Geographic patterns in growth of the giant Pacific sea scallop, *Patinopecten caurinus*

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Giant Pacific or weathervane sea scallops, *Patinopecten caurinus*, were first fished commercially in the Gulf of Alaska in 1967, when 3449 kg of unshucked sea scallops (estimated 341 kg of meats) were landed at Kodiak, Alaska (Haynes and Powell, 1968). The discovery of commercially exploitable stocks of giant Pacific sea scallops led to a fishery that expanded rapidly, and landings increased to 856 metric tons (t) of schucked meats by 1969 (ADF&G, 1979). For the next two decades, scallop landings fluctuated greatly (ADF&G, 1987), a result of limited stocks, restrictive regulations, and more lucrative opportunities in other Alaska fisheries (Kaiser, 1986). Since 1990, however, the fishery has changed from a part-time fleet to a dedicated full-time fleet with the influx of larger, more efficient vessels. This change has led to sustained near-record harvests (up to 823 t) and the adoption of new management measures for the fishery (Shirley and Kruse, 1995; NMFS[1]).

Most of the biological literature on giant Pacific scallops relates to fishing exploration (Rathjen and Rivers, 1964; Haynes and Powell, 1968; Ronholt and Hitz, 1968; Haynes and McMullen, 1970; Bourne, 1988), aquaculture (Beattie, 1985; Thompson et al., 1985; Rhee, 1989), or reproductive biology (Hennick, 1970 and 1971; Robinson and Breese, 1984). Age and growth of giant Pacific scallops have been studied in populations off Oregon (Starr and McCrae, 1983), Washington and the Strait of Georgia (Haynes and Hitz, 1971), northern Gulf of Alaska (Kaiser, 1986; Hennick[2]), and the lower Cook Inlet region (Hammarstrom and Merritt, 1985).

A lack of data on biological productivity has affected recent efforts to develop a fishery management plan (FMP) for Alaska giant Pacific scallop stocks (NMFS[1]). It has inhibited the development of yield models and a numeric specification of overfishing (an FMP requirement) and resulted in a simple numeric range given for optimal yield. However, there is a renewed interest in acquiring better information for stock assessments and biological parameters needed to implement an exploitation-rate harvest strategy for the fishery (NMFS[1]).

This note presents results of a comparative growth study of stocks of giant Pacific scallops in the Gulf of Alaska. Samples for this study were collected during the initial explorations for commercial quantities of these scallops in 1968 (Haynes and Powell, 1968); thus these data yield prefishery biological parameters that can provide a baseline to evaluate fishery impacts on the giant Pacific scallop populations in Alaska.

Methods

Giant Pacific scallops were collected at six locations in the Gulf of Alaska from 27 April to 6 June 1968 (Fig. 1). Sampling was done from the chartered FV *Viking Queen* with a standard New Bedford type sea scallop dredge 3.96 m wide (equipped with 10-cm rings). A detailed description of this type of gear is given in Posgay (1957) and Bourne (1964). The locations and depths of sampling were 1) on Albatross Bank at 92–104 m, 2) on Marmot Flats at 73–104 m, 3) in lower Cook Inlet at 108–122 m, 4) off Cape St. Elias at 91–102 m, 5) off Ocean Cape at 82–91 m, and 6) off Lituya Bay at 64–75 m. Areas were selected for their geographic separation and likely abundance of scallops. Giant Pacific scallops were shucked aboard the vessel, and the upper valves were retained for age and growth analyses. At each location, 59–248 scallops were selected (Table 1); the only criterion for selection was that each sample include a wide range of sizes. Because larger (and rarer) scallops were more likely to be chosen, samples were not selected at random. Within a sample, however, the range of sizes at any given age was not great; for the purpose of fitting growth curves, we assumed that each age class was sampled randomly.

Ages were determined by counting clearly visible annuli (growth rings) on the outer surface of the upper valve. The first annulus is formed halfway during the second year of life; scallops spawn in the summer and the annuli are formed in the winter (Haynes and Hitz, 1971). This aging method has been used extensively to study mollusk growth, such as in studies on the North Atlantic sea scallop, *Placopecten magellanicus* (Stevenson, 1934; Stevenson and Dickie, 1954; Merrell et al., 1961), and on the European sea

[1] National Marine Fisheries Service. 1996. Fishery management plan for the scallop fishery off Alaska. Unpubl. document. Natl. Mar. Fish. Serv., P.O. Box 21668, Juneau, AK 99802, 123 p.

