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Fisheries biology of kina (*Evechinus chloroticus*)

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This series documents the scientific basis for stock assessments and fisheries management advice in New Zealand. It addresses the issues of the day in the current legislative context and in the time frames required. The documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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1. EXECUTIVE SUMMARY

Results from research surveys of kina (*Evechinus chloroticus*) in Dusky Sound, Arapawa Island, and D'Urville Island are presented. In Dusky Sound, where most of the research was done, no significant variation in the density of kina or macroalgae was due to fishing (130 removed during 1993). Spatial and temporal variation in kina density, density of macroalgae (*Carpophyllum flexuosum*, *Ecklonia radiata* and juveniles of both species), and percent cover (mainly crustose and articulate coralline algae, flat reds, and *Codium* spp.) was shown to be independent of experimental fishing. The volume of gonad varied with size (diameter), but this relationship varied among locations (Dusky Sound, Arapawa Island, D'Urville Island) indicating variation in size at first maturity over small distances. The relative volume of gonad (gonad index) varied seasonally and spatially in Dusky Sound. Although the relative gonad size decreased for large kina (> 120 mm diameter), there was no significant variation in the viability of gametes among kina of different sizes. Growth rate of Dusky Sound kina, estimated by two independent methods, was about 25 mm in diameter per year up to about 75 mm (size at first maturity).

The results show that variation in a range of biological parameters occurs over small distances. Such variation should be taken into account when defining stock boundaries for managing kina stocks.

2. INTRODUCTION

2.1 Overview

This paper refers to commercial catch data and to ongoing investigations of experimental kina fishing in Dusky Sound (SUR 5). It updates an earlier assessment which described prefishing surveys of kina-dominated communities in Dusky Sound (McShane et al. 1993a) and includes preliminary survey information from D'Urville Island and Arapawa Island (SUR 7). The results of biological studies describing reproduction, growth, and survival of kina in Dusky Sound are presented.

2.2 Description of the fishery

Kina inhabit shallow waters (generally less than 10 m) off the coastline of New Zealand. Kina are caught by diving, shorepicking, or bottom trawl or dredging in all coastal waters of New Zealand, including the Chatham Islands. Most are caught by diving, but there is a dredge fishery for kina in Tory Channel (SUR 7). Kina are harvested for their roe (the gonad of the animal) and are sold mainly on the domestic market. The total fishery is small but recent initiatives to develop export markets have led to the establishment of an experimental fishery in Dusky Sound (SUR 5). The proposed annual catches in this latter fishery far exceed previous total harvests.

The commercial fishery is divided into eight Fishstocks and is managed under a competitive quota system (SUR 4 has no annual catch limit). Permit holders do not have individual catch entitlements, but collectively can catch no more than the annual competitive quota.

Kina are accessible to divers or shore pickers and current estimates of the size of the recreational fishery are small. Kina have been used traditionally by Maori for food. Current fishing levels by Maori have not been quantified.

2.3 Literature review

Prefishing surveys of kina-dominated communities in Dusky Sound were described by McShane & Naylor (1991) and McShane *et al.* (1993a). These assessments included a review of relevant literature to date. The experimental fishery in Dusky Sound was described by McShane (1992), McShane *et al.* (1992, 1993b, 1994a). Results of preliminary surveys of kina dominated communities in SUR 7 were described by McShane & Naylor (1993).

3. REVIEW OF THE FISHERY

3.1 Catch and landings data

Recent reported landings and competitive quotas are shown in Table 1. Catches have generally been less than the competitive quota for each FMA.

Table 1: Reported landings (t) of kina by Fishstock from 1983-84 to 1992-93 and actual competitive quotas (t) from 1986-87 to 1992-93. – no data.

Fishstock	SUR 1		SUR 2		SUR 3		SUR 4		SUR 5	
	Landings	Quota	Landings	Quota	Landings	Quota	Landings	Quota	Landings	Quota
1983-84*	81.42	-	180.27	-	12.64	-	3.98	-	2.60	-
1984-85*	64.46	-	83.81	-	2.42	-	7.44	-	6.17	-
1985-86*	71.95	-	139.11	-	6.24	-	52.73	-	0.22	-
1986-87*	52.05	-	142.64	-	0.60	-	28.35	-	6.09	-
1987-88*	22.08	-	154.10	-	0.00	-	76.50	-	4.01	-
1988-89*	13.36	-	49.72	200.00	0.25	100.00	124.89	-	0.00	200.00
1989-90†	10.17	-	309.16	200.00	5.19	100.00	195.30	-	13.37	200.00
1990-91†	69.16	-	88.75	200.00	21.31	100.00	35.92	-	121.47	200.00
1991-92†	78.72	-	36.65	200.00	15.62	100.00	192.59	-	227.88	200.00
1992-93†	89.59	-	170.36	200.00	9.92	100.00	21.84	-	377.03[1]	200.00

Fishstock	SUR 7		SUR 8		SUR 9	
	Landings	Quota	Landings	Quota	Landings	Quota
1983-84*	55.07	-	0.00	-	0.25	-
1984-85*	99.63	-	0.00	-	0.94	-
1985-86*	85.59	-	0.00	-	2.02	-
1986-87*	52.63	-	0.00	-	0.00	-
1987-88*	174.85	-	0.01	-	0.05	-
1988-89*	5.30	150.00	0.00	50.00	0.00	-
1989-90†	48.18	150.00	0.00	50.00	0.00	-
1990-91†	58.66	150.00	0.01	50.00	0.00	-
1991-92†	113.56	150.00	0.21	50.00	0.00	-
1992-93†	209.48	150.00	0.00	50.00	0.00	-

* FSU data

† QMS data, [1] excludes experimental harvest, Dusky Sound (133 t).

