GROWTH RATE OF THE ICELAND SCALLOP *Chlamys islandica* IN GILBERT BAY, LABRADOR, A MARINE PROTECTED AREA

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by

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Abstract

The sustainability of the Iceland scallop fishery is one of the conservation issues associated with the Gilbert Bay Marine Protected Area in southeastern Labrador. The average size of Iceland scallop in Gilbert Bay is significantly smaller than the average scallop size in the nearby Strait of Belle Isle. Local fishers have suggested this could be due to a slower growth rate of scallops in the MPA.

To estimate the growth rate of scallops in Gilbert Bay, three methods of determining the age of scallops were used: counting external shell growth rings, counting shell hinge ligament growth zones, and counting internal shell layer growth increments. No significant difference was found between the ligament and internal shell methods of aging, but both methods were significantly different from the external shell growth ring method. Counting hinge ligament growth zones was recommended as the most accurate and most convenient method. The growth parameters of Iceland scallop in Gilbert Bay were found by fitting the von Bertalanffy equation to the shell height-at-age data. Based on counting hinge ligament growth zones, the von Bertalanffy model found asymptotic shell height (SH_{∞}) of scallops in Gilbert Bay was 117 mm with a growth parameter K of 0.07 year^{-1}. Scallop growth in Gilbert Bay is not significantly different from scallop growth in the Strait of Belle Isle and not significantly different from scallop growth in the Nuuk area of West Greenland.

No significant difference was found in variation of scallop growth throughout Gilbert Bay. Scallops in Gilbert Bay are currently smaller than in the Strait of Belle Isle, likely due to factors other than growth rate, such as variance in recruitment, natural mortality or fishing mortality. Refined harvesting regulations could ensure the sustainability of Iceland scallop populations in Gilbert Bay.

Acknowledgements

I would like to express my deep and sincere gratitude to my co-supervisor, Dr. Joe Wroblewski, for providing me this study opportunity. His guidance, patience and thoughtfulness are greatly appreciated. I am also deeply grateful to my other co-supervisor, Dr. Ray Thompson, for his guidance on the aging of scallops, constructive comments and his support throughout my graduate work. I would like to extend my sincere thanks to my committee members: Dr. David Schneider for his guidance in the statistical analysis, and Dr. Evan Edinger for providing advice on the shell sectioning methodology. Sincere thanks also to Dr. Paul Snelgrove and Dr. Don Diebel for providing microscope and lab space.

I would like to give my special thanks to Glenn Piercey, Renita Aranha and Dr. Owen Sherwood for their assistance in the shell sectioning work. I also wish to thank my friends Wenjun Peng, Bei Sun, Zhao Sun, and Ying Zhang for their help in the work.

This research was conducted as part of the Gilbert Bay MPA monitoring program under a Collaborative Research Agreement between Department of Fisheries and Oceans, Canada (DFO) and Memorial University of Newfoundland. I held a Graduate Studies Fellowship from Memorial University of Newfoundland.

Iwish to give my loving thanks to my parents, my sister, and especially my husband, upon whose constant encouragement and love I have relied throughout my studies.

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Chapter 1

Introduction

There is increasing recognition of the profound effect humans are imposing on marine ecosystems, leading to the degradation of the oceans (Norse, 1993; Pikitch *et al.*, 2004). To protect marine biodiversity and ocean habitats, Marine Protected Areas (MPAs) have been introduced as a tool for marine conservation and fishery management. Designation of MPAs is increasing as humans seek to reduce overexploitation of marine resources and preserve the integrity of the ocean's unique biodiversity (Hu and Wroblewski, 2009).

In Canada, MPAs are established under the *Oceans Act* of 1997 to conserve commercial species and protect non-commercial species (Wroblewski *et al.*, 2009). Protection is afforded to endangered or threatened marine species and their habitats, unique habitats, and marine areas of high biodiversity or biological productivity (Jamieson and Levings, 2001).

1.1 The Gilbert Bay MPA

Gilbert Bay is a narrow inlet located on the southeast coast of Labrador (Figure 1.1). With a total area of approximately 60 km^2, the bay is 25 km long and 1-3 km wide. According to a multibeam survey of Gilbert Bay conducted by the Canadian Hydro-graphic Survey in 2002, most of the area is shallower than 30 m, and only about 6% being deeper than 100 m (Copeland *et al.*, 2006). Generally, the mouth of Gilbert Bay is deeper than the inner bay region. The bay connects to the Labrador Sea through

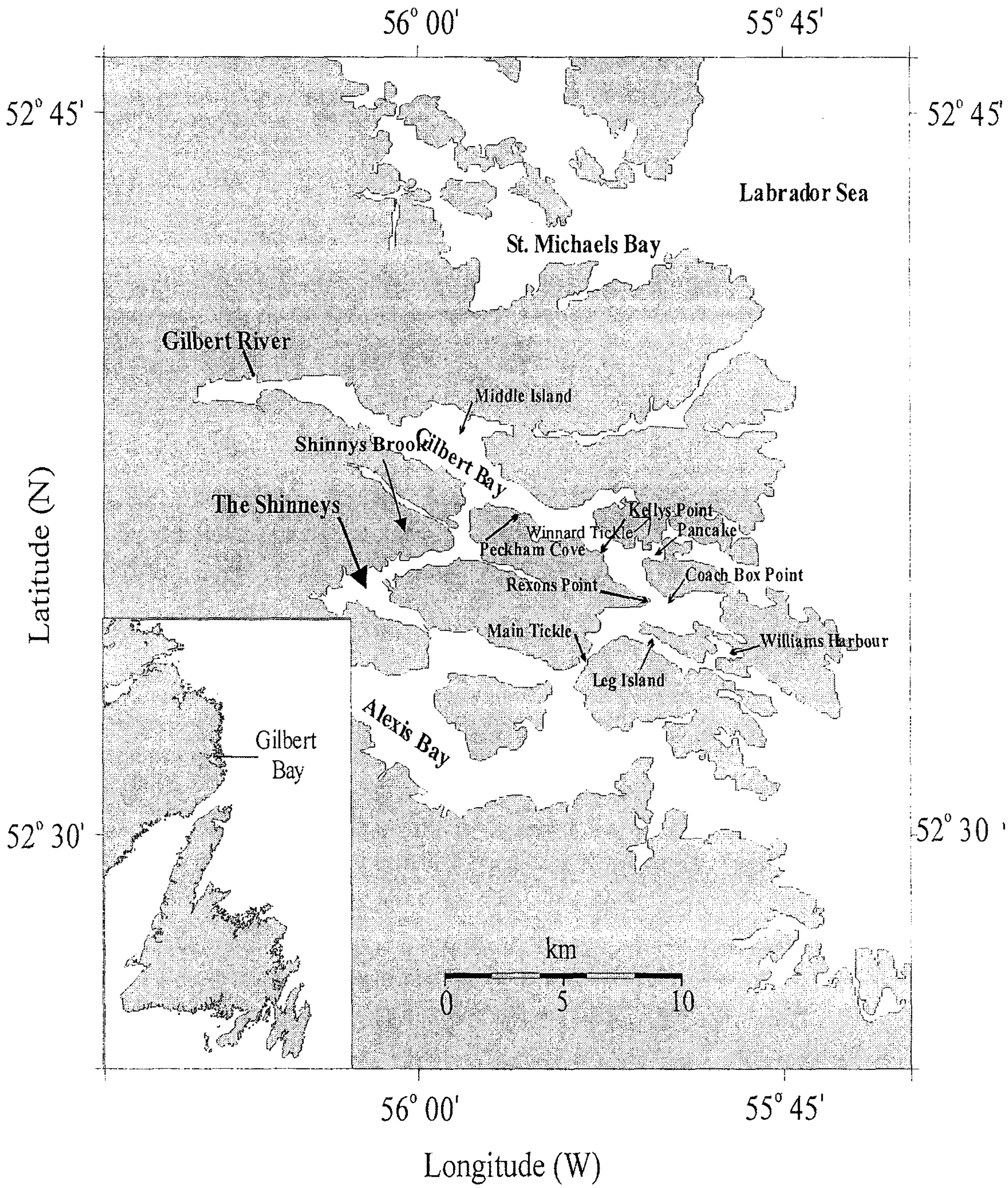

Figure 1.1 Map of Gilbert Bay, southeastern Labrador showing location of sampling sites.

Williams Harbour Run and Winnard Tickle and with Alexis Bay through Main Tickle. With Gilbert River and Shinneys Brook flowing into Gilbert Bay, the bay has estuarine oceanographic conditions. The surface water salinity increases near the mouth of the bay (30 ppt), compared to that in the inner part which is 27 ppt (Figure 4 in Wroblewski *et al.*, 2007).

Gilbert Bay was announced by the Minister of Fisheries and Oceans Canada in 2005 as the first MPA established in eastern Canada's subarctic coastal zone (Government of Canada, 2005). The management plan of Gilbert Bay was developed jointly by coastal community leaders, marine resource users, researchers from Memorial University of Newfoundland, and representatives of the provincial and federal governments. The Oceans Branch of Fisheries and Oceans Canada (DFO) is the lead agency for managing the Gilbert Bay MPA. The primary objective of the MPA is to protect its resident population of Atlantic cod (*Gadus morhua*) (Green and Wroblewski, 2000; Morris and Green, 2002; Hu and Wroblewski, 2009). While focused on protecting this unique cod population and its spawning habitat, the management plan of the MPA supports general marine conservation of the Gilbert Bay ecosystem (Jamieson *et al.*, 2001; Fisheries and Oceans Canada, 2007), including efforts to conserve the Iceland scallop commercial resource in the MPA (Wroblewski *et al.*, 2009).

Unlike some other MPAs, Gilbert Bay is not a harvest refugium or "no-take reserve." The management plan includes regulations to conserve the Iceland scallop, for which there is a commercial fishery (Morris *et al.*, 2002).

The fishery for Iceland scallops in Gilbert Bay is an "open fishery"; for example, no quota or seasonal regulation are set and any boat less than 35 feet licensed by DFO to harvest scallop along the Labrador coast can fish scallops in Gilbert Bay. Since 2005, under MPA regulations, commercial harvesting of Iceland scallops is permitted only in the central and seaward regions of the bay (Government of Canada, 2005). Dredging for scallops is permitted in MPA Zones 2 and 3, but not in Zone 1A or Zone 1B, which are closed to protect cod-spawning grounds (Figure 1.2). Zone 1B, the region of Gilbert Bay known as The Shinneys, has a pristine scallop habitat (Copeland *et al.*, 2007) which has not been dredged. Since the early 1990s The Shinneys and the upper reaches of Gilbert Bay (which equate to Zone 1 of the MPA) have been considered Inland Waters under the *Fisheries Act* of Canada to regulate the recreational fishing of migrating salmonids at the entrance to the Shinneys Brook and the Gilbert River (Fisheries and Oceans Canada, 2007; Wroblewski *et al.*, 2007). The closure of Zones 1A and 1B under MPA regulations could lead to rebuilding of scallop beds in those zones and export of planktonic scallop larvae to adjacent zones. Annual reseeding of the harvested areas with young scallops produced in protected Zones 1A and 1B may help to maintain landings in Zones 2 and 3.

1.2 Iceland scallops in the Gilbert Bay MPA

The Iceland scallop (*Chlamys islandica*) is a marine, suspension-feeding, bivalve mollusk with a subarctic distribution (Lubinsky, 1980). Habitat with a hard bottom consisting of sand, gravel, shell fragments and stones, supports a resident population of Iceland scallop (Gilkinson and Gagnon, 1991; Naidu, 2001). In Canada, Iceland scallops have been investigated from the Gulf of St. Lawrence to Cumberland Sound, Baffin Island, as well as in Hudson Strait and Hudson Bay (Cosens, 1990), and in northern James Bay (Lubinsky, 1980). They are also harvested in Greenland, Iceland, Norway and Russia (Pedersen, 1994; Naidu, 2001; Garcia, 2006).

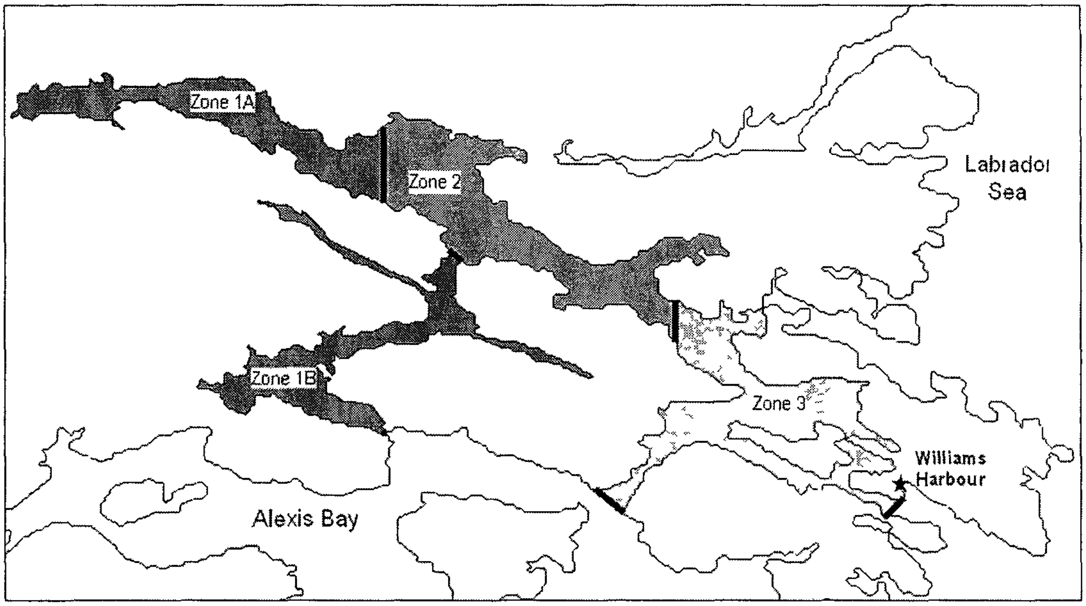

Figure 1.2 Map of the Gilbert Bay MPA showing management zones. Zone 1A (near the Gilbert River) and 1B (The Shinneys) are closed to dredging for scallops. The management plan for the MPA envisions that Iceland scallop beds in Zones 1A and 1B will reseed the scallop fishing grounds in Zone 2 and Zone 3.

The Iceland scallop is epibenthic (Crawford, 1992). It is mainly found on sand, gravel, and dead shells, which provide attachment substrates, rather than on soft, muddy bottoms (Pedersen, 1994). The greatest Iceland scallop densities have been found between 20 and 110 m depth, although some beds extend to nearly 600 m (Hansen and Nedreaas, 1986; Pedersen, 1994). The Iceland scallop is found in the ocean regions that are less than 30 meters depth (Fletcher and Haggerty, 1975), as well as greater depths where the bottom substrate is suitable. The regions of Gilbert Bay where scallop dredging has been traditionally conducted consist of substrates of boulder, cobble, and pebble gravel suitable for Iceland scallops (Morris *et al* , 2002).

Growth rate of the Iceland scallop varies seasonally probably due to feeding conditions and temperature (Vahl, 1980; MacDonald and Thompson, 1985). The most rapid growth occurs during the phytoplankton bloom, from April to June (Vahl, 1978). Growth rate also varies according to age. For example, in Iceland, the growth rate decreases from 8-10 mm per year during the first year to 0-3 mm per year for the shells that are older than 15 years (Garcia, 2006). As a result of variation in growth rate between regions, age and size at maturity and maximum age also differ among Iceland scallop populations. Iceland scallops reach maturity at 40-50 mm shell height (SH) at an age of 5-7 years in Norway and Iceland, but a lower size for age is found in Greenland, where 30-50 mm SH corresponds to an age of 4-9 years (Pedersen, 1994; Garcia, 2006). In most areas, Iceland scallops grow to a maximum size of 80-110 mm, although individuals measuring 140 mm have been found in northwest Iceland (Garcia, 2006).

The Iceland scallop was first commercialized along the Strait of Belle Isle beginning in 1969. In the early 1990s, as the northern cod stock declined and fishers turned to harvesting other marine resources, the Iceland scallop fishery in Gilbert Bay became commercially viable. The scallop fishery has intensified since DFO declared a moratorium on fishing northern Atlantic cod in 1992 (Shelton, 2005). During the early years of the scallop fishery in Gilbert Bay, harvests were mostly near the mouth of the bay, but the next decade fishing effort gradually moved further into the bay (Morris *et al.*, 2002).

The sustainability of the scallop fishery is one of the two main conservation issues associated with the commercial scallop fishery in Gilbert Bay; the other issue is the incidental damage to marine life and habitat on the ocean bottom while dredging for scallops, including young scallops. A monitoring program for the Gilbert Bay MPA is currently gathering scientific data that will address these conservation issues (Fisheries and Oceans Canada, 2007).

There is little scientific information on the Iceland scallop stocks off Labrador (Naidu *et al.*, 2000), and therefore there has been no attempt to manage this resource on a sustainable basis (Naidu *et al.*, 2001). Iceland scallop beds along the Labrador coast are pulse harvested, resulting in boom and bust local landings (DFO, 2001).

One index of the state of a scallop resource is the size of scallops being harvested relative to past catches, or in comparison with scallops harvested from stocks elsewhere. Wroblewski *et al.* (2009) collected the first scientific data on the Gilbert Bay scallop stock by observing catches of commercial harvesters during the 2006 fishing season. They found that the mean size of scallops harvested varied spatially within Gilbert Bay (Figure 1.3). Scallops in the fishing area near Middle Island had the largest mean SH, while scallops harvested near Coach Box Point were the smallest.

While scallop shell sizes differ according to location in Gilbert Bay, the data show no clear geographical trend (Figure 1.3 and Figure 1.4). Nevertheless, it is noteworthy that the largest scallops were found at Middle Island, which is the most remote location from Williams Harbour, the base for the fishing fleet, whereas the smallest scallops were at Coach Box Point, which is readily accessible from Williams Harbour (Figure 1.4). This pattern in the data matches the distribution of historical and recent fishing effort in Gilbert Bay, with the lowest number of dredge tows in the upper reaches of the bay, and the greatest in seaward regions (Saxby, 2007). The concentrated fishing effort near the mouth of the bay can be explained by economic cost; it is more costly in fuel for the commercial

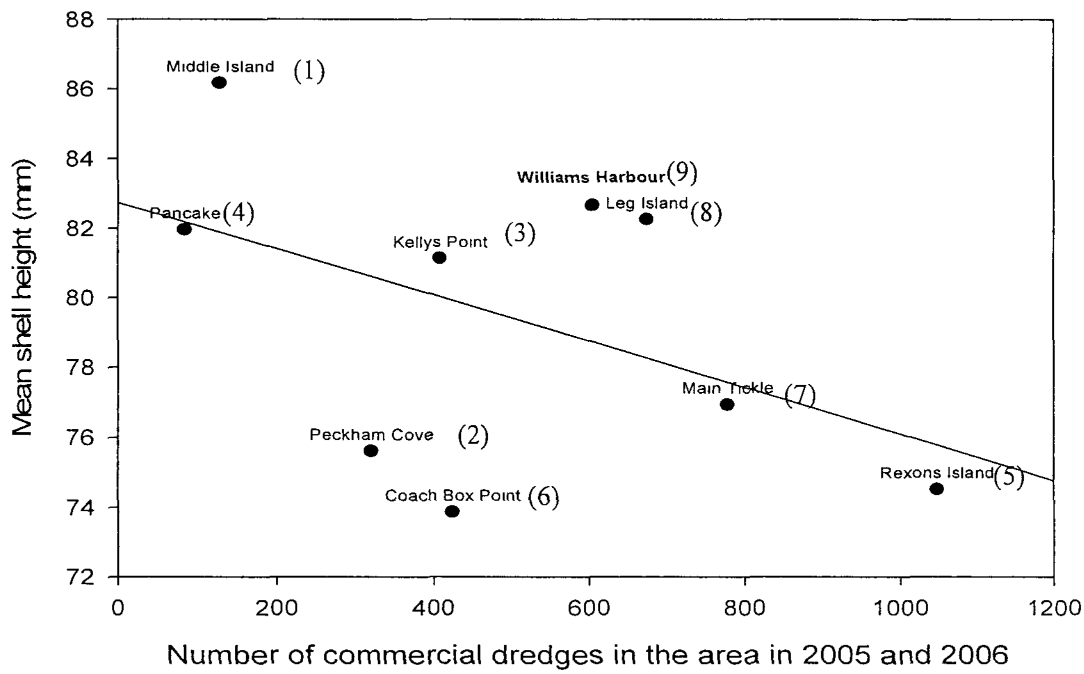

Figure 1.3 The relationship between the mean shell size of Iceland scallops and commercial dredging at the nine locations in Gilbert Bay in 2005 and 2006. The line is the linear regression for the mean shell height in relation to the number of commercial dredges in 2005 and 2006 (Modified from Saxby, 2007). The locations of the nine sites are shown in Figure 1.4.

vessels to move up Gilbert Bay to dredge when scallops can be harvested closer to the home port (Williams Harbour).

An alternative explanation posed in this research is that scallops in the upper bay grow faster than those in the lower bay; in other words, that there is variability of scallop growth among different locations within the bay.

