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Growth and mortality in an isolated bed of saucer scallops, *Amusium japonicum balloti* (Bernardi)

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Summary

Saucer scallops, *Amusium japonicum balloti* found in the vicinity of Bundaberg, Queensland in November 1977 were separated both spatially and by depth from other scallop beds and were of relatively uniform size, suggesting they may have originated from a discrete spatfall. These scallops existed in an elongated bed with the longer axis lying parallel to the prevailing tidal flow. Growth of scallops in the bed was modelled using a von Bertalanffy curve, with parameter estimates such that L_t (mm)=105.5 $(1-e^{-0.0448\,t})$ with *t* in weeks. Tagging experiments indicated that movement by individual scallops was limited and that no population movements occurred. A weekly instantaneous natural mortality coefficient was estimated at 0.097, which is sufficient to suggest extinction of the bed in approximately one year, and which is much greater than in other scallop populations studied. The high incidence of the ascaridoid nematode *Sulcaris sulcata* and the high mortality rate of scallops were speculatively linked with a high density of loggerhead turtles *Caretta caretta* in the study area.

INTRODUCTION

The saucer scallop *Amusium japonicum balloti* (Bernardi) is fished commercially in waters off the central Queensland coast, where the majority of the catch is taken in water depths of between 35 m and 60 m. In October 1977 small saucer scallops were taken by trawlers fishing in the vicinity of Bargara, (24°50′S, 152°28′E), in depths of 11 to 14 m at a distance of 1 to 5 km offshore (Figure 1). The proximity of these scallops to the shore gave an opportunity for a detailed field study of growth, mortality and reproduction in an isolated bed of the species.

MATERIALS AND METHODS

Samples of scallops were taken at approximately monthly intervals from October 1977 to November 1978 in the area bounded by 24°46′ to 24°52′S and 152°26′ to 152°30′E. A 3 m wide beam trawl fitted with a 25 mm stretched mesh net was towed from an outboard powered motor boat. Each trawl shot was of 15 minutes duration and conducted at a ground speed of approximately 3.7 km/hour. In all but isolated instances, trawl shots were carried out against the direction of tide flow. The position at the commencement of each trawl shot was located by the use of landmarks. This point was then relocated on a 1:24 000 scale aerial photograph. When possible a second position fix was made at the conclusion of the shot; if not the distance covered was estimated to be 930 m (3.7 km×0.25h).

Between six and twelve shots per day were made over three successive days to give an instantaneous measure of relative density in any one month. At the conclusion of each shot all captured scallops were counted with shell heights of up to 1500 animals being measured to the nearest mm. Shell height was recorded as the distance between a scallop's auricles and the opposite margin (Williams and Dredge 1981).

During the first six months of sampling, approximately 100 scallops a month were tagged and released in the sample area, using the technique reported by Williams and Dredge (1981). A monthly subsample of between 35 and 70 scallops was retained for examination of the condition of the gonad and adductor muscle, and to obtain data on the relationship between adductor weight, shell height and total animal weight. The number of nematodes visible to the naked eye in the adductor of each scallop was noted.

In the period 3 to 6 January 1978 and again on 25 January 1978, samples were collected over an extended area to examine variation of catch rate with area and to establish the geographic limits of the bed. The sample obtained on 30 September 1978 was obtained using a commercial otter trawl and therefore no data on abundance were available for this month.

