Conception Bay subset of sites. Challenges sourcing local fisher support in Cannings Cove resulted in Indian Bay being surveyed before the two other Bonavista Bay sites (Man Point and Cannings

Cove). This minor variation in site order and timing is not expected to affect the interpretation of results.

2.5. ANALYSIS

Juvenile cod were assigned to age groups based on visual examination of the length frequency distribution (length modes) consistent with previous survey procedures and the observed growth conditions for the previous two years in the Terra Nova Juvenile Cod Survey program (Gregory et al. in prep¹). The annual mean number of fish caught per haul across all sites and for each age group is used to generate a time series for comparison across Fleming survey years. Prior to 2020, these annual means were based on the first haul or the average of the first two hauls. Only one haul per site was conducted in 2020 for time series comparison purposes. The 95% confidence interval for the annual mean catch per haul was computed using randomized resampling ($r=5000$) with replacement (Manly 2006).

3. RESULTS

3.1. SITE VISITS

During the 2020 survey a total of 42 sites were visited and 40 of these were successfully sampled. Figure 8.1 shows the number of sites visited each active year of the Fleming survey program since its inception. The average number of sites included in the Fleming time series each survey year since 1959 is 35.2 sites. However, if the number of sites surveyed for the first two years, 1959 and 1960, are disregarded as start-up years then the number of sites surveyed in 2020 is consistent with the historical average number of sites visited since 1961 (39.2 sites).

3.2. HABITAT

Habitat was assessed during each site survey. Habitats were classified using a visual survey of the seabed along a transect from the beach through the site to the extent of the area sampled by the seine. The length of the survey transects varied because in some instances, the seabed dropped off dramatically and it was no longer possible to observe the seabed type. Two general groups of seabed type were used for the classification: sediment and vegetation. The description of the habitat for each site is listed in Figure 9.1 Appendix III.

3.3. CATCH

3.3.1. Species

Sixteen different species of fish and shellfish were sampled in 2020 (Table 7.6). Note that some species of fish: lumpfish, stickleback, sculpin, crab, etc. were grouped by genus to remain consistent with previous surveys.

A total of 1,275 fish and shellfish were collected during the survey. All successfully surveyed sites yielded at least one fish. Figure 8.2 contains the catch broken down by species/genus. A summary of the catch sampled at each site is provided in Figures 9.2, 9.3 and 9.4 (Appendix III).

3.3.2. Juvenile Atlantic Cod

A total of 665 juvenile Atlantic cod were sampled in the 2020 Fleming survey. The distribution of catches of age 0, 1 and 2 cod among sites are shown in Figure 8.3.

Five sites: North Harbour, Half Island, Harricot Beach and Trepassey were not sampled; and the tow at Masters Head was unsuccessful due to entanglement. These sites are included in the map to indicate their location, but do not factor into mean catch calculations (Figure 8.3).

The total catch, not including stickleback, for the survey was 1,185 individual fish and crab. The total 665 juvenile Atlantic cod sampled constitute 56.12% of the total catch (not including stickleback).

Seven of the forty sites sampled yielded more than 20 Atlantic cod. Sixteen sites had between 1 to 20 Atlantic cod sampled and zero cod were collected at 17 sites. The catch count for Atlantic cod for all sites where at least one Atlantic cod was sampled is broken down by site in Table 7.5.

The juvenile Atlantic cod sampled during the fall of 2020 range in size from 31 mm to 226 mm. The size distribution across all sites is shown in Figure 8.4 using a bin size of 2.0 mm.

Most of the juvenile Atlantic cod sampled (92.48%) measured approximately 100 mm or less. Length group categories for the 2020 survey were set at:

- *LG0*: length <110 mm;
- *LG1*: 110 mm <=length <=195 mm; and
- *LG2*: length >195 mm.

The mean catch per tow for 2020 (total of n = 40 sites) for each age group:

- *LG0*: 15.375 cod per haul;
- *LG1*: 1.175 cod per haul; and
- *LG2*: 0.075 cod per haul.

The mean catch per tow by age group for the 2020 survey is shown in Figure 8.5 with its respective 95% confidence interval. In general, the mean juvenile cod catch for each group is similar to the mean catches from the 1990s and latter part of the 1959–64 time series. The 2020 average catch rate for 0-, 1-, and 2-groups: 15.38, 1.18, and 0.08 cod per haul respectively are generally consistent with the average cod per tow (first tow) reported from the Fleming survey in the post collapse era: 15.58, 6.89, and 0.91 cod per tow for 0-, 1- and 2- groups respectively.

For most years and most age groups, the catch per tow average for two tows is less than the catch per tow for the first tow only and the 95% confidence interval has similar bounds for both the catch per tow means (i.e. first tow only and mean of both tows). The notable exception to this are the catch means for the 2-group in 1959. For that year, the mean of two tows is 1.5 cod per haul and it lies on the upper limit of the 95% confidence interval of the catch mean for the first tow only (0.5 cod per haul). This is a result of the combination of a low number of 2-group cod caught overall and exacerbated by the relatively small number of sites (n=6 sites) considered in the 1959 Fleming data series. This situation manifests itself differently with 0- group catch mean in 1959 and 1-group catch mean in the following year, 1960 (n=17 sites). A wide 95% confidence interval is observed for both catch means (first tow and two tow average) as a result of some high cod catch numbers at only a few sites.

The time series for mean number of individuals caught for each year of the Fleming survey by length group are shown in Figures 8.6–8.8.

4. DISCUSSION

Surveys of juvenile cod abundance have the potential to provide an index of recruitment (Helle et al. 2000). However, the abundance of age 0 cod does not always provide a strong signal of year-class strength (Laurel et al. 2017). Processes occurring during the post-settlement stages can modify cohort size prior to recruitment to the fishery (Fromentin et al. 2001). The result may be a weak signal, for example, detected on a rank scale (Ings et al. 1997). Alternatively, a signal may be variable with stronger relationships observed during certain periods, such as those favoring high growth rates of juveniles (Campana et al. 1989). Therefore, long-term monitoring of multiple pre-recruit age classes across large spatial scales may be required to more fully understand cod recruitment dynamics.

A previous analysis of data from the Fleming survey sites found that the abundance of age one and two cod declined over the time-series (1960–64 and 1990–96) (McCain et al. 2016). Subsequent sampling for 1997, 2001 and 2020 (this study) indicate that abundance of age one and two cod remains at or near the lowest values observed in the time-series. Recruitment near-shore (this study) remains low despite increases in adult biomass (Dwyer et al. in prep²). The reasons for this disconnect between juvenile abundance and spawning stock biomass (SSB) in Northern cod are unknown. For North Sea cod, Kempf et al. (2009) found that age one abundance was correlated with water temperature and an index of predation, rather than SSB.

In 2020, a single seine haul was made at each site. During previous surveys, annual abundance indices were based on the abundance at age averaged over two tows per site. The seine used in this study is an efficient gear (95%) and has been shown to capture most cod within the swept area (Schneider et al. 1997b). Therefore, cod data from the first tow may represent a density estimate (per 880 m²). Substantial, and sometimes higher, numbers of juvenile cod are caught in the second relative to the first tows at sites, indicating lateral movement into the site may occur immediately following the first tow. A comparison of annual indices based on one versus two hauls per site showed that the trends tend to be similar between calculation methods, with a few exceptions. Most notably, values differed in 1959 when there were few sites sampled. The variance is decreased by averaging across two tows (smaller error bars). Indices based on two tows per site may sample cod from a larger area (>880 m²) and have reduced variability relative to indices calculated from one tow per site.

5. SUMMARY

The Fleming survey was reinitiated in 2020 with sampling conducted at 40 sites. It is the 14th year of the survey, which was previously conducted from 1959 to 1964, 1992–97 and in 2001. An average of 15.4, 1.18 and 0.075 length group zero, one and two cod respectively were sampled in 2020, based on one seine haul per site. Values for length group zero and one cod were comparable to those observed during the 1990s, but the length group two value was the lowest in the time-series.

The 2020 sampling reestablished the logistical framework for a renewed survey of juvenile cod abundance along the Northeast Coast of Newfoundland.

² Dwyer, K., Ings, D., Mello, L., Novaczek, E., Regular, P., Rideout, R., Rogers, R., and Wheeland, L. In prep. Assessment of the Northern cod (*Gadus morhua*) stock in NAFO Divisions 2J3KL in 2020. DFO Can. Sci. Advis. Sec. Res. Doc.

Cod recruitment is a complex process. Long-term monitoring of multiple pre-recruit age/length groups is required to disentangle the effects of environmental variables, adult population size and other biological processes on pre-recruited fish abundance indices.

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8. APPENDIX I - TABLES

Table 8.1: Sites identified for survey in 2020.