Shells of Iceland scallops in Gilbert Bay in 2006 were significantly smaller than the scallop mean shell size in the Strait of Belle Isle, northeastern Gulf of St. Lawrence, in 1999 and 2000 (the only comparable data available) (Wroblewski *et al.*, 2009) (Figure 1.5). Several factors may contribute to the fact that Iceland scallops harvested in

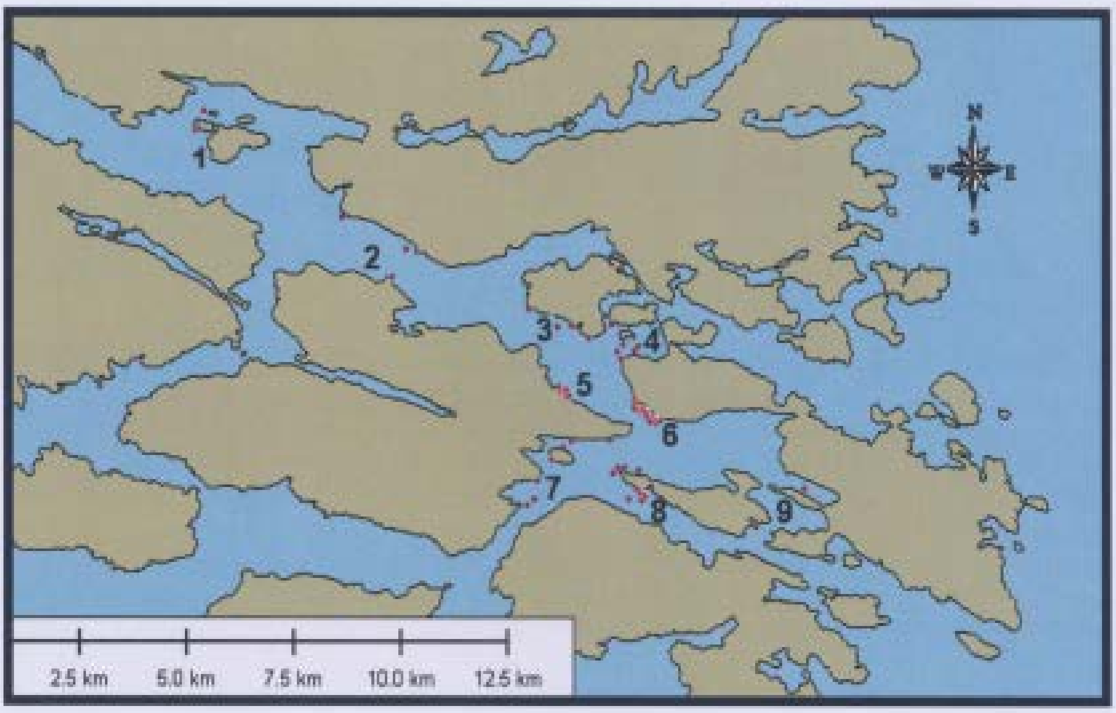

Figure 1.4 The locations in Gilbert Bay where data on the shell height of Iceland scallops harvested in 2006 were obtained (each red dot was the initial location of each sampling tow). 1, Middle Island; 2, Peckham Cove; 3, Kellys Point; 4, Pancake; 5, Rexons point; 6, Coach Box Point; 7, Main Tickle; 8, Leg Island; 9, Williams Harbour (Wroblewski *et al.*, 2009).

Gilbert Bay are smaller than those harvested in the Strait of Belle Isle, such as natural variation in recruitment and intense predation by sea stars in Gilbert Bay, differential fishing mortality (i.e. repeated dredging of scallop beds in Gilbert Bay), and a combination of these factors. In light of the need for biological information for fishery management purposes, Wroblewski *et al.* (2009) recommended that research be conducted on recruitment, growth rate, and natural mortality of Iceland scallops in Gilbert Bay. This thesis focuses on growth rates of Gilbert Bay Iceland scallops.

1.3 Purpose of this study

The main objective of this study was to determine the growth rate of the Iceland scallop in Gilbert Bay. I determined the accuracy of three methods for aging Iceland scallops: counting external shell growth rings, counting hinge ligament growth zones, and counting internal shell growth lines in the sectioned shells. I investigated the growth rates of Iceland scallops in Gilbert Bay and compared it to published growth rates for Iceland scallops in the Strait of Belle Isle and in coastal waters of West Greenland. If growth of Iceland scallops in Gilbert Bay is similar to that of scallop stocks in the Strait of Belle Isle and other regions of the North Atlantic such as West Greenland, then the small size of scallops presently being harvested in Gilbert Bay is likely due to other factors such as variance in recruitment, natural mortality or fishing mortality.

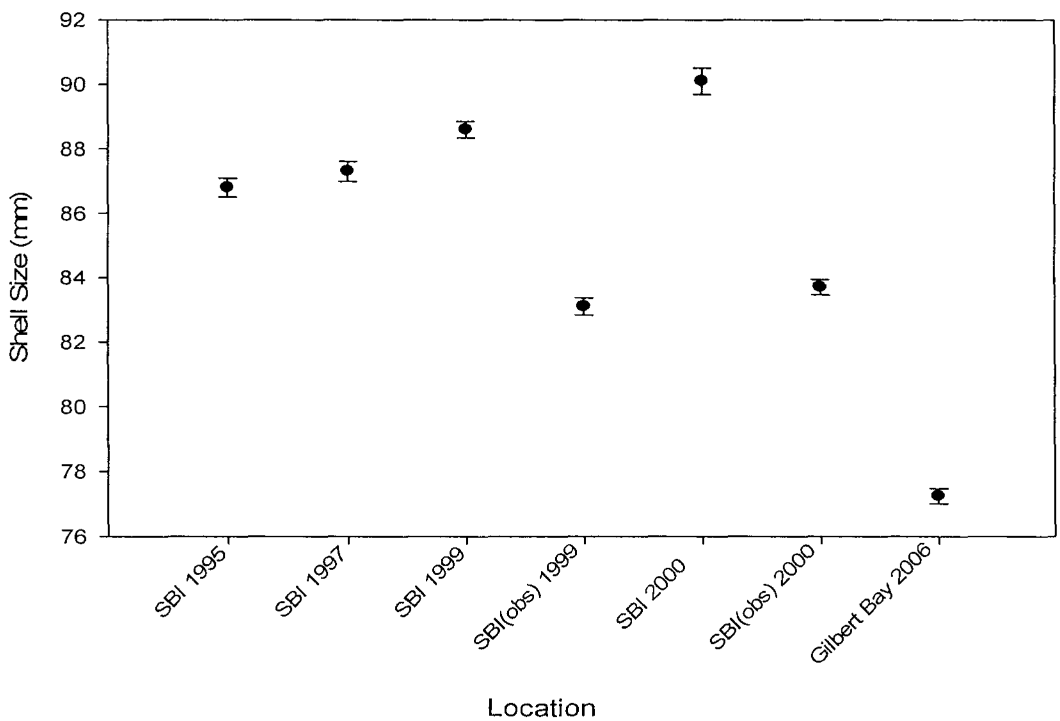

Figure 1.5 Mean shell size of Iceland scallops in Gilbert Bay (Saxby, 2007), in the Strait of Belle Isle based on research vessel surveys, and in the Strait of Belle Isle (SBI) based on observer data (Naidu *et al.*, 2001). Bars are the 95% confidence intervals (Wroblewski *et al.*, 2009).

Chapter 2

Comparison of methods for determining age of Iceland scallops

2.1 Introduction

Age and growth rate information for bivalves has usually been obtained by analyzing shell growth increments. Iceland scallop growth is often measured as an increase in shell height with age (Pedersen, 1994). Three methods are presently used for aging individual bivalves: counting external shell growth rings on the shell surface from the umbo to the ventral margin (Merrill, 1961), counting increments from the peak to the base of the pyramid-shaped calcareous portion of the ligament (Trueman 1953; Merrill, 1961; Johannssen, 1973; Pedersen, 1994), and counting internal shell growth lines inside the sectioned shell (MacDonald and Thomas, 1980; Arneri *et al.*, 1998; Hua *et al.*, 2001; Garcia-March, 2007; Oshima *et al.*, 2004).

To date, there is no accepted standard method for determining the age of Iceland scallops. Pedersen (1994) demonstrated that the hinge ligament growth zones are laid down annually, and counted ligament growth increments to determine the growth parameters of Iceland scallops in West Greenland. Naidu (1988) determined the growth rate of Iceland scallops in the Strait of Belle Isle by reading the external shell growth rings.

In this study, I compared these three methods in determining the growth of Iceland scallops in Gilbert Bay, and provided a recommendation on the most accurate and convenient method(s).

2.2 Material and methods

2.2.1 Collection from the field

From 26 September to 1 October 2007 Dr. Joe Wroblewski and MPA community coordinator Marilyn Penney, working on board the CFV *Little Shell* (Redgeway Russell, Captain) in the Gilbert Bay MPA, collected 693 Iceland scallops from 27 dredge tows in the areas that had been sampled in 2006 (Figure 2.1, Appendix I) (Wroblewski, 2007). The seven locations in Gilbert Bay where Iceland scallops were collected in 2007 were: 1, Middle Island; 2, Peckham Cove; 3, Kellys Point; 4, Rexons Point; 5, Coach Box Point; 6, Main Tickle; 7, Leg Island. Only one area sampled in 2006 was not resampled in 2007, that being Area 9 near Williams Harbour (see Figure 6 in Wroblewski *et al.*, 2009). Only two dredge tows were made in Area 9 during 2006, so it was decided to omit this previously under-sampled area from the 2007 field sampling. Two tows with only 17 scallops in total were collected near Pancake. These scallops were combined with those collected in the area opposite Kellys Point (Figure 2.1).

At sea, the shell height of the scallops was measured. The standard protocol followed was provided by Frank Cahill, DFO, Northwest Atlantic Fisheries Centre, St. John's NL.

2.2.2 Three methods of determining the age of scallops

Three methods were used in determining the age of Iceland scallops collected in 2007: Counting external shell growth rings, counting hinge ligament growth zones, and counting internal growth lines. Ages of all the 693 scallops were determined by external and ligament methods, 30 individuals were systematically selected from the entire collection of 693 shells. Their ages were determined by the internal method. For the section of observer comparison, 20 of the 30 shells were used to determine the age by five observers with three methods.

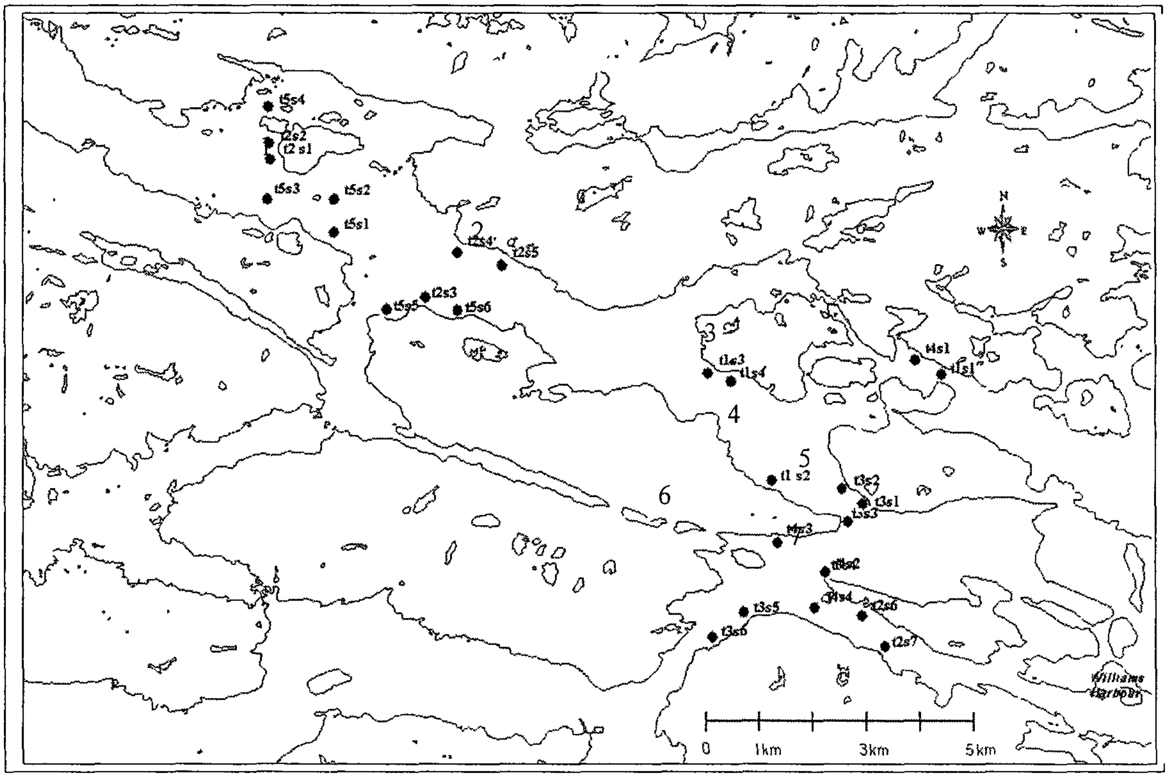

Figure 2.1 The seven locations in Gilbert Bay where Iceland scallops were collected in 2007. 1, Middle Island; 2, Peckham Cove; 3, Kellys Point; 4, Rexons Point; 5, Coach Box Point; 6, Main Tickle; 7, Leg Island. The black dots are the spacific trips (T) and sets (S).

2.2.2.1 Counting growth rings on the external shell

The external shell growth rings (Figure 2.2) were counted by eye. Normally, the upper valve is more difficult to read because of the dark colour of the shell or the attachment of marine fouling organisms such as barnacles and algae. Although these organisms were removed with brushes or forceps, the results were recorded based on reading the clearer lower valve. The rings are radially distributed from the umbo at the anteriormargin of the shell. Every pair of light and dark rings was considered as one year of growth (Figure 2.2). Contrast could often be improved by immersing the specimen in water.

Figure 2.2 The external shell growth rings on the surface of a lower valve of an Iceland scallop from Gilbert Bay. The growth lines suggest that the scallop is 7-years old.

2.2.2.2 Counting growth zones on the hinge ligament

The inner layer of the ligament is a large, pyramid-shaped structure (Figure 2.3) situated between the valves under the umbo. It consists of a calcified lateral region joined to each valve, with a soft central region between the laterals (Trueman, 1953; Merrill *et al.*, 1966). When the soft central region is removed, growth zones can be observed on the calcified lateral region (Figure 2.3). The most conspicuous lines are border lines between equal parts of the ligament, and the occurrence of these lines was interpreted as indicating broken continuity of growth. The exposed lateral calcified part was used for age determination because the structure of the lateral region is much better defined than that of the central region. The lateral ligament was observed under a binocular microscope with magnifications of 10× for the larger shells and 40× for the smaller shells. For improved contrast, one could immerse the specimen in water and then dry it with tissue paper.

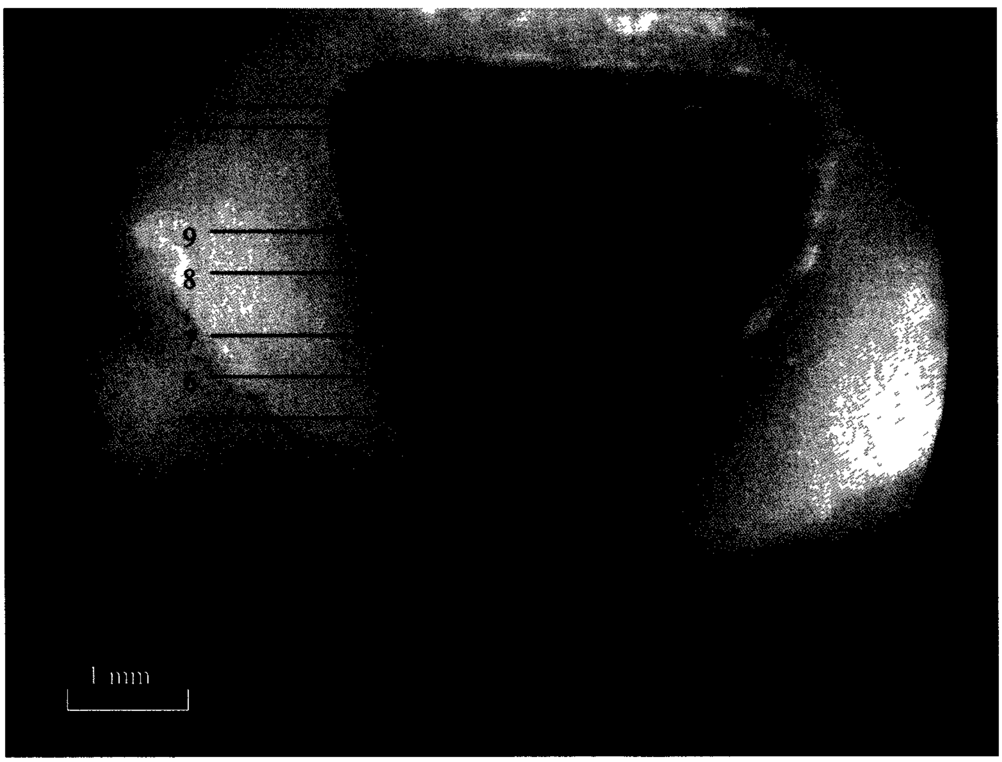

Figure 2.3 Growth zones on the ligament of an Iceland scallop from Gilbert Bay, observed under a binocular microscope. The growth zones suggest that the scallop is 11-years old.

2.2.2.3 Counting internal shell growth lines in sectioned shells

Thirty Iceland scallops were systematically selected from the 693 scallops collected in September 2007. The shell sizes ranged from 17.25 mm – 104.25 mm, measured to the nearest 0.05 mm with a vernier caliper. The shells were sectioned with a Buchler IsoMet low speed saw at a speed of six, which was around 160 revolutions/minute (Figure 2.4). For the shells that were larger than 30 mm SH, the valves were directly sectioned from the umbo to the ventral margin along the axis of maximum growth longitudinally. Shells less than 30 mm SH were embedded in epoxy resin for support during sectioning (Figure 2.5). The transverse section of each half was roughly polished with 12, 9, and 6 micron alumina first (Figure 2.6), then finely polished with 0.3 and then 0.05 micron alumina.

After the section was polished, two methods were evaluated to determine the age. The first was scanning the entire section and counting the rings on the digital images (Figure 2.7). This method provided a whole view of the entire shell section, which was convenient for counting the rings. The disadvantage was that the rings could not be clearly observed on the scanned images even after magnification in Adobe Photoshop (Figure 2.8). The second method was counting the rings under a binocular microscope (Figure 2.9), the image being clearer than the scanning image, but for larger shells the observer must move the shell continuously for a consistent count of the rings.

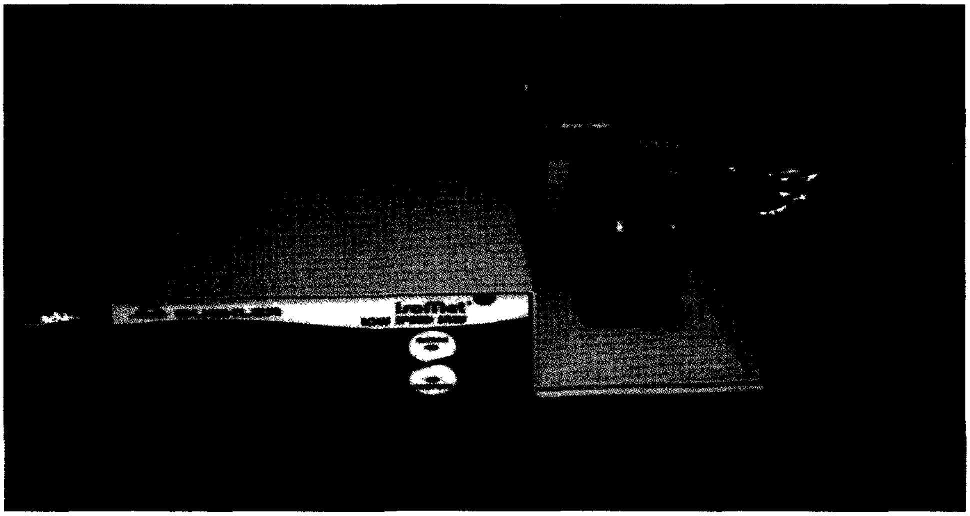

Figure 2.4 The Buehler IsoMet low speed saw used for cutting the shells.

Figure 2.5 Shells are embedded in epoxy (A) and sliced after being dried (B).

Figure 2.6 The transverse section of a sliced shell is polished with 12, 9, 6, 0.3 and then 0.05 micron alumina.

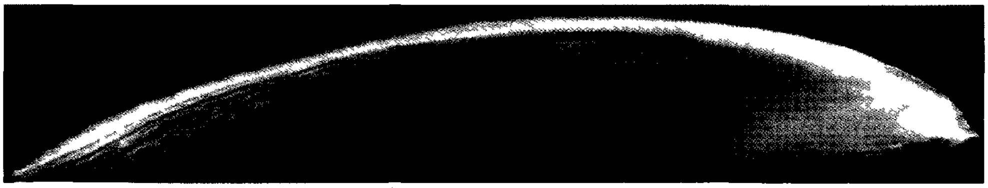

Figure 2.7 An optical scanned image of the sectioned shell with no magnification.

Figure 2.8 An optical scanned image that was magnified by Photoshop. It turned out to be not a good method to read the rings.