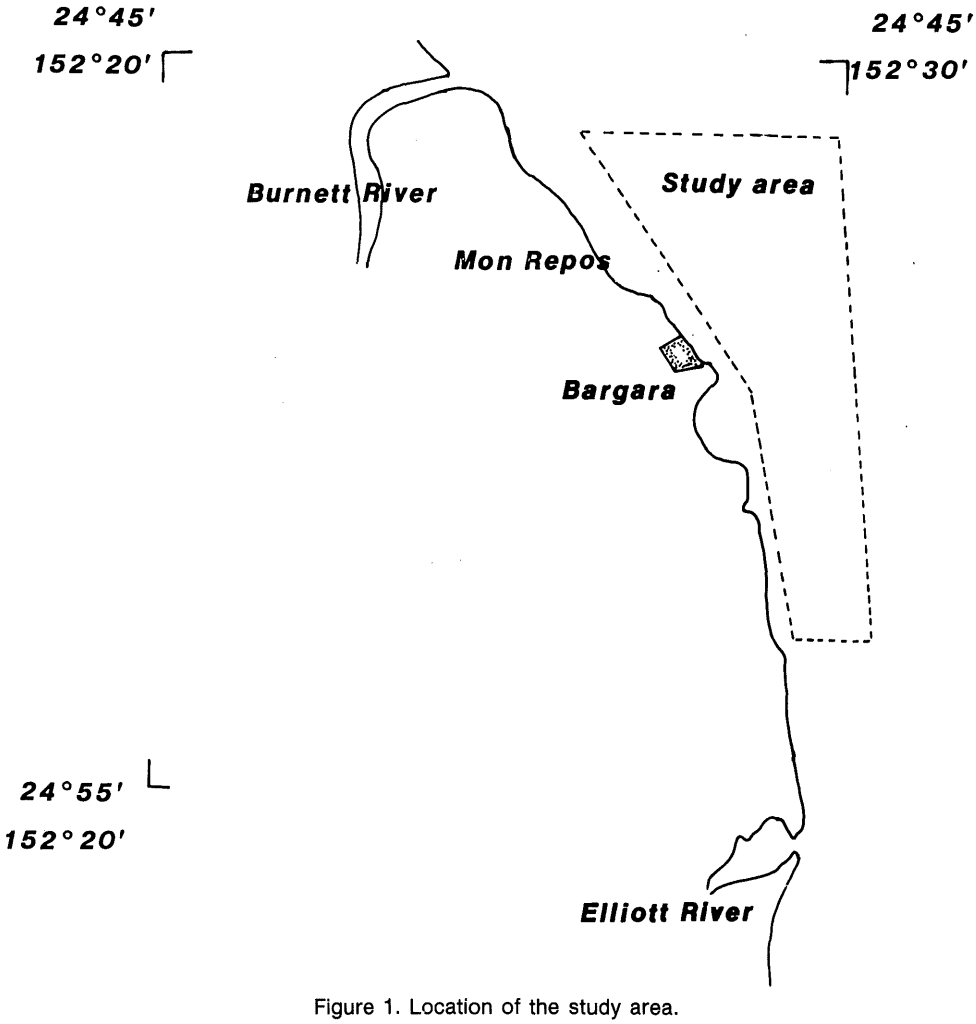

Figure 1. Location of the study area.

RESULTS

Distribution

Table 1 shows the catch per trawl shot in a series of 2 km×2 km grids and indicates the distribution and abundance of scallops in the study area in January 1978. The ratio of variance to mean for catch/trawl shot was 89.1 (n=42) suggesting contagious distribution (Elliott 1977). The data in Table 1 show density gradients from both north to south and east to west. Sampling was not sufficiently extended to reach a point of zero abundance, but the data suggest that scallops in the bed occurred in an area of at least 16 km×4 km (=64 km²), although at low densities on the extremities of the bed.

Table 1. Catch per shot of scallops, and number of trawl shots in 2 km×2 km grids off Bargara during January 1978

23°45′S 152°26′E	Distance south (km)	Distance east (km) 0–2	2–4	4–6	6–8	8–10	Mean scallops trawl shot (number of trawl shots)
	0–2	0 (1)	28 (2)				18.6 (3)
	2–4*	18 (1)	95 (1)				56.5 (2)
	4*–6		59.2 (5)	21 (1)			52.8 (6)
	6–80		37 (1)	170.8 (5)	12 (2)		118.1 (8)
	80–10			106.2 (6)	142 (4)	31 (2)	105.6 (12)
	10–12			60 (1)	139.8 (5)		126.5 (6)
	12–14				46 (1)	50.7 (3)	49.5 (4)
	14–16					30 (1)	30 (1)
Mean scallops/ trawl shot (number of trawl shots)		9 (1)	53.7 (9)	123.3 (13)	111.4 (12)	40.6 (6)	

* Approximate position of coastline.