Sites				
Harricot Beach	Bryants Cove	Lockston's Arm	Bridgeport	Tommy's Arm
Half Island	Bristols Hope Cove	Cap Cove	Luke's Arm	Woodfords Arm (outcrops)
Mother Hicks Cove	Masters Head	Cannings Cove	Fortune Hbr. (NW bottom)	Woodfords Arm (middle)
Mosquito Cove	Little Mosquito Cove	Man Point	Fortune Hbr. (Fox Cove 1)	Woodfords Arm (bottom)
North Harbour	Bald Point Beach	Indian Bay	Fortune Hbr. (Fox Cove 2)	Lower Wolfe Cove
Trepassey	Long Beach (E)	Rubens Cove	Fortune Hbr. (SW bottom)	Green Island
Davies Head (N)	Long Beach (W)	Grassy Island	Fortune Hbr. (SE bottom)	Halls Bay, Beachy Cove
Davies Head (S)	Middle Lance Cove	Seal Island	Wild Bight	Shimmey Cove
Crockers Cove	Burgoynes Cove	Fox Island	Julies Harbour	Middle Arm (Green Bay)

Table 8.2: Complete listing of Fleming survey sites and years of survey.

Location	Site no.	1959	1960	1961	1962	1963	1964	1992	1993	1994	1995	1996	1997	2001	2020
Harricot Beach	1	-	-	X	X	X	X	X	X	X	X	X	-	X	-
Half Island	2	-	-	-	X	X	-	X	X	X	X	X	X	X	-
Mother Hicks Cove	3	-	-	-	-	-	-	X	X	-	X	X	X	X	X
Admirals Beach	4	-	X	X	X	-	-	-	-	-	-	-	-	-	-
Mosquito Cove	5	-	X	X	-	X	X	X	X	-	-	X	X	X	X
North Harbour	6	-	-	X	X	-	X	X	X	X	X	X	X	X	-
Trepassey	10	-	-	-	X	X	X	X	X	X	X	X	X	X	-
Cape Broyle	12	-	X	-	X	X	X	-	-	-	-	-	-	-	-
Davies Head (N)	16	X	X	X	-	X	-	X	X	X	X	X	-	-	X
Davies Head (S)	17	X	X	X	X	-	-	X	X	X	X	X	X	-	X

Location	Site no.	1959	1960	1961	1962	1963	1964	1992	1993	1994	1995	1996	1997	2001	2020
Crockers Cove	18	X	X	X	X	-	-	X	X	X	-	X	X	X	X
Bryants Cove	19	X	X	X	X	X	X	X	X	X	-	X	X	X	X
Bristols Hope Cove	20	X	X	X	X	X	X	X	X	X	-	X	X	X	X
Ranem Cove	25	-	-	X	X	X	X	-	-	-	-	-	-	-	-
Masters Head	26	-	-	-	-	-	-	X	X	X	X	X	X	X	X
Little Mosquito Cove	27	-	-	X	X	X	-	X	X	X	X	X	X	X	X
Bald Point Beach	28	-	-	X	X	-	-	X	X	X	X	X	X	X	X
Long Beach (E)	29	-	X	-	-	-	X	X	X	X	X	X	X	-	X
Long Beach (W)	30	-	-	-	X	-	X	X	X	X	X	X	X	-	X
Lower Lance Cove	31	-	-	X	X	X	X	-	-	-	-	-	-	-	-
Middle Lance Cove	32	-	-	-	X	-	X	X	X	X	X	X	X	X	X
Burgoynes Cove	33	-	-	-	-	X	X	X	X	X	X	X	X	X	X
Lockston's Arm	34	X	X	X	X	X	-	X	X	X	X	X	X	X	X
Cap Cove	35	-	-	-	-	X	X	X	X	X	X	X	X	X	X
Cannings Cove	40	-	X	X	X	X	X	X	X	X	X	X	-	X	X
Man Point	41	-	X	-	X	-	X	X	X	X	X	X	-	X	X
Jamestown	42	-	-	-	X	-	-	-	-	-	-	-	-	-	-
Great Chance Hbr. (bottom)	43	-	-	-	X	X	-	-	-	-	-	-	-	-	-
Great Chance Hbr. (right)	44	-	-	-	X	X	X	-	-	-	-	-	-	-	-
Eastport	45	-	-	X	X	-	X	-	-	-	-	-	-	-	-
Indian Bay	46	-	X	X	X	X	-	X	X	X	X	X	X	X	X
Rubens Cove	50	-	-	-	X	X	X	X	X	X	-	X	X	X	X
Grassy Island	51	-	-	X	-	X	-	X	X	X	X	X	X	X	X

Location	Site no.	1959	1960	1961	1962	1963	1964	1992	1993	1994	1995	1996	1997	2001	2020
Seal Island	52	-	-	-	-	X	X	X	X	X	X	X	X	X	X
Fox Island	53	-	-	-	X	X	X	X	X	X	X	X	X	X	X
Bridgeport	57	-	X	-	X	X	X	X	X	-	X	X	X	X	X
Luke's Arm	58	-	X	X	X	X	-	X	X	-	X	X	X	X	X
Fortune Hbr. (NW, bottom)	65	-	X	-	-	X	-	X	X	X	X	X	X	X	X
Fortune Hbr. (Fox Cove 1)	66	-	-	-	-	-	-	X	X	-	-	-	-	-	X
Fortune Hbr. (Fox Cove 2)	67	-	-	X	-	X	-	X	X	X	X	X	X	X	X
Fortune Hbr. (SW bottom)	68	-	-	X	X	X	-	X	X	X	X	X	X	-	X
Fortune Hbr. (SE bottom)	69	-	-	-	X	X	-	X	X	-	X	X	X	X	X
Wild Bight	70	-	-	X	X	X	-	X	X	X	X	X	X	X	X
Julies Hbr.	71	-	-	-	X	X	X	X	X	X	X	X	X	X	X
Tommy's Arm	72	-	-	X	X	X	X	X	X	X	X	X	X	X	X
Woodfords Arm (outcrops)	75	-	-	X	X	X	X	X	X	X	-	X	X	X	X
Woodfords Arm (middle)	76	-	-	X	-	X	X	X	X	X	-	X	-	X	X
Woodfords Arm (bottom)	77	-	-	X	-	X	-	X	X	X	-	X	-	X	X
Lower Wolfe Cove	78	-	-	X	X	X	X	X	X	X	X	X	X	X	X
Green Island	79	-	-	-	-	-	X	-	X	X	X	X	X	X	X
Halls Bay, Beachy Cove	80	-	-	X	X	X	X	X	X	X	X	X	X	X	X
Shimney Cove	81	-	-	X	X	X	X	X	-	X	-	X	X	X	X
Little Bay Arm	82	-	-	-	X	X	X	-	-	-	-	-	-	-	-
Middle Arm (bottom)	83	-	-	-	-	X	-	-	-	-	-	-	-	-	-
Middle Arm (Green Bay)	84	-	X	-	-	X	-	X	X	X	X	X	X	X	X
King's Point (Green Bay)	85	-	-	X	X	X	X	X	X	X	X	-	-	-	-

Table 8.3: Fleming survey dates for major bays. St. Mary's Bay (SMB incl. Trepassey), Conception Bay (CB), Trinity Bay (TB), Bonavista Bay (BB), Notre Dame Bay (NDB incl. Gander Bay, New World Island, Fortune Harbour, Halls Bay, Green Bay).

Bay	1959	1960	1961	1962	1963	1964	1992	1993	1994	1995	1996	1997	2001	2020
SMB	-	12 Sept	08 Sept	17 Sept	19 Sept	19 Sept	22 Sept	22 Sept	23 Sept	21 Sept	19 Sept	23 Sept	21 Sept	30 Sept
-	-	20 Sept	14 Sept	21 Sept	25 Sept	25 Sept	23 Sept	23 Sept	-	27 Sept	23 Sept	29 Sept	26 Sept	-
CB	02 Oct	28 Sept	21 Sept	26 Sept	05 Oct	24 Sept	28 Sept	28 Sept	29 Sept	28 Sept	28 Sept	02 Oct	03 Oct	06 Oct
-	08 Oct	29 Sept	23 Sept	27 Sept	07 Oct	25 Sept	29 Sept	29 Sept	04 Oct	29 Sept	05 Oct	-	-	-
TB	10 Oct	03 Oct	25 Sept	01 Oct	10 Oct	29 Sept	20 Sept	30 Sept	30 Sept	30 Sept	01 Oct	07 Oct	05 Oct	13 Oct
-	12 Oct	04 Oct	30 Sept	14 Oct	12 Oct	03 Oct	06 Oct	06 Oct	06 Oct	07 Oct	04 Oct	11 Oct	09 Oct	14 Oct
BB	16 Oct	06 Oct	03 Oct	11 Oct	17 Oct	06 Oct	08 Oct	08 Oct	07 Oct	08 Oct	05 Oct	18 Oct	08 Oct	15 Oct
-	-	10 Oct	07 Oct	16 Oct	19 Oct	08 Oct	09 Oct	09 Oct	08 Oct	09 Oct	06 Oct	-	13 Oct	16 Oct
NDB	23 Oct	17 Oct	09 Oct	17 Oct	21 Oct	12 Oct	14 Oct	14 Oct	14 Oct	14 Oct	13 Oct	20 Oct	14 Oct	20 Oct
-	26 Oct	27 Oct	24 Oct	26 Oct	31 Oct	22 Oct	21 Oct	21 Oct	22 Oct	20 Oct	22 Oct	27 Oct	20 Oct	29 Oct

Table 8.4: Dates for each site surveyed in 2020.