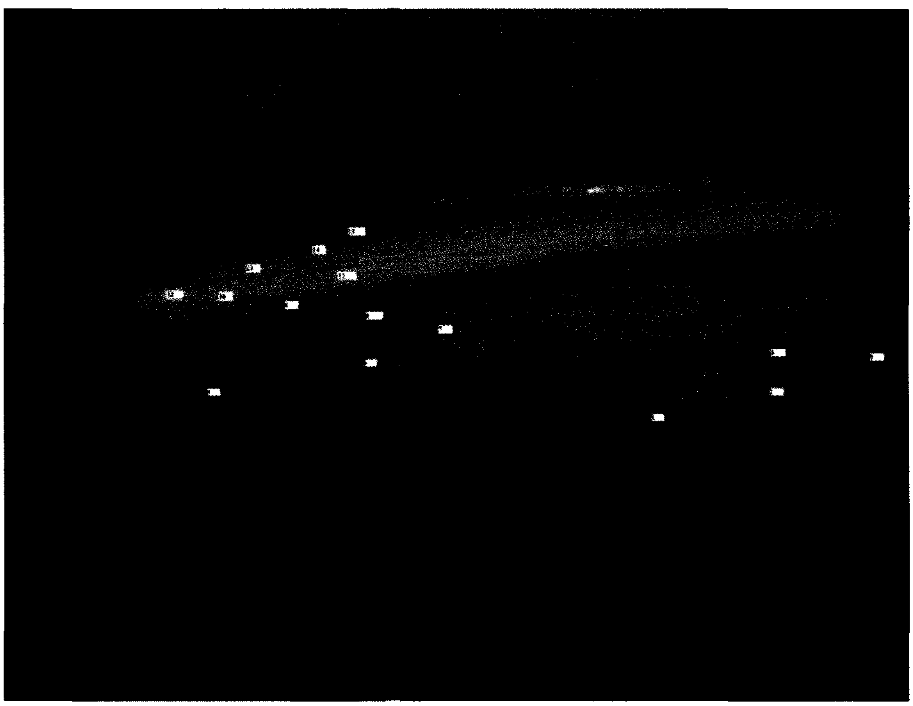

Figure 2.9 Internal shell growth lines in a sectioned shell examined under the microscope. Each white box marks a ring. There are fifteen rings in total, suggesting a 15-year-old scallop.

2.2.3 Data analysis

To test how much consistency there was in the age determination, a comparison was made among five observers. Statistical analysis was also conducted to determine if there was any significant difference among the three aging methods.

The von Bertalanffy model (von Bertalanffy, 1938):

$$SH_t = SH_\infty (1 - e^{-K(t-to)}) \tag{2.1}$$

was used for determining growth parameters of Iceland scallops (Pedersen, 1994). For this equation, SH_t is shell height at time t, SH_∞ is the mean asymptotic shell height, K is the growth coefficient determining the rate of change in size increment, and t_0 is a scale correction giving the hypothetical age at zero shell height. The von Bertalanffy functions were fitted by iteration, using the three parameter exponential growth available in the fit curve procedure of Sigma Plot. A linear form of the von Bertalanffy model was obtained by transforming both variables to natural logarithms and fitting the data to a straight line,

$$\mathrm{Ln}\,(1 - SH/ SH_\infty) = K *(t-t_0) \tag{2.2}$$

This technique has been used throughout the study to describe relationships between shell height and age.

Shell height-at-age was analyzed by analysis of covariance (ANCOVA) where age 't' was considered the continuous variable. 'Method' of age determination or 'Observer' was treated as the categorical variable. The ANCOVA determined simultaneously the effects of two factors on the response variable and the variance among the slopes of each treatment of the categorical factors. The following general linear model was used in the statistical analysis:

$$\text{Ln}\ (1 - SH/\ SH_{\infty}) = \beta_0 + \beta_{(t-t0)} *(t-t_0) + \beta_O *\text{Observer} + \beta_{(t-t0)*O} *(t-t_0) *\text{Observer} + \text{Error} \quad (2.3a)$$

or

$$\text{Ln}\ (1 - SH/\ SH_{\infty}) = \beta_0 + \beta_{(t-t0)} *(t-t_0) + \beta_M *\text{Method} + \beta_{(t-t0)*M} *(t-t_0) *\text{Method} + \text{Error} \quad (2.3b)$$

An analysis of variance (ANOVA) was used to test for the equality of population sample means by determining whether the variance between samples being tested was significantly greater than variance within samples. In order to determine the effect of a single factor 'Method' or 'Observer' on population means, a one-way ANOVA was used. The General Linear Model (GLM) for the one-way ANOVA was:

$$\text{Age} = \beta_0 + \beta_O *\text{Observer} \quad (2.3c)$$

or

$$\text{Age} = \beta_0 + \beta_M *\text{Method} \quad (2.4d)$$

For a two-way ANOVA, both 'Method' and 'Observer' were considered as categorical variables, the GLM being expressed as:

$$\text{Age} = \beta_0 + \beta_O *\text{Observer} + \beta_M *\text{Method} + \beta_O *\text{Observer}*\text{Method} \quad (2.3e)$$

The statistical analysis was done by iterative estimation, by using the General Linear Model procedure of S-PLUS to compare regressions and for analysis of variance, using normal error and identity link. The linear regression procedure in S-PLUS was used to construct the linear transformation of the von Bertalanffy model and to test the parameters.

2.3 Results

2.3.1 The effect of the observer in determining the age of Iceland scallops

2.3.1.1 External shell growth ring method

An ANCOVA revealed no significant interaction term ($p = 0.905$) among five observers and age determination, indicating that the relation of SH to age was consistent among the observers (Table 2.1). The one-way ANOVA table demonstrated the mean ages of the twenty Iceland scallops determined by five observers were similar (Table 2.2).

Table 2.1 Analysis of covariance for SH by age and observer. Age was determined by counting external shell growth rings.

Source	Df	Sum of Squares	F	P
Observer	4	0.000	0.000	1.000
Age	1	31.485	239.163	<0.0001
Observer*Age	4	0.135	0.034	0.905

Table 2.2 One-way analysis of variance for age by observer. Age was determined by counting external shell growth rings.

Source	Df	Sum of Squares	F	P
Observer	4	51.8	0.884	0.476

The von Bertalanffy growth curve parameters, asymptotic shell height (SH_∞), growth coefficient (K) and theoretical age at length zero (t_0), together with r^2, are summarized in Table 2.3. Also reported in Table 2.3 are the length and age ranges of the samples. The oldest specimen was determined by observer A (17 years), but the same specimen was estimated at age 10, 13, 14 and 15 years by the other observers, respectively. The average ages determined by five observers counting external shell growth rings ranged from 3.2 years to 13.6 years, with the minimum 2 years and maximum 16 years. Larger shells were not always associated with older ages, i. e. an individual shell with a SH of 85.25 mm was estimated at an average age 10.4 years, while the average age for another shell with a SH of 65.45 mm was 11.2 years.

The asymptotic shell height estimated from the von Bertalanffy equation ranged from 112 mm to 311 mm with the author's estimation being 145 mm. With the exception of data from observer C, the same trend was seen in asymptotic shell heights, whereas the K values (representing the relative rate at which the animals in the samples reached their asymptotic sizes) were similar among observers. Shell heights at age 0 ranged from -0.02 mm to 0.18 mm with the author's estimation 0.05 mm (Figure 2.10).

Table 2.3 Von Bertalanffy growth model: fitted parameters for 20 individuals randomly selected from 693 Iceland scallops collected from Gilbert Bay in 2007. Ages were determined by five observers (A,B,C,D, and E) counting external shell growth rings. Observer E is the author.

Observers	**A**	**B**	**C**	**D**	**E**
SH_{∞} (mm)	114.67	112.52	311.67	175.65	145.02
K ($year^{-1}$)	0.10	0.13	0.02	0.06	0.08
t_0 (years)	0.11	0.18	0.00	-0.02	0.05
r^2	0.81	0.69	0.89	0.85	0.94
SH range (mm)	17.25-104.25	17.25-104.25	17.25-104.25	17.25-104.25	17.25-104.25
Age range (years)	3-17	2-14	2-16	2-15	2-14
No.	20	20	20	20	20

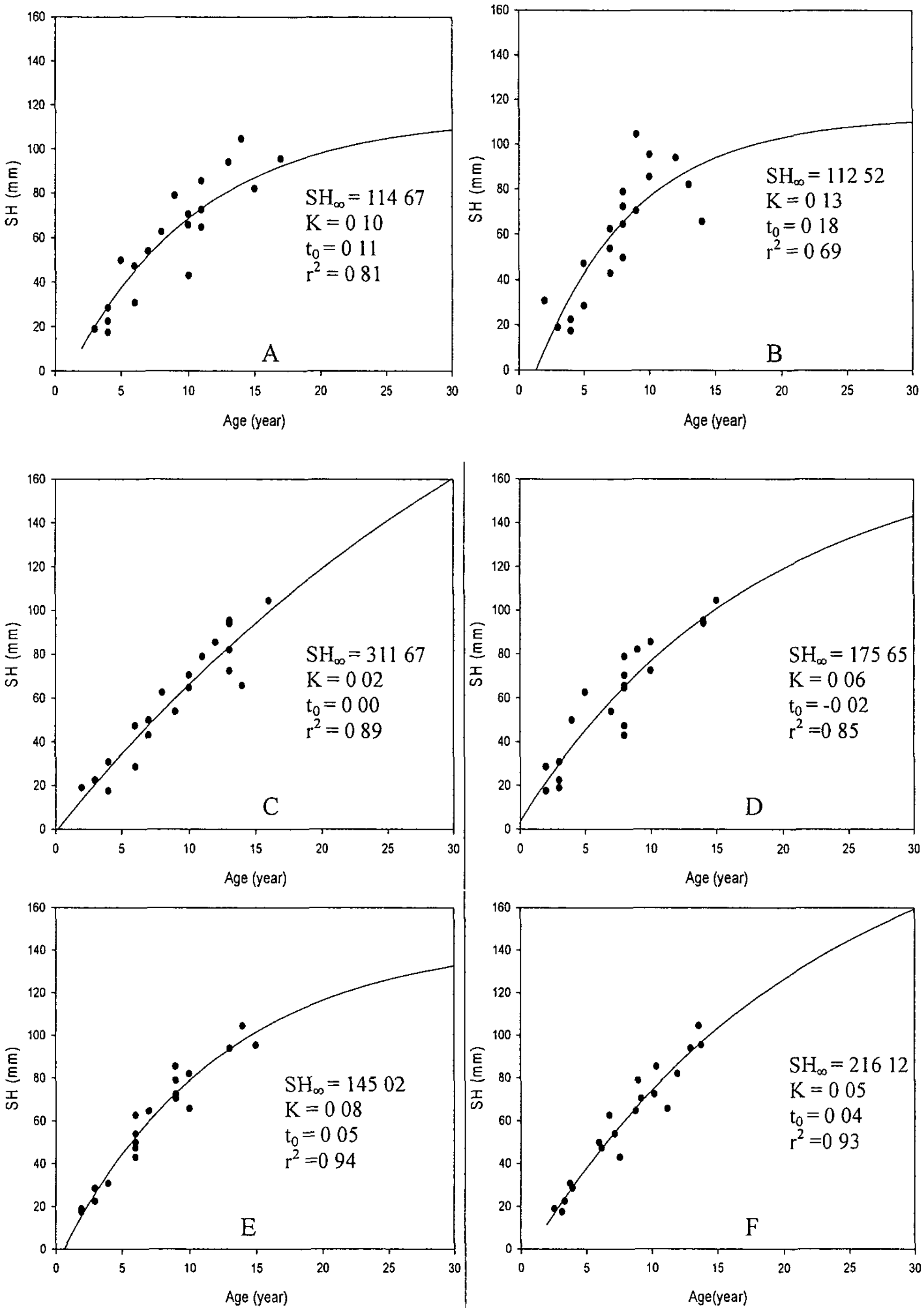

Figure 2.10. Age specific shell height (SH) fitted to von Bertalanffy equations for the 20 Iceland scallops systematically selected from the 693 individuals collected from Gilbert Bay in 2007. Age was determined by counting external shell growth rings. A, B, C, D and E are results from five observers, respectively; E is the result of the author, F represents the mean SH at mean age determined by five observers.

2.3.1.2 Ligament growth zone method

The interaction term for observer by age in the ANCOVA demonstrated no significant difference among the age determinations of five observers. The slopes of shell height versus age determined by five observers were similar (Table 2.4), although the one-way ANOVA indicated that there was a significant difference among the five observers determining the mean ages of the twenty scallops (Table 2.5).

Table 2.4 Analysis of covariance for SH by age and observer. Age was determined by the ligament method.

Source	Df	Sum of Squares	F	P
Observer	4	0.02479	0.0394	0.9969933
Age	1	28.16316	179.0668	<0.001
Observer*Age	4	0.69376	1.1028	0.3603204

Table 2.5 Results of the one-way analysis of variance for age by observer. Age was determined by the ligament method.

Source	Df	Sum of Squares	F	P
Observer	4	430.105	2.628	0.039

The calculated asymptotic shell heights ranged from 91 mm to 130 mm (Table 2.6, Figure 2.11) with the author's estimation 122 mm. SH_{∞} values were generally lower than those observed by counting external shell growth rings. K values ranged from 0.05 year^{-1} to 0.17 year^{-1}, which were generally higher than those estimated by counting external shell growth rings. The average ages of scallops determined by five observers ranged from 2 years for the smaller shell to 19 years for the large shell.

Table 2.6 Von Bertalanffy growth model: fitted parameters for 20 individuals randomly selected from 693 Iceland scallops collected from Gilbert Bay in 2007. Ages were determined by five observers (A,B,C,D, and E) counting hinge ligament growth zones. Observer E is the author.

Observers	A	B	C	D	E
SH_{∞} (mm)	103.34	97.74	91.46	129 99	121.80
K (year^{-1})	0.12	0.17	0.13	0.05	0.06
t_0 (years)	0.10	0.16	0.21	-0.02	-0.01
r^2	0.79	0.84	0.83	0.91	0.93
SH range (mm)	17.25-104.25	17.25-104.25	17.25-104.25	17.25-104.25	17.25-104.25
Age range (years)	2-17	2-17	4-23	2-24	2-25
No.	20	20	20	20	20

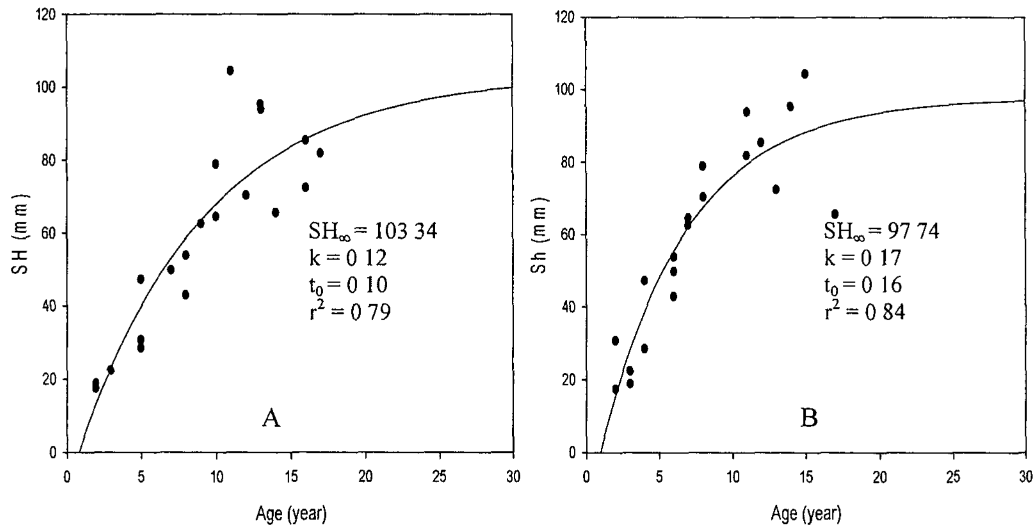

Figure 2.11 Age specific shell height (SH) fitted to von Bertalanffy equations for the 20 Iceland scallops selected from the 693 individuals collected from Gilbert Bay in 2007. Age was determined by counting hinge ligament growth zones. A, B, C, D and E are results of five observers, respectively; E is the result of the author, F represents the mean SH at mean age determined by five observers.

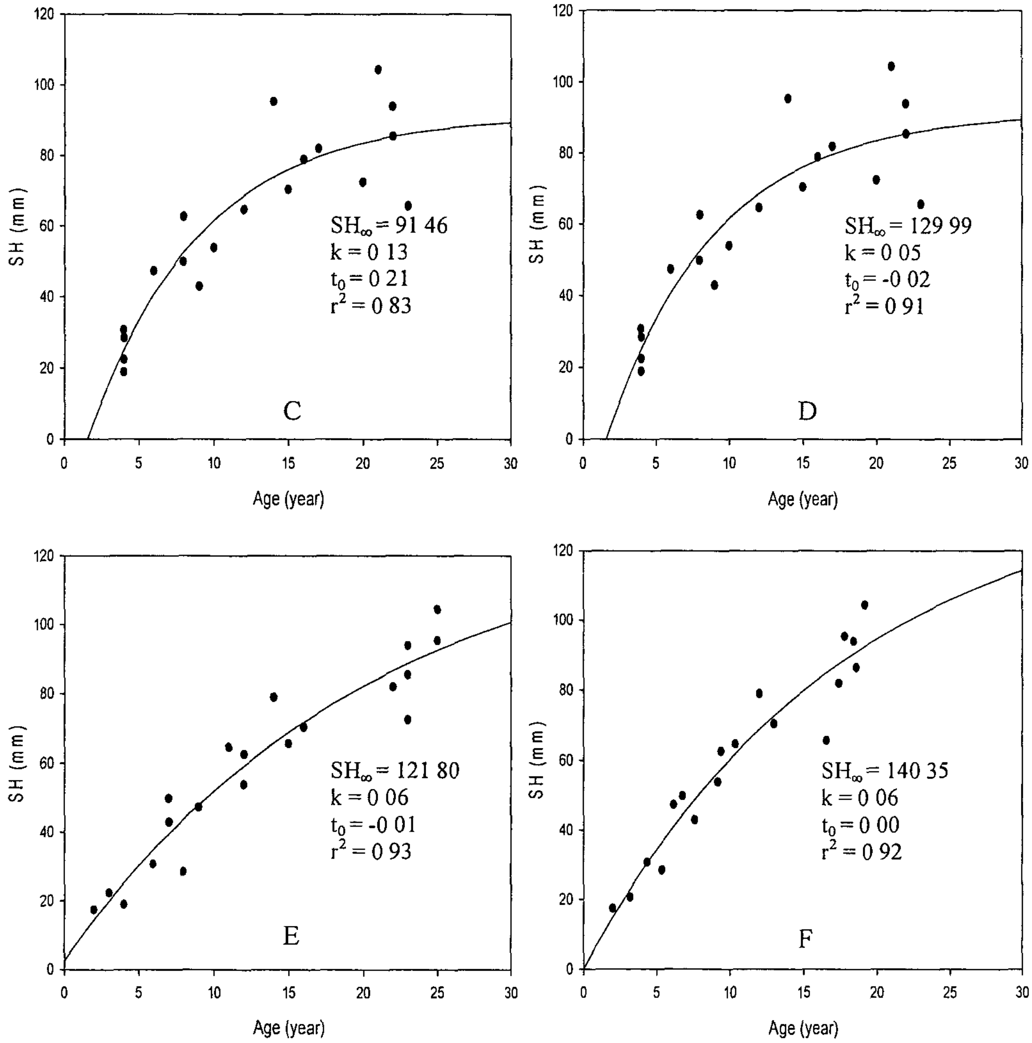

Figure 2.11 Continued.

2.3.2 Shell height-at-age of Gilbert Bay scallops comparing the three methods of aging

The purpose for having other students to estimate the age is to test if there is any bias in the auther's determination. The results showed that the age estimation among observers using external method and ligament mothod are consistent. So the observers were not asked to determine ages by using internal method because it was time-consuming and required more experience.

Linear regressions were used to express the relationship among the ages determined by each pair of the three methods. The linear relationship between ages determined by internal shell growth lines and both ages determined by hinge ligament growth zones and ages of external shell growth rings were $t_{Ligament} = 1.10\ t_{Internal} - 0.43$ (Figure 2.12) and $t_{External} = 0.52\ t_{Internal} + 1.25$ (Figure 2.13), with r^2 of 0.92 and 0.81, respectively. The linear relationship between ages determined by hinge ligament growth zones and ages determined by external shell growth rings was $t_{External} = 0.47\ t_{Ligament} + 1.46$ with an r^2 of 0.87 (Figure 2.14). The ages determined by internal shell growth lines were more similar to ages from hinge ligament growth zones, than ages determined by external shell growth rings. A correlation analysis was made among the three methods. Ligament method and internal method are highly associated, with a correlation coefficient of 0.961. The correlation between external method and both ligament method and internal method were lower, with coefficients of 0.933 and 0.899, respectively.

The von Bertalanffy equation related shell height to age classes represented in each method (Figure 2.15). SH_∞ was greatest for the external shell growth ring method and smallest for the internal shell growth line method. The growth coefficient K was lower for age estimated by hinge ligament growth zones, scallops reaching asymptotic height more slowly. However, caution must be exercised in comparing growth coefficients when SH_∞ values are different. The three regression curves shown in Figure 2.15 indicate faster scallop growth rate when individuals are aged by the external shell growth ring method. The growth curve determined by counting hinge ligament growth zones was quite close to that determined with internal shell growth lines.

