BIOLOGY OF A RESIDENT COD (*Gadus morhua*) POPULATION IN GILBERT BAY, LABRADOR

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Biology of a resident cod (*Gadus morhua)* population in Gilbert Bay, Labrador.

By

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ABSTRACT

I studied the biology of a resident population of Atlantic cod (*Gadus morhua*) in Gilbert Bay (52°35' N, 55°52' W), Labrador. Gilbert Bay has an area of approximately 34 km^2, and is generally less than 30 m deep. Water temperatures are sub-zero in winter but surface water warms rapidly after ice leaves the bay, usually in early May. Gilbert Bay cod spawned from mid-May to mid-June, 1999, and eggs hatched in about 24 days. A steep density gradient in the upper 5 m of the water column in The Shinneys, an arm of the bay where most data were collected, may be important in keeping eggs in the bay. Larvae and pelagic juveniles appeared to be more abundant in 1998 than in 1999. Cod ranging in size from 15 to 100 cm (2 - 15+ years of age) were captured in shallow water (< 5m) throughout the summer. Tagging indicated that some Gilbert Bay cod move to the mouth of the bay during summer, but others were recaptured at the same location as tagged. Sexual maturity can be attained at 32 cm TL, and 4 years of age, but some females were not sexually mature at a length of 42 cm and age of 8 years. Gilbert Bay cod grow more slowly than adjacent offshore cod. Histological evidence indicates that some females may not spawn every year after reaching sexual maturity. Differences in life history characteristics of this population compared to other Atlantic cod within the North Atlantic Fisheries Organization (NAFO) divisions 2J 3K and 3L is further evidence of reproductive isolation. This resident population of Atlantic cod could be easily over exploited and should be managed separately from other northern cod.

ACKNOWLEDGMENTS

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TABLE OF CONTENTS

PAGE

PAGE

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Atlantic cod (*Gadus morhua*) have a wide distribution, occurring on both sides of the North Atlantic. On the west side of the Atlantic, Atlantic cod range from Greenland to Cape Hatteras (Scott and Scott 1988). Within the range of Atlantic cod the northern Atlantic cod extends from Cape Chidley southward to the northern part of the Grand Banks (Lear and Parsons 1993). This stock (or stock complex) is further divided into the northern Labrador portion, consisting of North Atlantic Fisheries Organization (NAFO) divisions 2G and 2H, and the southern Labrador- East Newfoundland portion, consisting of 2J, 3K, and 3L (Fig.1). Templeman (1962, 1979, 1981) described differences in growth rate, age and size at maturity, spawning areas, timing of spawning, migration patterns, and morphology within the northern Atlantic cod stock. These differences indicate different life histories exist within the stock. More recently, genetic analysis has suggested that sub-populations exist within the northern Atlantic cod population (Ruzzante *et al.* 1997; Ruzzante *et al.* 1999; Ruzzante *et al.* 2000). Northern Atlantic cod has been considered a stock complex containing several stocks with varying degrees of intermixing throughout its range (Halliday and Pinhorn 1990), particularly during large scale shoreward and along shore movements in search of food (de Young and Rose 1993). Reports of Atlantic cod overwintering and spawning inshore have long suggested that a component of northern Atlantic cod exist inshore (Thompson 1943; Templeman 1979).

Most northern Atlantic cod, at least historically, tended to migrate inshore in summer, feeding on capelin, and return offshore in fall to overwinter and spawn (Lear

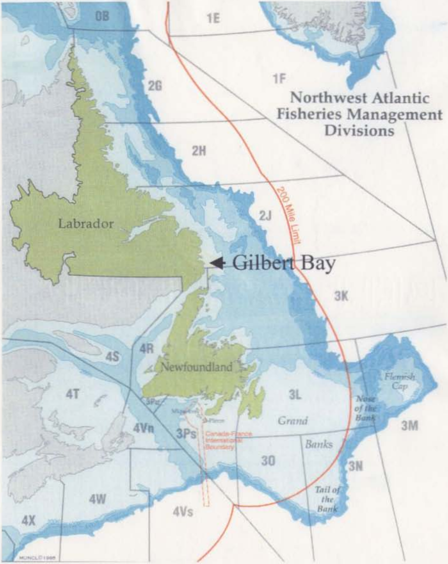


Figure 1. Map of Newfoundland and Labrador and Northwest Atlantic Fisheries Organization Management Divisions. The general location of Gilbert Bay is indicated.

1984; Lear and Green 1984). Most spawning traditionally took place along the Labrador Shelf and northeast Newfoundland Shelf, at depths < 250 m from March until April (Serebryakov 1965; Postolaky 1968). Cod eggs rise toward the surface (Anon 1995; Ouellet 1997) and are carried southward with the Labrador current, hatching in 30-60 days (Templeman 1981; Lear and Green 1984; deYoung and Rose 1993; Anderson and deYoung 1994) depending on water temperature (Laurence and Rogers 1976; Page and Frank 1989; Pepin *et al.* 1997). Metamorphosis of larvae into pelagic juveniles occurs at lengths greater than 20 mm, dorsal fins are completely developed at 26-30 mm and pectoral fins are last to form (Fahay 1983). Settlement to a benthic habitat occurs at approximately 25-50 mm (Fahay 1983), however larger pelagic juveniles are more common offshore (Anderson *et al.* 1995). As cod approach maturity they accompany adult migratory cod offshore (Lear and Green 1984) to eventually spawn and continue the annual inshore-offshore migration. This is a gradual process, whereby 1 year old Atlantic cod are found near shore, 2 and 3 year old Atlantic cod further from shore, and 4 and 5 year old Atlantic cod at offshore spawning areas (Lilly 1992; Anderson and Gregory 2000). Some juvenile Atlantic cod remain inshore throughout the winter in deep water within bays and off the headlands (Lilly *et al.* 1999).

Study of northern cod has focused on the migratory component of this stock complex, because it comprised the majority of northern cod taken in the commercial fishery. Study of this component was important for management purposes, whereas smaller components, such as bay stocks, were considered to be relatively unimportant. Since the moratorium on northern cod in 1992, recovery of offshore populations has not occurred (Shelton and Healey 1999). Adult mortality of northern cod appears high, growth rates are low (Lilly *et al.* 1999) and offshore stocks are not rebuilding as rapidly as predicted by the Department of Fisheries and Oceans (DFO). Presently the majority of northern cod are found in high density in a few inshore locations (Shelton and Healey 1999).

Research surveys and fishermen have detected an abundance of cod in several of the large bays of eastern Newfoundland since 1995 (Rose 1999; Lilly *et al.* 1999). Thompson (1943), reported that sedentary cod are found all along the coast, but as a rule do not support large fisheries. Hutchings *et al.*(1993) suggested that spawning is evident inshore in southeastern Labrador and in large Newfoundland bays, particularly in St. Marys Bay , Placentia Bay, Trinity Bay, and Bonavista Bay. Wroblewski *et al.*(1994) and Smedbol and Wroblewski (1997) reported that Atlantic cod overwinter and spawn in Trinity Bay. Inshore spawning also occurs in Norwegian fiords (Moller 1968; Jacobsen 1987). Inshore spawning appears to be a reproductive strategy of some Atlantic cod (Smedbol 2000), and may contribute significantly to juvenile cod in inshore Newfoundland waters (Hutchings and Myers 1994)

Little is known about the migration patterns of the different components of northern cod. Components may include offshore non-migratory cod, inshore-offshore migratory cod , and non-migratory inshore cod (Lilly *et al.* 1999; Ruzzante *et al.* 1999). Further, it is not known whether individuals contribute consistently to a particular component or change their behaviour over time. For example, there is speculation that the high density of cod found in Trinity Bay since 1995 may have originated from elsewhere (George Rose, Memorial University, personal communication). Inshore cod from Placentia Bay also move into other eastern Newfoundland bays, including Trinity Bay and as far north as Notre Dame Bay (Brattey *et al.* 1999). No clear geographic distinction has yet been identified between the distribution of juvenile cod spawned inshore and those spawned offshore (Robert Gregory, Memorial University, personal communication). It is difficult to distinguish between individuals belonging to the inshore component and individuals that make use of both the inshore and offshore habitats.

Different life history strategies may result from an organism's attempt to maintain the highest possible level of fitness in a given environment (Stearns and Crandell 1984). A "selective environment" reflects those elements of the external environment that result in differential contributions of offspring, under differential selective pressures (Brandon 1988). The selective environment is measured by using the organisms as measuring instruments. Measurements of growth and reproduction subsequently permit an interpretation of life history. An organism's life history may be looked upon as the resultant of three biological processes, namely maintenance, growth and reproduction (Gadgil and Bossert 1970). Differences in the division of energy due to unavoidable stress, resulting in differences in growth rate and size and age-at-reproduction, can be interpreted as differences in life history strategy, because it may affect the number of offspring produced.

The evolution of differing life history strategies is primarily affected by changes in behaviour (Odling-smee 1998), and may result in spatial and temporal isolation of a population. Genetic differences between populations may then be expected to develop over periods of time. Animal species or populations that are adapted to a wide range of environmental conditions are most likely to have better success under changing conditions.

The first written accounts of cod in Gilbert Bay, Labrador, were made by Powell (1987), who reported that sports fisherman caught dark brown cod (Fig. 2) in 1972 with lures in a sort of salt water pond. Mr. Ted Penny, a resident of Port Hope Simpson, began fishing cod commercially in Gilbert Bay in 1973 (Powell 1987). Powell (1987) also suggested that although cod were far from plentiful along the coast in the Gilbert Bay area, Mr. Penny caught a great deal of cod in Gilbert Bay. Commercial fishing began again in Gilbert Bay in 1998.

Relatively small 'populations' of inshore cod are susceptible to overfishing. Since they are non-migratory they are susceptible to fishing pressure throughout the fishing season. The absence of migratory fish in traditional fishing areas results in a concentration of fishing pressure upon local inshore stocks. Identifying and characterizing localized assemblages of cod inshore may enable specific management practices, rather than employing a potentially destructive single management plan for all of northern cod.

Recent genetic data have indicated that cod in Gilbert Bay are distinct from Atlantic cod of both the offshore and inshore (Ruzzante *et al.* 2000). Genetic differences and differences in behaviour (Green and Wroblewski submitted) suggest that Atlantic cod from Gilbert Bay are perhaps locally adapted. As a result, I predicted that life history characteristics of this population differ from other Atlantic cod, particularly northern Atlantic cod.

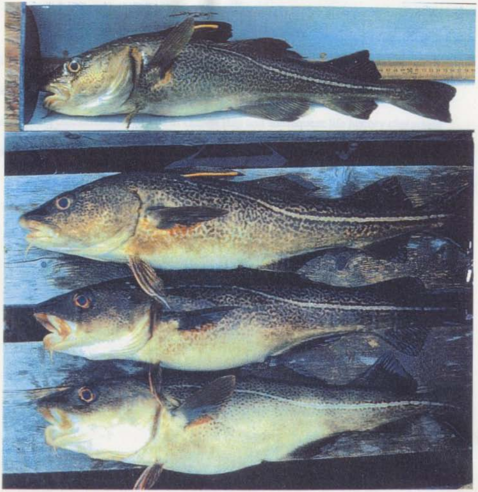


Figure 2 : Atlantic cod sampled in The Shinneys, May 1999

The purpose of this study was to describe life history characteristics of cod in Gilbert Bay. Information regarding growth, size and age-at-maturity, movement patterns, feeding, spawning areas and the timing of spawning was collected. Differences in behavioural characteristics of cod in Gilbert Bay and subsequent life history characters may provide the biological basis for separate management of Gilbert Bay cod.