Date	Site names
Sept 30	Mosquito Cove, Mother Hicks Cove
Oct 6	Bryants Cove, Bristols Hope Cove, Crockers Cove, Davies Head (S, N)
Oct 13	Bald Point Beach, Little Mosquito Cove, Long Beach (E, W)
Oct 14	Burgoynes Cove, Middle Lance Cove, Lockston's Arm, Cap Cove
Oct 15	Indian Bay
Oct 16	Man Point, Cannings Cove
Oct 20	Grassy Island, Seal Island, Fox Island
Oct 21	Bridgeport
Oct 25	Rubens Cove, Luke's Arm
Oct 26	Fortune Harbour - NW bottom, Fox Cove (1,2), SE bottom, SW bottom
Oct 27	Wild Bight, Julies Harbour, Tommy's Arm, Woodfords Arm (outcrops, middle, bottom)
Oct 28	Beachy Cove, Green Island, Lower Wolfe Cove
Oct 29	Shimmey Cove, Middle Arm (Green Bay)

Table 8.5: Numbers of Atlantic cod sampled in 2020.

Site	Count
Burgoynes Cove	136
Indian Bay	112
Long Beach (E)	89
Shimmey Cove	85
Cannings Cove	77
Little Mosquito Cove	51
Man Point	27
Halls Bay, Beachy Cove	14
Lockston's Arm	14
Davies Head (N)	13
Long Beach (W)	12
Mother Hicks Cove	8
Davies Head (S)	6
Julies Harbour	5
Green Island	3
Tommy's Arm	3
Cap Cove	2
Middle Arm (Green Bay)	2
Woodfords Arm (middle)	2
Fortune Harbour (SE bottom)	1
Lower Wolfe Cove	1
Mosquito Cove	1
Woodfords Arm (outcrops)	1

Table 8.6: Species sampled in 2020.

Species			
Atlantic cod	Cunner	Sand lance	Thorny skate
Atlantic herring	Greenland cod	Sculpin	White hake
Mummichog	Lumpfish	Smelt	Winter flounder
Crab	Rock gunnel	Stickleback	Yellowtail flounder

9. APPENDIX II - FIGURES

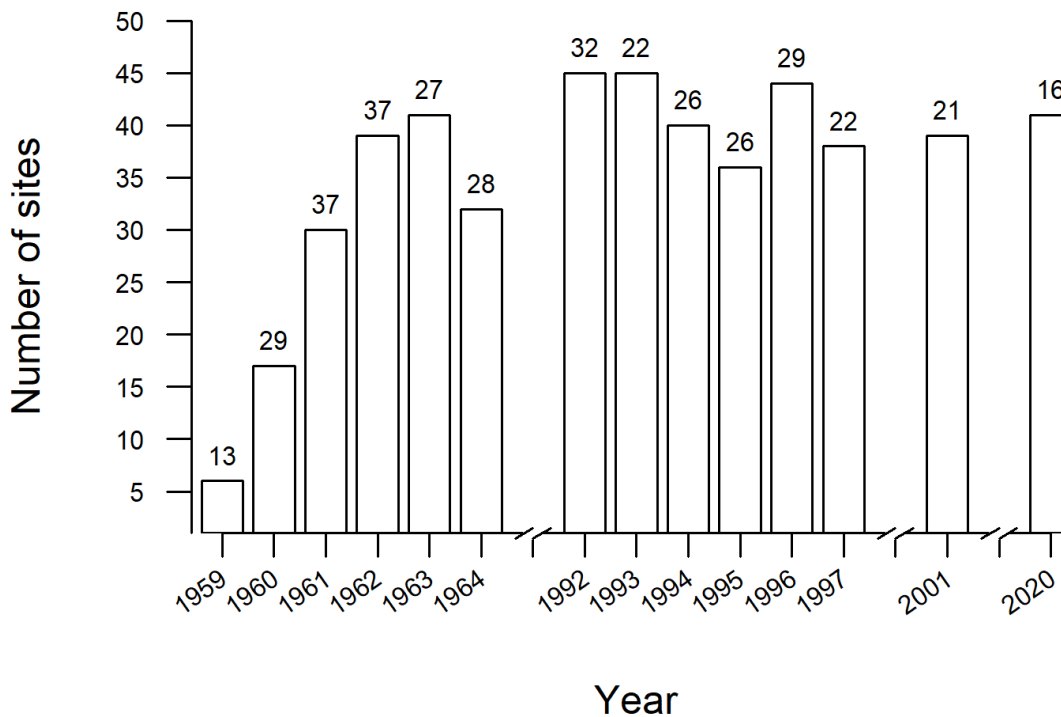


Figure 9.1: Count of sites visited for each year of the Fleming survey and number of survey days each year (above each bar).

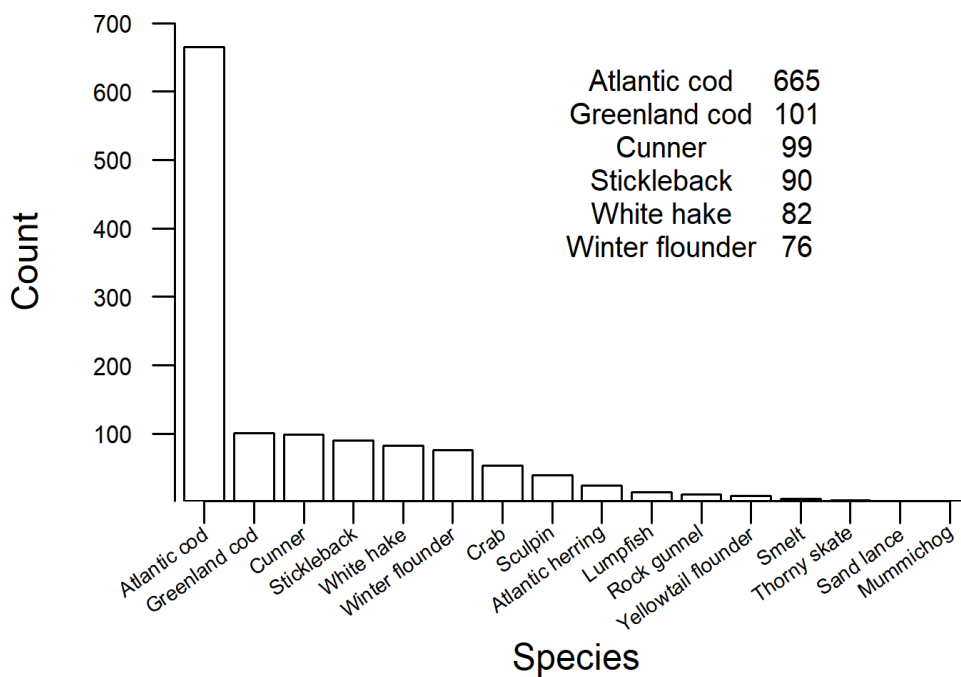


Figure 9.2: Catch breakdown by species in 2020 with top species listed (inset).