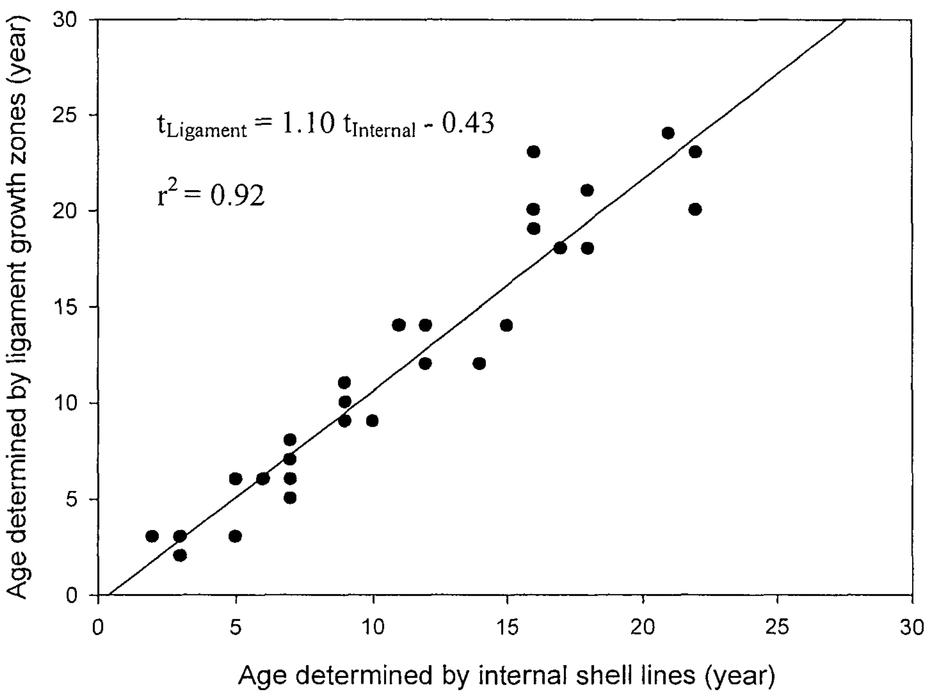

Figure 2.12 Linear regression between ages of 30 Iceland scallops determined by the ligament method and the internal method. The 30 scallops were systematically selected from the 693 individuals collected in Gilbert Bay in 2007.

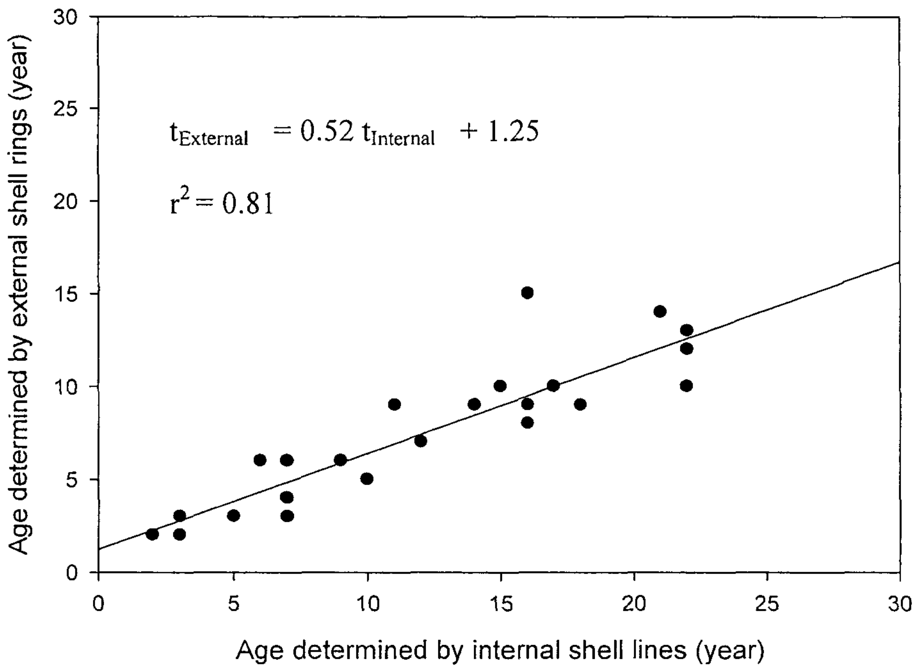

Figure 2.13 Linear regression between ages of 30 Iceland scallops determined by external method and internal method. The 30 scallops were systematically selected from the 693 collected in Gilbert Bay in 2007.

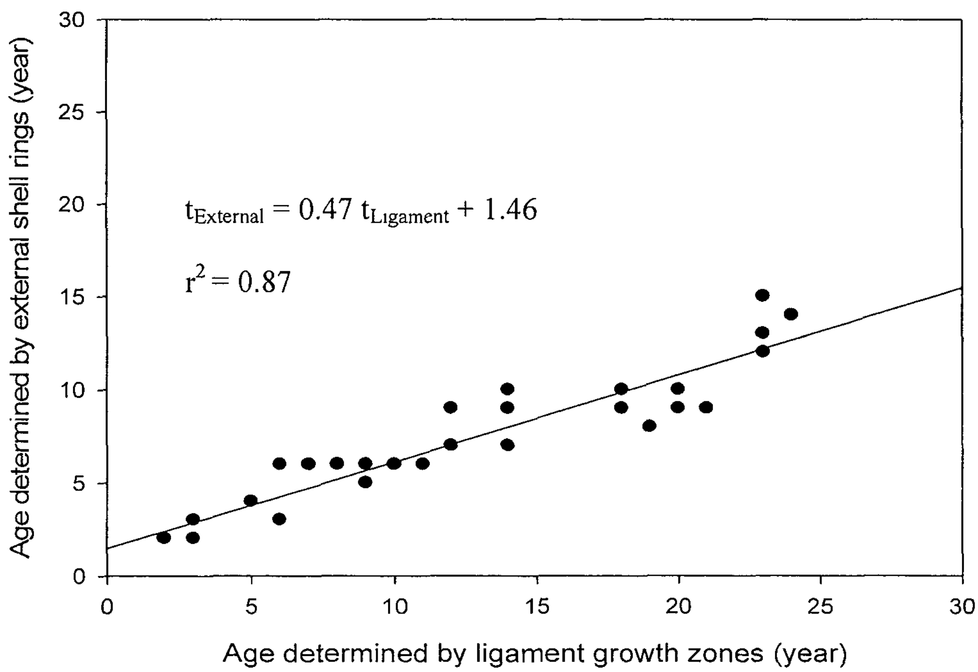

Figure 2.14 Linear regression between ages of 30 Iceland scallops determined by external method and ligament method. The 30 scallops were systematically selected from the 693 collected in Gilbert Bay in 2007.

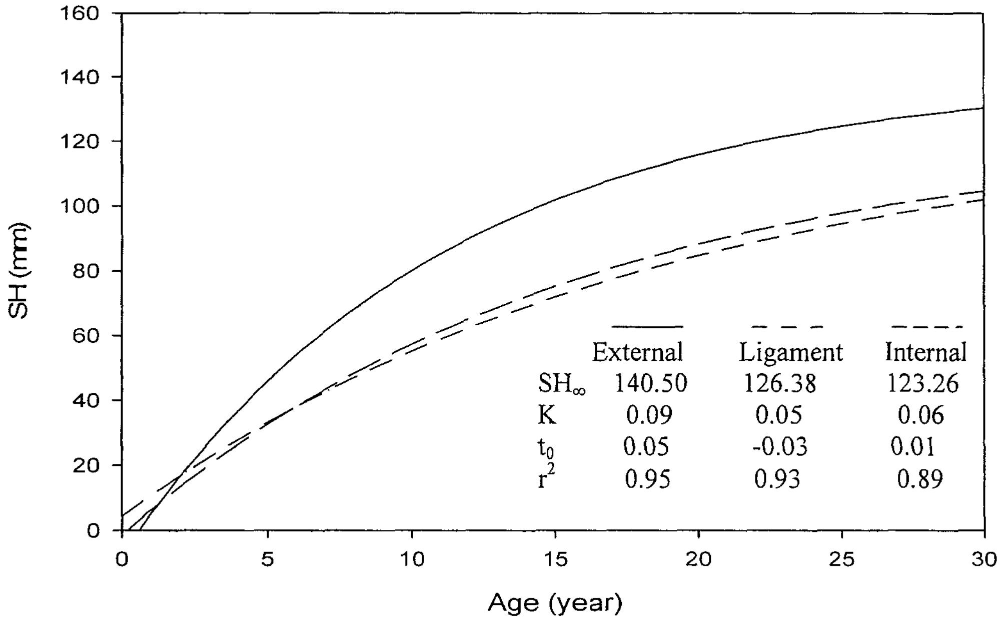

Figure 2.15 Age specific shell heights fitted to von Bertalanffy equations for 30 Iceland scallops randomly selected from the 693 collected in Gilbert Bay in 2007. Ages were determined by counting external shell growth rings (External), hinge ligament growth zones (Ligament) or internal shell growth lines (Internal).

The von Bertalanffy growth curve parameters, asymptotic shell height (SH_∞), growth coefficient (K) and theoretical age at size zero (t_0), r^2, are summarized in Table 2.7, together with SH and age ranges. The greatest ages are 15, 24 and 22 for external, ligament and internal methods, respectively. However, the largest specimen is not always associated with the greatest age. For example, the largest shell with SH at 104.25mm was measured at 24 years by using the ligament method (maximum age for this method), but 14 (external method) and 21 years (internal method), which are not the maximum ages. The maximum age for external method is 15 years and 22 years for internal method. The age ranges for hinge ligament growth zones and internal shell growth line methods were similar (2-24 years and 2-22 years, respectively), and larger than that of the external shell growth ring method (2-15 years).

Table 2.7 Von Bertalanffy growth model fitted parameters for 30 individuals randomly selected from 693 Iceland scallops collected from Gilbert Bay in 2007. Ages were determined by three methods: counting external shell growth rings, counting hinge ligament growth zones and counting internal shell growth lines.

	External	**Ligament**	**Internal**
SH_∞ (mm)	140.50	126.38	123.26
K (year^{-1})	0.09	0.05	0.06
t_0 (years)	0.05	-0.03	0.01
r^2	0.95	0.93	0.89
SH range (mm)	17.25-104.25	17.25-104.25	17.25-104.25
Age range (years)	2-15	2-24	2-22
No.	30	30	30

The interaction term in the analysis of covariance for the statistical comparison of the linearly transformed von Bertalanffy growth curves (Table 2.8) showed a significant difference ($P < 0.001$) among the three methods of age determination. A significant interaction between method and age indicates there is variance among the slopes of the three regressions. For the comparison of ligament and internal methods, the ANCOVA revealed no significant effects of methods on age determination, with an interaction P-value 0.32 (Table 2.9). The differences between the external method and both the ligament and the internal methods are significant ($P < 0.001$) (Table 2.9).

Table 2.8 Analysis of covariance for comparison of the three age determination methods for 30 scallops: external shell growth rings, hinge ligament growth zones and internal shell growth lines. The 30 scallops were randomly selected from 693 individuals collected in Gilbert Bay in 2007. * P value of interaction is < 0.05, indicating a significant difference among the three methods of age determination.

Source	**Df**	**Sum of Squares**	**F**	**P**
Method	2	0.00	1.1	0.33
Age	1	0.24	177624.1	<0.001
Method*Age	2	0.00	14.9	<0.001*

Table 2.9 Analysis of covariance for comparisons between each pair of the three age determination methods for 30 scallops: external shell growth rings, hinge ligament growth zones and internal shell growth lines. The 30 scallops were randomly selected from 693 individuals collected in Gilbert Bay in 2007. 'P' represents the P value of the interaction term.
* indicates a significant difference.

	External	Ligament
Ligament	P < 0.001*	
Internal	P < 0.001*	P = 0.32

Table 2.10 Results of the analysis of variance for comparison of the mean age of 30 scallops determined by the three methods: external shell growth rings, hinge ligament growth zones and internal shell growth lines. The 30 scallops were randomly selected from 693 individuals collected in Gilbert Bay in 2007.
* indicates a significant difference in mean age determined by the three methods.

Source	Df	Sum of Squares	F	P
Method	2	234.7	3.42	0.001*

Table 2.11 Analysis of variance for comparing the mean ages determined by each pair of the three aging methods for 30 scallops: external shell growth rings, hinge ligament growth zones and internal shell growth lines. The 30 scallops were randomly selected from 693 individuals collected in Gilbert Bay in 2007.
* indicates a significant difference.

	External	Ligament
Ligament	P = 0.001*	
Internal	P = 0.001*	P = 0.65

The analysis of variance showed that methods had an effect on the mean age for all age classes of the 30 individuals selected from 693 scallops in Gilbert Bay (P = 0.001) (Table 2.10). There was a significant difference between the mean ages determined from hinge ligament growth zones and external shell growth rings (P = 0.001) (Table 2.11); ages determined by internal shell growth lines was significantly higher than those determined by the external method (P = 0.001). Similar mean ages were obtained from the internal method and the ligament method (P = 0.65) (Table 2.11).

2.4 Discussion

Annual growth increments can be counted and measured by examination of the 'winter checks' or rings of ridges on the valve surface. During growth of young Iceland scallops (e.g. < 12 years), the inner surface of the outer fold of the mantle generates new tissue and nacreous aragonite on the inner side of the shell while the outer surface deposits a calcareous-layer material, both components of the shell. Shell depositions slow in winter, and changes in shell height and thickness are small. At the resumption of growth, new material is deposited at the shell margin. As a result, a ridge has been formed by the winter growth check (Crawford, 1992).

For the population of Iceland scallop *Chlamys islandica* examined here and for others described elsewhere (Johannessen, 1973) there is a discrete annual reproductive cycle with a well-synchronized spawning period. The spawning of *Chlamys islandica* occurs once a year normally from late June to early July. A light and a dark band are formed annually on the shells. As the light zone is laid down between December and May, and is found to succeed the ring (winter check) on older shells, it represents the start of the growth in spring (Johannessen, 1973). This winter check is reflected in the structure of the shell surface (Naidu, 1988), in the lateral calcified part of the shell hinge ligament (Pedersen, 1994) and in the sectioned shell. The ligament and internal shell methods for determining age were similarly accurate. The similarity between results of the hinge ligament method and the internal shell growth method were demonstrated by both statistical analysis and the von Bertalanffy model fitted curves. Compared to hinge ligament and internal shell method, the external annuli appeared to underestimate the age and overestimate the growth rate of the Iceland scallop in Gilbert Bay.

MacDonald (1984) concluded that neither the hinge ligament growth zones nor the external shell growth rings was ideal for determining the age of individual sea scallops (*Placopecten magellanicus*), but the growth zones on the ligament more accurately revealed the true age (scallops of known-age were examined) and gave more consistent results than counting external annuli on the shell. Jones *et al.* (1978) and MacDonald *et al.* (1980) expressed a preference to use the internal shell growth lines to determine the age of the Atlantic surf clam *Spisula solidissima* and the soft-shell clam *Mya arenaria*, rather than using the external shell growth rings, which was more commonly used but less accurate. The superiority of the internal shell growth line method has been confirmed by Hua *et al.* (2001) for freshwater mussels (*Cyprogenia stegaria and Lexingtonia dolabelloides*). When the individuals grow older, the growth rings on the surface of the shell may merge and may not be as distinguishable, so an impartial observer would probably underestimate age and overestimate growth rate for old individuals.

Johannessen (1973) concluded that age cannot be determined on all individuals of Iceland scallop by counting the rings on the shell surface. Winter check marks were not seen on the valves of all specimens, but were always visible on the ligament (Johannessen, 1973). Proportionally, As the distance from the umbo to the growth line in the ligament corresponds to the distance from the umbo to the winter rings on the shells, both structures were made at the same time. Unlike the winter rings on the shell, the ligament growth zones can always be produced, making individual age determination much more reliable (Johannessen, 1973).

As scallops age, annual growth increments decrease and the separation between the check marks becomes unclear. Also, well-defined checks are not usually found in the first five to seven years of growth of Iceland scallops, but alternating light and dark zones can be seen on the dorsal valve surface. These zones correspond to annual growth rings (Johannessen, 1973). In our study, the upper valve was often fouled by barnacles, sponges and marine algae. Although these were removed by forceps and brushes, the rings on the shell surface were still blurred; older scallops are more likely to be covered with marine fouling organisms, so that the annual rings were hard to detect (Crawford, 1992). Some researchers clean the valves with a mild acid wash to facilitate age determination; in this study, we removed fouling organisms from the shells by using forceps and a brush on the shell surface, and cleaned the lateral ligament with freshwater.

Some specimens exhibited light or dark lines, called false rings, on the shell surface which were hard to distinguish from the real growth lines. Neves and Moyer (1988) concluded that every external shell growth ring corresponded with an internal shell growth line, but there were no corresponding internal shell growth lines for any false rings on the shell. Wave action, physical damage and any other environmental stress may contribute to the formation of false lines (Tevesz and Carter, 1980).

Although growth lines in the sectioned shells are considered to be a more accurate method to determine ages of marine or freshwater bivalves, scallops are more likely to be damaged during the slicing procedure, especially younger individuals, which are more fragile. The epoxy technique is time-consuming and it is hard to determine whether the shell is fragile and needs to be supported. Another disadvantage of using the internal shell growth line method is that it requires the shell to be longitudinally sectioned from the umbo to the ventral margin along the axis of maximum growth. There are two problems associated with this: one is that there could be error in determining the axis of maximum growth; the other is that even if a line based on the maximum growth is drawn from the umbo to the ventral margin, the low-speed saw could possibly cut the shell deviating from the line. The ligament method is more convenient than sectioning the shells. All one needs to do is clean the lateral part of the hinge ligament after the soft part of the ligament is removed.

Several non-linear growth equations can be used for mean SH fitting to age, such as Gompertz model (Ricker, 1975; Hernandez-Llamas and Ratkowsky, 2004), von Bertalanffy function and polynomial expression (Rafail, 1972; Macdonald and Thompson, 1988; Urban, 2002). The Gompertz and von Bertalanffy function are flexible with respect to their shape and they always assume that an asymptotic SH exists. One serious limitation associated with asymptotic SH estimation occurs when large individuals are undersampled, as they are in many studies. The problem is even greater when the population being studied is being harvested, or has been harvested, because this tends to remove large individuals disproportionately. This problem can be circumvented by fitting polynomials to the growth data. Multiple growth curves can be compared statistically and the equation reduces to a linear function and hence there is no attempt to force asymptotic behavior when none is observed (Roff, 1980). The problem with the polynomial approach is that the coefficients themselves have no biological significance (MacDonald and Thompson, 1988).

Therefore, the choice of a particular equation should be dictated by circumstances: for example, if t_0 is very small, the growth curve may be linearized, as was in this study, by taking logarithms of the variables (this procedure may also stabilize the variances which is desirable for linear regression analysis). Another reason for using the von

Bertalanffy function is that it permits a comparison of growth curves already found in the literature (Roff, 1980). In this study, I used the von Bertalanffy growth function to simulate scallop SH-at-age, because it was the method used in the literatures of Pedersen (1994) and Naidu (1998), which I cite to compare with scallop growth in Gilbert Bay in Chapter 3.

Care must be taken when comparing shell growth rates from different age determination methods, especially when the von Bertalanffy function is used (MacDonald and Thompson, 1988). It is not appropriate to base comparisons on the parameter K when the asymptotic shell heights or lengths differ considerably among methods, because K is inversely related to SH_{∞} (Ralph and Maxwell, 1977; Haukioja and Hakala, 1979). Furthermore, K is a growth coefficient and should not be regarded as a growth rate *per se* (Ricker, 1975). Attempts to combine SH_{∞} and K into a single parameter have been made (Galluci and Quinn, 1979; Appeldoorn, 1983), but this does not overcome the fundamental problem that the two are interdependent (Beukema and Meehan, 1985).

In this study, the von Bertalanffy equation predicted value for both SH_{∞} and the growth coefficient K was higher for external method than either ligament method or internal method. Both the statistical analysis (Table 2.8) and von Bertalanffy fitted curves (Figure 2.15) indicated that the results from counting hinge ligament growth zones were more similar to those from counting internal shell growth lines than to those from counting external shell growth rings. The SH_{∞} value determined by the ligament method was closer to that obtained by the internal method than to that of the external shell method, and the coefficient K was more similar between the ligament and internal shell methods. With the highest SH_{∞} (140.50 mm), the external shell method gave the highest K (0.09 $year^{-1}$), while the internal shell growth line method was associated with the lowest SH_{∞} and higher K as well.

Conclusions for this section will be summarized in Chapter 4 (Conclusions and recommendations).

Chapter 3

Growth rates of Iceland scallops in Zones 2 and 3 of the Gilbert Bay MPA

3.1 Introduction

Shell growth of scallops is known to vary seasonally, and may also vary between areas, due to local feeding conditions and temperature (Vahl, 1980; MacDonald and Thompson, 1985). Most growth takes place during the spring phytoplankton bloom (Thorarinsdottir, 1993). There are also age-related changes in scallop growth rate. During the first year, growth rate of Iceland scallops is about 8-10 mm $year^{-1}$, decreasing to 0-3 mm $year^{-1}$ at 10-15 years (Garcia, 2006).

In most parts of the world, Iceland scallops grow to a maximum size of 80-110 mm, although individuals measuring 140 mm have been found in northwest Iceland (Garcia, 2006). There are records of Iceland scallops reaching age 20 years in Iceland (Garcia, 2006). In the Nuuk area of west Greenland, scallops were estimated to be older than 30 years (Pedersen (1994).

There is little scientific information on growth of Iceland scallops in the Gilbert Bay MPA. Wroblewski *et al.* (2009) collected the first scientific data on the Gilbert Bay scallop stock by recording catches of commercial harvesters during the 2006 fishing season. They found that the SH frequency distribution of Iceland scallops varies with location in Gilbert Bay, and the grand mean of scallop SH in Gilbert Bay is smaller than that in the Strait of Belle Isle. These could be due to variation in recruitment of new scallops, variation in shell growth rate, variation in natural mortality (i. e. predation by sea stars) and fishing mortality (harvesting intensity).

In this chapter, I estimated growth rate of scallops at different locations within Gilbert Bay, and compared the SH-at-age data with those collected in the Strait of Belle Isle and in the Nuuk area of West Greenland, the only available published data on Iceland scallop SH-at-age.

In chapter 2, I discussed the advantages and disadvantages of the three methods that are normally used to determine the age of Iceland scallops, and concluded that the ligament method was more convenient and accurate. Therefore, hinge ligament growth zones were used to determine the shell growth rates of Iceland scallops in Zone 2 and 3 of the Gilbert Bay MPA.