2. DESCRIPTION OF STUDY AREA

Gilbert Bay is located on the south coast of Labrador, 52°34.93' N, 56° 01.25' W, near the communities of Williams Harbour (Fig 3), and Port Hope Simpson. It is connected to Alexis Bay by a channel (main tickle) between Denbigh Island and the mainland. Gilbert Bay is approximately 22.7 km long covering 34 km^2. Water depths are approximately 80 m at the mouth of Gilbert Bay, and become increasingly shallower towards the head of the bay where depths are approximately 20 m. Sills 5 m and 7 m are located at the head of Gilbert Bay and across the center of Gilbert Bay, respectively. The entrance to Gilbert Bay is approximately 500 m wide, and sheltered from the Labrador Sea by several islands near its mouth. Adjoining the main arm of Gilbert Bay are several smaller arms, including Snooks arm, Long Arm, and an area known as The Shinneys (Fig.3). These arms connect with the main arm of Gilbert Bay in an area called River Out.

The Shinneys is 13.6 km long, and covers an area of about 8.3 km^2 (Fig. 4) . A channel, approximately 30 m deep, runs northwest to southeast, elsewhere water depth is usually less than 10 m. Surface water is dark brown, particularly during the spring thaw due to fresh water runoff from the Shinneys River.

The sampling for this study was concentrated in The Shinneys. Preliminary data indicated that Atlantic cod were present there, and that it was a potential spawning area. A DFO cabin at the mouth of the Shinneys River provided field research facilities and easy access to the site. As well The Shinneys is considered an inland water under the Newfoundland fishery regulations, and is therefore protected against commercial fishing.

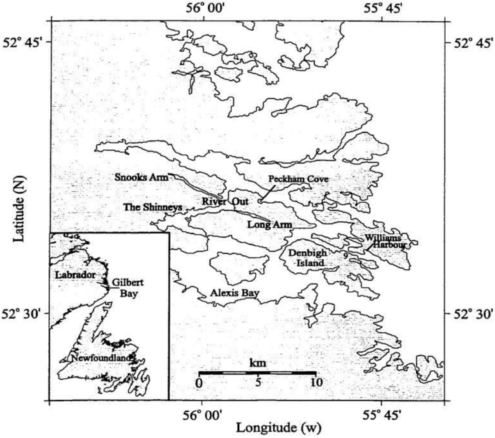


Figure 3. Map of Gilbert Bay, Alexis Bay, and several islands along the coast of Labrador

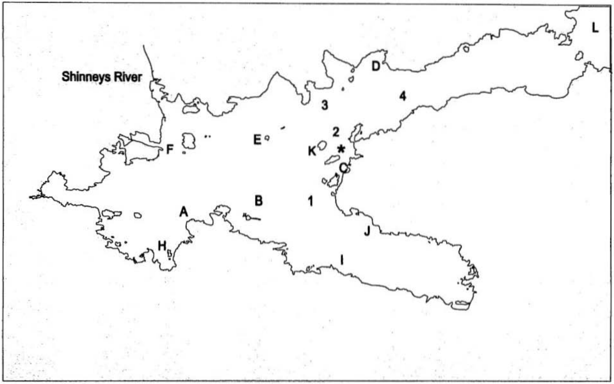


Figure 4. Map of The Shinneys. Letters indicate angling locations, numbers indicate CTD profile locations and temperature probe location is marked with a [*]

3. MATERIALS AND METHODS

3.1 PHYSICAL ENVIRONMENTAL INFORMATION

Some temperature and salinity data have been collected in Gilbert Bay since 1996. From August 1996 until April 1998 temperature data were collected in Peckham Cove (Fig. 3). Beginning in June 1998 until November 1999 temperature was recorded in The Shinneys (Fig. 4). Temperatures were recorded every hour at 5 m at Peckham Cove and 3 m and 8 m in The Shinneys. Two VEMCO Ltd. Mini Log-T data loggers recorded water temperature. Vertical profiles of salinity, temperature, and density (CTD profiles) were recorded using a Seabird Electronics Inc. Seacat SBE 19-03, at four locations (Fig. 4) in The Shinneys in 1997. Profile information was collected from the surface to the bottom.

3.2 GENERAL FISH SAMPLING PROCEDURE

In 1998 and 1999, seven sampling trips were made to Gilbert Bay (Table 1). Each year sampling began soon after land-fast ice had left the bay, followed by additional trips during summer. Adult and juvenile Atlantic cod were sampled by angling at several locations in The Shinneys (Fig. 4). Early life history stages (egg, larvae, and pelagic juveniles) were collected with a plankton net at several locations in Gilbert Bay. During the 1998 Atlantic cod food fishery, samples and measurements were taken from fish caught by fishers in Gilbert Bay.

Table 1. Summary of sampling dates and activities in Gilbert Bay during 1998 and 19

Year	Sampling Date	Sampling Procedure
1998	June 3 - June 10	Angling
	June 24 - June 30	Angling
	July 19 - August 6	Angling and Ichthyoplankton Survey
	August 28 - August 29	Food Fishery Observation and Sample Collection
1999	May 10 - June 1	Angling and Ichthyoplankton Survey
	June 23 - June 24	Ichthyoplankton Survey
	August 6 - August 12	Angling and Ichthyoplankton Survey

3.3 ADULT LIFE HISTORY INFORMATION

3.3.1 Angling

Samples were collected from outboard motor boats, 4 and 6 m in length. Demersal juveniles and adult Atlantic cod were caught by angling using a straight 1 ounce jigging lure, usually at depths between 2 and 10 m. Fish were measured (total length TL) on a measuring board (Fig. 5), to the nearest mm. Weights were measured, with the Acculab model VI balance, to the nearest gram. If conditions were too rough to obtain accurate weight measurements, only lengths were measured. Most fish larger than 25 cm were tagged and released.

3.3.2 Life history data: general procedures

Approximately 10% of fish captured during 1998 and 1999 (Table 2), were sampled to determine size (length and weight), age, sex, maturity and stomach contents. Few fish larger than 50 cm were sampled. Because of the few large (> 60 cm) fish in the population, fish of this size were all released after being measured. Fulton's condition factor (Fulton condition factor = total body weight / total length^3) was used to assess the relationship between length and weight. Ovaries and testes were inspected to determine sex and maturity status and some ovaries were preserved for later histological analysis. Otoliths were removed and stored dry in scale envelopes. Stomach contents were examined to identify food items. The same data were collected from fish sampled during the 1998 food fishery.

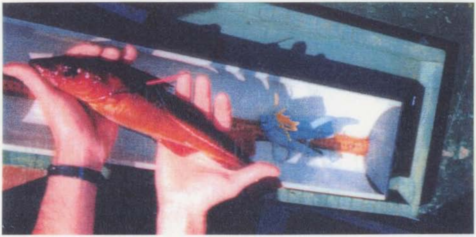


Figure 5. Measuring board and Atlantic cod.

Table 2. Summary of angling data from Gilbert Bay during 1998 and 1999.

	Sampling dates	# Caught	# Tagged	# Killed*	Recaptures
1998	June 3 - 10	441	364	68	0
	June 24 - 30	306	299	24	0
	July 19 - August 5	150	19	15	1
	Sub-total	897	682	107	1
1999	May 20 - June 1	685	563	91	10
	June 24 - 25	5	0	5	0
	Aug 6 - 12	422	0	15	17
	Sub-total	1112	563	111	27
	Total	2009	1255	218	28

*Animals were sacrificed in accordance with animal care protocol, by a firm blow on the head.

3.3.3 Tagging

Most angled fish larger than 25 cm were tagged to obtain data on growth and movement. Yellow and orange Floy T-bar tags were used. Tags were attached dorsally, on the left side of the body, adjacent to the first dorsal fin (Fig. 5).

3.3.4 Sex determination and maturity status

Sex and maturity status were determined by the release of eggs or milt, by visual inspection of the gonads of sampled fish, and histologically. During spawning males and females in spawning condition released eggs and milt upon capture and sex could be determined non-lethally. The determination of maturity status of gonads followed the method described by Morrison (1990). If only non-hydrated eggs were observed it was assumed that the fish had not started spawning. Hydrated eggs were easily distinguished from non-hydrated eggs by their larger size, and transparent rather than opaque appearance. Immature females were difficult to distinguish from females which had spawned in a previous year (s) but had not matured in the current year. Ovaries that appeared immature, based on size, were preserved in Bouin's solution, for histological examination.

State of maturity was determined as follows:

1. Immature. Juvenile fish with little or no gonadal development that has not spawned in the past.

2. Mature. Fish will spawn during the current spawning season.

	Ovaries contain oocytes that are visible to the unaided eye. Testis contain milt.
3.Mature Non-spawner.	Fish not spawning during that particular year as determined by lack of gonadal development, but with having evidence of previous spawning indicated histologically.
4. Ripe.	Female ovary contains hydrated eggs that are often released upon examination. Male testis contains milt.
5. Spent.	Ovaries are flaccid and opaque in colour, with empty follicles and few if any mature eggs. Testis are extended but flaccid, pink in colour and milt is not present.

3.3.5 Histological analysis

Ovaries of some Atlantic cod were preserved for histological examination. Sixteen ovaries that appeared immature and two ovaries from spent females were examined, to compare the ovarian wall thickness of immature and mature females. Upon removal from a fish entire ovaries were placed in Bouin's solution for one month. Samples were then transferred to a 70% ethanol solution until processing several months later. To prepare tissue samples, ovaries were embedded in paraffin wax, sectioned using a microtome and stained in haematoxylon and eosin for observation.

To begin the embedding process, tissue samples were dehydrated in an alcohol series and cleared with xylene. Tissue samples were oriented in wax to produce cross sections through the ovarian wall when sectioned. A microtome was used to cut 7 μm thick cross sections which were then mounted onto slides. The cross sections were stained following a haematoxylin and eosin staining procedure described by Ham (1974). After a cover slip was mounted on the slide, sections were observed under 100x magnification to determine maturity status.

Maturity status was based on ovarian wall thickness, and presence or absence of empty egg follicles. In Atlantic cod, thick ovarian wall tissue indicates that spawning has occurred in the past, while a relatively thin ovarian wall suggests immaturity (Margaret Burton, Memorial University, pers comm). Post spawned females can be identified by the absence of maturing eggs, presence of empty follicles, and a thick ovarian wall. Empty follicles indicate that eggs have matured and been released. These observations along with information on age were used to estimate the range in size and age at first maturity.

3.3.6 Aging

Otoliths from 320 Atlantic cod were aged according to the technique described by Keir (1960). Otoliths were etched and broken along the sulcus acousticus. Both halves were then mounted in plasticine with the broken surface facing upward and viewed under a dissecting microscope. Light transmitted through the otolith illuminated a series of opaque and translucent bands, that represent periods of summer and winter growth, respectively (May 1966). Accentuation of the banding pattern was produced by casting a shadow over the top edge of the otolith with a razor blade.

To confirm my readings all otoliths were read blind by DFO personnel with extensive experience in aging Atlantic cod. There was an 87% agreement between my readings and those of DFO personnel. Where disagreements did occur they usually differed by a single year. Otoliths that produced discrepancies in age analysis were often of a poor or very poor quality according to criteria (Keir 1960) used by DFO.

3.3.7 Stomach content

Stomach contents were identified in the field. Stomach fulness was estimated on a 4 point scale where 4 was full and 1 was empty. Stomachs were opened and all the contents were examined. Food items were identified and counted.