[2] Hennick, D. P. 1973. Sea scallop, *Patinopecten caurinus*, investigations in Alaska. Commer. Fish. Res. Develop. Act, project 5-23-R, completion rep. (unpubl.). Alaska Dep. Fish and Game, Juneau, AK 99801, 38 p.

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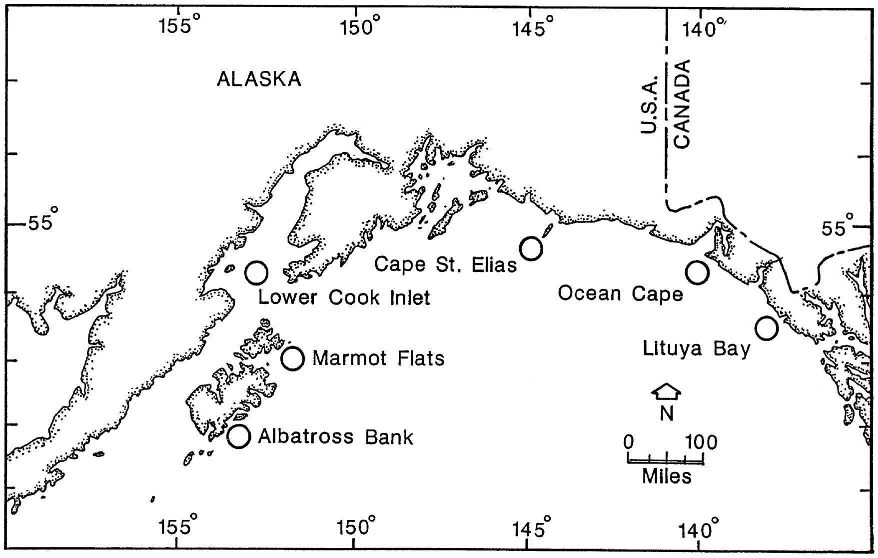

Figure 1

The six areas in the Gulf of Alaska sampled for giant Pacific sea scallops during the *Viking Queen* survey, 1968.

scallop, *Pecten maximus* (Gibson, 1956; Mason, 1957), and shows reasonably good agreement with "true" (isotopically predicted) ages when growth rings are clearly visible (Dare and Deith, 1989). Application of the method to *Patinopecten caurinus* has been verified by Haynes and Hitz (1971).

Terminal shell heights (size of shell to the last annulus; hereafter called "shell heights") were used to fit a growth model for each sample (Table 1). No attempt was made to determine the sex of the scallops because of indications that growth differences between sexes were insignificant.[3] After our sampling, scientists of the ADF&G provided sex and age data for scallops taken in August 1970 northwest of Kodiak Island. The von Bertalanffy growth model was fitted to these data, and growth differences between sexes were tested as described in the following section.

Estimation and fitting of von Bertalanffy curves

Mean shell heights by age were plotted for sea scallops in each sample (Fig. 2). Growth decreased steadily with age, suggesting that sigmoid growth was not present or that the shell heights used were beyond the point of inflection; thus the von Bertalanffy growth model was considered appropriate for our study. In this model, length of the i^{th} individual at age t is

$$\ell_{it} = \ell_{\infty}\left[1 - e^{-K(t-t_0)}\right] + e_i;\ e_i \sim N(0,\sigma^2).$$

Kimura (1980) showed that maximum likelihood estimation for the von Bertalanffy curve is equivalent to finding least-square estimates of model parameters (see also Cerrato, 1990). Least-square estimates for the three parameters were obtained by nonlinear regression methods. Analysis of residuals showed that the von Bertalanffy model provided an adequate fit for all samples. The precision (variance) of parameter estimates varied with age composition of the sample. For example, samples with few young scallops showed relatively large variances for the parameters K and t_0, whereas samples with few old scallops resulted in imprecise estimates of asymptotic length (Table 2). However, the residual mean square error (MSE), denoting variability about fitted growth equations, did not vary widely among samples.