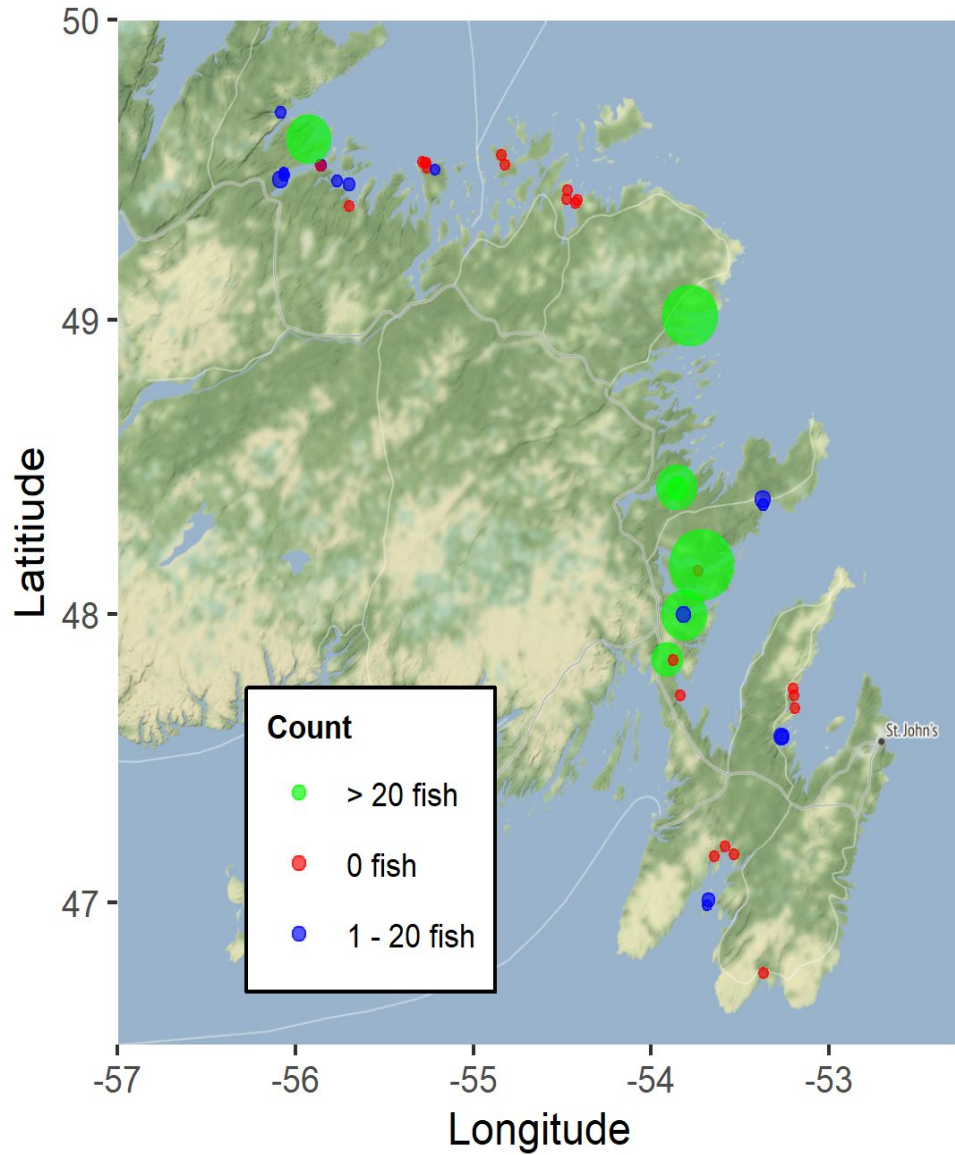


Figure 9.3: The number of Atlantic cod sampled at Fleming sites in 2020. The size of each marker is scaled relative to the total juvenile Atlantic cod count measured at that location: no juv. cod sampled (red); between one and twenty juv. cod sampled (blue); and more than twenty juv. cod sampled (green).

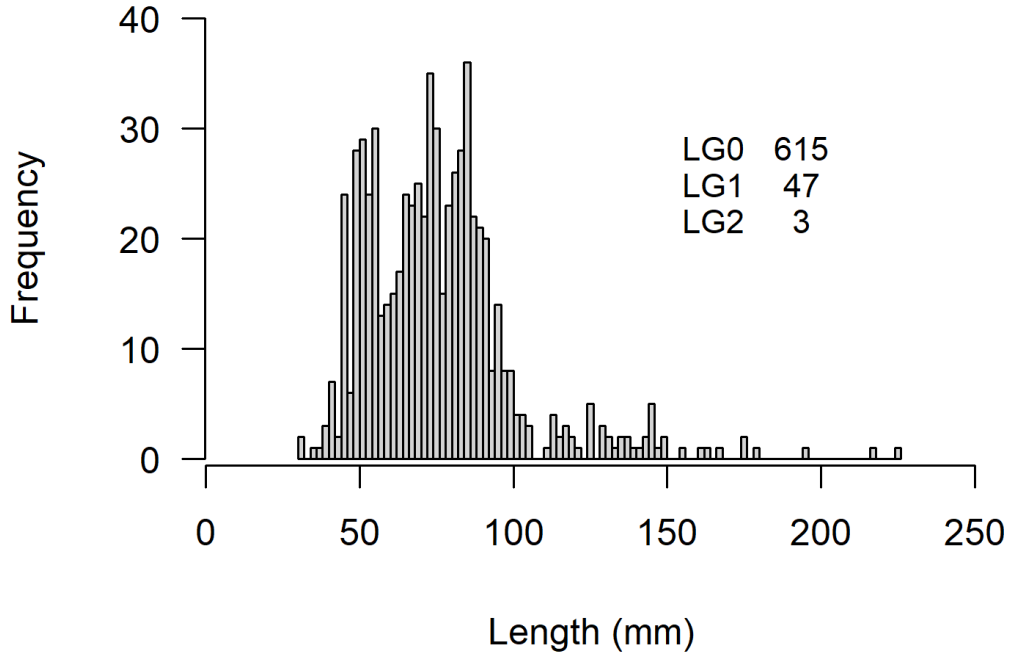


Figure 9.4: Juvenile Atlantic cod measurement counts in 2020 with length groups (inset).

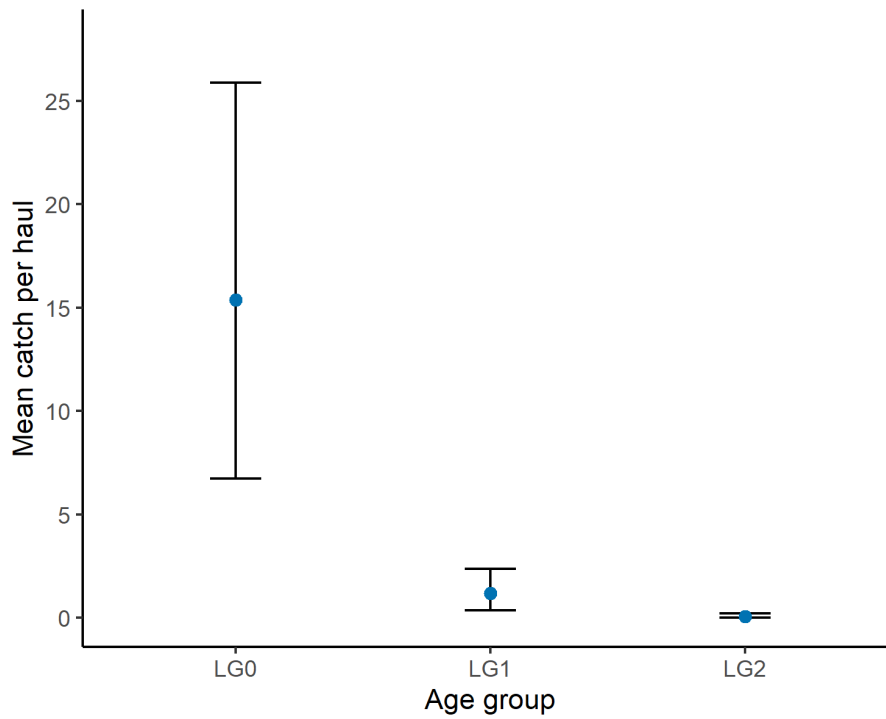


Figure 9.5: Mean catch per haul by length group in 2020 with the 95% confidence interval calculated using randomized resampling with replacement.