A small scallop dredge, 20 x 90 cm, with a 3 mm mesh liner, was used to collect benthic samples from angling sites. Samples of the organisms collected during dredge tows were later used to verify the identity of major food items.

3.4 EARLY LIFE HISTORY INFORMATION

3.4.1 Collection and identification of eggs, larvae, and pelagic juveniles.

Atlantic cod eggs, larvae, and pelagic juveniles were collected during ichthyoplankton surveys (Table 1). A 1 m diameter ring net with a 333 μm mesh was used. Horizontal tows of 15 minutes duration were made at a depth of 2 m or 7 m.

Depth of the net was measured by the angle at which the tow rope entered the water, and was controlled by boat speed. Two m depth tows were approximately 914 m long, and 7 m depth tows were approximately 655 m long. Distances were estimated using aerial photographs and ground-truthed by measurements taken on the ground. The volume of water sampled was calculated based on the area sampled by the net and the length of the tow. Near surface tows (2 m) on average sampled 718 m^3 of water and 7m tows sampled 515 m^3 of water.

In 1998, samples were collected at various locations in Gilbert Bay, including The Shinneys. In 1999 samples were collected primarily in The Shinneys, and only limited sampling was done in the remainder of Gilbert Bay. The first samples in 1999 were collected on 28 May and 1 June. Based on the water temperature and the known rate of Atlantic cod development (Page and Frank 1989; Pepin *et al.* 1997), the second sampling period was timed to coincide with the predicted hatching time of eggs sampled in May. Sampling was conducted on June 23 and 24. A third set of samples was collected between August 6 - 12, near the same date as the 1998 sampling.

3.4.2 Preservation techniques

Eggs were preserved in a 5% un-buffered formalin / seawater solution. Some larvae and pelagic juveniles were preserved in formalin and others in 95% ethyl-alcohol. Formalin preservation ensured that pigmentation characteristics necessary to identify Atlantic cod eggs and larvae were preserved. Alcohol preservation was suitable for later genetic analysis and aging. Ovaries were preserved in Bouin's solution.

3.4.3. Atlantic cod Egg Development

Developing embryos were staged to provide an indication of spawning time and hatching time. The four stage scheme described by Markel and Frost (1985) was used. Eggs were characterized as stage I from the time of spawning until visible formation of the embryonic axis, about mid-gastrula. From this point until the embryonic axis reached half way around the yolk, eggs were considered stage II. After the embryonic axis was more than half way around the yolk, until it reached all the way around the yolk, eggs were considered stage III. The final stage of development was from stage III until hatching.

3.4.4 Identification of Atlantic cod eggs and larvae (< 15 mm)

Gadus morhua eggs in stage four of development, and larvae less than 15 mm in length, were identified to species based on pigmentation characteristics (Fahay, 1983). *Gadus morhua* larvae have three ventral accumulations of pigment, and two dorsal accumulations of pigment, on the tail. Egg diameter was also used as a guide to identify cod eggs. Cod eggs are between 1.2 and 1.6 mm in diameter (Fahay 1983).The only eggs observed in samples other than cod eggs were flatfish eggs. These were easily distinguished by their large size (Fahay 1983). No other gadids were captured during angling in Gilbert Bay, therefore it is unlikely that eggs from other gadid species were present in the immediate area.

3.4.5. Identification of Atlantic cod larvae and pelagic juveniles

It is difficult to distinguish between *Gadus morhua* and *Gadus ogac* during the late larval and early pelagic juvenile stages of development based on morphology (Ian Bradbury, Memorial University personal communication.). However between 30 and 40 mm, *G. morhua* may be distinguishable from *G. ogac* by the amount of pigmentation on the second anal fin. The second anal fin of *G. morhua* is pigmented back to the 8th or 9th fin ray, whereas fin pigmentation of *G. ogac* reaches further back than the 9th fin ray (Scott Grant, LGL, Ltd, St. John's, personal communication). Nuclear DNA analysis was used to confirm that larval and pelagic juvenile Atlantic cod captured in Gilbert Bay were *G. morhua*. Analysis was conducted by Dr. S. Carr at Memorial University of Newfoundland.

3.5 MATHEMATICAL ANALYSIS

3.5.1 Analysis of growth data

For the purpose of comparison growth is best described numerically. A growth equation developed by von Bertalanffy (1938), $l_t = L_\infty (1 - e^{-k(t-t_0)})$ has been shown to represent fish growth very well (Beverton and Holt 1957) and is the most commonly used model (Hilborn and Walters 1992). For this equation, l_t is length at age t, L_∞ is the theoretical maximum or final length, k is a constant (Brody growth coefficient) determining the rate of change in length increment, and t_0 is a scale correction giving the hypothetical age at zero length. A computer program developed by Dr. Y. Chen, Marine Institute, Memorial University, was used to fit growth data of Gilbert Bay cod to the von Bertalanffy growth equation.

3.5.2 Analysis of length frequency data

A Pearson chi^2 test of association described by Hayes (1981), was used to evaluate length frequency data . The probability estimates were based on sample relative frequencies, and analyzed in a 2 x 2 contingency table. In this test for independence, the expected frequency in any cell is taken to be the product of the frequency in the column times the frequency in the row, divided by the total N. The Pearson chi^2 in a test for association is:

$$\text{chi}^2 = \sum \sum (f_{ojk} - f_{ejk})^2 / f_{ejk}$$

where f_{ojk} is the frequency actually observed in cell (A_j, B_k), f_{ejk} is the expected frequency for that cell, and the sum is taken over all cells. In this 2 x 2 table the degrees of freedom is one. This analysis was used to compare the frequency of empty verses non-empty stomachs for ripe and non-ripe Atlantic cod, during the time of spawning.

4. RESULTS

4.1 TEMPERATURE AND SALINITY

Water temperature in The Shinneys remains sub-zero for 6 months, from December until May (Fig.6 and 8). After ice leaves the bay, usually in early May, near-surface water temperature increases rapidly as a result of local warming (Fig. 7). In 1999 water temperature at 3 m depth in The Shinneys increased from -1°C to 4°C between 7 May and 10 May. Water temperature at 8 m depth increased gradually from -1°C to 0°C between 10 May and 11 June, and then increased rapidly to 4°C by16 June. Water temperatures increased to 15°C at 3 m, and 12°C at 8 m depth in August. Water temperatures began to decrease in September, reaching 0°C in December.

Vertical profiles of temperature, salinity and density recorded on 1 June, 1997, are shown in Figure 8. All three parameters changed rapidly to a depth of 5-6 m. Water temperatures decreased from 5-6°C at the surface to -1°C at a depth of 5 m. Surface salinity ranged from 7 ppt to 13 ppt, with increasing distance from The Shinneys River. Salinity increased from 7 - 13 ppt at the surface to 28 ppt at 5 m depth.

4.2 ADULT LIFE HISTORY INFORMATION

4.2.1 Angling data

Angling catches for 1998 and 1999 are summarized in Table 2. In 1998, 897 Atlantic cod were captured, 678 were tagged and 107 were sacrificed for analysis. In 1999, 1112 fish were captured, 563 were tagged, and 111 were sacrificed. Twenty eight tagged fish were recaptured. Weight was obtained for 779 fish. Fish ranged in length from 15 cm to 100 cm.

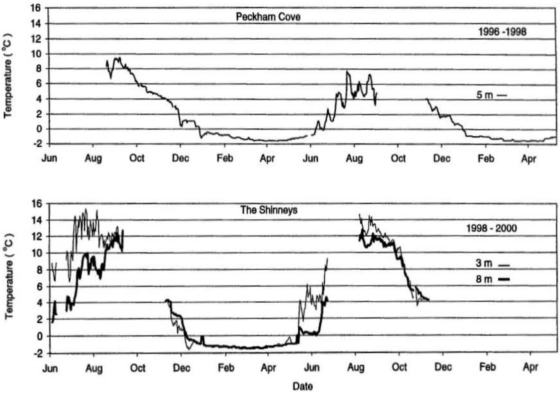


Figure 6. Water temperature recorded in Gilbert Bay at Peckham Cove, and The Shinneys.

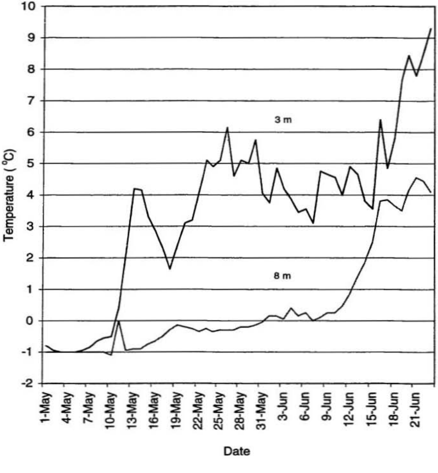


Figure 7: Water temperature of The Shinneys at depths of 3 m and 8 m during May and June, 1999.

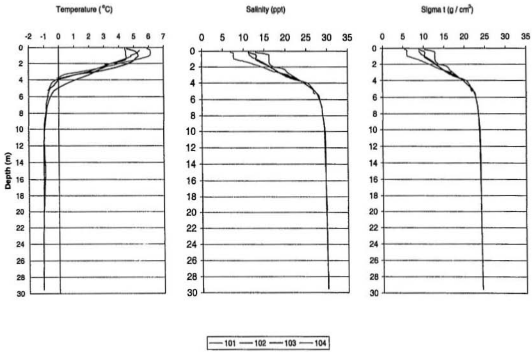


Figure 8: Vertical profiles of temperature, salinity, and sigma t sampled at four locations in The Shinneys June 1, 1997. Sample locations are indicated on Figure 4.

4.2.2 Length frequency analysis

The length range of Atlantic cod caught in 1998 and 1999 was very similar, however the frequency of various size groups differed (Fig. 9). During 1999, compared to 1998, we caught 10.8 % more fish less than 30 cm, 10.5 % fewer fish between 30 and 50 cm, and 9% more fish greater than 50 cm (Fig. 10). The 1999 length frequency distribution is shifted to the right of the 1998 distribution (Fig. 11). The mean length (42 cm) was the same each year.

In May 1998 and June 1999 the length frequency distributions of Atlantic cod caught in The Shinneys were similar(Fig. 12). The average length of Atlantic cod caught in The Shinneys in August was less than the average length of fish caught in May and early June. No fish less than 30 cm TL were caught in River Out in August in 1998 or 1999. Fish caught in The Shinneys in August combined with those captured in River Out in August, produce a length frequency distribution similar to that in The Shinneys in May 1999 and June 1998 (Fig. 12).