3.2 Methods

3.2.1 Age determination

During 26 September to 1 October 2007 693 Iceland scallops were collected by Dr. Joe Wroblewski and MPA community coordinator Marilyn Penney, working on board the CFV *Little Shell* in Gilbert Bay MPA Zones 2 and 3. Dredge tows were made at seven locations along the main axis of Gilbert Bay: 1, Middle Island (No. of scallops collected (N) = 100); 2, Peckham Cove (N = 137); 3, Kellys Point (N = 76); 4, Rexons Point (N = 67); 5, Coach Box Point (N = 54); 6, Main Tickle (N = 121); 7, Leg Island (N = 138) (Figure 2.1).

The shell height is defined as the longest distance from shell hinge to ventral shell margin and it was measured to the nearest 0.05 mm with a vernier caliper. Age was determined by counting growth zones on the ligament at the umbo using a binocular microscope and following the procedures described by Johannssen (1973). The increase in shell height with age was used to determine scallop growth in Gilbert Bay and the variability of scallop growth at different areas within the bay.

3.2.2 Data analysis

Three hypotheses were tested: 1) The Gilbert Bay scallop growth rates are equivalent throughout the bay, 2) The Gilbert Bay scallops grow at the same rates as those in the Strait of Belle, and 3) The Gilbert Bay scallops grow at the same rates as those in the Nuuk area of West Greenland.

The von Bertalanffy model (Formula 2.1) (von Bertalanffy, 1938) was used for determining growth parameters. The functions were fitted by iteration, using the three parameter exponential growth available in the fit curve procedure of Sigma Plot. Shell height-at-age was analyzed by analysis of covariance (ANCOVA) where age 't' was the continuous variable, and 'Area' was the categorical variable. The ANCOVA determined simultaneously the effects of two factors on the response variable and the variance among the slopes for each area. The von Bertalanffy equation estimated SH_{∞} for all 693 scallops when growth rates of scallops within Gilbert Bay were compared. While comparing growth rates of scallops from Gilbert Bay with those from the Strait of Belle Isle and the Nuuk area of West Greenland, I used the average SH_{∞} of both locations, estimated from von Bertalanffy equation by using external method and ligament method of age determination, respectively. The following general linear model was used in the analysis:

$$Ln(1 - SH/SH_{\infty}) = \beta_0 + \beta_{(t-t0)} *(t-t_0) + \beta_A *Area + \beta_{(t-t0)*A} *(t-t_0) *Area + Error \quad (3.1a)$$

An analysis of variance (ANOVA) was used to test the equality of population sample means by determining whether the variance between samples being tested was significantly greater than variance within samples. In order to determine the effect of a single factor 'Area' on population means, a one-way ANOVA was used. The General Linear Model (GLM) for the one-way ANOVA was:

$$Age = \beta_0 + \beta_A*Area. \quad (3.1b)$$

The statistical analysis was done by iterative estimation, by using the General Linear Model procedure of S-PLUS to compare regressions and for analysis of variance, , using normal error and identity link. The linear regression procedure in S-PLUS was used to construct the linear transformation of the von Bertalanffy model and to test the parameters.

3.3 Results

3.3.1 Growth of Iceland scallops in Gilbert Bay

The mean shell heights versus age for scallops from the seven areas sampled in Gilbert Bay in 2007 are shown in Figure 3.1. The curves are close to each other, except for those of area 3 (Kellys Point) and area 4 (Rexons Point), where scallops grow more slowly before age 8. Scallop growth does not differ among areas, except at early age at Kellys Point and Rexons Point (Figure 3.1). Analysis of covariance for comparison of scallop growth at seven areas indicates significant differences in growth rate among the areas in Gilbert Bay ($P < 0.001$) (Table 3.1). I excluded data from areas 3 and 4 and examined scallop growth at the remaining five areas (Middle Island, Peckham Cove, Coach Box

Point, Main Tickle and Leg Island). Statistically, there was no significant difference among these five areas (P = 0.19) (Table 3.2).

Table 3.1 Results of the analysis of covariance for comparison of scallop growth at seven areas in Gilbert Bay.
* Significant difference in growth rate among the areas in Gilbert Bay is indicated because the interaction P value is < 0.001.

Source	Df	Sum of Squares	F	P
Area	6	0.052	1.207	0.31
Age	1	19.76	2732.61	<0.001
Area*Age	6	0.35	7.97	<0.001*

Table 3.2 Analysis of covariance for comparison of scallop growth at five areas in Gilbert Bay, excluding Kellys Point and Rexons Point.
The P value for interaction term is 0.19 > 0.05, indicating no significant difference in growth rate among the remaining five areas in Gilbert Bay.

Source	Df	Sum of Squares	F	P
Area	4	0.04	1.68	0.16
Age	1	9.95	1894.16	<0.001
Area*Age	4	0.03	1.55	0.19

Table 3.3 Analysis of covariance for comparison of scallop growth at different areas in Gilbert Bay.
* P < 0.05, indicating significant difference in growth rate between the two areas compared.

	Middle Island	Main Tickle	Kellys Point
Peckham Cove	P = 0.40	-	-
Leg Island	P = 0.01*	P = 0.04*	-
Coach Box Point	-	-	P = 0.004*

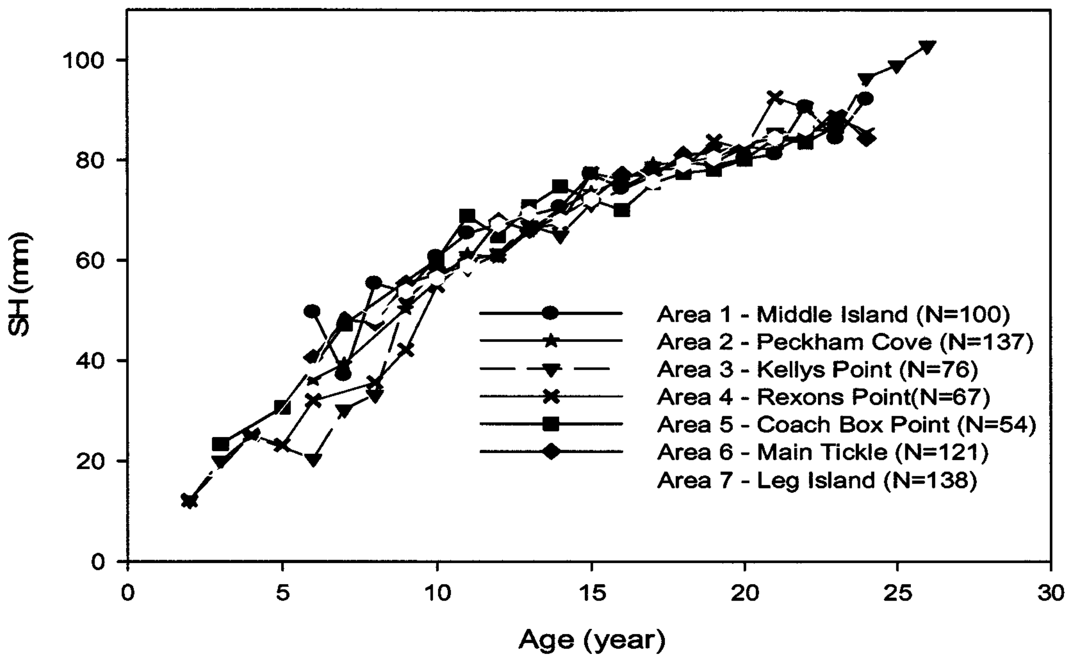

Figure 3.1 Mean shell height versus age for Iceland scallops at seven areas within Gilbert Bay (Total sample number is 693). Ages were determined by counting hinge ligament growth zones. The locations of the areas are shown in Figures 1.1 and Figure 2.1.

There was no significant difference between scallop growth at Middle Island, located at the upper part of the bay, and Leg Island which is in the seaward region of the bay (P = 0.01) (Table 3.3). At Middle Island and at Peckham Cove, both located in the inner bay, the growth rates of Iceland scallops were similar ((P = 0.40) (Table 3.3, Figure 3.3). For the comparison of scallop growth at Main Tickle and Leg Island, both located near the mouth of the bay, a significant difference was found (P = 0.04) (Table 3.3, Figure 3.4). I also compared the scallop growth at Kellys Point and Coach Box Point, where similar levels of commercial fishing effort had been conducted during 2005 and 2006 (Figure 1.4), and a significant difference was found (P = 0.004) (Table 3.3, Figure 3.5). At early age, scallops at Coach Box Point grew faster than scallops at Kellys Point (Figure 3.5).

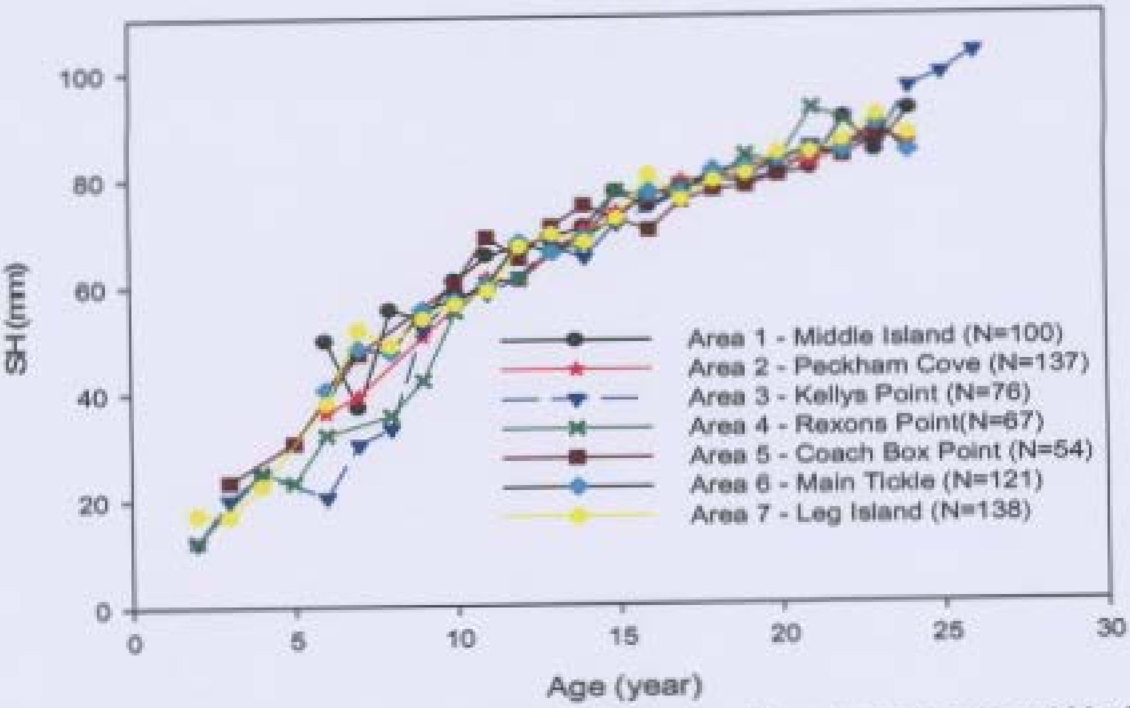

Figure 3.1 Mean shell height versus age for Iceland scallops at seven areas within Gilbert Bay (Total sample number is 693). Ages were determined by counting hinge ligament growth zones. The locations of the areas are shown in Figures 1.1 and Figure 2.1.

There was no significant difference between scallop growth at Middle Island, located at the upper part of the bay, and Leg Island which is in the seaward region of the bay (P = 0.01) (Table 3.3). At Middle Island and at Peckham Cove, both located in the inner bay, the growth rates of Iceland scallops were similar ((P = 0.40) (Table 3.3, Figure 3.3). For the comparison of scallop growth at Main Tickle and Leg Island, both located near the mouth of the bay, a significant difference was found (P = 0.04) (Table 3.3, Figure 3.4). I also compared the scallop growth at Kellys Point and Coach Box Point, where similar levels of commercial fishing effort had been conducted during 2005 and 2006 (Figure 1.4), and a significant difference was found (P = 0.004) (Table 3.3, Figure 3.5). At early age, scallops at Coach Box Point grew faster than scallops at Kellys Point (Figure 3.5).

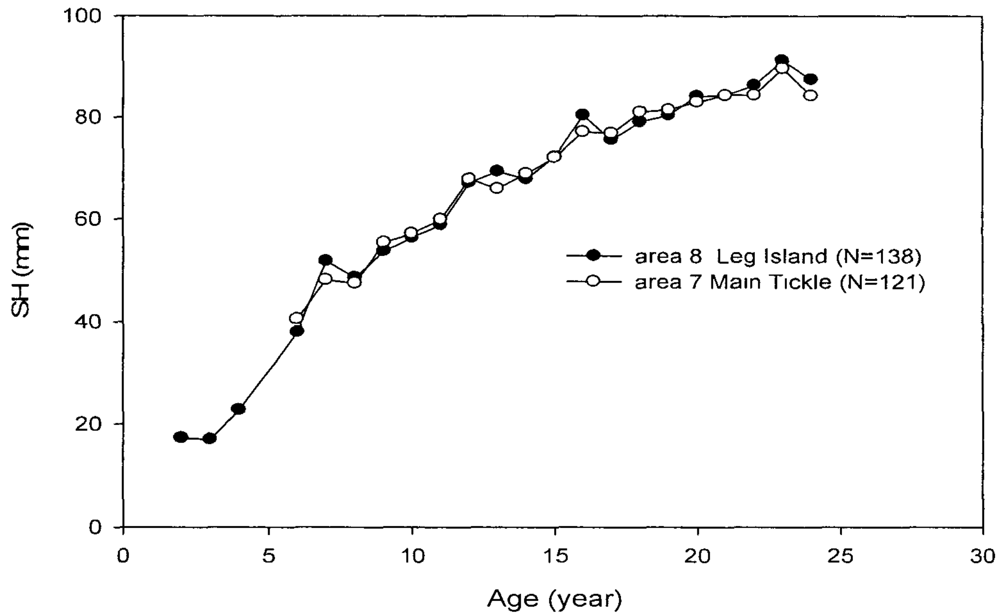

Figure 3.4. Mean shell height versus age for Iceland scallops at Leg Island and at Main Tickle, near the mouth of Gilbert Bay. Ages were determined by counting hinge ligament growth zones.

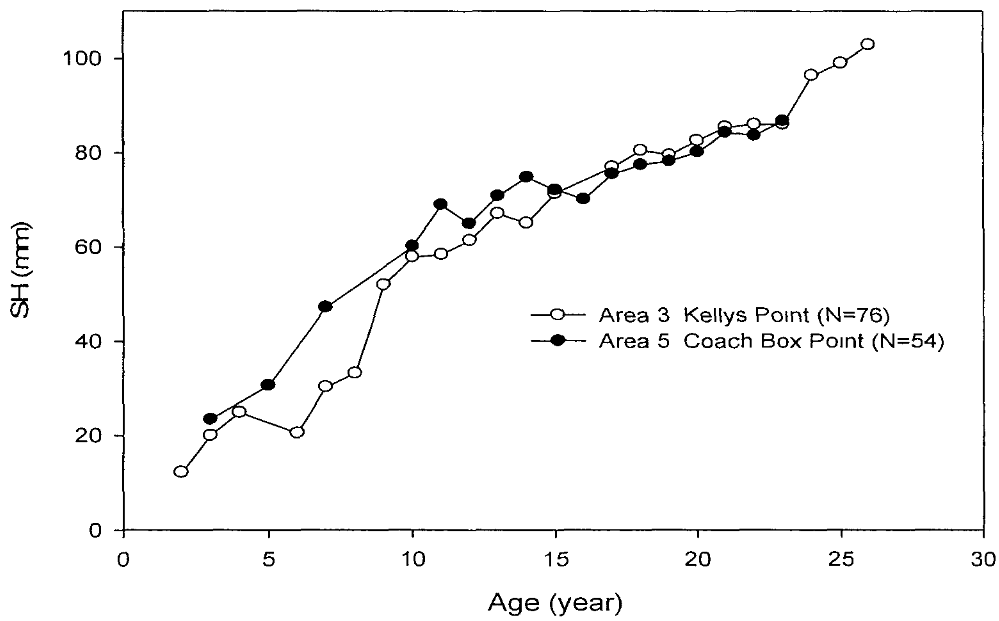

Figure 3.5 Mean shell height versus age for Iceland scallops at Kellys Point and at Coach Box Point. Both locations had a similar level of commercial fishing effort during 2005 and 2006 but the shell sizes harvested were significantly different (see Figure 1.5). Ages were determined by counting hinge ligament growth zones.

The von Bertalanffy fitted curve and parameters for the growth of Iceland scallops in Gilbert Bay (data combine from all sites) are shown in Figure 3.6. The mean asymptotic shell height is 116.78 mm, which is higher than the maximum shell height recorded. The model projects that scallops will not reach the asymptotic shell height until they are over 30 years old. Except where the two largest mean SH values (98.90 mm and 102.85 mm) deviated from the curve, the data fit the curve well. The von Bertalanffy growth curve parameters for all the seven areas in Gilbert Bay, together with the SH and age ranges, are summarized in Table 3.4. The fitted curves are presented in Figure 3.7. The values of SH_∞ for scallops at Middle Island, Peckham Cove and Coach Box Point were slightly below the maximum SH recorded (95.75 mm, 97.18 mm and 89.55 mm, respectively).

Generally, a higher growth coefficient is associated with a lower SH_∞. For example, SH_∞ has a trend of Coach Box Point < Middle Island < Leg Island. The trend for K values was the reverse: Coach Box Point > Middle Island > Leg Island. The r^2 values for all seven areas were equal to or higher than 0.93, indicating that the independent variable 't' effectively explained the dependent variable 'SH'.

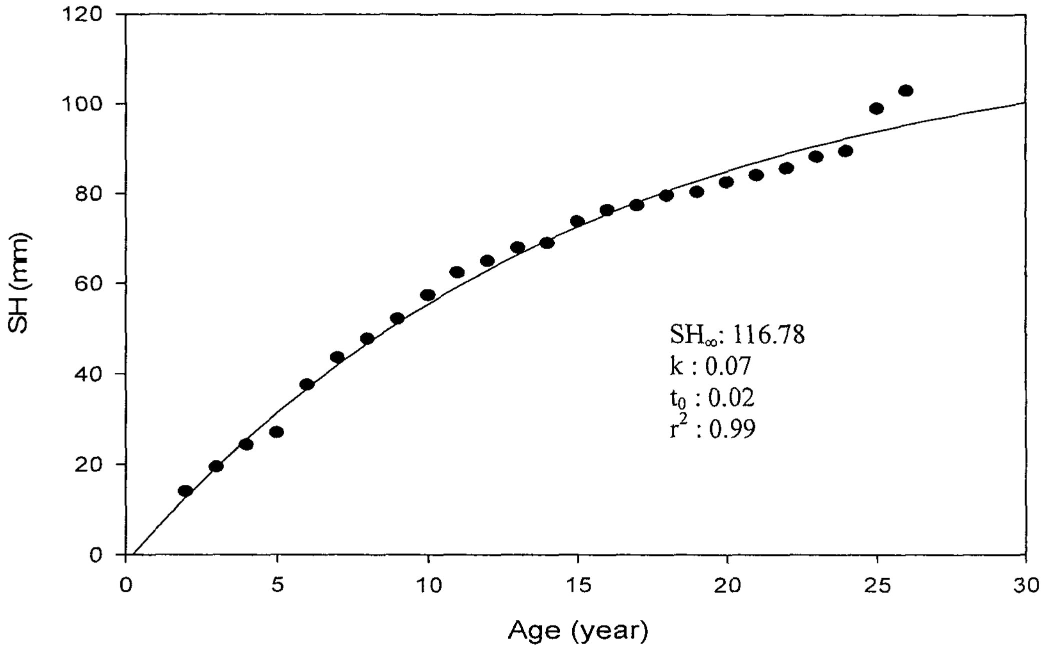

Figure 3.6 Age-specific shell heights fitted to the von Bertalanffy equation for Iceland scallops collected from Gilbert Bay (N=693) in 2007. Ages were determined by counting hinge ligament growth zones.

Table 3.4 Von Bertalanffy growth model fitted parameters for scallops at seven locations in Gilbert Bay. Age was determined by counting hinge ligament growth zones. The names and locations of the areas are presented in Figure 2.1. The total number of scallops collected was 693 and the number of individuals collected in each area is presented in the table.