Movement

Only 17 of the 600 tagged scallops were recaptured and returned. Of these 13 were taken by commercial trawlers and the remainder by the author during monthly sampling. Periods at liberty ranged from 32 to 366 days. The recapture position of animals taken during sampling could be recorded to an accuracy of 1 km along the line of the sample trawl shot. Animals recaptured by commercial trawler could be located with the accuracy of approximately 4 km, with the exception of five recaptures for which no recapture positions were given. Within these constraints, all but two tagged scallops showed no appreciable movement. These two scallops, released at 24°50′S, 152°29′E, were recaptured 5 km south-east of the release point after periods at liberty of 300 and 366 days.

Size frequency

Size (shell height) frequency histograms for each set of samples are set out in Figure 2. Each set of data other than that for November 1978 is assumed to be unimodal, and

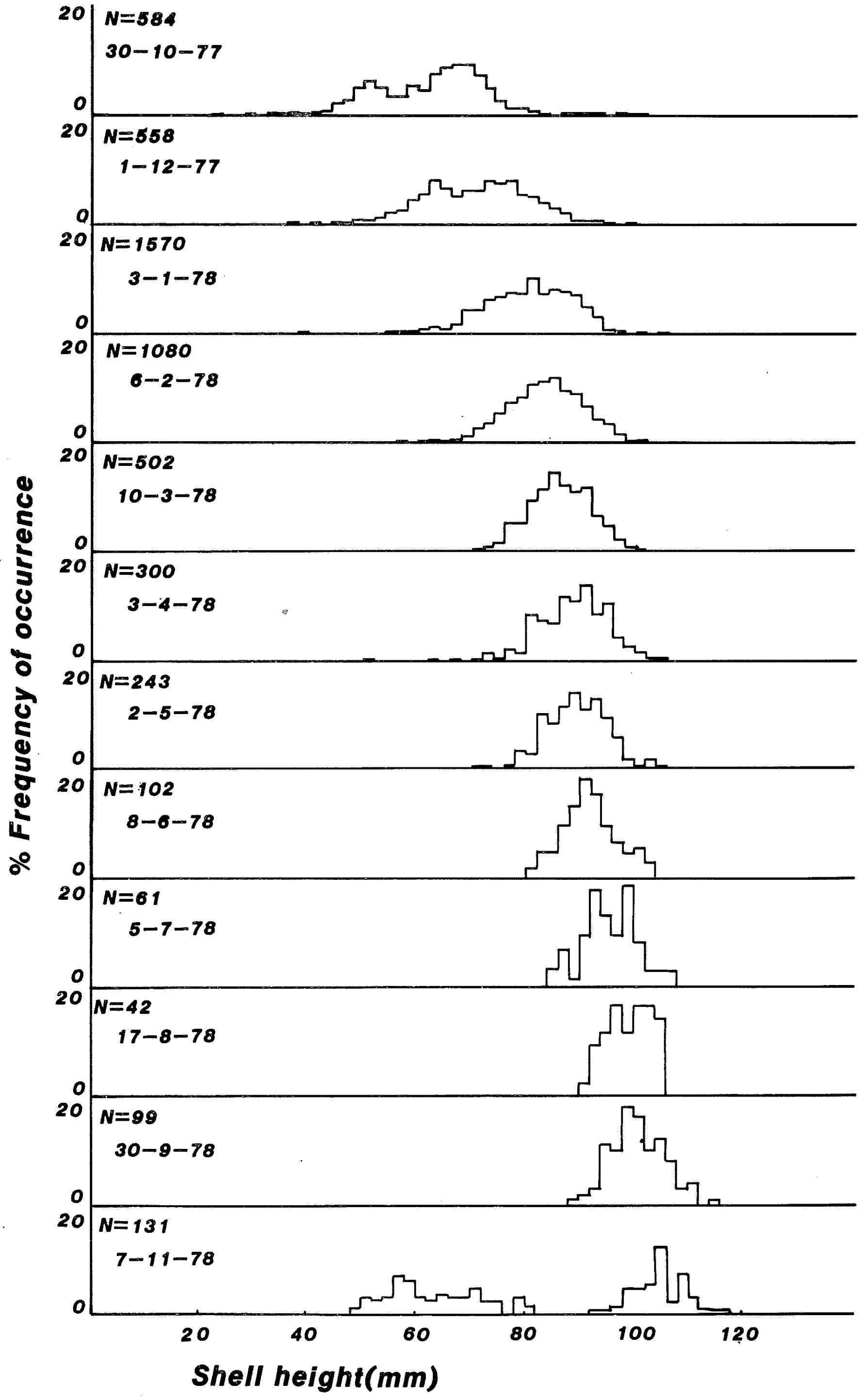

Figure 2. Size frequency histograms of saucer scallops *A. japonicum balloti* from October 1977 to November 1978.