4.2.3 Age and growth

Length at age was determined for 302 fish, ranging from 17 to 65 cm and 2 to 15 years (Fig. 13). The von Bertalanffy growth curve (Fig. 14) fitted the mean length at age data from cod sampled in The Shinneys. L infinity was approximately

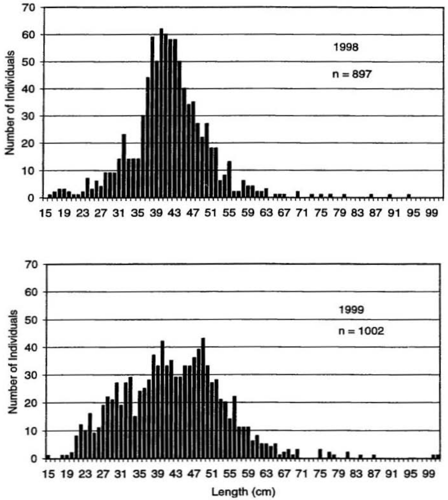


Figure 9. Length frequency distributions of Atlantic cod sampled in The Shinneys during 1998 and 1999

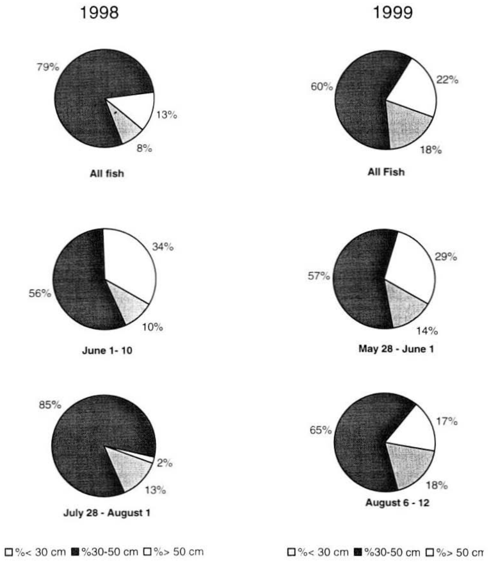


Figure 10. Proportions Atlantic of cod caught in The Shinnies during 1998 and 1999 grouped into three length intervals , < 30 cm, 30 - 50 cm and > 50 cm.

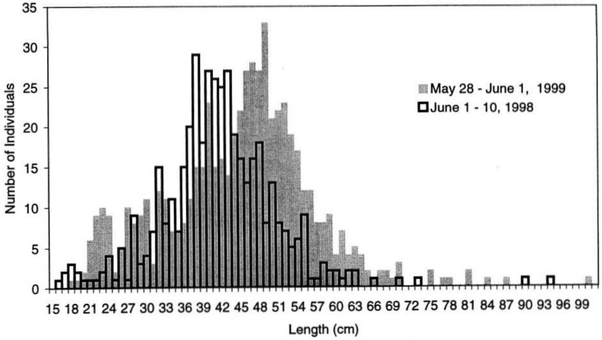


Figure 11. Comparison of the length frequency distribution of angled Atlantic cod in The Shinneys in May 1998 and June 1999.

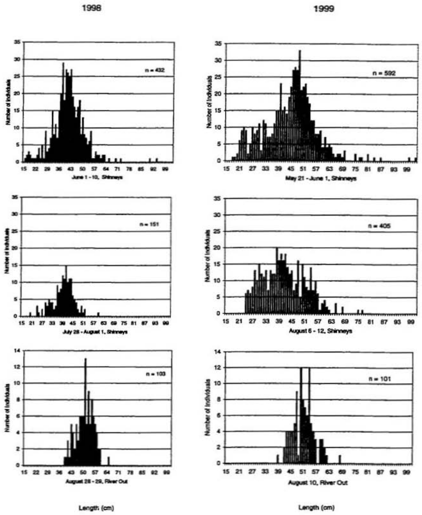


Figure 12. Length frequency distribution of Atlantic cod sampled in The Shinneys in May and August and River Out in August, during 1998 and 1999.

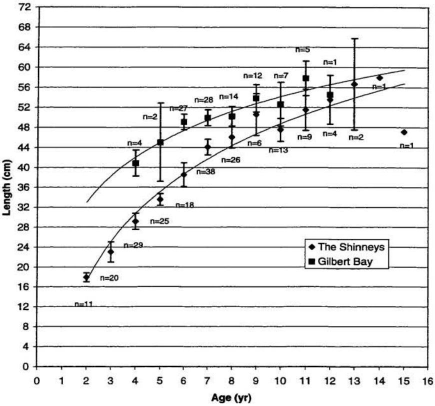


Figure 13: Length-at-age of Atlantic cod sampled in The Shinneys and Gilbert Bay. 95% confidence intervals are indicated.

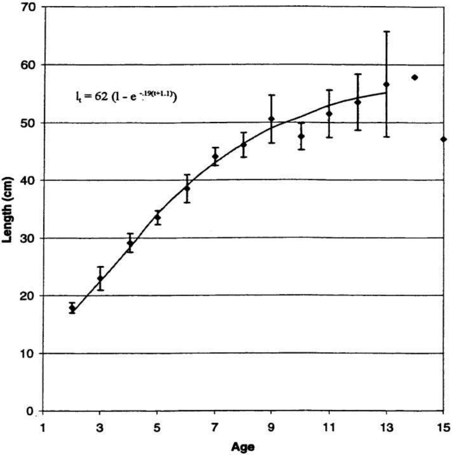


Figure 14. Mean length-at-age of Atlantic cod sampled in The Shinneys fitted to the von Bertalanffy growth curve. 95% confidence intervals are indicated.

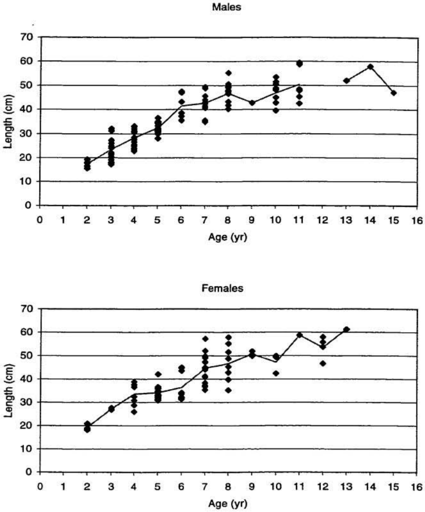


Figure 15. Length at age of male and female Atlantic cod captured in The Shinneys during 1998 and 1999. Line connects mean length at age

60 cm. In general fish 13 yrs or older were no longer than some 10 year old fish, indicating a slow growth rate at this age. Fish as large as 100 cm were captured, but no ages were determined for fish larger than 65 cm because of their low numbers. Lengths-at-age were variable, particularly for females ages 7 and 8 (Fig.15). Males appeared to have less variability in length-at-age. On average females tended to exhibit slower growth than males from 4 years of age to 6 years of age (Fig.15).

Data from recaptured fish show a decreasing growth rate as age increased (Fig.16). Growth rate was determined from 17 fish which were recaptured after a minimum of 324 days post release. These fish ranged from 5 to 13 years of age, and 30 to 63.5 cm in length. The data indicated a great deal of variation in growth rate within year classes, particularly for 7 yr old Atlantic cod.

The 1998 and 1999 length frequency distributions contain distinct modes in the 15-30 cm length range. In the 1998 length frequency data, the mode between 16 and 20 cm, with an average length of 18 cm, represents 2 year old Atlantic cod (Fig. 17). Three year old Atlantic cod (21-25 cm) are not well represented in the 1998 length frequency distribution, but they are well represented in the 1999 length frequency distribution. In 1999 few two year old Atlantic cod were caught. It is difficult to identify individual year class modes older than 3 yrs in the length frequency distributions.

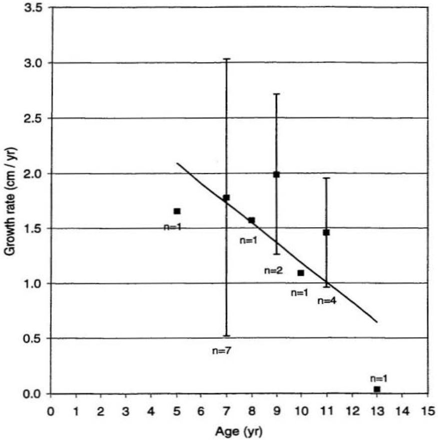


Figure 16. Mean annual growth rate-at-age of Atlantic cod tagged and recaptured in The Shinneys. Growth information was determined from recaptured tagged fish (see Table 3) .

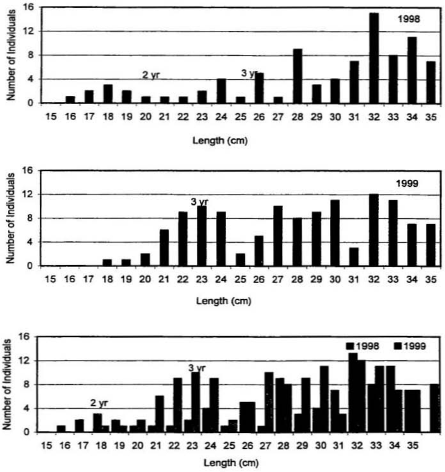


Figure 17: Length frequency distributions of Atlantic cod sampled in The Shinneys indicating year classes 2 and 3.

Table 3 . Location data for 28 tagged Atlantic cod recaptured in The Shinneys and River Out. Site locations correspond to Figure 4.

Tag site	Date	Recapture site	Recapture date	Days between capture	Distance from tagging location (km)
X**	14-Aug-96	A	21-May-99	1011	10
Y**	04-Aug-97	B	27-May-99	661	7
Y**	03-Aug-97	C	27-May-99	662	7
C*	21-May-99	L	10-Aug-99	71	5
D*	07-Jun-98	L	10-Aug-99	396	5
C	08-Jun-98	C	01-Aug-98	54	0
C	29-Jun-98	B	20-May-99	324	0.6
C	08-Jun-98	C	22-May-99	348	0
B	09-Jun-98	B	24-May-99	349	0
C	08-Jun-98	C	25-May-99	347	0
A	25-Jun-98	B	25-May-99	334	0
C	08-Jun-98	B	29-May-99	355	0.6
C	26-Jun-98	B	31-May-99	339	0.6
B	25-Jun-98	B	08-Aug-99	409	0
B	28-Jul-98	B	08-Aug-99	397	0
C	28-Jun-98	B	08-Aug-99	397	0.6
C	29-Jun-98	C	09-Aug-99	397	0
B	05-Jun-98	B	09-Aug-99	430	0
B	05-Jun-98	B	09-Aug-99	430	0
B	05-Jun-98	B	09-Aug-99	430	0
C	22-May-99	C	11-Aug-99	67	0
A	26-May-99	B	11-Aug-99	71	0.8
K	02-Jun-98	B	11-Aug-99	435	0.7
B	24-May-99	B	11-Aug-99	69	0
B	24-May-99	B	11-Aug-99	69	0
B	27-May-98	B	11-Aug-99	441	0
B	25-Jun-98	B	12-Aug-99	413	0
C	22-May-99	J	12-Aug-99	72	0.9

** Initially tagged in Gilbert Bay
* Recaptured in River Out

4.2.4 Tag recaptures from sampling

Most (16 of 23) fish recaptured in The Shinneys were caught where they were tagged (Table 3). Seven others were recaptured less than one km from where they were tagged, and two fish were recaptured in River Out in August.

Three fish initially tagged as part of a Atlantic cod farming experiment conducted in Gilbert Bay (Wroblewski *et al.* 1998) were recaptured in The Shinneys in May 1999 (Table 3). These fish were caught and tagged in Gilbert Bay in August 1996 and 1997, and placed in cages there. One fish tagged in 1996 and recaptured in The Shinneys in 1999 was a female in spawning condition. The other two fish, both males tagged in August 1997, were ripe when recaptured in The Shinneys in May 1999.

In May, 1999, the ratio of tagged to untagged fish caught during sampling was 1 : 60. Most of the fish caught were males. Our inability to catch as many female Atlantic cod suggests recaptures were biased towards males. During August 1999 we captured 422 fish via angling and the ratio of tagged to untagged fish was 1 : 24.8.

4.2.5 Tag recaptures from the commercial fishery

A total of 41 tags was returned to DFO from commercial fishing in Gilbert Bay in 1998 and 1999. From tag returns we identified the general location of recapture, date of recapture, and average size of tagged Atlantic cod caught in the commercial fishery (Table 4) . In 1998, 678 Atlantic cod were tagged in The Shinneys. Information from eight recaptures was collected from the 1998 commercial index fishery conducted between September 24 and October 16. This fishery took place throughout the main arm of Gilbert Bay . During the 1999 commercial fishery, 33 Atlantic cod with external tags were caught near the mouth of Gilbert Bay. Tagged fish were recaptured at the mouth of Gilbert Bay as early as 8 July and as late as 16 October, 1999.