	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7
SH_∞ (mm)	95.75	97.18	146.61	145.91	89.55	100.49	101.33
k (year^{-1})	0.10	0.10	0.04	0.05	0.13	0.09	0.09
t_0 (years)	0.02	0.18	0.01	0.02	0.14	-0.00	0.06
r^2	0.93	0.99	0.97	0.98	0.97	0.98	0.98
SH range (mm)	36.55-94.5	36.1-96.2	12.15-104.25	12.2-96.6	22.25-88.85	36.45-94.55	13.3-95.2
Age range (years)	6-24	6-24	2-26	2-22	3-23	6-24	2-24
No.	100	137	76	67	54	121	138

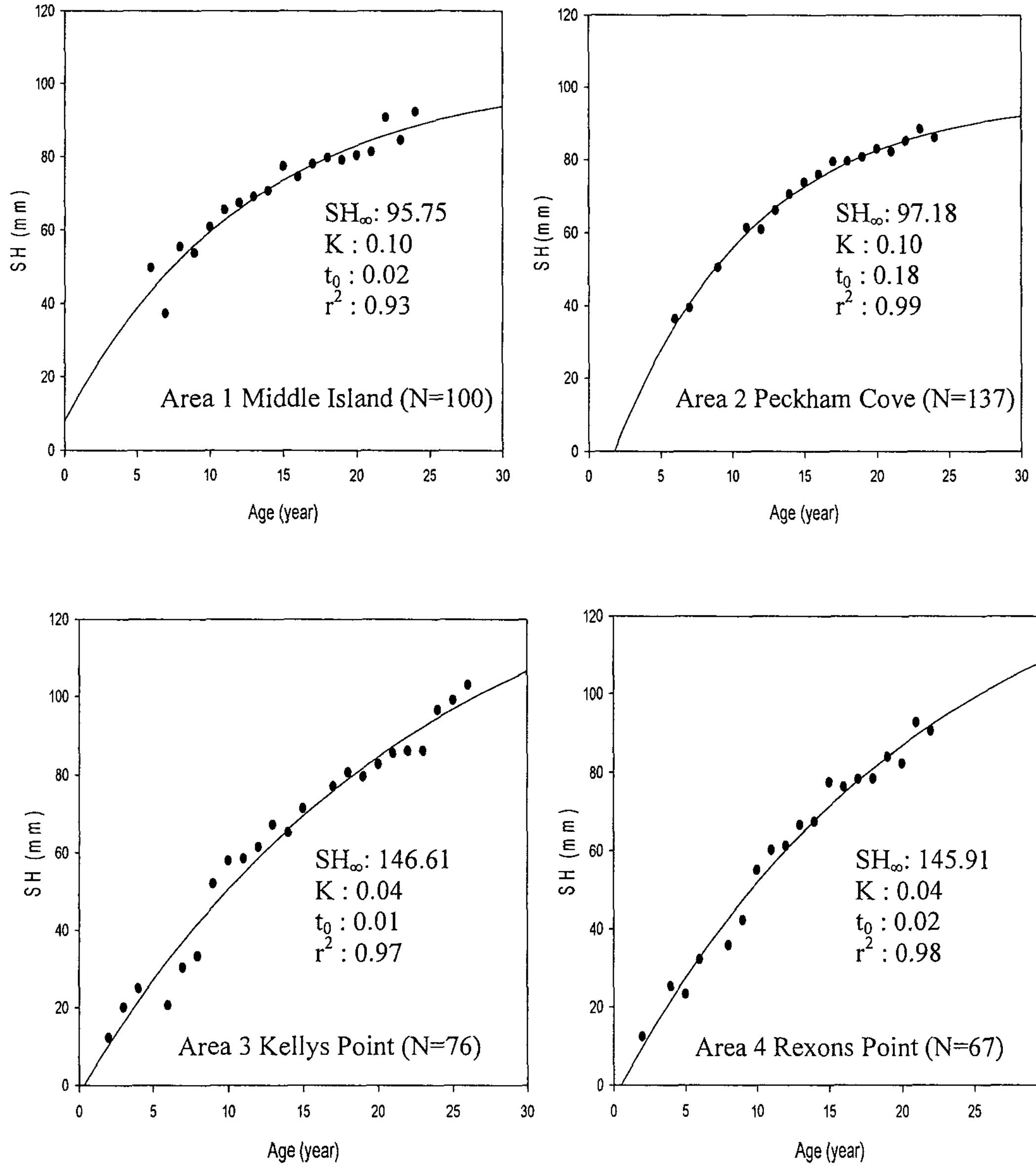

Figure 3.7 Age-specific shell heights fitted to von Bertalanffy equations for scallops collected at seven areas within Gilbert Bay in 2007. Ages were determined by counting growth zones on the hinge ligament.

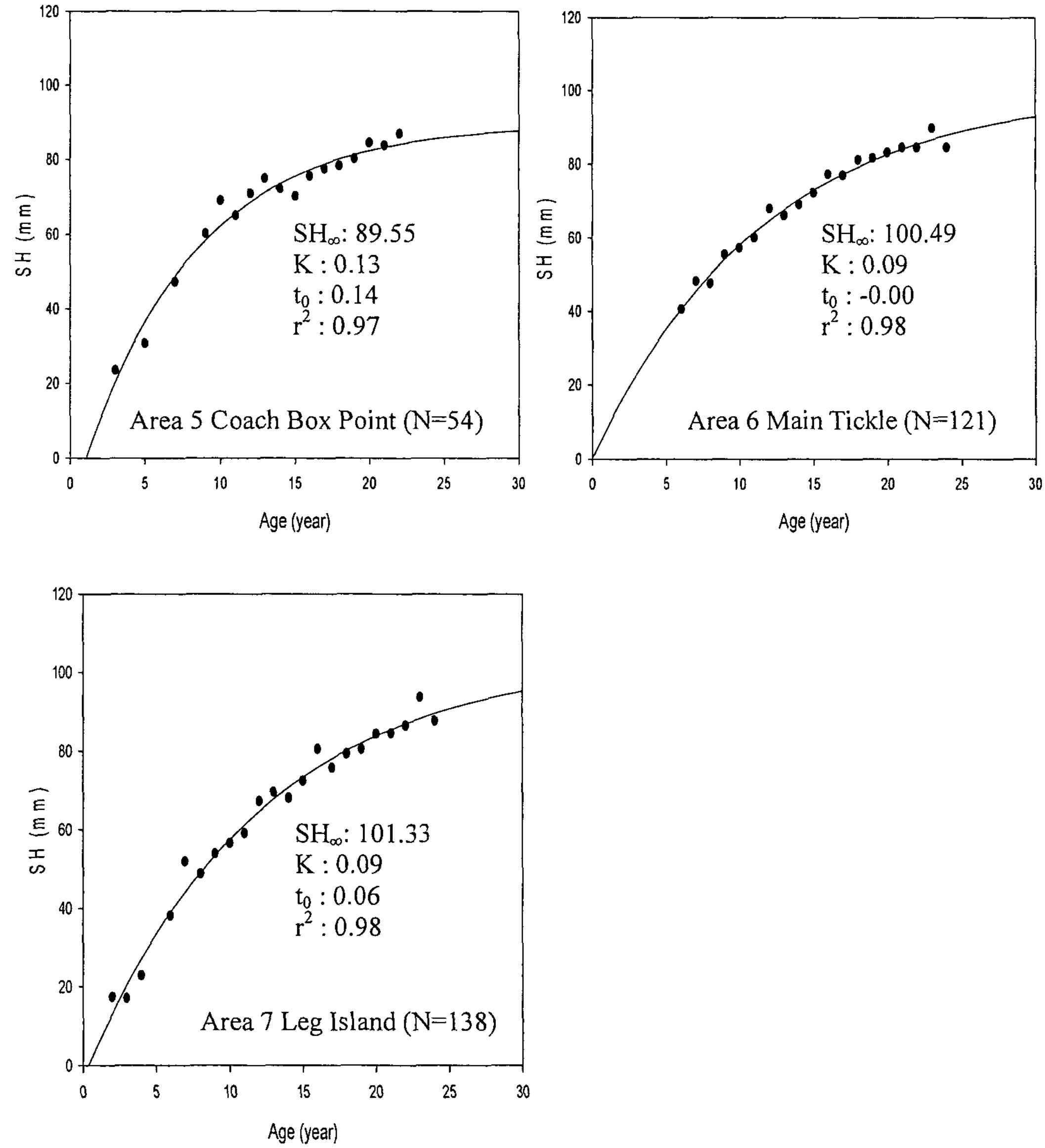

Figure 3.7 Continued.

3.3.2 Comparison of scallop growth in Gilbert Bay with scallop growth in the Nuuk area of West Greenland

The increase in shell height with age was used to compare scallop growth in Gilbert Bay to literature values of scallop growth in the Nuuk area of West Greenland. To be consistent with the methodologies in the literature (Pedersen, 1994), I used the method of counting hinge ligament growth zones to determine the growth rate of scallops in Gilbert Bay.

The SH growth rate found in Gilbert Bay was similar to that in the Nuuk area of West Greenland (Pedersen, 1994). Scallops collected from Gilbert Bay attained greater ages than those from West Greenland. In the research on west Greenland scallops by Pedersen (1994), individuals with more than 21 annual zones were assigned the age 21^+, but in this study all ages were recorded as the number of growth zones that were observed. To keep consistent with Pedersen (1994), all individuals other than 21 years here were regarded as 21^+ in the statistical comparison. Scallops in West Greenland grow slightly faster than those in Gilbert Bay (Figures 3.8 and 3.9). Therefore, scallops in Greenland reached the asymptotic shell height earlier than scallops in Gilbert Bay. The value of growth coefficient K for scallops in Greenland was higher, with a relatively lower SH_∞ than for scallops in Gilbert Bay. The r^2 for both locations given by the von Bertalanffy equation was very high (0.99), meaning that the model fitted the data well.

Table 3.5 Analysis of covariance for comparing scallop growth in Gilbert Bay (this study) to scallop growth in the Nuuk area of West Greenland (NAWG) (Pedersen, 1994) and to scallop growth in the Strait of Belle Isle (SBI) (Naidu, 1988). P values for both comparisons are > 0.05, indicating scallop growth rate in Gilbert Bay is similar to scallop growth rates in the other two regions.

		NAWG (Ligament)	**SBI (External)**
Gilbert Bay	**Ligament**	P = 0.69	-
	External	-	P = 0.19

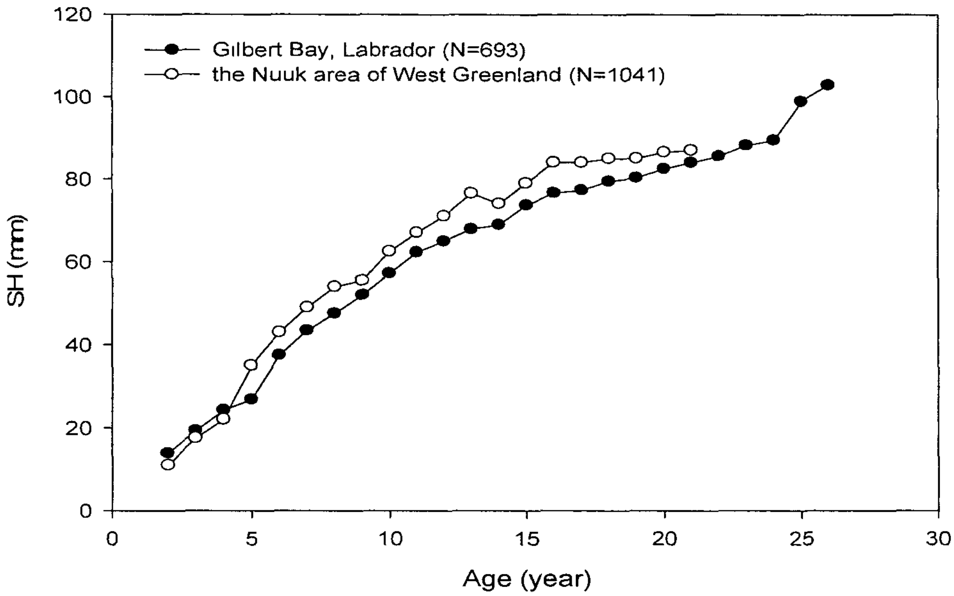

Figure 3.8 Mean shell height versus age for Iceland scallops in Gilbert Bay (this study) and in the Nuuk area of West Greenland (data of Pedersen, 1994). In both studies, ages of Iceland scallops were determined by counting growth zones on the hinge ligament.

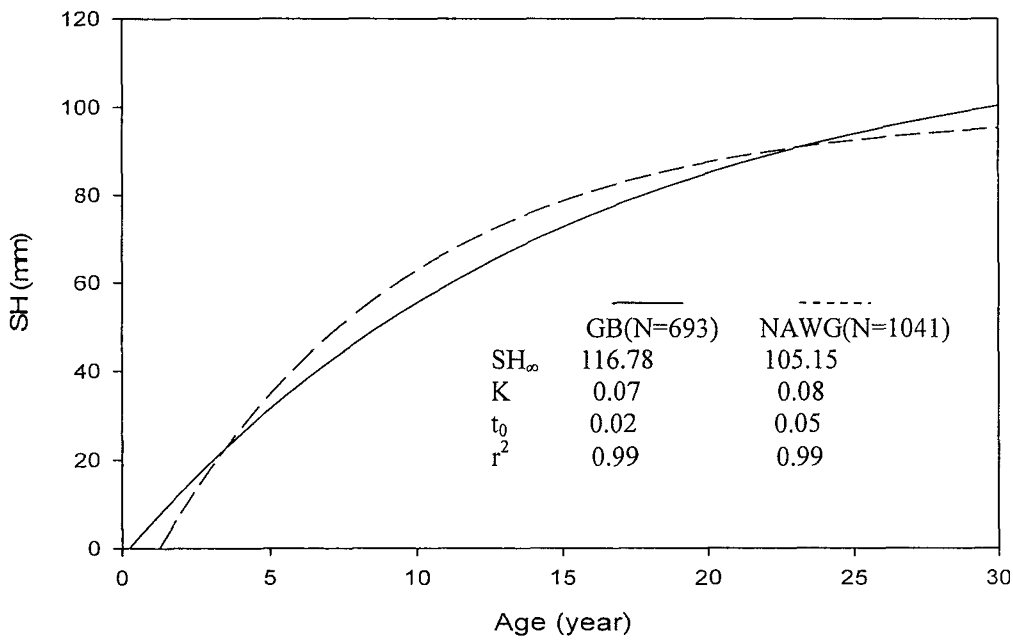

Figure 3.9 Age-specific shell heights fitted to von Bertalanffy equations for Iceland scallops collected from Gilbert Bay (GB) in 2007 (this study) and from the Nuuk area of West Greenland (NAWG) by Pedersen (1994). Ages were determined by counting growth zones on the hinge ligament.

Comparison of regressions by analysis of covariance showed that growth rate did not differ significantly between scallops in Gilbert Bay and those in the Nuuk area of West Greenland ($P = 0.69$) (Table 3.5). The von Bertalanffy growth curve parameters for both locations are shown in Table 3.6. The youngest specimen in Gilbert Bay was 13 mm, slightly larger than that in West Greenland (11 mm), while the oldest specimen was 102.85 mm, considerably larger than that collected in West Greenland. The maximum shell height may affect both the asymptotic prediction and the growth coefficient. The youngest individuals were 12.55 mm at 2 years, and 11 mm at 2 years, for Gilbert Bay and West Greenland, respectively. The mean shell height for scallops over 21 years in Gilbert Bay was 86.2 mm, very close to that of West Greenland scallops (87 mm).

Table 3.6 Von Bertalanffy growth model fitted parameters for scallops in Gilbert Bay (GB), the Nuuk area of West Greenland (NAWG) and the Strait of Belle Isle (SBI). Methods used for aging scallops in the NAWG (N=1041) and the SBI (N=284) are counting hinge ligament growth zones and counting external shell growth rings, respectively. Both methods were used in determining ages of scallops from Gilbert Bay (N=693).

	GB		**NAWG**	**SBI**
Methods	**Ligament**	**External**	**Ligament**	**External**
SH_{∞} (mm)	116.78	101.4	105.15	110.96
K ($year^{-1}$)	0.07	0.17	0.08	0.14
t_0 (years)	0.02	0.19	0.05	0.12
r^2	0.99	1.00	0.99	0.99
Mean SH range (mm)	13-102.85	15.44-93.69	11-87	6.8-90.8
Age range (years)	2-26	2-15	2-21	1-14
No.	693	693	1041	284

3.3.3 Comparison of scallop growth in Gilbert Bay with scallop growth in the Strait of Belle Isle

The increase in shell height with age was used to compare scallop growth in Gilbert Bay to the literature value of scallop growth in the Strait of Belle Isle. To keep consistent with the methodologies in the literature (Naidu, 1988), I used the method of counting external shell growth rings when comparing Gilbert Bay scallops to scallops in the Strait of Belle Isle.

Comparison of scallop growth between Gilbert Bay and the Strait of Belle Isle showed similar growth rate in both locations (Figure 3.10). This result was confirmed by the analysis of covariance with a P value of the interaction term ($P = 0.19$) (Table 3.5). The von Bertalanffy fitted curves show that scallops in Gilbert Bay reached the asymptotic shell height more rapidly, with a higher growth parameters K (0.17 year $^{-1}$) and a lower SH_∞ (101.4 mm). The predicted SH_∞ for the Strait of Belle Isle was 110. 96 mm, which is reasonable, since the maximum value recorded here was 104.25 mm (Table 3.6, Figure 3.11).

The Strait of Belle Isle is located nearby the Gilbert Bay MPA, and the environment for Iceland scallops is generally similar, so that the scallop growth parameters are likely to be similar. The mean shell height for scallops in Gilbert Bay varied from 15.44 mm to 93.69 mm, a slightly narrower range than that of the Strait of Belle Isle (6.8 – 90.8 mm). The age ranges were similar in both locations, 2-15 years and 1-14 years, respectively.

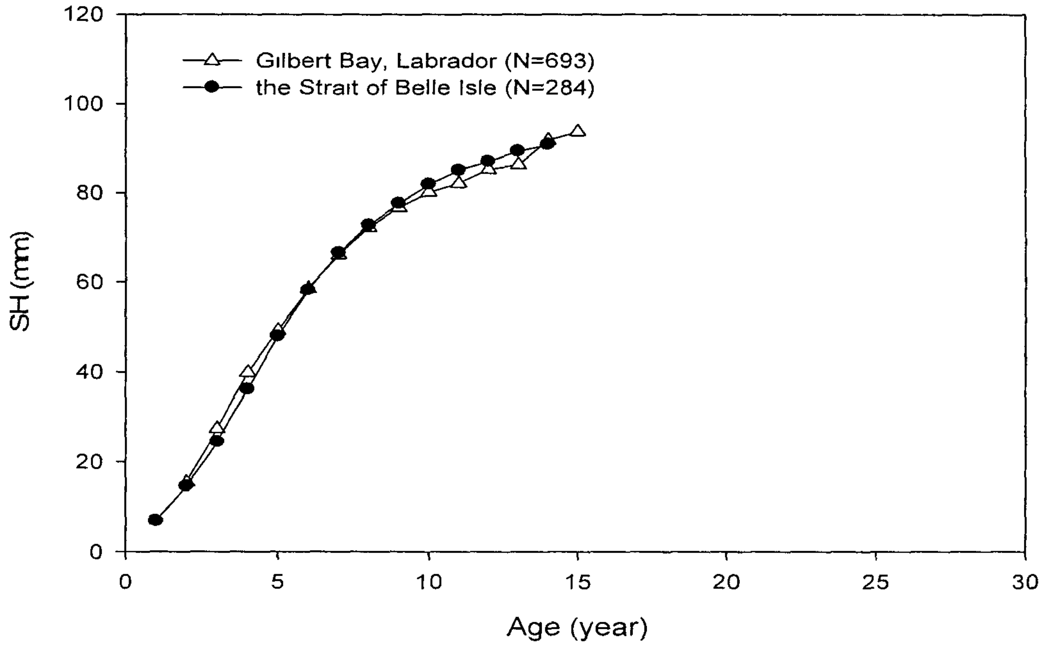

Figure 3.10 Mean shell height versus apparent age for Iceland scallops in Gilbert Bay (this study) and in the Strait of Belle Isle (data of Naidu, 1988). In both studies, ages were determined by counting external shell growth rings.

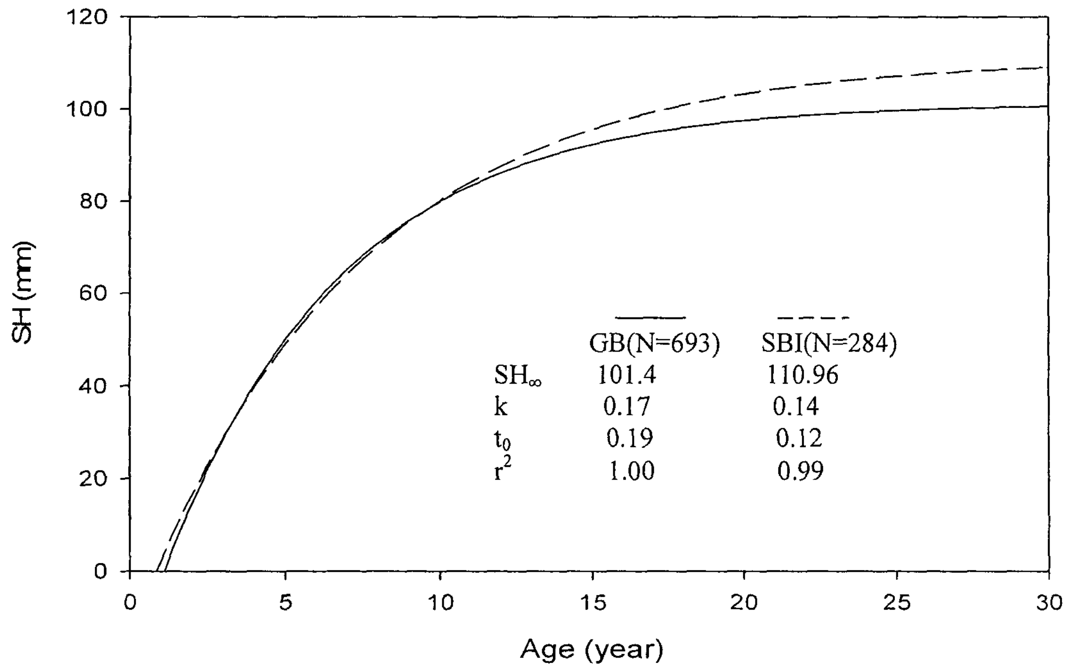

Figure 3.11 Age specific shell heights fitted to von Bertalanffy equations for scallops collected from Gilbert Bay (GB) in 2007 (this study) and from the Strait of Belle Isle (SBI) by Naidu (1988). Ages were determined by counting external shell growth rings.