the increase in the mean size of scallops from October 1977 to September 1978 is assumed to represent growth of a single settlement of scallops in that time. The size frequency data for November 1978 includes two distinct cohorts: scallops from the pre-October 1977 settlement, and additional recruits which became vulnerable to the trawl net between September and November 1978.

Growth

Growth was measured by the rate of increase in the mean size of scallops in monthly samples. This method is suitable providing there is no recruitment, emigration or size differential mortality. Tagging experiments indicate that emigration did not occur and periods of recruitment were clearly indicated in the size frequency data. The possible existence of size selective mortality and its effect upon apparent growth of saucer scallops could not be determined from the present results. However, these factors are assumed to be of little significance when compared with the overall rapid growth rate of the species.

Mean shell heights and standard deviations for each set of samples are given in Figure 3, with the curve between points fitted by eye. There was no significant diference between male and female shell heights in any single sample, suggesting that growth rates in the species were not sexually dimorphic. Values of l_t and l_{t+1}, where l refers to shell height at time *t*, and l_{t+1}, to shell height at time t+1 weeks, were taken from the curve. The von Bertalanffy parameters K and L_∞ were estimated by means of a Walford plot (Gulland 1969) as being 0.0448/week and 105.5 mm respectively. No estimate of the von Bertalanffy parameter t_0 can be made from the existing data. Conan and Shafee (1978), gave estimated t_0 values for the black scallop *Chlamys varia* (L) between −0.273 years and +0.263 years. Assuming that the value of t_0 is small in relation to (t times K) *A. japonicum balloti*, as is the case for *C. varia*, the von Bertalanffy growth model approximates: L=105.5 $(1-e^{-(0.0048\,t)})$ with t expressed in weeks. This curve is plotted in Figure 3. Because the absolute age is not known at any time, the fitted curve has been adjusted to pass through the first data point in Figure 3.

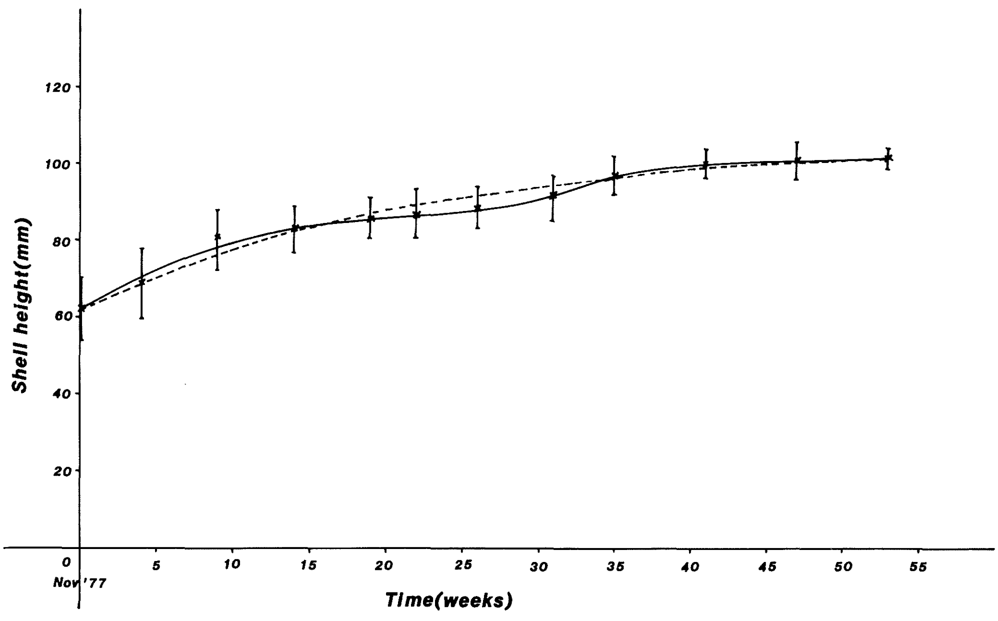

Figure 3. Mean shell height, standard deviation of *A. japonicum balloti* over time (solid line). von Bertalanffy curve with parameters derived from size frequency data in Figure 2 in broken line. November 1978 data include only those scallops with shell heights greater than 80 mm.