Table 4. Summary of tag returns from the commercial fishery in Gilbert Bay in 1998 and 1999.

Commercial fishery	Tag Date	Recapture date	n	Mean length (cm)	St. Dev (cm)
1998 Index	June 4 - 8, 1998	Sept 24 - Oct 16	8	42.4	9.1
1999 part 1*	June 5 - 9, 1998	July 8 - 31	2	53.7	6.8
	May 20-31, 1999	July 8 - 31	4	56.6	9.2
1999 part 2	June 3 - 30, 1998	Sept 13 - Oct 16	14	42.8	7.7
	July 28,1998	Sept 13 - Oct 16	3	44.1	16.4
	May 21 - 29, 1999	Sept 13 - Oct 16	10	49.8	9.3

* The 1999 commercial fishery consisted of two parts, part one July 8 - 31, and part 2 September 13 - October 16.

4.2.6 Condition

Condition of Atlantic cod, on average, was between 0.85 and 0.96 (Table 5). Condition in June 1998 and late May 1999 was similar. In addition the condition of Atlantic cod in August was not different from that in May and June. The weight on length relationship (Fig. 18) was:

$$W = 6 \times 10^{3} L^{-3.11}, r^2 = 0.98$$

where W represents weight (g) and L represents length (cm). Weight-length relationships of female and male Atlantic cod sampled in the Shinneys in May are shown in Figure 19.

4.2.7 Stomach contents

Atlantic cod in The Shinneys ate a wide variety of benthic organisms (Fig. 20). Fish comprised a small portion of the diet. Occasionally stickleback (*Gasterosteus aculeatus*), gunnels (*Pholis* spp.), and radiated shannies (*Ulvaria subbifurcata*) were found in stomach samples. Individual Atlantic cod tended to have a small number of different food items in their stomach. On average 1.7 food types were found in a stomach suggesting that individual Atlantic cod tended to specialize on certain food items. However, a wide range of different food items was eaten by different fish.

Atlantic cod sampled during the 1998 food fishery were also primarily feeding on benthic invertebrates. Samples were collected from three locations in Gilbert Bay: the outer part of the bay, River Out, and the inner part of Gilbert Bay. Generally the same range of food items was found in stomach samples as in The Shinneys. However, samples from the outer part of Gilbert Bay indicated that fish were feeding primarily on scallops (Fig. 21).

Table 5. Condition of Atlantic cod, sampled in The Shinneys at various length intervals and sampling dates. Condition (Formula in text) of males and females are indicated for Atlantic cod sampled in May 1999.

	Sampling dates	Length intervals																	
		10 - 20 cm			20 - 30 cm			30 - 40 cm			40 - 50 cm			50 - 60 cm			> 60 cm		
		n	Mean	S.D.	n	Mean	S.D.	n	Mean	S.D.	n	Mean	S.D.	n	Mean	S.D.	n	Mean	S.D.
1998	June 1 - 10	9	0.78	0.087	22	0.85	0.098	50	0.87	0.065	44	0.90	0.072	14	0.88	0.066			
	June 24 - 30	1	0.75		4	0.82	0.045	53	0.91	0.068	112	0.92	0.097	19	0.93	0.057	4	0.99	0.120
	July 28 - Aug 6				11	0.85	0.045	49	0.86	0.055	46	0.87	0.069	4	0.88	0.144			
1999	May 20 - June 1	1	0.66		34	0.84	0.140	80	0.86	0.110	121	0.87	0.130	81	0.89	0.078	18	0.90	0.100
	Males (May)				3	0.87	0.068	29	0.86	0.064	81	0.86	0.150	48	0.87	0.070	10	0.90	0.100
	Females (May)							26	0.90	0.160	32	0.98	0.090	23	0.91	0.055	4	0.91	0.120
	Aug 6 - 12				1	0.90					10	0.90	0.050	2	0.91	0.110			

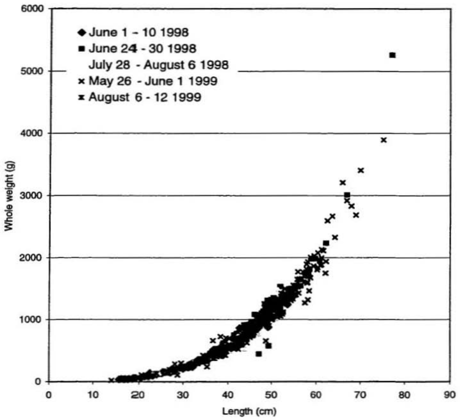


Figure 18. Weight-length relationship for Gilbert Bay cod sampled June 1-10, 1998 (n= 143), June 24 - 30, 1998 (n = 198), July 28 - August 6, 1998 (n = 116), May 26 - June 1, 1999 (n = 339), and August 6 - 12 1999 (n = 13).

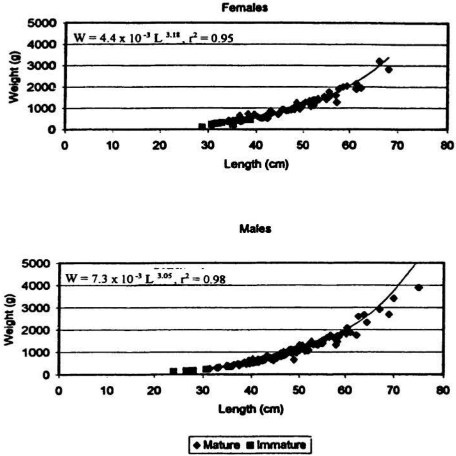


Figure 19. Weight-length relationship of mature (n = 153) and immature (n = 5) male and mature (n = 74) and immature (n = 15) female Atlantic cod sampled in The Shinneys May 1999.

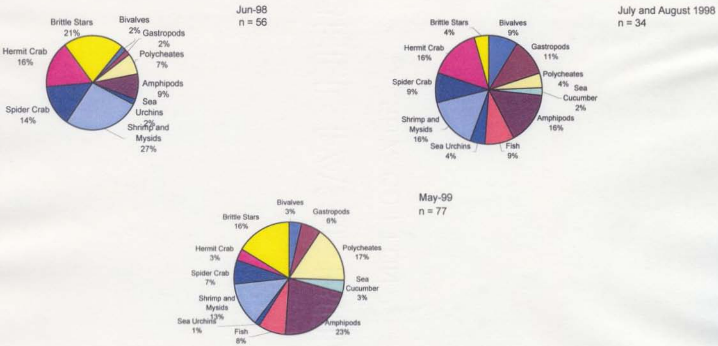


Figure 20 : Occurrance of major food types found in Atlantic cod stomachs from June 1998, July- August 1998, and May 1999.

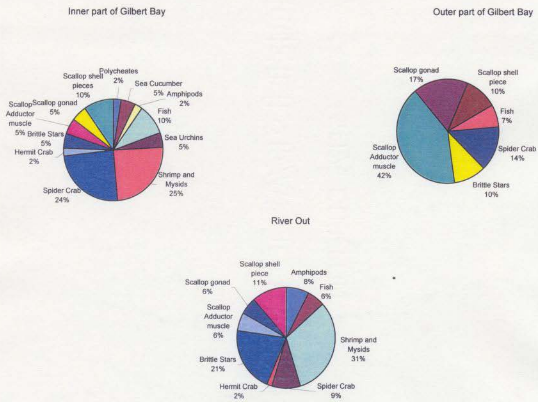


Figure 21: Occurrance of major food types found in Atlantic cod stomachs, sampled at three locations in Gilbert Bay August 27 and 28 ,1998.

Fourteen of sixteen fish with food in the stomach had eaten scallops. Twelve of the sixteen Atlantic cod sampled had the adductor muscle in their stomach, five had scallop gonadal tissue and three had pieces of scallop shell. Some fish had all three. Scallop parts were also found in stomach samples from the other locations, although this did not occur as often as in samples collected from the outer part of Gilbert Bay. Brittle stars, spider crab and shrimp occurred most often in stomach samples from River Out and the inner part of Gilbert Bay. On average 2.4 different food items were found in individual stomach samples.

4.2.8 Stomach contents of ripe fish

During the spawning season ripe Atlantic cod, both males and females, appeared to have less food in their stomach than non-ripe Atlantic cod but the difference was not significant ($chi^2 = 3.64$, df = 1, Alpha = .05) (Fig. 22). There was no significant differences in the presence of food between immature males, immature or non-spawning females, ripe males or ripe females. Since samples were collected by angling, all fish were actively pursuing a potential food item at the time of capture. Atlantic cod stomachs were generally half full, estimated to the nearest 1/4, and no fish were observed to have extremely distended stomachs.

4.2.9 Spawning

The majority of fish captured between May 20 and June 1, 1999, were ripe, releasing milt or eggs upon examination. We captured and released 594 Atlantic cod, 434

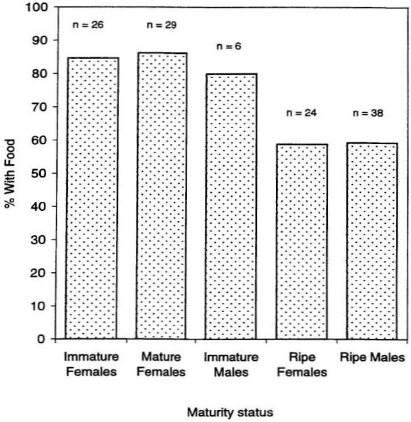


Figure 22 . Percentage of sampled Atlantic cod with food items in their stomach during the spawning season, May 21 - June 1, 1999.

were ripe and released eggs or milt. The remaining 164 fish did not release eggs or milt, thus sex could not be determined without observing internal reproductive structures. The majority of ripe Atlantic cod captured were males; 334 Atlantic cod released milt when examined and 100 Atlantic cod released eggs. Males as small as 32 cm released milt, and females as small as 36 cm released eggs. Fish that did not release eggs or sperm were usually less than 40 cm in length.

Seventy-four fish were examined to determine sex and sexual maturity status, based on examination of the gonad. Testes of 27 Atlantic cod ranging in size from 24 - 52 cm were examined. The smallest mature male was 31 cm, and the largest immature male was 35.5 cm. Males were observed to reach sexual maturity between 4 and 6 years of age. Ovaries of 47 Atlantic cod, ranging in size from 28.8 - 61.3 cm were examined to determine maturity status. The smallest mature female was 31.4 cm and the largest immature female was 42.1 cm. Females were observed to reach sexual maturity between four and eight years of age.

Histological analysis indicated that our field observations were correct in determining the maturity status of female cod that appeared immature based on examination of the ovary. The ovarian wall of immature fish (Fig. 23.1) was several times thinner than that of mature fish (Fig. 23.2). Figure 23.3 is a cross section through the ovarian wall of a mature non-spawner. This fish was captured during the 1999 spawning season. It did not have empty egg follicles, only immature eggs were observed, and it had thick ovarian wall tissue. Figure 23.4 is a cross section of a cod ovary with atretic eggs.

The atretic eggs are larger in size than immature eggs, suggesting these eggs began to mature but that resorption occurred at some point in development.

Figure 23. Histological cross sections through cod ovaries. Ovaries were sampled during the 1999 spawning season and show evidence of spawning omission and atresia.