3.4 Discussion

Iceland scallop aggregations are usually found between 20 and 110 m depth, although some beds extend to nearly 600 m (Garcia, 2006; Hansen and Nedreaas, 1986). Gosner (1971) reported that Iceland scallops are found at depths of 18 to 327 m but the depth range for scallops in a particular area is often narrower. For example, along the Norwegian coast scallop beds are commonly between 15 and 60 m (Garcia, 2006). In Cumberland Sound and Hudson Strait, Iceland scallops are typically most dense between 30 and 90 m (Crawford, 1992). The specimens used in this study of Gilbert Bay in Labrador were collected at depths between 5 and 30 m. Nearly 60% of Gilbert Bay is shallower than 30 m (Copeland *et al.*, 2006).

Although individual Iceland scallops measuring up to 140 mm have been found in northwest Iceland (Garcia, 2006), the maximum shell height is generally around 120 mm (Crawford, 1992). The largest shell measured in this study was 104 mm, collected at Kellys Point in Gilbert Bay. The calculated asymptotic shell height in Gilbert Bay is 117 mm, close to the maximum shell height recorded for the species.

Saxby (2007) concluded that the shell size frequency distribution of harvested scallops varied spatially within Gilbert Bay (Figure 3.12). Scallops were larger in the upper and central regions of the bay, while shell heights were generally smaller in the seaward region, where fishing effort has been historically concentrated (Morris *et al.*, 2002). This result was confirmed in this study.

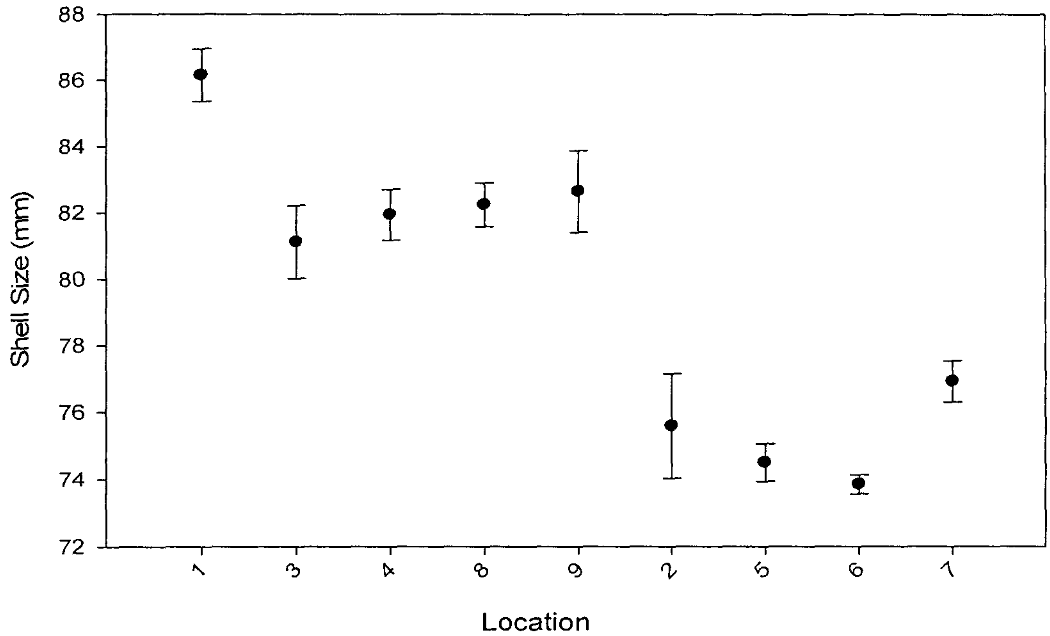

Figure 3.12 Individual 95% confidence intervals for SH, based on pooled standard deviations. The names of the nine scallop fishing locations are shown in Figure 1.4. Scallops at Middle Island (location 1) are significantly larger than at all other locations (Saxby, 2007).

Growth rate of scallops is also influenced by environmental factors, including water temperature and salinity, habitat suitability, and food availability (Pedersen, 1994). The CTD transect by Wroblewski *et al.* (2007) shows that seawater temperature in Gilbert Bay decreases with depth but does not vary substantially with distance along the main axis of the bay (Figure 3.13). All the locations in Gilbert Bay sampled in this study experienced a similar seasonal temperature cycle of approximately five winter months with near 0° C seawater temperatures, followed by seasonal warming (Figure 3.14, Wroblewski *et al.*, 2009). The seasonal thermocline extends 25-30 m into the water column (Wroblewski *et al.*, 2007). Salinity increases with depth, but does not vary considerably along the main axis of the bay (Figure 3.15). Scallop growth rate did not vary substantially among the seven locations of the Bay, which was consistent with the absence of seawater temperature and salinity differences.

Habitat, another factor influencing scallop growth rate, does vary among the seven sampled regions of Gilbert Bay (Figure 2.1), and research is underway to quantify habitat characteristics (Copeland *et al.*, 2007). The presence of scallop aggregations might be related to planktonic food availability or resuspension of detrital particulate organic matter. In estuaries, the plankton food source is more abundant in the seaward region due to the higher level of nutrients and a higher production of phytoplankton and zooplankton. The influence of food (plankton) availability on scallop growth rate in Gilbert Bay is unknown at this time. There has been no published research on plankton production in Gilbert Bay, but plankton concentration is likely to vary spatially due to the estuarine circulation in the bay (Wroblewski *et al.*, 2009). The two curves in Figure 3.2 indicate that individuals less than age 5 were absent at Middle Island but occurred at Leg Island. An analysis of covariance was conducted to compare scallop growth excluding data with ages below 5 years. The analysis then showed scallops at Middle Island and Leg Island grow at similar rates ($P = 0.30$). The reason that growth rates are similar throughout Gilbert Bay is possibly that the food sources, water temperature and salinity for adjacent areas are similar.

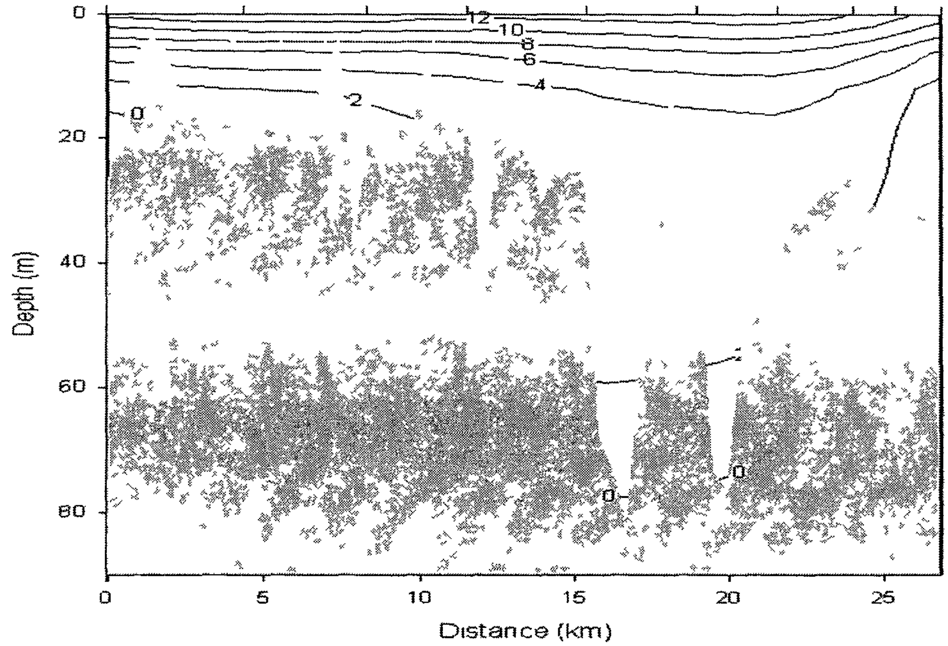

Figure 3.13 Seawater temperature (℃) profile along the main axis of Gilbert Bay measured on 23 August 2004. Distance is the distance seaward from the mouth of Gilbert River (Wroblewski *et al* , 2007).

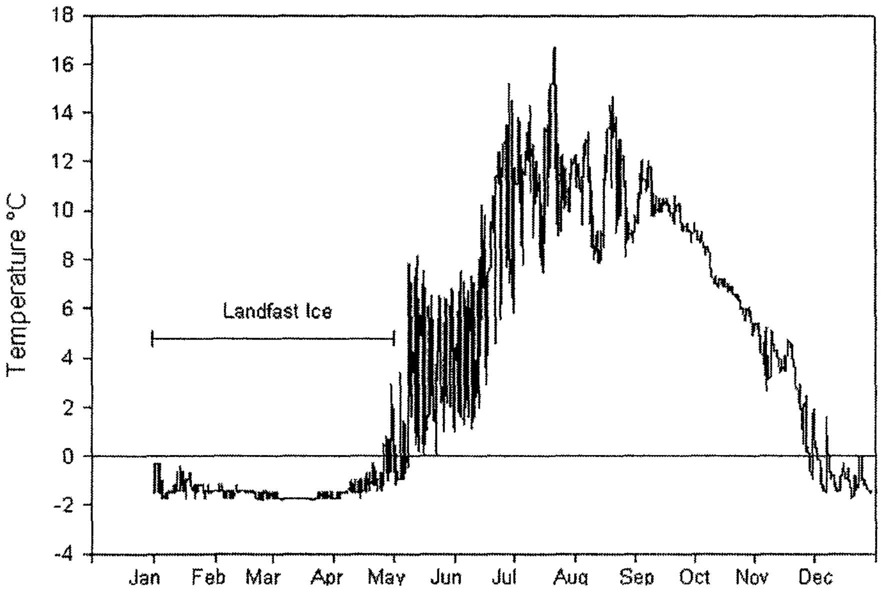

Figure 3.14 Seawater temperature at 4 m in a water column of 13 m depth recorded hourly during 2006 at a monitoring site in Gilbert Bay near Williams Harbour. During the winter Gilbert Bay is covered by landfast ice and water temperatures are < 0° C (Wroblewski *et al* , 2009).

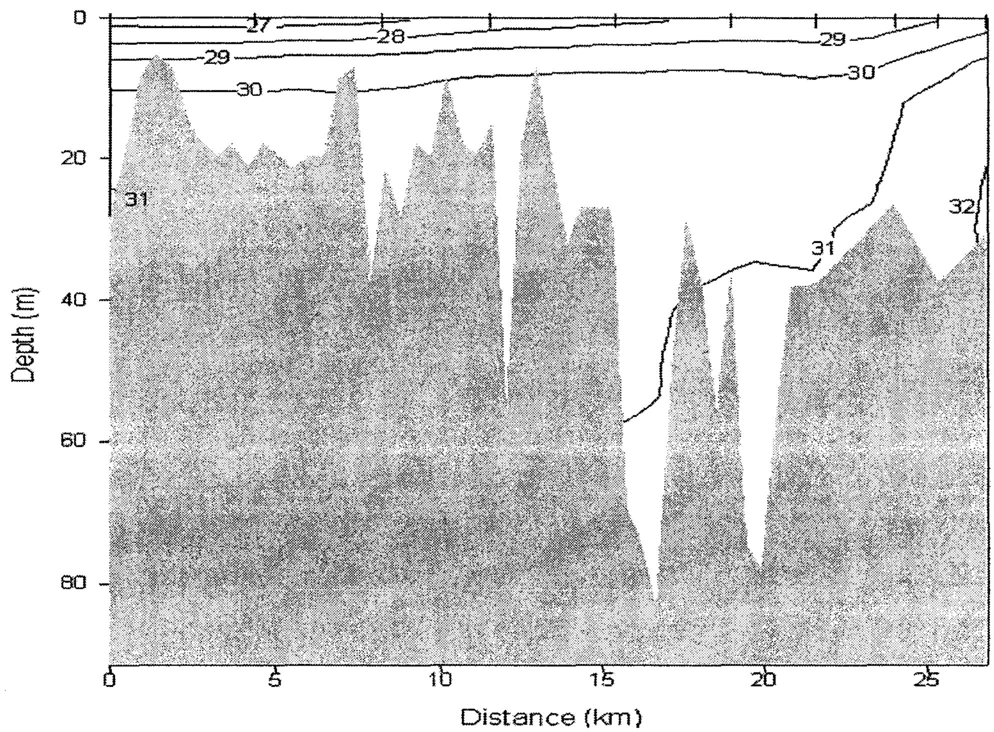

Figure 3.15 Seawater salinity profile in Gilbert Bay measured on 23 August 2004 based on vertical profiles. Distance is the distance seaward from the mouth of Gilbert River (Wroblewski *et al.*, 2007).

The mean SH values of scallops at Peckham Cove and Coach Box Point are unexpectedly low (below the regression straight line in Figure 1.3). Compared with scallops at Kellys Point, scallops at Coach Box Point experienced a similar level of commercial fishing effort, but they were considerably smaller in SH (74 mm vs. 82 mm). At an early age, scallops grow more rapidly at Coach Box Point than at Kellys Point (Figure 3.5). So mean SH of scallops at Coach Box Point should be larger than those at Kellys Point. Therefore, the reason for recorded SH at Coach Box Point being lower than that at Kellys Point may be due to factors other than differential growth rates. Natural mortality and fishing mortality may contribute to size variation between the two areas.

Natural mortality of Iceland scallops in Gilbert Bay is unknown. What can be confirmed is the presence of sea star species known to feed on Iceland scallop. The main predatory sea stars living in Gilbert Bay are *Asteria rubens*, *Crossaster pappossus* and *Leptasterias polaris* (Wroblewski, 2007). Cluckers (recently dead scallops, with the hinge ligament still attached to both half shells) were often observed in the dredge hauls, suggesting predation by sea stars may be common (Wroblewski *et al.*, 2009) (Figure 3.16). Small Iceland scallops are particularly vulnerable to predators (Arsenault and Himmelman, 1996a). Predation will inevitably influence the recruitment of young individuals. Mass mortality of scallops associated with increased sea temperature has been observed in Norway for *Chlamys islandica* (Garcia, 2006) and on several occasions for *Placopecten magellanicus* in Canada (Dickie and Medcof, 1963). For juvenile scallops, higher water temperature is a significant factor in high predation by sea stars and is also linked with higher predation rate due to decreased escape responses of the scallops (Barbeau and Scheibling, 1994).

It is noteworthy that Kellys Point, where the mean SH is greater, is more remote from William Harbour than Coach Box Point, where the mean SH is relatively lower. This pattern in the data matches the distribution of historical and recent fishing effort in Gilbert Bay, with fewer dredge tows in the upper reaches of the bay and more in seaward regions.

In order to compare scallop growth in Gilbert Bay with that of the Nuuk area of West Greenland and the Strait of Belle Isle, different aging methods were used to be consistent with the methodologies in the literature. Scallops in the three locations grow at similar rates. Pedersen (1994) concluded that the SH growth rates found at West Greenland were generally slower than for populations in Iceland, Canada (Strait of Belle Isle) and Norway, but also noted that the growth rate data were based on different age determination methods. In the previous section, we concluded that different methods may give different age determinations, explaining the different results of this study from those of Pedersen (1994).

Figure 3.16 Sea stars (*Asteria rubens*, *Crossaster pappossus* and *Leptasterias polaris*), predators of scallops, captured in the scallop dredge tows made in Gilbert Bay, Labrador in September 2007

The similarity in growth rate of Iceland scallops in Gilbert Bay and the other two locations may be due to the similar environmental factors, such as bottom substrate, water temperature and tidal currents. Large areas of Gilbert Bay have a mud or gravel-mud bottom, only a small portion having a hard substrate bottom suitable for Iceland scallops (Copeland, 2006). Scallops in this study were collected from those hard bottoms. The bottom in the northern Gulf of St. Lawrence is mainly sand and gravel with broken shells of bivalves (Arsenault and Himmelman, 1996b). In the Nuuk area of West Greenland, the largest scallop concentrations generally occur at depths from 20 to 60 m in the outer regions of fjords between islands and in narrow sounds where the substrates are mainly composed of sand and gravel. Similar to Gilbert Bay, regions of West Greenland that are characterized as mud fjords contained no scallops (Pedersen, 1994).

Temperature is a major factor in determining the overall geographic distribution of the

Iceland scallop, as it interacts with several other factors such as depth, bottom substrate type, food availability, salinity, predation and competitors (Brand, 2006). *Chlamys islandica* is a low-temperature living species and is distributed within the sub-arctic transitional zone at a maximum sea temperature of 12-15 °C (Jonas, 2004). The bottom temperature in the Nuuk area of West Greenland in winter is -1.5 °C (Buch, 1984). In Gilbert Bay, seawater temperatures are <0 °C from December to May, and in the Strait of Belle Isle a mean winter temperature of -1.5 °C is found. The similarity of sea water temperature is also consistent with the result that scallop growth does not vary in the three locations.

Iceland scallops are generally found attached by byssal threads to a coarse substratum in areas with strong tidal currents (Vahl and Clausen, 1980). In the Nuuk area, the West Greenland Current, a weak cold water current but warmer than Labrador Current, flows to the north, and large scallop beds are found in outer areas that are associated with strong tidal currents. Both Gilbert Bay and the Strait of Belle Isle are influenced by the Labrador Current, a continuation of the West Greenland Current and the Baffin Island Current. Therefore, it is reasonable that scallops in West Greenland, the Strait of Belle Isle, and Gilbert Bay grow at similar rates because of the similarity of tidal currents. Scallops in all three areas are similarly governed by cold Arctic water.

The grand mean for SH of Iceland scallops in Gilbert Bay determined in previous research in 2006 (Wroblewski *et al.*, 2009) was compared with values obtained for scallops in the Strait of Belle Isle in 1995, 1997, 1999, and 2000 research vessel surveys, as well as the mean SH of scallops in the Strait of Belle Isle in 1999 and 2000 based on data from commercial fishing vessels (Figure 1.5). The grand mean in Gilbert Bay in 2006 is lower than any of the mean values to Iceland scallops sampled in the Strait of Belle Isle (Figure 1.5). Because the growth rates of scallops in these locations do not differ, possible reasons that might explain the difference in SH are fishing mortality and natural mortality.

A higher level of fishing mortality, i.e. repeated dredging at a locality, causes the mean shell size to be smaller than in locations with a lower fishing effort (Pedersen, 1994). Size selective dredging removes the largest individuals, as they are captured most efficiently. For scallop beds significantly impacted by fishing, the larger individuals that could be expected in an unfished population are not present. Intense dredging activity shifts the mean shell size of the frequency distribution to the left (Wroblewski *et al.*, 2009). Dredging also contributes to the natural mortality. Annual natural mortality in the Iceland scallop, computed from percent occurrence of cluckers, is significantly higher on exploited beds than on unfished grounds (Naidu, 1988). There is no information for natural mortality of Iceland scallops in Gilbert Bay. A number of deformed shells were found in the dredge hauls during 2007 (Figure 3.17).

Copeland *et al.* (2007) obtained one specimen of Iceland scallop from The Shinneys, in Gilbert bay, at 5.5 m depth which measured 21.20 mm in SH. We determined the specimen to be 5 years old by using the ligament method. Compared to the mean SH-at-age of scallops in MPA Zones 2 and 3 (26.82 mm at 5 years), the growth of scallops in The Shinneys is likely the same as scallop growth along the main axis of the bay. The closure of Zones 1A and 1B under MPA regulations could contribute to rebuilding of scallop beds in those zones, and export of planktonic scallop larvae to adjacent MPA zones 2 and 3 where scallops are harvested.

Figure 3.17 Shell deformities in Iceland scallops collected from Gilbert Bay in 2007.

Chapter 4

Conclusions and recommendations

Iceland scallops collected from Gilbert Bay were found to be of similar age by counting hinge ligament growth zones and internal shell growth lines. In comparison to these two methods, counting external shell rings estimated scallops in Gilbert Bay to grow at higher rates. Aging shells by counting internal shell growth lines is precise, but time consuming. Counting hinge ligament growth zones can provide age determinations similar to the internal shell growth line method, and is much more convenient, because it does not require slicing the shells.

This study provides the first data on the SH-at-age of the Iceland scallops in the MPA of Gilbert Bay. There was no significant difference in scallop growth between the upper part of the bay (Middle Island, Peckham Cove) and the lower bay (Coach Box Point, Main Tickle and Leg Island). Scallops at Rexons Point may grow more slowly than those in the other areas sampled, but more research is required to confirm this.

Iceland scallop growth is similar in Gilbert Bay, the Strait of Belle Isle and in the Nuuk area of West Greenland. The mean SH of scallops in Gilbert Bay is currently smaller than that in the Strait of Belle Isle, likely due to other factors, such as greater rate of young scallop recruitment, higher level of natural mortality for large individuals, or intensive commercial harvesting in the past decade. The mean age of scallops harvested is an index of the status of the scallop resource in the Gilbert Bay MPA.

The next step for Iceland scallop research in the Gilbert Bay MPA should be to determine the recruitment, natural mortality, and the current fishing mortality of the scallop stock. Size selective fishing mortality may explains the smaller scallop size within Gilbert Bay compared to that in the Strait of Belle Isle, but this needs further research to confirm.

It will take a continued monitoring of the commercial scallop harvest before it can be determined whether the MPA management plan, which partially closes scallop beds to fishing, results in a sustainable fishery for Iceland scallops. The limited habitat suitable for Iceland scallops in the bay suggests that biological productivity of the Gilbert Bay scallop stock is low. For a sustainable scallop fishery, the annual harvest cannot exceed this annual production. Refined harvesting regulations may be required to achieve a sustainable fishery for scallops in Gilbert Bay.

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Appendix 1 Shell height (SH), age determined by counting hinge ligament growth zones (Age_L) and age determined by counting external shell growth rings (Age_E) of 693 Iceland scallops collected by dredging using CFV *Little Shell* in Gilbert Bay during 26 September to 1 October 2007. See Figure 2.1 for location of scallop fishing areas 1-7. Set is dredge tow number.