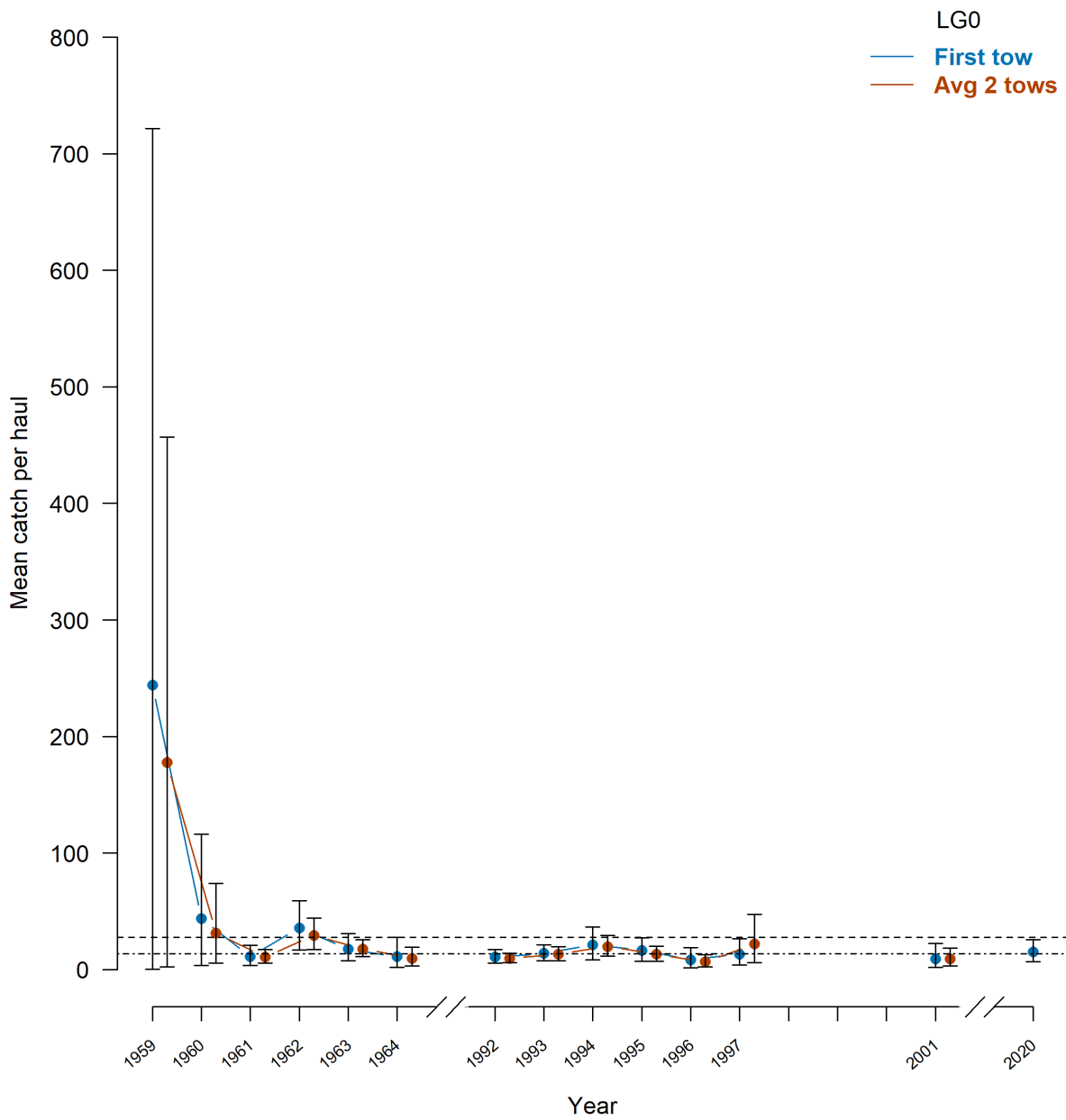


Figure 9.6: Catch means for length group 0 using first tow (blue) and average of two tows (red) including 95% confidence intervals. Dashed (mean=27.59) and dot-dashed (mean=13.65) lines represent the pre and post collapse periods respectively.

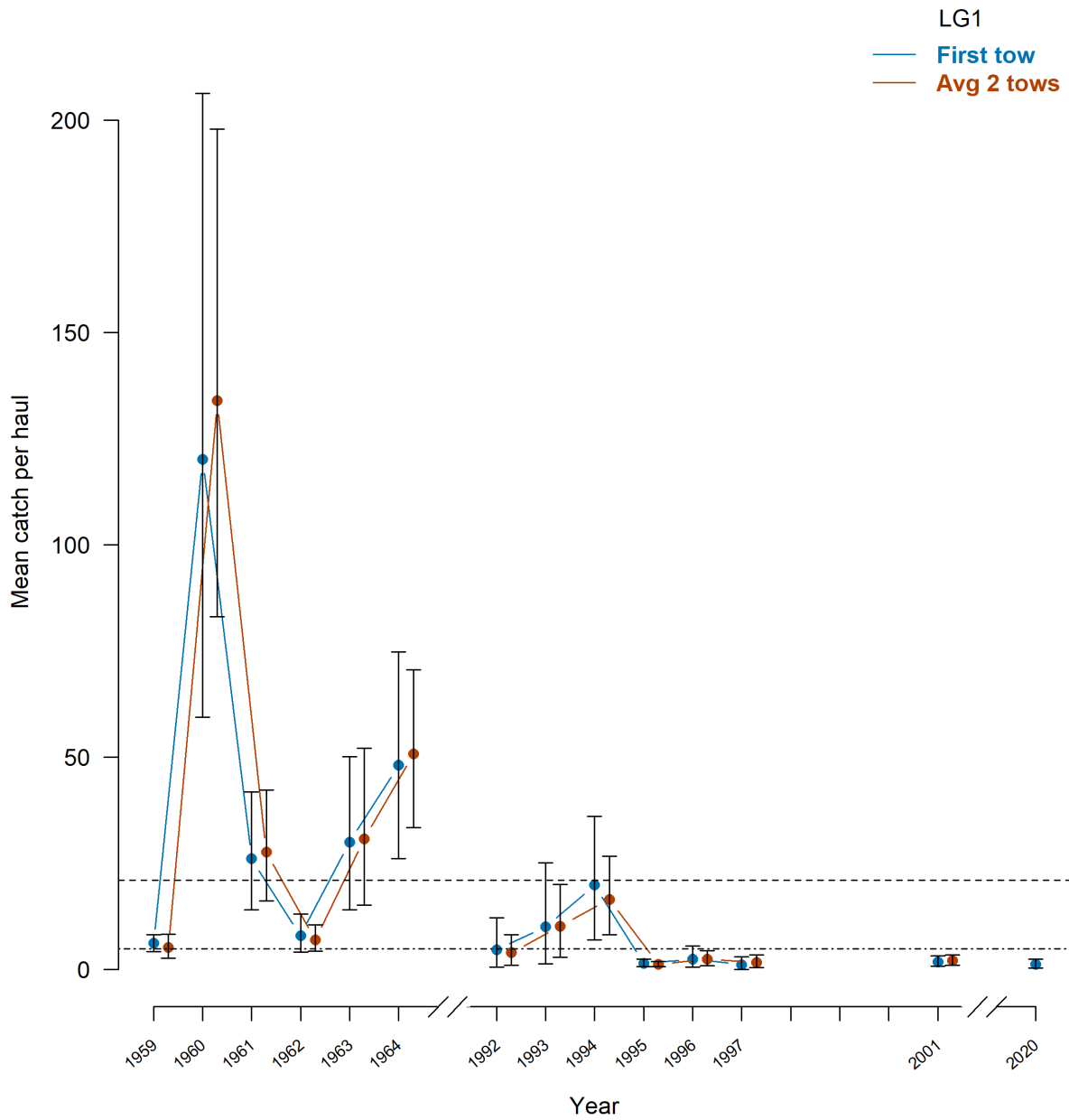


Figure 9.7: Catch means for length group 1 using first tow (blue) and average of two tows (red) including 95% confidence intervals. Dashed (mean=21.03) and dot-dashed (mean=4.89) lines represent the pre and post collapse periods respectively.