Comparison of growth curves for different areas

No significant difference (P>0.15) in growth between sexes was detected in the ADF&G samples, supporting the presurvey decision not to determine the sex of the scallops. Growth of scallops from the six areas was compared by likelihood ratio tests by using two probability models: model 1 specified equality of the von Bertalanffy parameters of each area; model 2 allowed separate parameters for each area (Kimura, 1980). The first model consisted of pooling the data over all areas, yielding one growth equation; the second model allowed separate growth equations for each area. Because there was no *a priori* hypothesis concerning growth differences between the areas, 15 simultaneous tests were performed to evaluate pairwise differences in growth. These tests were equivalent to testing k independent hypotheses at a significance level of α. Applying Bonferonni's inequality (Miller, 1966) to the 15 tests resulted in an experimental-wise significance level $\leq k \times \alpha$. We chose α to equal 0.003, giving an experimental-wise significance level of 0.045. Likelihood ratio tests

[3] ADF&G. 1970. Unpubl. observations. Alaska Dept. Fish and Game, Kodiak, AK 99615.

indicated highly significant differences ($P<0.003$) in growth between scallops from each area.

Results and discussion

Sea scallops from the Gulf of Alaska showed a consistent trend in growth geographically: from southeastern Alaska northward and then westward around the perimeter of the Gulf of Alaska, sea scallops tended to be larger. Differences in mean shell height were small at early ages but became more pronounced as the scallops grew older (Fig. 2).

This geographic trend in growth was probably not related to time and depth of sampling. Time of sampling varied little between areas; all areas were sampled within a period of 45 days. Depth of sampling did vary between areas, however, because scallop growth rates are known to vary by water depth, e.g. scallops off Oregon are smaller in deeper waters and have reduced asymptotic lengths (Ronholt and Hitz, 1968; Starr and McCrae, 1983). If this depth-size relationship holds true in Alaska waters, then current estimates of asymptotic size for scallops from the northern areas are biased downwards compared with those from Lituya Bay, where scallops were sampled in shallower waters.

Comparisons of our growth results with two analyses of giant Pacific scallop samples taken after the start of commercial fishing (Kaiser, 1986; Hennick[2]) showed significantly different estimates of asymptotic size. For scallops off Kodiak, values of l_∞ from Hennich's data (182.8 mm) and Kaiser's data (189.8 mm) are larger than our estimate (175.7 mm); for scallops off Yakutat, values of l_∞ from Hennick's data (151.5) and Kaiser's data (143.7 mm) are smaller than our estimate (158.6 mm). Scallop fishing before 1980 occurred entirely in these two areas (Shirley and Kruse, 1995). The reduction in asymptotic size for scallops off Yakutat may indicate an increase in fishing mortality on larger individuals. Both analyses also showed that giant Pacific scallops for a given annular ring are larger from the Kodiak area than from Yakutat, a result that supports our conclusions of geographic growth trends for the giant Pacific sea scallop.

Table 1

Mean shell heights (mm) and standard deviations (SD, in parentheses) and number of giant Pacific sea scallops of given ages sampled from six areas in the Gulf of Alaska. Areas listed are from northwest to southeast.

	Sampling areas											
	Albatross Bank		Marmot Flats		Lower Cook Inlet		Cape St. Elias		Ocean Cape		Lituya Bay	
Age (yr)	Length (SD)	*n*	Length (SD)	*n*	Length (SD)	*n*	Length (SD)	*n*	Length (SD)	*n*	Length (SD)	*n*
1		0		0		0		0		0		0
2		0		0		0		0	51.9 (6.5)	7	37.5 (9.2)	2
3		0		0	70.7 (5.3)	11	77.1 (6.3)	36	76.9 (5.0)	22	69.5 (0.7)	2
4	90.9 (5.8)	47	107.8 (3.3)	4	89.5 (5.5)	19	100.8 (6.4)	21	95.6 (5.7)	117	86.8 (8.3)	62
5	114.2 (4.3)	44	121.2 (3.0)	9	113.1 (6.6)	48	116.6 (6.0)	42	107.1 (5.0)	29	96.9 (7.2)	14
6	134.3 (6.8)	3	137.6 (4.1)	13	127.6 (5.4)	77	135.3 (8.1)	7	117.5 (7.2)	27	110.5 (5.4)	16
7	141.0 (4.5)	21	143.25 (4.8)	8	136.6 (6.0)	58	141.3 (5.2)	4	127.6 (4.5)	11	114.8 (5.6)	33
8	148.8 (3.0)	9	151.6 (2.3)	10	141.3 (6.3)	18	141.0	1	134.5 (7.3)	20	199.7 (6.5)	64
9	157.7 (3.1)	3	156.9 (3.9)	10		0	151.7 (4.5)	3	141.2 (5.9)	9	124.1 (4.2)	9
10	166.0	1	162.5 (0.7)	2		0	152.0	1	144.0 (4.9)	4	129.0 (5.6)	2
11		0	173.0	1		0	153.0	1	155.0	1		0
12		0	166.0 (1.4)	2		0		0		0		0
13		0		0		0	153.0 (0.0)	2		0		0
14		0		0		0	158.5 (4.9)	2		0		0
15		0		0		0	157.0	1		0		0
16		0		0		0		0	156.0	1		0