Area	Set	Latitude (N)	Longitude (W)	
1	1	52° 38.23'	55° 59.29'	
		SH (mm)	Age_L (years)	Age_E (years)
		78.95	20	11
		85.1	20	11
		77.55	12	9
		80.85	18	10
	2	52° 38.35'	55° 59.35'	
		SH (mm)	Age_L (years)	Age_E (years)
		49.65	6	6
		77.3	15	9
	3	52° 37.55'	55° 58.38'	
		SH (mm)	Age_L (years)	Age_E (years)
		37.65	7	3
		45	9	5
		52	8	6
		58.35	8	6
		78.75	15	9
		72.9	17	10
		79.45	15	10
		60.85	12	6
		74.15	14	8
		70.85	14	7
		78.75	19	9
		77.5	17	11
		86.55	15	12
		88.85	17	11
		76.15	13	11
		81.4	18	9
		90	24	12
		94.5	24	14
		84.25	20	10
		84.1	21	12
		74.15	14	9
		84.25	20	11
		93.75	22	13

Appendix 1 Continued.

Area	Set	Latitude (N)	Longitude (W)	
1	3	52° 37.55'	55° 58.38'	
		SH (mm)	Age_L (years)	Age_E (years)
		83.65	19	9
		91	24	13
		66.65	9	7
		74.55	16	9
		93	24	12
		78.2	15	10
		80.3	18	11
		79	19	11
		79.45	18	12
		82.35	23	11
		75.3	14	11
		76.05	16	9
		83.9	18	11
		79	19	10
		78.3	18	12
		82.25	23	10
		88.5	23	14
	4	52° 37.86'	55° 58.37'	
		SH (mm)	Age_L (years)	Age_E (years)
		66	12	8
		62.75	12	7
		74.45	15	9
		69.05	12	7
		79.2	19	10
		80.1	18	11
		55.65	8	6
		66.1	13	7
		72.55	15	9
		75.25	17	10
		76.5	18	10
		64.05	14	7
		63.85	13	7
		71.65	15	8
		67.45	16	8
		76.9	20	9
		80	17	8

Appendix 1 Continued.

Area	Set	Latitude (N)	Longitude (W)	
1	4	52° 37.86'	55° 58.37'	
		SH (mm)	Age_L (years)	Age_E (years)
		77.3	20	11
		71.7	20	9
		76.45	21	9
	5	52° 37.95'	56° 00.00'	
		SH (mm)	Age_L (years)	Age_E (years)
		36.55	7	4
		49.1	9	5
		56.3	10	8
		62.4	11	6
		67	11	8
		66.35	11	7
		74	15	8
	6	52° 38.68'	55° 59.35'	
		SH (mm)	Age_L (years)	Age_E (years)
		58.9	10	6
		75.55	19	10
		75.45	18	9
		72.55	14	8
		69.65	14	7
		85.3	17	10
		56.8	10	6
		62.8	14	7
		70.55	10	8
		65.35	11	7
		65.65	11	6
		73.75	17	9
		77.6	16	8
		74.55	14	7
		83.25	20	11
		65.25	17	7
		67.3	12	7
		75.45	16	11
		79.5	17	9
		67.45	14	7
		69.7	13	7
		80.25	17	9

Appendix 1 Continued.

Area	Set	Latitude (N)	Longitude (W)	
1	6	52° 38.68'	55° 59.35'	
		SH (mm)	Age_L (years)	Age_E (years)
		77.6	19	9
		87.35	22	13
		75.1	16	10
		78.75	15	8
		82.85	21	12
2	1	52° 36.93'	55° 57.03'	
		SH (mm)	Age_L (years)	Age_E (years)
		56.3	12	6
		73.85	16	8
		79.05	20	12
		74.85	14	8
		71.15	15	8
		75	16	10
		84.2	16	11
		77.4	14	9
		83.25	19	11
		70.5	15	8
		79.1	18	10
		85.2	19	14
		78.95	17	9
		77	18	9
		78.4	20	10
		63.5	13	7
		70.2	13	7
		79.85	17	10
		81.75	18	12
		86.35	17	11
		86.35	18	13
		74.85	18	11
		85.75	23	12
		62.35	15	7
		72.1	17	8
		80.45	24	12
		83.4	20	12
		72.25	21	9
		76.2	16	9

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
2	1	52° 36.93'	55° 57.03'	
		SH (mm)	Age_L (years)	Age_E (years)
		83.9	24	14
		69.85	13	8
		81.25	22	12
		87.15	23	12
		83.85	18	12
		58.6	11	6
		73.05	16	8
		59.5	13	6
		64.45	14	7
		72.95	18	9
		91.65	24	14
		65.8	13	8
		89.1	24	14
		67.4	14	7
		73.35	16	9
		54.7	11	6
		72.5	18	9
		78.45	19	10
		77.35	17	11
		73.1	16	9
		72.05	18	9
		69.4	14	8
	2	52° 37.39'	55° 56.46'	
		SH (mm)	Age_L (years)	Age_E (years)
		67.3	11	8
		70.15	14	8
		84.6	20	12
		90.65	23	13
		96.2	23	14
		68.65	15	8
		75.45	20	9
		78.55	17	11
		82.2	20	11
		84.3	17	11

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
2	3	52° 37.28'	55° 55.75'	
		SH (mm)	Age_L (years)	Age_E (years)
		80	19	9
		74.85	17	8
		78.4	19	9
		75.65	16	9
		76.35	16	8
		80.5	21	10
		87.35	22	12
		81.5	17	10
		86.65	20	12
		89.4	22	13
		36.1	6	3
		64.4	12	7
		75.65	16	8
		77.95	17	9
		82.6	20	10
		66.5	13	7
		77.9	17	9
		80.6	18	11
		81.1	21	10
		62.3	16	7
		65.85	14	7
		78.9	18	9
	4	52° 36.82'	55° 57.62'	
		SH (mm)	Age_L (years)	Age_E (years)
		70.9	16	8
		75.6	19	9
		72.95	17	10
		78.5	22	12
		39.2	7	4
		50.35	9	5
		73.15	15	9
		78.5	18	9
		84.45	23	12
		79.35	17	8
		81.85	21	10
		79.45	21	10

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
2	4	52° 36.82'	55° 57.62'	
		SH (mm)	Age_L (years)	Age_E (years)
		85.6	22	11
	5	52° 36.80'	55° 56.50'	
		SH (mm)	Age_L (years)	Age_E (years)
		75.25	16	9
		82.85	21	11
		89.9	18	12
		84.3	24	14
		85.5	23	12
		84.95	21	10
		84.7	22	11
		71.15	14	9
		75.3	16	10
		85.15	22	10
		64.25	11	8
		80.55	15	9
		81.75	20	10
		87.25	21	13
		81.4	18	10
		72.2	16	7
		89.25	20	12
		80.8	22	9
		84.85	17	11
		81.7	17	10
		81.85	15	10
		85.25	20	11
		85.25	20	9
		82.95	19	12
		79.25	20	11
		79	22	9
		91.65	22	14
		61.35	12	7
		72.6	14	8
		72.9	15	9
		85.7	20	10
		88.45	21	11
		81.85	18	10

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
2	5	52° 36.80'	55° 56.50'	
		SH (mm)	Age_L (years)	Age_E (years)
		88.45	22	12
		77.9	15	10
		81.85	21	11
		88.1	23	12
		87.5	22	13
		77.15	15	9
		81.75	16	9
		95.4	16	12
3	1	52° 36.29'	55° 52.55'	
		SH (mm)	Age_L (years)	Age_E (years)
		53.2	9	6
		54.4	10	6
		66.65	15	7
		86.85	22	11
		85.15	21	13
		68.45	13	7
		69.25	14	8
		58.35	11	7
		70.85	15	8
		84.25	22	12
		76.7	17	9
		83.05	18	9
		74.4	17	9
		79.3	19	11
		80.85	20	10
		72.25	13	9
		82.95	22	12
		79.6	20	10
		50.3	9	5
		58.5	13	7
		70.1	15	9
		83.15	23	9
		53.85	9	6
		61.15	12	7
		64.95	13	7
		77.1	17	9

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
3	1	52° 36.29'	55° 52.55'	
		SH (mm)	Age_L (years)	Age_E (years)
		55.8	9	6
		68.9	15	8
		98.9	25	14
		70.2	14	9
		73.35	15	9
	2	52° 36.17'	55° 52.22'	
		SH (mm)	Age_L (years)	Age_E (years)
		78.85	17	10
		78.1	19	11
		80.6	19	10
		72.7	15	8
		78.85	17	8
		79.65	18	10
		90.45	22	14
		59.65	12	6
		78.35	19	9
		76	17	8
		56.5	10	6
		68.2	14	9
		80.2	20	11
		77.05	15	10
		78.7	17	10
		79.85	19	10
		89.55	20	13
		79.9	19	12
		70.45	15	8
		74.4	17	8
		46.4	9	5
		71	13	9
		81	18	10
		85.15	22	13
		78.15	18	9
		88.55	24	13
		72.4	10	8
		79.7	19	11

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
3	3	52° 36.18'	55° 48.93'	
		SH (mm)	Age_L (years)	Age_E (years)
		61.15	14	8
		63.2	12	6
		71.85	14	8
		88.8	23	13
		85.7	21	11
		104.25	24	14
		20.45	6	3
		30.2	7	4
		33.15	8	5
		47.85	10	5
	4	52° 36.36'	55° 49.33'	
		SH (mm)	Age_L (years)	Age_E (years)
		53.15	14	6
		61.15	14	7
		102.85	26	15
		12.15	2	2
		16.1	3	2
		23.8	3	3
		24.8	4	3
4	1	52° 34.90'	55° 50.50'	
		SH (mm)	Age_L (years)	Age_E (years)
		79.25	18	11
		83	18	10
		87.1	19	12
		88.35	21	15
		82.85	17	10
		82.1	18	10
		83.35	20	12
		78.9	17	8
		71.65	18	7
		69	12	8
		80.2	17	10
		82.35	18	10
		81.85	15	9
		90.35	22	11
		70.1	15	8

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
4	1	52° 34.90'	55° 50.50'	
		SH (mm)	Age_L (years)	Age_E (years)
		71.7	16	8
		79.9	17	9
		79.85	19	12
		48.55	10	5
		59.15	11	7
		67.9	14	6
		82.75	17	10
		85.25	15	12
		85.9	16	11
		96.6	21	12
		55.45	10	6
		68.5	14	7
		74.85	17	8
		78.4	16	9
		80.9	18	10
		84.35	19	11
		23.1	5	3
		32	6	4
		25.1	4	3
		35.6	8	4
	2	52° 35.24'	55° 51.60'	
		SH (mm)	Age_L (years)	Age_E (years)
		68.3	14	8
		77.4	17	9
		44.2	9	4
		55.6	10	6
		60.9	14	6
		76.85	17	9
		61.3	10	7
		71.95	16	9
		76.75	16	8
		53.65	10	6
		65.45	14	10
		79.75	15	10
		63	12	8
		70.5	14	7

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
4	2	52° 35.24'	55° 51.60'	
		SH (mm)	Age_L (years)	Age_E (years)
		76.55	18	13
		72.45	16	8
		71.3	18	7
		77.5	18	9
		60.95	11	7
		63.5	12	7
		76.95	18	9
		40	9	4
		48.8	12	5
		70	15	8
		80.85	20	11
		77.15	15	9
		78.9	18	13
		65.35	13	6
		69.25	14	7
		67.45	13	8
		69.4	17	9
		12.2	2	2
5	1	52° 35.00'	55° 50.14'	
		SH (mm)	Age_L (years)	Age_E (years)
		76.4	17	7
		76.25	18	9
		78.9	19	9
		82	22	10
		70.8	17	11
		73.4	18	13
		79.85	22	13
		57.25	10	5
		66.6	16	9
		75.55	14	9
		78.65	19	13
		86.7	23	12
		71.75	17	11
		77.2	18	9
		70.65	16	7
		79.25	19	10

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
5	1	52° 35.00'	55° 50.14'	
		SH (mm)	Age_L (years)	Age_E (years)
		88.85	22	13
		81.2	20	10
		86.5	21	13
		62.9	10	6
		70.75	17	7
		73.25	15	9
		72.3	17	9
		24.4	3	3
	2	52° 35.19'	55° 50.46'	
		SH (mm)	Age_L (years)	Age_E (years)
		71.65	14	9
		80.2	20	11
		82.7	18	10
		84.3	21	11
		76.9	14	10
		75.65	19	10
		64.25	12	7
		69.2	15	8
		78.8	17	9
		67.7	12	7
		79.55	17	10
		82.1	21	12
		70.75	13	7
		73.65	15	8
		47.1	7	6
		65.6	12	7
		69.7	11	8
		83.35	20	10
		72.15	17	9
		82.85	20	10
		58.1	12	7
		72.85	16	10
		81.55	17	10
		68.7	12	7
		74.6	11	8
		62.3	11	6

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
5	2	52° 35.19'	55° 50.46'	
		SH (mm)	Age_L (years)	Age_E (years)
		72.85	20	9
		80.1	17	10
		30.55	5	3
		22.25	3	4
6	1	52° 34.07'	55° 52.07'	
		SH (mm)	Age_L (years)	Age_E (years)
		82.7	17	11
		82.05	16	10
		74.35	17	9
		64.15	14	7
		81.45	18	10
		66.05	13	6
		48.35	6	5
		94.45	23	14
		81.8	19	9
		49.65	8	5
		61.8	13	6
		73.15	18	9
		80.45	20	10
		84.65	21	12
		47.85	9	5
		68	14	7
		74.5	16	8
		77.8	14	9
		83.8	19	8
		80	20	10
		50.1	8	6
		61.8	15	7
		66.85	15	7
		81.75	19	11
		87.15	22	12
		48.2	11	6
		60.55	10	7
		68.75	14	6
		78.25	19	8
		74.8	17	8

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
6	1	52° 34.07'	55° 52.07'	
		SH (mm)	Age_L (years)	Age_E (years)
		81.2	18	9
		77.9	18	9
		77.55	15	9
		80.9	16	10
		86.1	20	12
		67.55	13	7
		78.55	17	9
		83.4	21	11
		48	7	6
		64.05	14	7
		66.7	14	8
		81.75	17	9
		82.4	21	12
	2	52° 33.86'	55° 52.58'	
		SH (mm)	Age_L (years)	Age_E (years)
		60.4	11	6
		67.65	11	6
		65.1	12	5
		72.9	14	8
		76	16	8
		91.35	23	12
		48.25	7	4
		55.2	10	6
		59	9	6
		67	15	8
		70.95	14	8
		84.25	18	11
		84.3	24	11
		85.4	21	12
		67.05	14	6
		67.4	16	8
		70.95	17	8
		71.15	9	7
		79.4	20	12
		55.4	10	7
		57.55	10	7

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
6	2	52° 33.86'	55° 52.58'	
		SH (mm)	Age_L (years)	Age_E (years)
		63.45	11	8
		68.8	13	8
		75	17	8
		80.3	21	8
		61.65	12	7
		73.65	16	10
		81.15	15	10
		83.05	16	9
		82.5	19	8
		91.05	23	13
		36.45	6	3
		36.7	6	4
		43.75	9	5
		71.1	17	8
		80.85	15	9
		82.15	17	9
		86.55	20	11
		65.55	15	7
		77.1	18	10
	3	52° 34.77'	55° 51.53'	
		SH (mm)	Age_L (years)	Age_E (years)
		69.9	15	9
		72.25	15	11
		80.85	18	10
		85.65	22	13
		87.8	21	11
		68.2	14	9
		77.75	17	9
		76.85	12	9
		81.9	18	10
		84.35	21	13
		85.6	19	12
		69.6	14	8
		78.9	21	10
		84.25	20	12
		86.55	22	13

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
6	3	52° 34.77'	55° 51.53'	
		SH (mm)	Age_L (years)	Age_E (years)
		81.85	19	10
		76.5	19	9
		83.8	22	10
		79.15	16	11
		83.1	19	10
		81.9	21	11
		84.35	20	11
		88.65	18	12
		77.35	17	9
		80.5	18	11
		78.7	22	11
		80.85	23	11
		86	18	13
		71.65	15	9
		76	17	9
		79.65	19	10
		79.7	18	12
		94.55	21	14
		65.55	13	7
		78.5	15	8
		77.35	16	9
		90.5	23	13
		42.75	8	6
7	1	52° 34.44'	55° 50.80'	
		SH (mm)	Age_L (years)	Age_E (years)
		52.55	9	4
		58.8	10	6
		67.7	14	7
		69.5	14	8
		68.1	14	7
		77.65	13	9
		85.8	20	11
		50.4	13	5
		58.15	10	6
		62.75	10	6
		71.55	17	8

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
7	1	52° 34.44'	55° 50.80'	
		SH (mm)	Age_L (years)	Age_E (years)
		76.6	13	8
		78.75	12	9
		71.35	12	8
		71.35	13	8
		75.15	13	9
		74.2	15	9
		38.6	6	4
		73.5	13	8
		65.55	11	7
		17.5	3	3
		36.85	6	5
		74.3	18	9
		48.45	10	5
		54.95	9	6
		64.75	15	6
		69.25	13	8
		79.35	15	8
		78.85	18	9
		81.75	20	10
		67.65	13	7
		79.9	13	9
	2	52° 34.15'	55° 50.93'	
		SH (mm)	Age_L (years)	Age_E (years)
		28.3	6	3
		18.7	3	2
		13.3	3	2
		42.95	8	4
		45.15	8	5
		61.4	10	6
		76.7	18	9
		88.2	21	12
		85.75	20	11
		88.2	20	12
		59.2	14	6
		70.35	13	8
		87.1	20	11

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
7	2	52° 34.15'	55° 50.93'	
		SH (mm)	Age_L (years)	Age_E (years)
		76.35	18	8
		78.3	17	9
		84.3	22	11
		45.45	7	4
		70.4	14	8
		63.9	11	7
		71.45	17	8
		70.2	17	7
		79.4	16	9
		85.25	18	11
		59.4	10	6
		67.1	14	7
		71.4	17	7
		78.25	15	9
		76.5	15	9
		76.5	15	8
		79.1	16	9
		48.35	12	5
		48.8	11	4
		61.35	15	7
		76.85	21	9
		82.9	17	9
		82.5	20	11
		64.45	15	6
		76.75	16	9
		86.65	21	11
		83.55	20	9
		81.3	21	10
		73.65	18	9
		81.25	21	10
		85.2	18	11
		43.65	10	4
		65.5	13	6
		67.3	12	6
		80.1	21	7
		78.55	20	9

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
7	2	52° 34.15'	55° 50.93'	
		SH (mm)	Age_L (years)	Age_E (years)
		86.5	23	11
	3	52° 34.43'	55° 50.84'	
		SH (mm)	Age_L (years)	Age_E (years)
		54.15	6	6
		76.8	18	10
		78.15	19	11
		91.8	23	13
		70.85	12	9
		80.65	16	10
		81.6	19	10
		57.75	8	7
		78.85	16	10
		85.2	16	12
		57.25	10	6
		65.25	12	7
		83.7	16	11
		78	17	11
		84.55	21	10
		67.85	12	8
		82.3	18	11
		58.1	7	7
		82.25	16	10
		84.55	20	7
		59.75	10	6
		69.25	14	7
		78.45	17	9
		84.3	20	11
		17.25	2	2
	4	52° 34.07'	55° 50.21'	
		SH (mm)	Age_L (years)	Age_E (years)
		81.9	18	10
		65.7	13	7
		88.35	22	15
		18.35	3	2
		22.75	4	3
		31.85	6	3

Appendix 1 continued.

Area	Set	Latitude (N)	Longitude (W)	
7	4	52° 34.07'	55° 50.21'	
		SH (mm)	Age_L (years)	Age_E (years)
		60.1	10	7
		65.15	14	7
		75.15	15	8
		78.05	17	11
		85.55	21	12
		95.2	23	15
		50.45	10	5
		58.7	13	7
		57.25	11	6
		74.45	14	7
		79.2	16	10
		89	21	14
		79.2	16	8
		81.15	19	9
		74.2	15	8
		83.5	21	11
		86.9	20	11
		69.65	15	5
		80.6	19	10
		87.65	20	10
		79.65	16	10
		77.85	20	10
		88.55	21	9
		86.4	21	12
		87.5	24	12

Appendix 2 Shell height (SH), age determined by counting hinge ligament growth zones (Age_L), counting external shell growth rings (Age_E) and age determined by counting internal shell growth lines (Age_I) of 30 scallops randomly selected from 693 Iceland scallops collected by dredging using CFV *Little Shell* in Gilbert Bay during 26 September to 1 October 2007. See Figure 1.1 and Figure 2.1 for location of scallop fishing areas 1-7.

Area	SH (mm)	Age_L (years)	Age_E (years)	Age_I (years)
1	47.1	7	6	7
	62.4	11	6	9
	80.1	18	10	17
	85.25	20	9	16
2	56.3	10	6	9
	64.4	12	7	12
	93.75	23	13	22
	95.2	23	15	16
3	53.2	9	6	9
	68.9	19	8	16
	70.2	14	9	11
	104.25	24	14	21
4	53.65	10	6	9
	72.25	21	9	18
	76.55	18	9	18
5	22.25	3	3	5
	24.4	3	3	3
	28.3	6	3	5
	42.75	8	6	7
6	35.6	6	3	7
	47.85	9	5	10
	49.65	6	6	6
	68	14	7	12
	94.45	23	12	22
7	17.25	2	2	3
	18.7	3	2	2
	30.55	5	4	7
	65.45	14	10	15
	78.75	12	9	14
	81.75	20	10	22