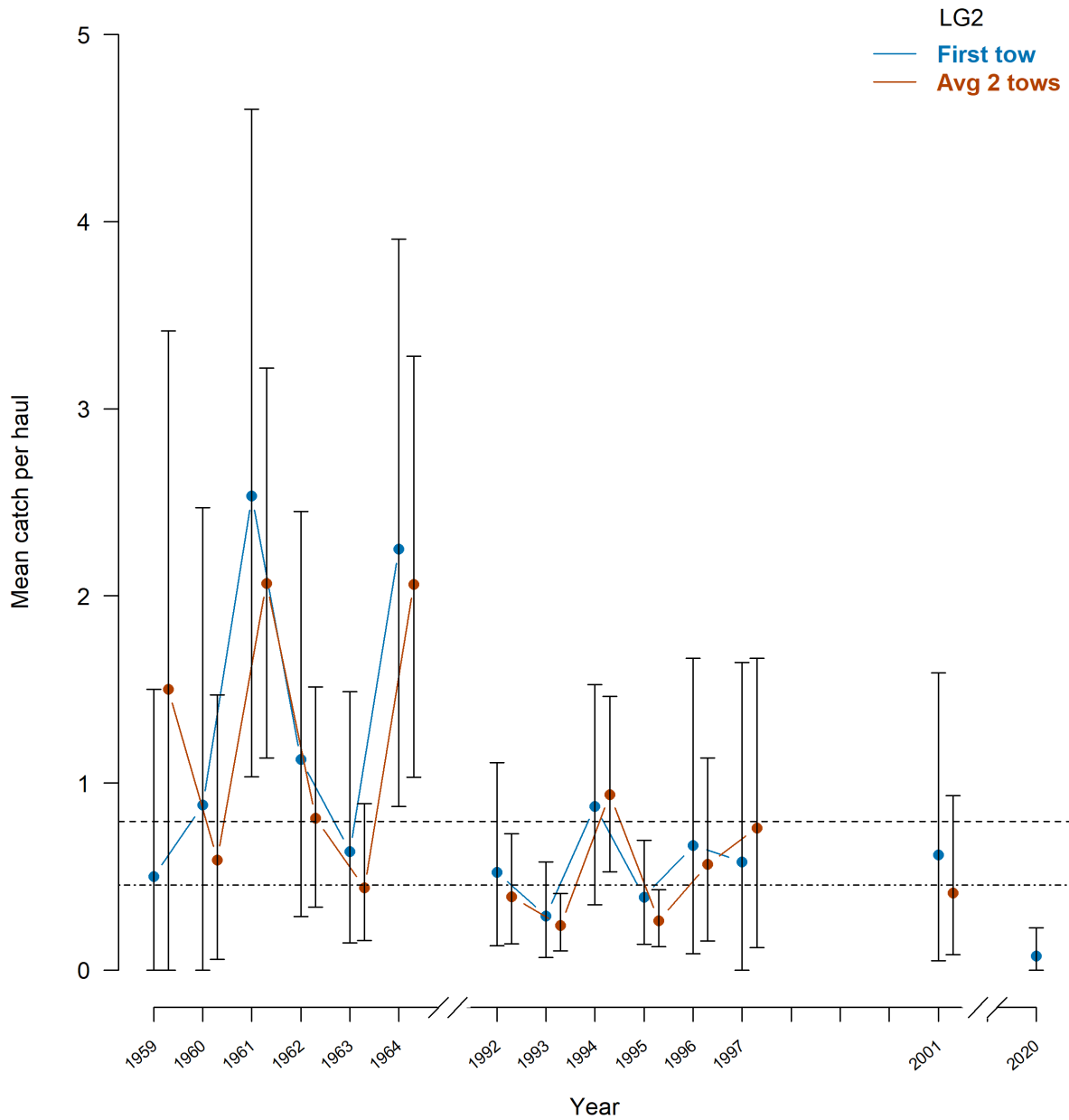


Figure 9.8: Catch means for length group 2 using first tow (blue) and average of two tows (red) including 95% confidence intervals. Dashed (mean=0.79) and dot-dashed (mean=0.46) lines represent the pre and post collapse periods respectively.

10. APPENDIX III - GENERAL SITE SUMMARIES

The catch and habitat summaries for each survey site. Note that stickleback were not measured during catch sampling, so only their presence is reflected in the detailed catch tables below. The habitat classification is given as an approximate percentage of total observed habitat (100%) along a transect at given site. The smallest observation size used is 5%. The habitat classifications are as follows.

- Sediment (sorted by aggregate size):
 - Boulder >15cm
 - Cobble 6cm to 15cm
 - Pebble 2mm to 5cm
 - Sand 50 μ m to 1mm
 - Mud
- Vegetation (sorted by type):
 - *Ascophyllum*
 - *Fucus*
 - *Zostera*
 - *Saccharina latissima*
 - Other (seaweed)

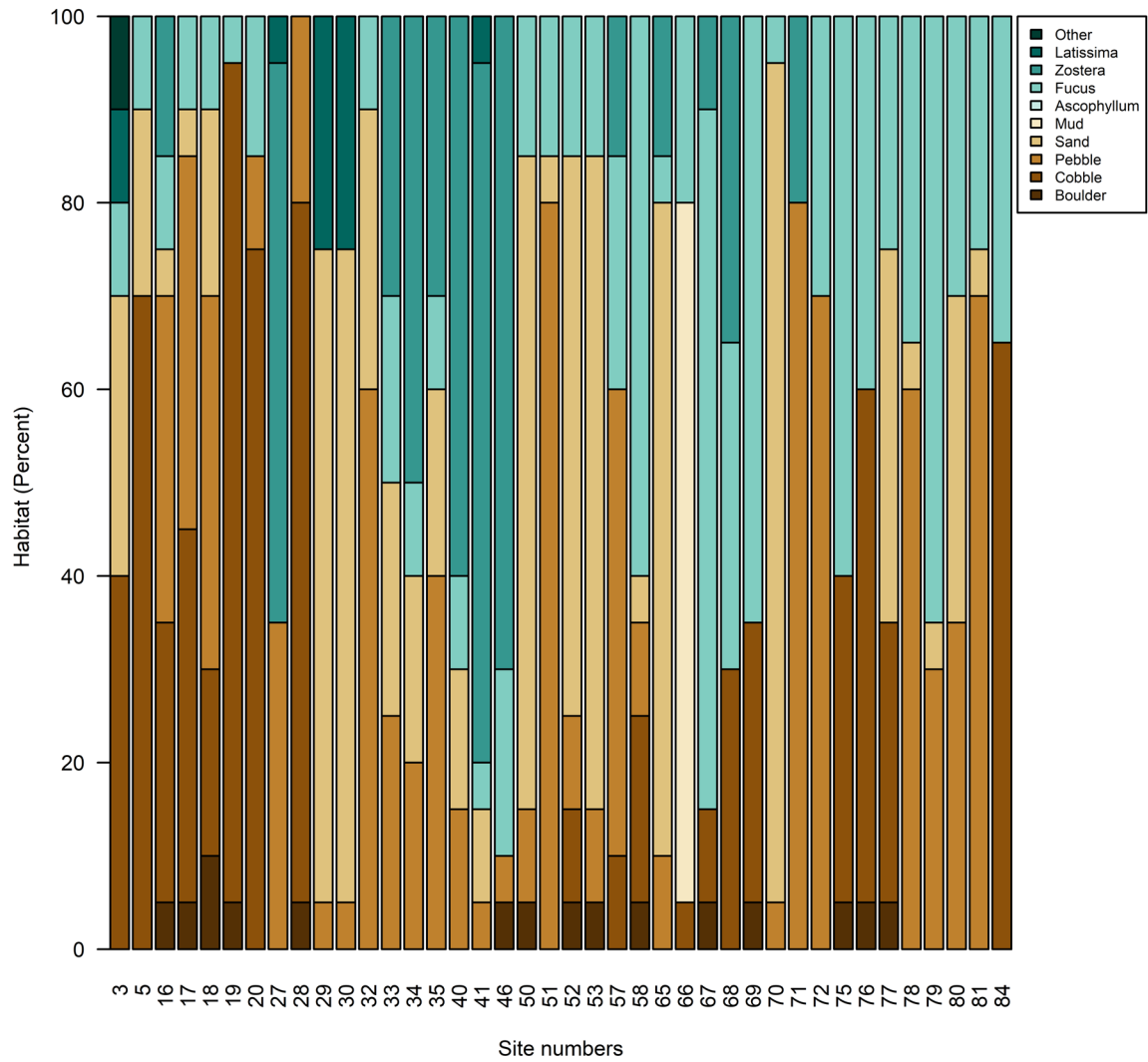


Figure 10.1: Habitat diversity (as percentage) for each site. See description of habitat component above.