While the growth curve is in general agreement with the data, there is a tendency for predicted shell heights to be slightly less than those recorded in summer months and slightly larger in winter. Cloern and Nichols (1978) have proposed a modification to the von Bertalanffy model such that a seasonal variation in growth may be incorporated. The modification utilises a sinusoidal function being fitted to a plot of time against *K*. Time was plotted against *K* for the present data, but the points did not show the sinusoidal form required.

For tag recapture data the von Bertalanffy equation can be transformed from the form:

$$L_t = L_\infty \left(1 - e^{-K(t-t_o)}\right)$$

$$L_r = L_\infty \left(1 - e^{-Kp}\right) - L_m e^{-Kp}$$

where,

L_r=length at recapture

L_m=length at marking

p. = period at liberty (Fabens 1965).

Estimates of K and $L\infty$ can be derived from tag recapture data using the Marquardt algorithm (Marquardt 1963). Estimates of K and $L\infty$ for *A. japonicum balloti* using tag recoveries from the present study had variances so great as to be unacceptable.

Values for K and $L\infty$ derived from size frequency data were incorporated into the von Bertalanffy growth model, which was then used to estimate theoretical growth of tagged, recaptured scallops in the period between release and recapture. These theoretical estimates of growth are compared with growth rates actually recorded in Table 2.

A Wilcoxon signed rank test was used to test for difference between observed and predicted growth of tagged scallops, and revealed a significant difference between the two sets of data (T=94, $0.05 > P > 0.02$).

Mortality

As far as could be ascertained from interviews with fishermen, no trawling was carried out in the study area in the period between November 1977 and April 1978. Results from tagging, both in this and other areas (Williams and Dredge 1981) suggest that individual scallops undertook only limited movements and that populations could be regarded as sedentary. Thus, in the absence of additional recruitment after the initial settlement, as indicated in the size-frequency histograms, any change in scallop density in the period between November 1977 and April 1978 could be ascribed to natural mortality. The average value of catch/trawl shot (Figure 4a) for each set of samples was used as an estimator of relative density at the time samples were taken, and a regression of log catch/shot against time used to estimate the natural mortality coefficient M (Figure 4b) (Gulland 1969). The slope of the regression line was established as −0.0972 ($b<0$, t =8.52, $P<$ 0.01), and the value of M as 0.097/week.

Parasitism

Nematodes from the adductor muscle of scallops taken in the study area during the period in which the present study was conducted were identified as *Sulcaris sulcata* (Rudolphi) (Cannon, pers. comm.).

Table 3 gives the frequency of nematode infection through the year and a chi-squared test indicates that the frequency of occurrence was not uniform through the year (χ^2=201.32, d.f.=11; $P<0.001$).

Table 2. Growth of tagged scallops compared with growth estimated from von Bertalanffy parameters, L∞=105.5 mm, K=0.0448/week, obtained from size-frequency data

Tagging data			von Bertalanffy estimate of shell height (mm) at recapture
Weeks at liberty	Shell height at release (mm)	Shell height at recapture (mm)	
5	71	75	77.9
5	79	82	84.3
5	87	89	90.7
8	79	84	87.0
10	89	92	95.0
10	89	92	95.0
14	77	92	90.3
18	91	93	99.0
27	59	87	91.6
27	69	85	94.6
35	65	97	97.9
36	78	92	100.0
40	78	102	100.9
41	80	104	101.4
43	66	100	99.7
45	36	93	96.2
52	61	106	101.2