Figure 23.1 Ovarian wall thickness of an immature Atlantic cod.
Bar = 200 μm

A Ovarian wall
B Immature oocyte

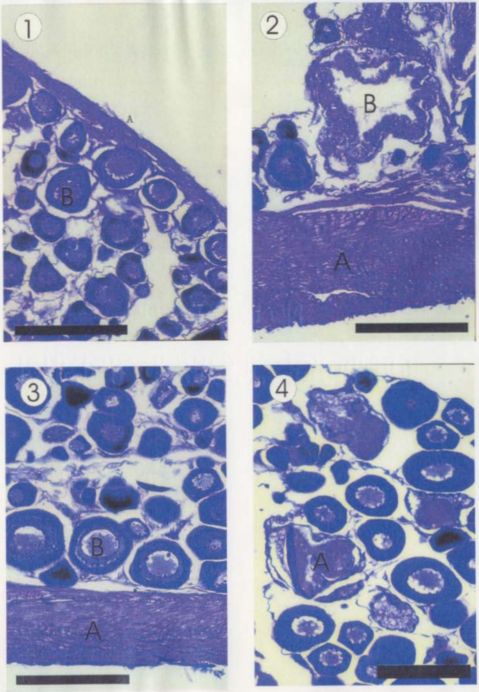
Figure 23.2 Ovarian wall thickness of mature post spawned Atlantic cod, with empty egg follicle.
Bar = 200 μm

A Ovarian wall
B Empty egg folicle

Figure 23.3 Ovarian wall thickness of mature non-spawning Atlantic cod.
Bar = 200 μm

Figure 23.4 Atretic eggs surrounded by immature oocytes.
Bar = 200 μm

A Atretic egg


1
A
B
2
B
A
3
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4
A

4.3 EARLY LIFE HISTORY OF GILBERT BAY COD

4.3.1 Spawning season, May 1999

Eggs were collected in The Shinneys on May 28 and June 1,1999 (Table 6). Egg density was variable, ranging from 3.6 eggs / m^3 to 53.8 eggs / m^3. Sampling indicated that eggs were located at a depth of approximately 7 m, and no eggs were collected in the upper 2 m of the water column. Most eggs (94%) collected in May and June were in the first stage of development. A few eggs were in the 2nd and 3rd stage of development (Fig. 23). Mean egg diameter was 1.46 mm (range of 1.25- 1.60 mm).

The density of cod eggs during the 23-24 June sampling period was much lower than in May and early June (Table 7). Egg density ranged from 0.3 to 5 eggs / m^3. Eggs and larvae were found throughout the water column. The majority of eggs were in the later stages of development or hatched, however approximately 18 % were in stage one of development (Fig 24).

Table 6. Egg density in individual 15 minute ichthyoplankton tows made during the 1999 spawning season in The Shinneys.

Date	Depth (m)	# of Eggs	# Eggs / m^3
28-May	2	0	
28-May	2	0	
28-May	7	6653	12.9
28-May	7	3455	6.7
1-Jun	2	0	
1-Jun	7	1872	3.6
1-Jun	7	27686	53.8
1-Jun	7	3417	6.6
			Mean = 16.7

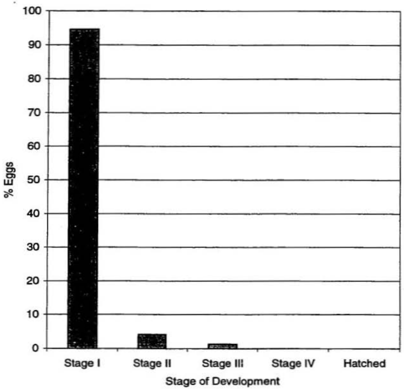

Figure 24. Developmental stage of Atlantic cod eggs from ichthyoplankton samples collected in The Shinneys on May 28 and June 1, 1999.

Table 7. Egg density from individual 15 minute ichthyoplankton tows, made on June 23-24 1999, near the time of peak hatching in The Shinneys.

Location	Depth (m)	# of eggs	Eggs / m^3
The Shinneys	1	952	1.3
	1	692	1.3
	3	1884	3.7
	5	1081	2.1
	7	2582	5.0
	7	479	0.7
	7	239	0.5
	8	191	0.3
Gilbert Bay (Main Arm)	7	184	0.4
			Mean = 1.7

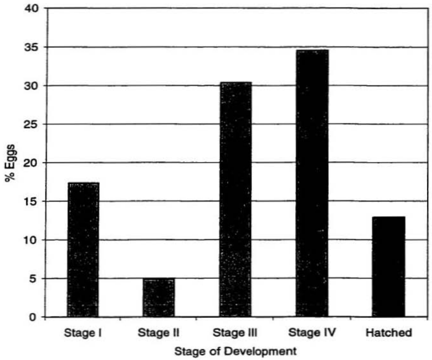

Figure 25. Developmental stage of Atlantic cod eggs and recently hatched larvae (<4 mm TL) from ichthyoplankton samples collected in The Shinneys, June 23, 1999.

4.3.2 Cod larvae

Densities of larval cod sampled in Gilbert Bay and The Shinneys in 1998 and 1999 are indicated in Table 8. The overall population density estimate of larvae and juvenile Atlantic cod was 38 % greater in 1998 than in 1999. The density of larvae and pelagic juvenile cod sampled in the Shinneys's was similar in 1998 and 1999, whereas densities in Gilbert Bay was an order of magnitude less in 1999 than in 1998. In 1999 cod density was higher in The Shinneys than in Gilbert Bay, however in 1998 densities were greater in Gilbert Bay than in The Shinneys.

Higher densities of larval cod were found near the surface at dusk, than during the day (Table 9). Samples taken between 19:00 and 21:00 hrs. had a significantly higher number of cod than samples taken earlier during the day. Evening sampling was done at only one site, and this site had a higher density of Atlantic cod than other areas sampled.

The range in length of Atlantic cod larvae and pelagic juveniles was greater in 1998 than in 1999 (Fig. 25). In 1998 Atlantic cod ranged in length from 16 mm to 55 mm, 65 % of which were pelagic juveniles. In 1999 most Atlantic cod were between 11 and 34 mm in length, and only 6.5% were pelagic juveniles. On average the length of Atlantic cod larvae captured in Gilbert Bay were larger than those captured in The Shinneys at the same time during 1998 and 1999 (Fig. 26).

Table 8. Density and mean length of Atlantic cod larvae from ichthyoplankton tows, conducted during the day, between late July and early August, 1998 and 1999.

Date	Location	Tows	Sample Size	Vol. sampled (m^3)	Larvae / 1000 m^3	Mean Length (mm)	St.Dev
1998	The Shinneys	12	13	8616	1.5	30.2	8.4
	Inner part of Gilbert Bay	18	67	12924	5.18	35.3	9.5
	Outer part of Gilbert Bay	17	9	12206	0.74	33.3	6.95
	Total	47	89	33746	2.64		
1999	The Shinnneys	37	45	26566	1.69	21.75	5.84
	Inner part of Gilbert Bay	11	4	7898	0.51	25.4	4.5
	Total	48	49	34464	1.42		

Table 9. Larval Atlantic cod density during the day and at dusk, from surface ichthyoplankton tows in The Shinneys. Evening samples were conducted at sample site F, indicated on Figure 4.

Location	Sampling time	Tows	Sample size	Vol. sampled (m^3)	Mean Larvae Density (Larvae / 1000 m^3)
Site F	17:30 - 20:00	9	44	6462	6.81
Site F	8:30 - 13:30	10	20	7180	2.92
Other Sites	8:30 - 13:30	27	25	19386	1.29

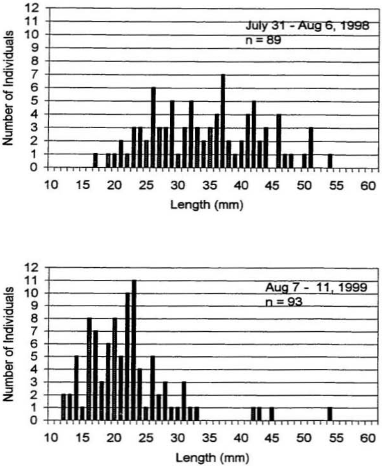

Figure 26. Length frequency distributions of Atlantic cod larvae (< 30 mm) and pelagic juveniles (>30 mm) sampled in Gilbert Bay and The Shinneys, 1998 and 1999.

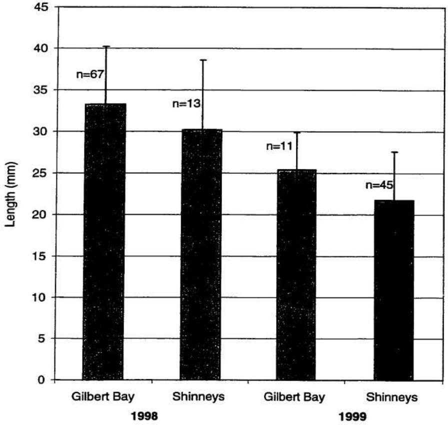

Figure 27. Mean length of Atlantic cod larvae sampled from the inner part of Gilbert Bay and The Shinneys, July 31-August 6 1998 and August 6 - 12, 1999.

4.3.3 Mortality prior to settlement

The density of cod eggs and larvae in The Shinneys decreased exponentially through the early stages of development (Fig. 27). Stage 1 eggs decreased from 17 eggs / m^3 in May-June to 1.7 eggs / m^3 by 23 June, when most eggs were about to hatch. Larval density was estimated to be 0.001 larvae / m^3 during the last sampling period, 6-12 August.

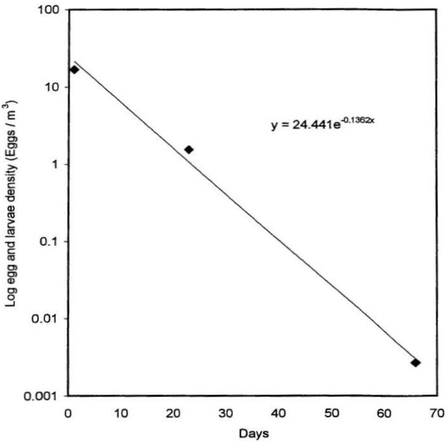

Figure 27.Mean density of eggs and larvae in 1999, based on ichthyoplankton tows in The Shinneys and main arm of Gilbert Bay.Samples were collected during spawning (day1), near peak hatching (Day 23), and prior to juvenile transformation (day 66)

5. DISCUSSION

Evidence from tagging, morphometric and physiological studies suggests that portions of the northern cod stock consists of local populations (Templeman 1962, 1979): some offshore Atlantic cod do not migrate inshore (Lear 1984), and some inshore Atlantic cod remain in bays year round (Goddard *et al.* 1994; Wroblewski *et al.*1994). Genetic data also suggest that subpopulations exist within the northern cod population (Ruzzante *et al.*1997), some of which are more distinct than others (Ruzzante *et al.* 2000). All studies have questioned whether northern cod is a panmictic unit.

Gilbert Bay has a genetically distinctive population of Atlantic cod (Ruzzante *et al.* 2000) and it is the only known inshore population of Atlantic cod along the Labrador coast. Movement patterns based on sonic tracking indicate that Atlantic cod in Gilbert Bay reside there throughout the year (Green and Wroblewski submitted). Adaptation of Gilbert Bay cod to this inshore environment, as inferred from genetic differences (Ruzzante *et al.* 2000) and movement, suggests that their life history characteristics may differ from other populations. The present study indicates that the biology of Gilbert Bay cod differs from that of other northern cod.