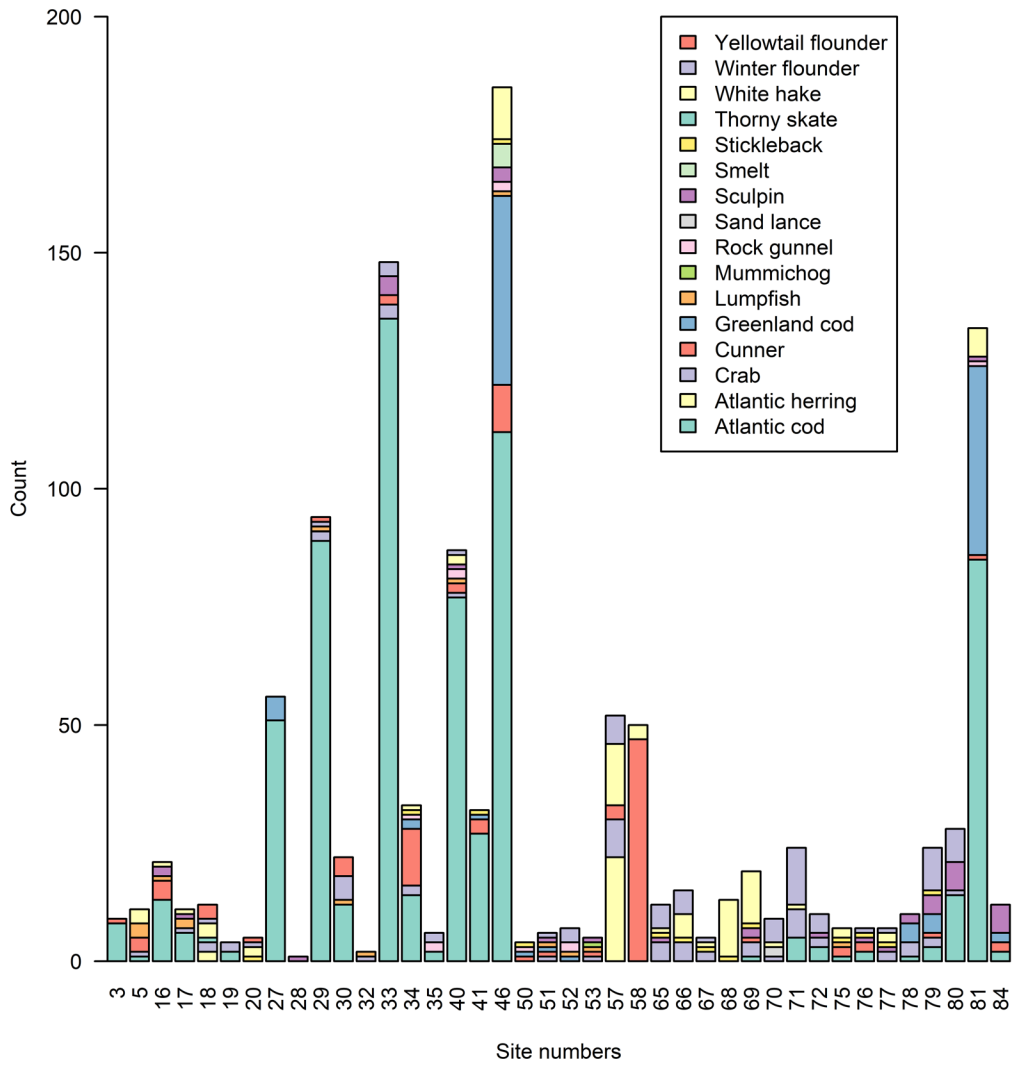


Figure 10.2: Taxa-specific abundance for each site.

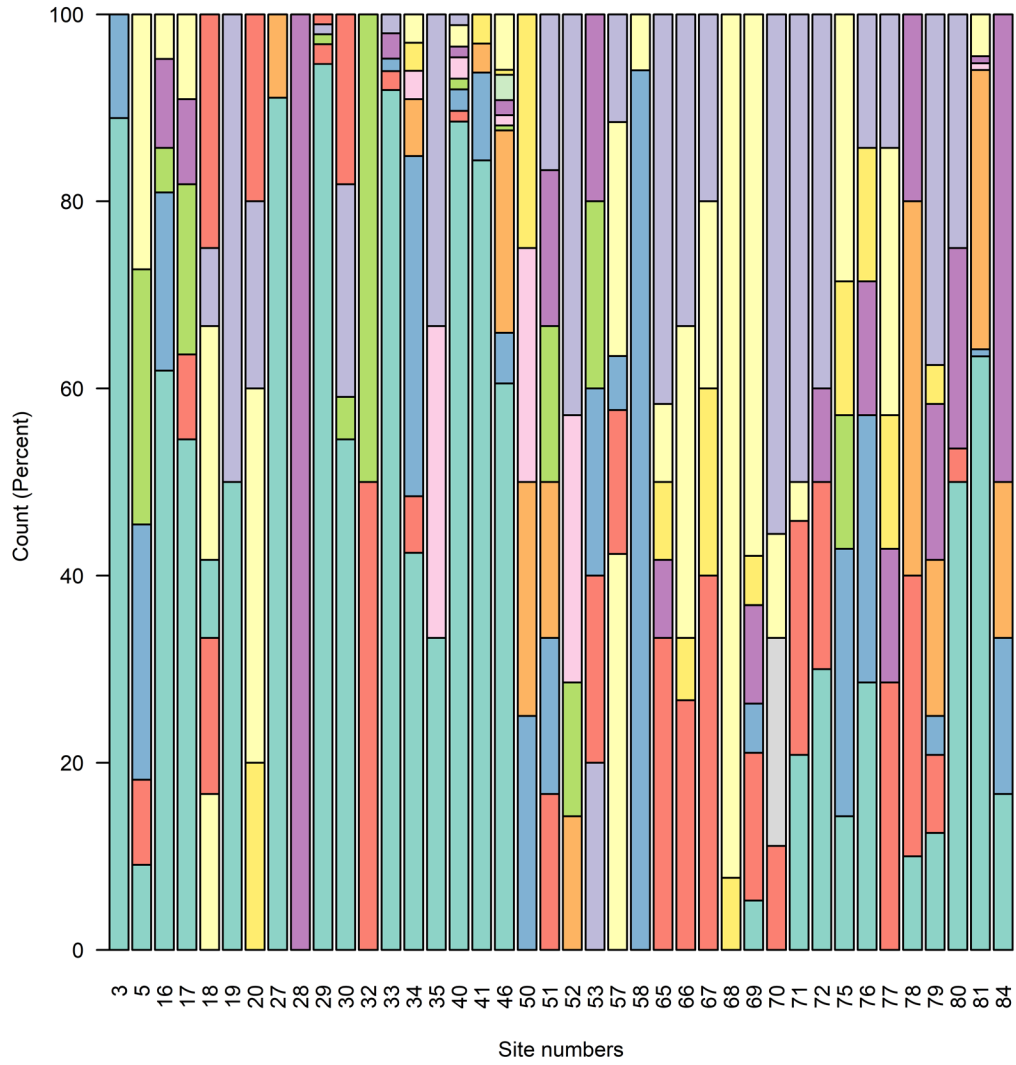


Figure 10.3: Taxa-specific abundance (as percentage) for each site.

Catch breakdown at Mother Hicks Cove #3

Species	Count	Mean	Stdev
Atlantic cod	8	64.25 mm	28.72
Cunner	1	25.00 cm	NA

Catch breakdown at Mosquito Cove #5

Species	Count	Mean	Stdev
Atlantic cod	1	51.00 mm	NA
Crab	1	12.00 cm	NA
Cunner	3	6.67 cm	2.52
Lumpfish	3	11.50 cm	0.87
White hake	3	70.00 mm	7.21

Catch breakdown at Davies Head (N) #16

Species	Count	Mean	Stdev
Atlantic cod	13	62.38 mm	21.40
Cunner	4	2.38 cm	0.25
Lumpfish	1	2.50 cm	NA
Sculpin	2	11.25 cm	10.25
White hake	1	89.00 mm	NA

Catch breakdown at Davies Head (S) #17

Species	Count	Mean	Stdev
Atlantic cod	6	63.33 mm	25.48
Crab	1	5.00 cm	NA
Lumpfish	2	12.00 cm	0.71
Sculpin	1	3.50 cm	NA
White hake	1	98.00 mm	NA

Catch breakdown at Crockers Cove #18

Species	Count	Mean	Stdev
Atlantic herring	2	4.00 cm	0.71
Crab	2	7.50 cm	0.71
Thorny skate	1	29.50 cm	NA
White hake	3	84.00 mm	2.65
Winter flounder	1	8.00 cm	NA
Yellowtail flounder	3	24.83 cm	1.76

Catch breakdown at Bryants Cove #19

Species	Count	Mean	Stdev
Thorny skate	2	21.75 cm	0.35
Winter flounder	2	10.00 cm	1.41

Catch breakdown at Bristols Hope Cove #20

Species	Count	Mean	Stdev
Stickleback	1	0.00	NA
White hake	2	72.50 mm	23.33
Winter flounder	1	3.50 cm	NA
Yellowtail flounder	1	25.00 cm	NA

Catch breakdown at Little Mosquito Cove #27

Species	Count	Mean	Stdev
Atlantic cod	51	53.16 mm	11.35
Greenland cod	5	48.60 mm	1.95

Catch breakdown at Bald Point Beach #28

Species	Count	Mean	Stdev
Sculpin	1	26.00 cm	NA

Catch breakdown at Long Beach (E) #29

Species	Count	Mean	Stdev
Atlantic cod	89	78.66 mm	23.95
Crab	2	9.25 cm	0.35
Lumpfish	1	17.00 cm	NA
Winter flounder	1	15.50 cm	NA
Yellowtail flounder	1	23.00 cm	NA

Catch breakdown at Long Beach (W) #30

Species	Count	Mean	Stdev
Atlantic cod	12	71.17 mm	24.52
Lumpfish	1	11.00 cm	NA
Winter flounder	5	9.20 cm	0.27
Yellowtail flounder	4	24.88 cm	1.93