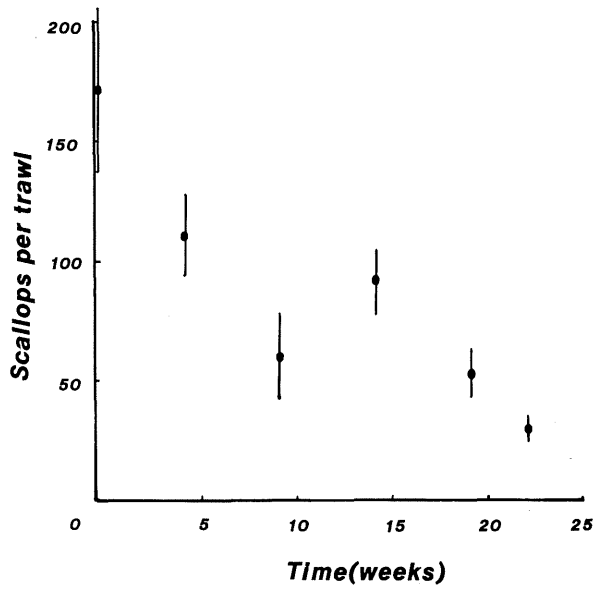

Figure 4a. Average catch per trawl shot versus time. Bars represent standard errors.

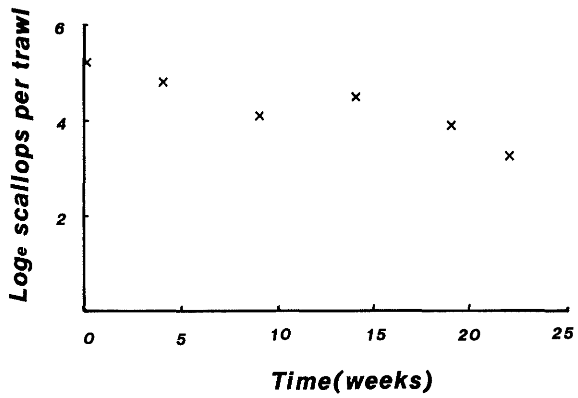

Figure 4b. Log_e of average catch per trawl versus time.

Table 3. Incidence of nematode infection in *A. japonicum balloti,* off Bargara

Date of capture	Sample size	Frequency of nematodes					Proportion of scallop infected	Mean nematodes per scallop
		0	1	2	3	⩾4		
31 Oct 77	35	35	—†	—	—	—	0	0
2 Dec 77	35	35	—	—	—	—	0	0
4 Jan 78	58	58	—	—	—	—	0	0
7 Feb 78	55	35	20	—	—	—	0.36	0.36
14 Mar 78	70	57	12	1	—	—	0.19	0.20
5 Apr 78	55	34	19	2	—	—	0.38	0.42
2 May 78	55	31	23	—	—	1	0.44	0.49
7 June 78	60	35	19	4	2	—	0.42	0.55
5 July 78	56	17	27	8	4	—	0.70	0.98
18 Aug 78	42	3	15	13	11	—	0.93	1.76
30 Sep 78	40	10	16	10	3	1	0.75	1.23
7 Nov 78	27*	5	2	10	5	5	—	—
	10	10	—	—	—	—	—	—

* Sample taken on 7 Nov 78 consisted of two size frequency groups viz. <75 mm (10 animals) and>95 mm (27 animals). These two groups have been separated, and excluded from further analysis.

†=no data.

DISCUSSION

Trawl samples taken in the present study and in other areas between 23°00′S, 152°00′E and 24°00′S, 153°00′E in 1979 and 1980 (M. Dredge, unpub. data) indicate that saucer scallops occur in distinct aggregations. These aggregations have asymmetric densities along their longtitudinal and latitudinal axes, and can cover areas in excess of 10×2 km with the elongated axis being parallel to prevailing tide flow (Anon., 1967). Bullis and Cummins

(1961) also noted the elliptical shape of scallop beds and suggested their shape may also be a consequence of strong tide flow. Results from tagging experiments, both in this study and previous work (Williams and Dredge 1981), suggests that whilst individuals are capable of active movement (Purchon 1977) net displacement over relatively long time spans is limited, and populations do not undergo any form of migration. By grouping into extensive, sedentary beds, *A. japonicum balloti* thus conforms to the behavioural pattern of a large number of scallop species (e.g., Caddy 1975).