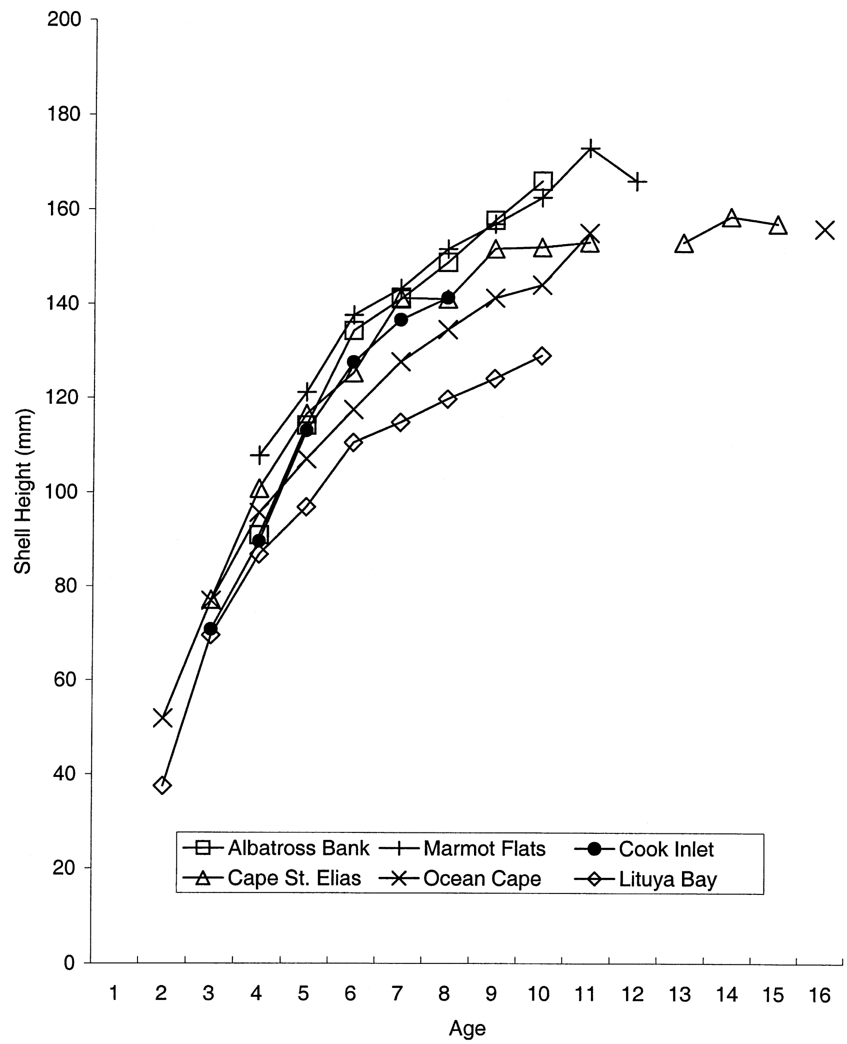

Figure 2

Mean shell heights by age for sea scallops collected in the Gulf of Alaska, 1968.

Table 2

Von Bertalanffy growth parameters (and standard errors) for sea scallops from six Gulf of Alaska areas. Sample areas are given in order from northwest to southeast.

		Parameter estimates (standard errors)			
Area	Sample size	σ^2	L_∞	k	t_0
Albatross Bank	128	23.71	170.1 (4.5)	0.346 (0.035)	1.791 (0.156)
Marmot Flats	59	15.13	175.7 (4.2)	0.265 (0.033)	0.455 (0.387)
Lower Cook Inlet	231	36.88	161.7 (4.1)	0.328 (0.030)	1.353 (0.139)
Cape St. Elias	121	37.64	159.7 (2.8)	0.326 (0.021)	0.974 (0.116)
Ocean Cape	248	34.80	158.6 (3.3)	0.244 (0.017)	0.265 (0.141)
Lituya Bay	204	47.41	130.5 (2.5)	0.367 (0.036)	0.962 (0.207)

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