Catch breakdown at Middle Lance Cove #32

Species	Count	Mean	Stdev
Crab	1	1.00 cm	NA
Lumpfish	1	13.50 cm	NA

Catch breakdown at Burgoynes Cove #33

Species	Count	Mean	Stdev
Atlantic cod	136	86.38 mm	31.11
Crab	3	9.67 cm	1.61
Cunner	2	11.75 cm	1.06
Sculpin	4	9.50 cm	0.82
Winter flounder	3	17.17 cm	0.58

Catch breakdown at Lockston's Arm #34

Species	Count	Mean	Stdev
Atlantic cod	14	64.07 mm	19.67
Crab	2	9.00 cm	4.24
Cunner	12	2.46 cm	0.40
Greenland cod	2	81.50 mm	0.71
Rock gunnel	1	17.00 cm	NA
Stickleback	1	0.00	NA
White hake	1	153.00 mm	NA

Catch breakdown at Cap Cove #35

Species	Count	Mean	Stdev
Atlantic cod	2	60.00 mm	1.41
Rock gunnel	2	11.00 cm	0.00
Winter flounder	2	7.75 cm	1.77

Catch breakdown at Cannings Cove #40

Species	Count	Mean	Stdev
Atlantic cod	77	56.42 mm	17.39
Crab	1	10.00 cm	NA
Cunner	2	6.00 cm	6.36
Lumpfish	1	12.50 cm	NA
Rock gunnel	2	14.25 cm	1.06
Sculpin	1	18.00 cm	NA
White hake	2	112.00 mm	4.24
Winter flounder	1	12.50 cm	NA

Catch breakdown at Man Point #41

Species	Count	Mean	Stdev
Atlantic cod	27	86.70 mm	28.80
Cunner	3	6.50 cm	5.50
Greenland cod	1	97.00 mm	NA
Stickleback	1	0.00	NA

Catch breakdown at Indian Bay #46

Species	Count	Mean	Stdev
Atlantic cod	112	88.79 mm	11.19
Cunner	10	3.60 cm	2.31
Greenland cod	40	100.47 mm	8.24
Lumpfish	1	1.50 cm	NA
Rock gunnel	2	14.75 cm	1.06
Sculpin	3	9.00 cm	1.32
Smelt	5	7.50 cm	0.00
Stickleback	1	0.00	NA
White hake	11	146.82 mm	13.88

Catch breakdown at Rubens Cove #50

Species	Count	Mean	Stdev
Cunner	1	10.00 cm	NA
Greenland cod	1	85.00 mm	NA
Rock gunnel	1	18.00 cm	NA
Stickleback	1	0.00	NA

Catch breakdown at Grassy Island #51

Species	Count	Mean	Stdev
Crab	1	5.50 cm	NA
Cunner	1	2.00 cm	NA
Greenland cod	1	93.00 mm	NA
Lumpfish	1	1.00 cm	NA
Sculpin	1	29.00 cm	NA
Winter flounder	1	8.50 cm	NA

Catch breakdown at Seal Island #52

Species	Count	Mean	Stdev
Greenland cod	1	122.00 mm	NA
Lumpfish	1	1.50 cm	NA
Rock gunnel	2	15.00 cm	0.00
Winter flounder	3	12.00 cm	1.00

Catch breakdown at Fox Island #53

Species	Count	Mean	Stdev
Crab	1	13.00 cm	NA
Cunner	1	2.50 cm	NA
Lumpfish	1	1.50 cm	NA
Mummichog	1	4.00 cm	NA
Sculpin	1	29.00 cm	NA

Catch breakdown at Bridgeport #57

Species	Count	Mean	Stdev
Atlantic herring	22	13.84 cm	1.82
Crab	8	8.31 cm	1.91
Cunner	3	3.50 cm	0.87
White hake	13	99.85 mm	26.84
Winter flounder	6	9.58 cm	2.78

Catch breakdown at Luke's Arm #58

Species	Count	Mean	Stdev
Cunner	47	9.16 cm	2.46
White hake	3	96.00 mm	9.00

Catch breakdown at Fortune Harbour (NW bottom) #65

Species	Count	Mean	Stdev
Crab	4	9.00 cm	2.31
Sculpin	1	12.50 cm	NA
Stickleback	1	0.00	NA
White hake	1	86.00 mm	NA
Winter flounder	5	9.50 cm	7.56

Catch breakdown at Fortune Harbour (Fox Cove 1) #66

Species	Count	Mean	Stdev
Crab	4	10.88 cm	2.25
Stickleback	1	0.00	NA
White hake	5	93.80 mm	7.53
Winter flounder	5	13.00 cm	7.04

Catch breakdown at Fortune Harbour (Fox Cove 2) #67

Species	Count	Mean	Stdev
Crab	2	9.00 cm	1.41
Stickleback	1	0.00	NA
White hake	1	94.00 mm	NA
Winter flounder	1	13.00 cm	NA

Catch breakdown at Fortune Harbour (SW bottom) #68			
Species	Count	Mean	Stdev
Stickleback	1	0.00	NA
White hake	12	122.17 mm	47.50

Catch breakdown at Fortune Harbour (SE bottom) #69			
Species	Count	Mean	Stdev
Atlantic cod	1	84.00 mm	NA
Crab	3	8.33 cm	0.58
Cunner	1	3.00 cm	NA
Sculpin	2	14.00 cm	12.73
Stickleback	1	0.00	NA
White hake	11	102.64 mm	23.50

Catch breakdown at Wild Bight #70			
Species	Count	Mean	Stdev
Crab	1	2.00 cm	NA
Sand lance	2	10.50 cm	0.71
White hake	1	68.00 mm	NA
Winter flounder	5	10.90 cm	3.54

Catch breakdown at Julies Harbour #71			
Species	Count	Mean	Stdev
Atlantic cod	5	74.60 mm	12.18
Crab	6	7.83 cm	1.72
White hake	1	115.00 mm	NA
Winter flounder	12	10.17 cm	4.26

Catch breakdown at Tommy's Arm #72			
Species	Count	Mean	Stdev
Atlantic cod	3	98.00 mm	66.70
Crab	2	7.50 cm	0.71
Sculpin	1	12.00 cm	NA
Winter flounder	4	8.75 cm	3.30

Catch breakdown at Woodfords Arm (outcrops) #75			
Species	Count	Mean	Stdev
Atlantic cod	1	45.00 mm	NA
Cunner	2	3.00 cm	0.00
Lumpfish	1	1.50 cm	NA
Stickleback	1	0.00	NA
White hake	2	81.00 mm	5.66

Catch breakdown at Woodfords Arm (middle) #76			
Species	Count	Mean	Stdev
Atlantic cod	2	81.00 mm	69.30
Cunner	2	2.75 cm	0.35
Sculpin	1	30.00 cm	NA
Stickleback	1	0.00	NA
Winter flounder	1	28.00 cm	NA

Catch breakdown at Woodfords Arm (bottom) #77			
Species	Count	Mean	Stdev
Crab	2	9.00 cm	1.41
Sculpin	1	29.00 cm	NA
Stickleback	1	0.00	NA
White hake	2	86.00 mm	1.41
Winter flounder	1	12.00 cm	NA

Catch breakdown at Lower Wolfe Cove #78			
Species	Count	Mean	Stdev
Atlantic cod	1	150.00 mm	NA
Crab	3	8.50 cm	1.00
Greenland cod	4	90.50 mm	6.19
Sculpin	2	23.25 cm	4.60

Catch breakdown at Green Island #79			
Species	Count	Mean	Stdev
Atlantic cod	3	81.67 mm	0.58
Crab	2	10.00 cm	1.41
Cunner	1	2.00 cm	NA
Greenland cod	4	100.00 mm	15.73
Sculpin	4	15.62 cm	8.34
Stickleback	1	0.00	NA
Winter flounder	9	14.33 cm	8.54

Catch breakdown at Halls Bay, Beachy Cove #80			
Species	Count	Mean	Stdev
Atlantic cod	14	83.36 mm	11.68
Crab	1	1.00 cm	NA
Sculpin	6	16.83 cm	12.72
Winter flounder	7	21.29 cm	10.20

Catch breakdown at Shimmy Cove #81			
Species	Count	Mean	Stdev
Atlantic cod	85	74.54 mm	13.03
Cunner	1	17.50 cm	NA
Greenland cod	40	111.53 mm	54.11
Rock gunnel	1	21.00 cm	NA
Sculpin	1	11.50 cm	NA
White hake	6	135.17 mm	23.09

Catch breakdown at Middle Arm (Green Bay) #84			
Species	Count	Mean	Stdev
Atlantic cod	2	65.50 mm	0.71
Cunner	2	2.75 cm	0.35
Greenland cod	2	98.00 mm	9.90
Sculpin	6	15.92 cm	5.96

Figure 10.4: Taxa-specific abundance, mean length and standard deviation for each site.