Williams and Dredge (1981) demonstrated that adductor weight to shell height ratios in *A. japonicum balloti* varied seasonally. They used increments in shell height as a more appropriate parameter than weight on which to model growth, and found that the von Bertalanffy curve adequately described growth in both sub-adult and adult *A. japonicum balloti.*

Size-frequency change in a single cohort of scallops in the present study demonstrated growth of *A. japonicum balloti* over a twelve month period, with the von Bertalanffy parameters of K and $L\infty$ being estimated at 0.0448/week and 105.5 mm respectively. K values ranging from 0.0515/week to 0.0588/week, and $L\infty$ values ranging from 102.0 mm to 108.5 mm, were estimated by Williams and Dredge (1981) for scallops taken from depths of 30m to 40 m between 22°45′S, 151°05′E and 23°55′S, 155°55′E. The growth coefficent K derived from scallops in the Bargara area is thus slightly less than that derived for others areas. This suports the observation made by Williams and Dredge (1981) that growth parameters in the species vary with time and area, and that variation in these parameters gives rise to uncertainity in estimates of population parameters.

There was a significant difference in apparent growth recorded from tag recaptures when compared with growth rates recorded from size-frequency analysis, with tagged scallops growing less than predicted. Conan and Shafee (1978) observed differences in von Bertalanffy growth parameters derived from tagging and length-frequency analysis in the black scallop *C. varia* but attributed the differences to the presence of two groups of recruits, one from a spring spawning and the other from an autumn spawning.

Sainsbury (1980) has suggested that von Bertalanffy parameters derived from growth increment data from tag returns may be biased due to variation in growth parameters amongst individuals. His findings that growth of individuals should be less than predicted if a single population value of K is used to describe their growth is not contradicted in the present study. It is also possible that handling and shell chipping which occurred during tagging operations may have led to growth retardation in tagged animals.

Plots of size frequency data indicate that the growth rate of *A. japonicum balloti* may be reduced in autumn and winter months. This was not unexpected as the species is a winter spawner and could be expected to convert an appreciable proportion of glycogen reserves to gonad tissue. However, when seasonal growth variation was tested against a formal model, no significant variation in the growth parameter K was observed with time.

Although a number of studies have been made on growth in scallops including those of Mason (1957), Taylor and Venn (1978) and Stephenson and Dickie (1954), there has been little consideration of differential growth rates of the separate sexes in gonochoristic species of the Pectinidae. In the present results, no differences were observed between mean sizes of males and females in any one month's data which suggest the two sexes have similar growth rates.

The natural mortality rate within this bed of scallops was considerably greater than for saucer scallops from areas with water depths of 30 to 40 m, where the species is most abundant (M. Dredge, unpub. data), and was sufficient to lead to extinction of the bed in a period of little more than a year. Medcof and Bourne (1964) have listed causes of natural mortality in *Placopecten magellanicus* Gmelin and included predation by fish and starfish and environmental stress. Changes in water temperature were said to debilitate scallops and leave them more vulnerable to predation. The wide temperature range incurred by saucer scallops in the bed under consideration could conceivably have induced such stress, although mortality appeared to be occurring at a constant rate and did not peak with a given temperature or temperature flux.

There are no data to support or refute the concept that predation by fish or starfish may have induced excessive mortality, but the study area was adjacent to Mon Repos beach, a major rookery for loggerhead turtles *Caretta caretta* L. (Limpus 1973) which are known predators of saucer scallops (Lester *et al.* 1980). Turtles were abundant in the study area throughout the summer months and were a conspicuous potential predator of scallops. Loggerhead turtles also act as a vector in the transmission of the nematode *S. sulcata* (Berry and Cannon 1981) and the high incidence of nematode infection seen in this bed of scallops may be linked to the presence of these turtles. Loggerhead turtles are abundant between November and February and presumably transmit eggs of *S. sulcata* during this period. The highest incidence of stage 3 to 4 *S. sulcata*, which are visible to the naked eye, was observed in midwinter, suggesting that development of the nematode from its egg stage through to stage 4 may take 4 to 6 months, which is little different to that recorded by Berry and Cannon (1981) in laboratory research animals.

Factors affecting the distribution of saucer scallops are poorly understood at this time. It is now evident that the species can survive in water depths far shallower than those in which it is normally fished. But there is an obvious need for further studies of how settlement and survival may be affected by water movement, food preferences and other factors.

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