5.1 AGE STRUCTURE

Most Gilbert Bay cod sampled were between 35 and 60 cm in length with few being sampled older than 10 years. A small number of larger and presumable older fish were captured. The age structure of Gilbert Bay cod in 1998 and 1999 suggests that the majority were born after the closure of the northern cod fishery in 1992. Length frequency distributions of fish caught in June, 1998 and May - June, 1999 are similar with the 1999 distribution shifted to the right. The shift is thought to represent growth, as determined from modal analysis of year classes 2 and 3, and length at age data.

Modal analysis of 2 and 3 year olds caught in The Shinneys in 1998 and 1999 may provide information on the relative strengths of the 1997, 1996 and 1995 year classes. During the second year of growth Gilbert Bay cod are estimated to grow from a mean length of 18 cm to a mean length of 23 cm. The number of two year olds caught in 1998 relative to 1999 indicates that the 1996 year class was stronger that the 1995 year class. The 1996 year class is well represented in the 1999 length frequency distribution as three year olds. The absence of a 2 year old mode in 1999 indicates that the 1997 year class was poor relative to the 1996 year class. In addition, ichthyoplankton surveys suggest higher larval densities in 1998 than in 1999. Together this information may suggest a recent trend whereby relatively unsuccessful year classes are followed by successful year classes.

A strong 1996 year class in Gilbert Bay is interesting in that inshore and offshore surveys indicated that the 1996 year class was a unsuccessful year class for northern cod. Beach seine surveys conducted in Newman Sound, Newfoundland (Robert Gregory, Memorial University, personal communication) and pelagic juvenile surveys conducted by DFO from southern Labrador to the southern Grand Bank, including inshore areas of the northeast coast of Newfoundland, (John Anderson, DFO personal communication) indicate that the 1996 year class was the smallest since 1994. This suggests that Atlantic cod in Gilbert Bay are exposed to different conditions than those offshore, and that factors determining their year class strength may be geographically localized. This difference in year class strength among various locations emphasizes the importance of geographic diversity within the spawning component of Atlantic cod.

5.2 GROWTH

Temperature strongly affects Atlantic cod growth (Brander 1995). Typically, Labrador Atlantic cod grow slowly (May *et al.* 1965) as a result of the low water temperature. The growth rate of Gilbert Bay cod is slower than that of Atlantic cod from NAFO division 2J, and more similar to, but still less than that of Atlantic cod in NAFO divisions 2G and 2H (May 1966), located further to the north. The curve describing growth in divisions (2G and 2H, 1963 - 64) is a fitted von Bertalanffy curve, with the following form:

$$l_t = 65\,(1 - e^{-.20\,(t-.35)}),$$

whereas the growth curve describing Gilbert Bay Atlantic cod when fitted to the von Bertalanffy curve is:

$$l_t = 62\,(1 - e^{-.19\,(t+1.1)}).$$

This slow growth rate is likely largely attributed to cold water temperatures in Gilbert Bay for approximately six months of the year. However, The Shinneys and most of Gilbert Bay is shallow, and the temperature regime fluctuates greatly between winter and summer. In Gilbert Bay, surface water temperatures in August are similar to surface temperatures (0-5 m depth) in Placentia Bay (Bradbury *et al.* 1999). Water temperatures near the surface are higher in Placentia Bay during April and May, but water temperatures in both areas reach 15 °C in August. Water temperatures in Labrador bays are similar to those along the south and east coasts of Newfoundland in August (Steele 1975). The initial seasonal increase in surface water temperature appears to occur later in the year in Gilbert Bay, than in bays along southern and eastern Newfoundland. Newfoundland bays are usually free of ice during winter allowing surface temperatures to increase earlier in spring. Since summer water temperatures in Gilbert Bay should permit rapid summer growth, factors other than water temperature may cause the relatively slow growth of Atlantic cod in Gilbert Bay.

Atlantic cod sampled during the inshore fishery in July and August 1963 and 1964 in NAFO division 2J, indicated that Atlantic cod in their 5th season of growth were on average 47 cm in length (May 1966). Similarly Lilly *et al.* (1999), based on samples from autumn bottom trawl surveys, indicated that the mean length of 5 year old northern cod was 47.7 cm. Five year old cod from The Shinneys sampled in May and June were on average 34 cm in length and 6 year old's were on average 37 cm. Age 5 Atlantic cod from Ogac Lake, Baffin Island ranged in size from 27 - 65 cm in length (Patraquin 1966). In NAFO division 2J, female cod mature between 5 and 6 years of age (Lilly *et al.* 1999) and historically 50 % of females matured at 6.5 yrs of age (May 1966). Therefore, the differences in growth between Gilbert Bay cod and those of coastal Labrador until age five are likely due to factors other than the energetic requirements of reproduction. At 10 years of age, cod sampled in 2J during 1991 bottom trawl surveys were 65.5 cm in length (Lilly *et al.* 1999), whereas Gilbert Bay cod were on average 47 cm long. Cod from Ogac Lake ranged in size from 40-101 cm at 10 years (Patriquin 1966).

Variation in length at age, based on the samples obtained in Gilbert Bay, are similar to that of northern cod of divisions 2J , 3K, and 3L (Lilly *et al.* 1999). However no cod > 65 cm TL were aged, therefore the variation in size at age may be greater than indicated. The largest cod captured in Gilbert Bay was 100 cm in length. Based on the fitted von Bertalanffy growth curve a cod of this length would be very old.

Increases in growth rate following a period of slow growth have been reported where data have been available for cod older than 11 years (May 1966). Such increases have been attributed to a possible change in diet as older fish consume relatively more fish, including other Atlantic cod (May *et al.* 1965; Powles 1958). Atlantic cod in Ogac Lake apparently have the largest variation in length at age on record and the population is described as consisting of fast growers and slow growers, with a selection pressure exerted for fast growers. Females in this population do not mature until 85-90 cm in length while males mature at a length of 55 - 70 cm. Only fast growing fish reach maturity while slower growing fish are cannibalized before reaching maturity (Patriquin 1966). Stomach contents of Gilbert bay cod indicate that cannibalism is not a significant contributor to mortality of smaller fish. However, stomach contents of fish larger than 65 cm were not examined.

Since there is presently a small number of large fish in the Gilbert Bay population any effects of cannibalism are likely small at the present time. Three accounts of cannibalism were observed when smaller fish (< 40 cm) were being reeled in after being caught. This activity may have been provoked by the unusual behaviour of the smaller fish after taking the lure. One 84 cm long cod did regurgitate an Atlantic cod that was 8 years of age. Based on its age its length could have ranged from 35 to 58 cm.

5.3 FEEDING

Capelin is a major food for Atlantic cod, particularly cod between 36 - 71 cm in length (Turuk 1968; Lilly 1984a). During the late 1970's when Atlantic cod and capelin were relatively abundant in NAFO division 2J, fish accounted for the largest portion of the Atlantic cod diet (deGraaf *et al.* 1980). When preferred foods are lacking Atlantic cod tend to feed more on benthic animals (Turuk 1968). However total energy compensation by feeding upon foods other than capelin, in the absence of capelin, is not thought to occur, particularly in NAFO division 2J (Lilly 1987). Lilly's (1987) review suggests that a decrease in capelin could result in changes in Atlantic cod vital rates such as growth, fecundity, age or size at maturity, and mortality.

Capelin have not been observed in Gilbert Bay for at least the last several years (George Rowe, Port Hope Simpson, personal communication). The consequences of the lack of a preferred food, if any, is a reduction in energy. Absence of primary food items, such as capelin, could affect the amount of energy allotted for maintenance, growth, and reproduction.

Alterations in the annual reproductive investment, by long lived iteroparous species such as winter flounder (*Pseudopleuronectes americanus*) have been associated with accumulated nutritional status and feeding (Burton 1994). Resorption of maturing oocytes and annual spawning omissions by Atlantic cod have been described by Rideout and Burton 2000, may be linked to the energetic status of females during some point in the reproductive cycle. In addition, females that mature but are in poor condition may down-regulate the amount of energy invested into spawning (Burton 1994). Life history theory predicts that females should alter their investment in a particular breeding attempt according to the likelihood of its success (Williams 1966). Histological evidence of spawning omission and atresia indicate that some individuals did not acquire the necessary energetic requirements to spawn. However Gilbert Bay cod do mature while feeding on the food available, which for the past several years did not include capelin.

Atlantic cod in Gilbert Bay fed primarily upon benthic invertebrates. Fish were seldom found in stomachs and capelin were not found in any of the stomach samples. Gilbert Bay cod feed on a wide range of food items, but individuals were observed to feed on a relatively small number of items. Abundance or availability of prey is thought to be important in selection of prey by predatory fish (Allen 1981) including Atlantic cod (Lilly and Rice 1983). Stomach samples indicated that individual cod were specializing on a small number of food items at a given time. Different cod in the same area were often feeding on different types of food. This suggests that individuals may develop a search image for a particular food item. How such a search image might be established or how long it might last is not known.

Atlantic cod captured at some locations in Gilbert Bay had scallops in their stomach, both with and without shell material. Commercial scallop fishing in the area may provide this food source. Only the scallop adductor muscle is kept by fisherman and the remainder, including the gonad, is discarded. Scallops are processed aboard the scallop boats and discards are thrown overboard. Gilbert Bay cod may feed primarily on discarded scallop parts but interestingly, the commercially important adductor muscle was found in a relatively large number of stomachs. Most likely, the dredges used to catch scallops crush some shells enabling cod to eat the contents, including the adductor muscle.

Some authors indicate that feeding by Atlantic cod stops during spawning (Rae 1967; Arntz 1973; Fordham and Trippel 1999) while others report that feeding continues (Klemetsen 1982 ; Dambergs 1964). Atlantic cod in Gilbert Bay did not stop feeding during spawning. All fish were captured by angling even during the spawning season indicating that fish were pursuing potential food items at the time of capture. The presence of food in the stomach of partially spent fish confirmed that they were feeding.

5.4 MOVEMENT

The majority of Gilbert Bay cod tagged with external tags were recaptured at their tagging site. Tagging sites were not far from each other and thus these recaptures indicate high site fidelity and /or homing behaviour. Green and Wroblewski (submitted), observed that about 50 % of Atlantic cod tagged with sonic transmitters in The Shinneys left The Shinneys during the summer but returned there later in the year. The other tagged fish remained in The Shinneys. Therefore some of the fish recaptured in the same location as initially tagged may have traveled to Gilbert Bay and returned, while others may not have moved far between initial tagging and recapture. Other sources of information, such as length frequency distributions, commercial tag returns, and net marks suggest that some cod move from The Shinneys in summer and return, supporting the sonic tracking evidence of Green and Wroblewski (submitted).

Length frequency distributions from The Shinneys and River Out in 1998 and 1999 suggest that some Atlantic cod move out of The Shinneys between May and August. Fish sampled in The Shinneys in spring are best representative of the entire population that make use of this area. In August the length distribution of fish collected in The Shinneys consisted of smaller fish than those collected in River Out. But when samples from these two areas are combined they are similar to length frequency distributions obtained in May and early June in The Shinneys. It is unlikely that all fish in the River Out area were from The Shinneys, but sonic tracking (Green and Wroblewski, submitted) indicates that some fish larger than 40 cm in length and > 5 yrs of age, move from The Shinneys to Gilbert Bay between early June and August.

Recovery of tagged fish in Gilbert Bay, and the presence of net marks on fish in

The Shinneys are direct evidence of movement of fish between these areas. During sampling in the River Out area we recaptured two tagged fish greater than 40 cm out of 100 captured. One fish was tagged in May of the same year in The Shinneys, and moved to River Out between May and the time of recapture. The other fish was tagged in The Shinneys in June 1998. Tagged fish captured in the commercial fishery near the mouth of Gilbert Bay show that some cod tagged in The Shinneys in spring move to the mouth of Gilbert Bay during summer or fall. Gillnet marks observed on four fish, two captured in The Shinneys and two in River Out, in August 1999 indicate that these fish were near the mouth of Gilbert Bay and had moved into the River Out area and The Shinneys. Commercial fishing was only permitted near the mouth of Gilbert Bay.

The movement of some cod from The Shinneys may have been a response to high water temperature, however temperature is not a complete explanation for the observed movement pattern. Rose and Leggett (1988) reported that Atlantic cod were not caught in water less than -0.5 or greater than 8.5 °C. In summer much of The Shinneys has bottom temperatures (> 10 °C) above the reported optimal temperature range of northern Atlantic cod. At the same depths cooler water temperatures are found in the main arm of Gilbert Bay during July and August (Green and Wroblewski, submitted). However some cod, large and small, remained in The Shinneys all summer. Individuals > 70 cm, were caught in < 3 m of water in August at water temperatures greater than 15 °C. Fish captured in The Shinneys showed no obvious signs of stress, such as poor condition, lesions, or external parasites. Therefore the movement of some cod from The Shinneys and not others, suggests that movement may be related to other factors.

5.5 EARLY LIFE HISTORY INFORMATION

The spring increase in water temperature in Gilbert Bay occurs just as ice leaves the area and may act as a proximal spawning cue. Before the water warms in the spring, and during the winter, Gilbert Bay cod are difficult to catch by angling (John Green, Memorial University, personal communication). After the water temperature begins to increase they are easier to angle suggesting that feeding has increased. Observations on ripe females indicated that little if any spawning occurs before the initial increase in water temperature.

Generally the spawning period for Atlantic cod populations lasts two to three months (May 1966; Templeman 1981; Myers *et al.* 1993; Smedbol and Wroblewski 1997). In Gilbert Bay the spawning period appears to be much shorter, possibly lasting less than a month from mid to late May to mid June. In 1999 we did not observe ripe females with hydrated eggs until the last week in May and few stage one eggs were collected when ichthyoplankton sampling was done on 23 and 24 June, 1999. Examination of five randomly sampled fish on 24 June suggested that spawning was complete at this time. Three of the fish were females that had completed spawning, one was a male that had completed spawning and the other an immature female.

Atlantic cod are know to spawn at sub-zero temperatures in bays surrounding the south and west coasts of Newfoundland (Lawson and Rose 2000a; G. A Rose, unpublished data). Iversen and Danielssen (1984) and Laurence and Rogers (1976) reported that Atlantic cod egg mortality increased when eggs were exposed to temperatures above 12°C. Gilbert Bay cod appear to commence spawning after water temperatures begin to increase just after the spawning sites become ice free, and complete spawning before water temperatures reach 12 °C.

Along the Labrador coast the majority of spawning occurs in March and April (May 1966). The timing of spawning in Gilbert Bay and in offshore areas does not coincide, possibly due to differences in water temperature. This difference in the timing of spawning is a potential mechanism for reproductively isolating Gilbert Bay cod.

The timing of spawning is thought to have evolved such that larvae hatch into a favorable environment (Bye 1984; Laprise and Pepin 1995) taking into account developmental rates and transport of eggs and larvae. Water temperature in the Atlantic region is thought to affect the timing of spawning in that spawning occurs first in more northern areas and progressively later southward (Templeman 1981; Myers et al. 1993). Atlantic cod in inshore areas generally spawn later than Atlantic cod in offshore areas (Anderson *et al.* 1995; Templeman 1989; Smedbol 1994) The spawning interval can be viewed as a window of opportunity during which larvae have the best chances of hatching into favorable conditions (Bye 1984). Larger Atlantic cod release more batches of eggs over a longer period than smaller Atlantic cod (Hutchings and Myers 1994; Kjesbu 1989), presumably helping ensure that some eggs encounter favorable conditions upon hatching. In Gilbert Bay the short spawning period may be due in part to the presence of few large females. On the other hand it may represent local adaptation to the hydrographic conditions in the bay.

Plankton tows made near the surface during the spawning season in 1999 did not collect any eggs, however tows at 7 m did. It appears that eggs were trapped below the low density surface (0-6 m) layer. In the Shinneys the out flow of The Shinneys River, the main stem of which is 56 km long with 14 tributaries covering a drainage area of 313 km^2 (Anderson 1985), reduces surface salinity and raises surface water temperature producing a steep density gradient to about 6 m depth. Density for stage 1 Atlantic cod eggs is reported to be greater than 25.5 kg/m^3 (Anderson and deYoung 1994) therefore they would be located beneath the sharp density gradient (Fig. 8). Since there is a sill at 6 m depth at the entrance of The Shinneys, the density gradient likely restricts or prevents the transport of eggs from The Shinneys. Solemdal (1967, 1973) and Anderson and deYoung (1994) suggest that the density of fish eggs is directly dependent on the ambient salinity (density) in which spawning adults occur. In The Shinneys, ripe fish were caught on the bottom, usually at depths greater than 5 m, thus they were exposed to salinities above approximately 27 ppt.

Near the time of hatching, eggs were collected at all depths sampled, indicating that mixing of the water column had occurred. On the 16 June, 1999, water temperature was the same at the surface as at 8m depth, suggesting that it was at about this time that a mixing event occurred. A density gradient appeared to reform shortly after this. Since the amount of fresh water from The Shinneys river is greatly reduced after the spring melt, stratification of the water column would then be mainly thermally driven.

Similar hydrographic conditions may occur near the head of Gilbert Bay as a result of the outflow from the Gilbert River. The Gilbert river is 81 km long, has 30 tributaries and covers a drainage area of 642 km^2. Sills located at the head of Gilbert Bay at approximately 6 m depth, and across the middle of Gilbert Bay at approximately 7 m depth may also reduce egg transport from Gilbert Bay assuming spawning occurs in these areas.

The range in length and abundance of cod larvae collected in Gilbert Bay in 1998 was different from 1999. Natural variation may explain the observed differences, however differences may be related to fishing pressure between sampling periods. Large Atlantic cod spawn over a longer period than smaller Atlantic cod (Hutchings *et al.* 1993; Kjesbu 1989). Our observations suggest that larger fish also begin spawning earlier in the season than smaller fish. Similar results have been reported by Ouellet (1997) in the Gulf of St. Lawrence and Lawson and Rose (2000a) in Placentia Bay. Other reports also suggest that larger fish continue spawning for longer in the season (Hutchings *et al.* 1993). If fewer large Atlantic cod spawned because they were removed, than we might expect a decrease in the size range of 0+ Atlantic cod, and a reduction in the larval density. The virtual absence of pelagic juveniles greater than 35 mm in 1999 may have been partially due to a decrease in the number of larger fish. However the size range of larvae may be determined by environmental conditions that vary each year, whereby the window of opportunity to produce successful offspring is either longer or shorter.

5.6 SUMMARY

The biology of Atlantic cod in Gilbert Bay is unlike that of other Atlantic cod populations. The age structure and growth of this population differs from cod directly offshore in NAFO division 2J. The small geographic distribution and restricted home ranges of Gilbert Bay cod are unlike that of migratory offshore Atlantic cod, and perhaps more restricted than any other inshore populations of Atlantic cod. Cod from Placentia Bay may move into Trinity Bay and as far North as Notre Dame Bay, but appear to return to Placentia Bay to spawn (Brattey 1999; Lawson *et al.* 1998; Lawson and Rose 2000b). Gilbert Bay cod are reproductively isolated, both in spawning location and time of spawning, from Atlantic cod in Divisions 2J, 3K, and 3L. Early life history characteristics of Gilbert Bay cod also differ from other Atlantic cod populations. Spawning occurs in shallow water (5-10 m), from mid-May to mid-June, whereas other Atlantic cod populations generally spawn in deeper water. Atlantic cod spawn on the continental shelf and slope (250 m) (Hutchings and Myers 1993) and within some bays (~ 60 m) along the south and east coast of Newfoundland (Hutchings and Myers 1993; Lawson and Rose 2000a). Eggs and larvae appear to be maintained in The Shinneys, and perhaps other parts of the bay, by a strong vertical density gradient during the spring runoff.

Atlantic cod in Ogac Lake have some characteristics similar to Gilbert Bay cod. Both populations have a restricted geographic range, spawn in relatively shallow water in late May, and are exposed to cold water conditions. At least some cod in Ogac Lake grow slowly, which may be related to temperature and feeding. In both areas cod < 70 cm, feed primarily on benthic organisms, and capelin are not part of the diet. Other cod populations usually feed on capelin or other fishes at some time during the year (Lilly 1987).

Interestingly, Gilbert Bay cod do not leave the bay although there is no physical boundary preventing them from leaving. During August 1998, offshore fish moved into Gilbert Bay (personal communication with fishermen), mixing with resident Atlantic cod. The distinction between offshore cod and Gilbert Bay cod was made based on colouration differences. Presumably mixing of offshore migratory Atlantic cod and Gilbert Bay cod occurs annually, with migratory fish moving back offshore in fall to overwinter and spawn. Year round residence in a small area is perhaps the primary difference between Gilbert Bay cod and other northern cod populations. Other differences in their life history characteristics have probably resulted from their subsequent local adaptation to the Gilbert Bay environment.

5.7 MANAGEMENT IMPLICATIONS

Commercial fishing in Gilbert Bay in 1998 and 1999 removed a portion of the spawning population. The Atlantic cod population in Gilbert Bay has relatively few large fish, and appears to consist mainly of fish spawned since the cod moratorium in 1992. The majority of cod have only recently matured (last 3-5 years). If Gilbert Bay cod are rebuilding from what was once a larger population with larger individuals, current fishing pressure may maintain the population at a low level, or deplete the population, by reducing the number of potential spawners, and stopping the recovery of this population.

The 1998 index fishery was conducted from 24 September to 16 October and removed an estimated 12 tons of Atlantic cod from Gilbert Bay. The size of fish caught in the commercial fishery corresponds to the size range of fish missing from the 1999 length frequency distribution. In total, commercial fishing in Gilbert Bay during 1998 and 1999 removed an estimated 31.8 metric tons of Atlantic cod. Estimates are based on observations of fishing activity and DFO catch estimates. Removal of fish has reduced the number of potential spawners, and possibly resulted in the reduction in abundance of larvae observed in 1999.

A relationship between the number of spawners and year class strength (recruitment) is difficult to determine for fish populations despite the efforts of fisheries scientists for many years (Hilborn and Walters 1992). Therefore any explanation for the lower larval densities and the virtual absence of larval fish greater than 35 mm in 1999 compared to 1998 is speculative at this time. But Gilbert Bay cod may be a good population to study this.

The differences described in this thesis suggest that the biology of Gilbert Bay cod is unlike other Atlantic cod populations, and it should be managed independently if it is to be maintained. Movement patterns and timing of spawning suggest that this population does not mix with other Atlantic cod during spawning and are therefore reproductively isolated. Genetic analysis of Gilbert Bay cod confirms that there is limited gene flow between this population and others (Ruzzante *et al.* 2000). Maturity is reached at a small size, and cod grow slower than other northern Atlantic cod, resulting in a decrease in the number of eggs produced. Movement, genetic data, and general biological characteristics suggest that this population does not have the same characteristics as northern cod which are used in the management of northern cod, and therefore should not be managed as part of this fish stock complex.

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