4. RESEARCH

4.1 Introduction

There is interest in developing fisheries for kina (*Evechinus chloroticus*) in New Zealand. An experimental fishery, recently started in Dusky Sound, provides an opportunity to examine the productivity of a kina stock and the impact of fishing on the composition of subtidal communities (McShane & Naylor 1991, McShane *et al.* 1993a). The results of four prefishing surveys of kina dominated communities in Dusky Sound have been described by McShane *et al.* (1993a) and include a description of the species composition of subtidal algal assemblages.

This last study showed that kina were abundant in Dusky Sound, and size composition results indicated an accumulation of large, presumably old, kina. Such large individuals (> 120 mm test diameter) are rarely targetted in fishing because of their poor roe (gonad) quality: roes of large kina are smaller relative to total weight and darker compared to smaller individuals. It is possible that large kina are reproductively senescent and contribute relatively little to reproduction. In the present study, we seek to test this hypothesis. We also present more detailed histological information on the reproductive biology of kina: previous information based on gonado-somatic indices had indicated a seasonal reproductive cycle with annual spawning in summer (McShane *et al.* 1993a).

We present information on the growth and mortality of kina: such processes are well understood for sea urchins (Ebert & Russell 1993), but estimates for any parameter can show large spatial variation. Sea urchins can form dense aggregations and density dependent growth has been shown from the results of experimental manipulation of kina populations over small areas (Andrew 1988). However, such density dependence has not been shown over larger areas more representative of commercial fisheries because the necessary studies have not been done. Here we present preliminary estimates of growth from several assemblages of kina, and provide the first estimates of natural mortality for this species.

We describe the development of a fishery for kina in Dusky Sound. In relation to this development, we assess the spatial and temporal variation in the density and morphometrics of kina and in the composition of macroalgal assemblages (McShane *et al.* 1993b). Most of the research was done in Dusky Sound and information from other localities (Wellington, Arapawa Island and D'Urville Island) is included for comparison.

4.1. Materials and methods

4.1.1 Population surveys

Surveys of about 10 days duration were conducted in Dusky Sound during July and October 1993 and January 1994.

Dusky Sound was stratified to take into account the variability in the density of kina among areas (McShane et al. 1993b) and the likely development of an experimental fishery which would be concentrated in the sheltered waters of Anchor Island (stratum 1, Figure 1). Ten sample sites were allocated randomly to each stratum on each occcasion.

Four sites from each stratum were chosen at random for examination of morphometric characteristics (McShane & Naylor 1991). At these sites, a subsample covering the size range of kina was chosen from the random sample normally gathered during population sampling (all individuals collected were measured for test diameter to the nearest millimetre). Gonad colour was assessed according to a five point scale (Table 2; colour photographs showing the different levels are shown in McShane *et al.* 1992) and the Aristotle's lanterns of individuals removed (*see* Black *et al.* 1984). The lanterns were stored individually with records of individual test diameter (to the nearest millimetre) and whole wet weight (to the nearest gram). The gonad volume was measured (McShane & Naylor 1991). Seasonal variation in the gonad volume of kina from Dusky Sound was compared with that of kina sampled from Wellington's south coast (McShane *et al.* 1994a).

Aristotle's lanterns were bleached (5% sodium hypochlorite) to remove any organic material. After bleaching (at least 48 h), the skeletal elements comprising the lantern were rinsed in fresh water before being drained and air-dried. The lengths of three jaws from each individual lantern were measured to the nearest 0.1 mm as shown in Levitan (1991). Jaw length was expressed as a function of test diameter - about 20 individuals were examined from each stratum. Analysis of variance was used to test for homogeneity of the slopes of jaw size versus test diameter between sites and for sites nested within areas (control versus fished).

Surveys of kina and associated biota were conducted off D'Urville Island and Arapawa Island in September 1993 (Figure 2). At 21 random sites of D'Urville Island and 31 off Arapawa Island, two research divers each descended to a randomly chosen depth between 0 and 10 m and directed a 1 m^2 quadrat in a randomly chosen direction as described below for Dusky Sound: the area surveyed by each diver at a site was considered a subsite. Five sites off D'Urville Island and six sites off Arapawa Island were randomly selected for assessment of morphometric parameters as described above for Dusky Sound.

4.1.2 Community composition: macroalgae

Floristic composition and density of kina in Dusky Sound were assessed by sampling in 10 randomly allocated sites in strata 1,2,3,7 and 8. Off Arapawa Island and D'Urville Island floristic composition was assessed at all sites. Density or percent cover was estimated for two replicate subsites at each site,.

We used a randomly placed and directed 1m^2 square quadrat as described for the assessment of kina density (25 contiguous quadrats). A flexible cord with five irregularly spaced knots was sequentially stretched across the diagonal of the quadrat and hits of the knots scored separately for encrusting, turfing, and canopy-forming macroalgae to the lowest identifiable taxon. Thus, up to 125 points were scored for each taxon. Where a canopy-forming macroalga, for example *Ecklonia radiata*, was encountered, it was scored before the understory of encrusting or turfing species being scored. We also recorded bare space (rock, sand, or gravel) and epibiota such as sponge, bryozoa and ascidians. In each of the 25 contiguous quadrats sampled by each diver at a site we also recorded counts of the large brown macroalgae (*E. radiata* and *Carpophyllum flexuosum*) and depth to the nearest metre. Floristic composition was therefore described for each stratum in terms of percent cover by taxon and density of large brown macroalgae for comparison among strata (1 and 7 for Dusky Sound, or areas off Arapawa Island and D'Urville Island) by analysis of variance (sites nested within strata). Strata 1 & 7 were compared because of their similarity in floristic composition: other strata differed in floristic composition (McShane *et al.* 1993a).

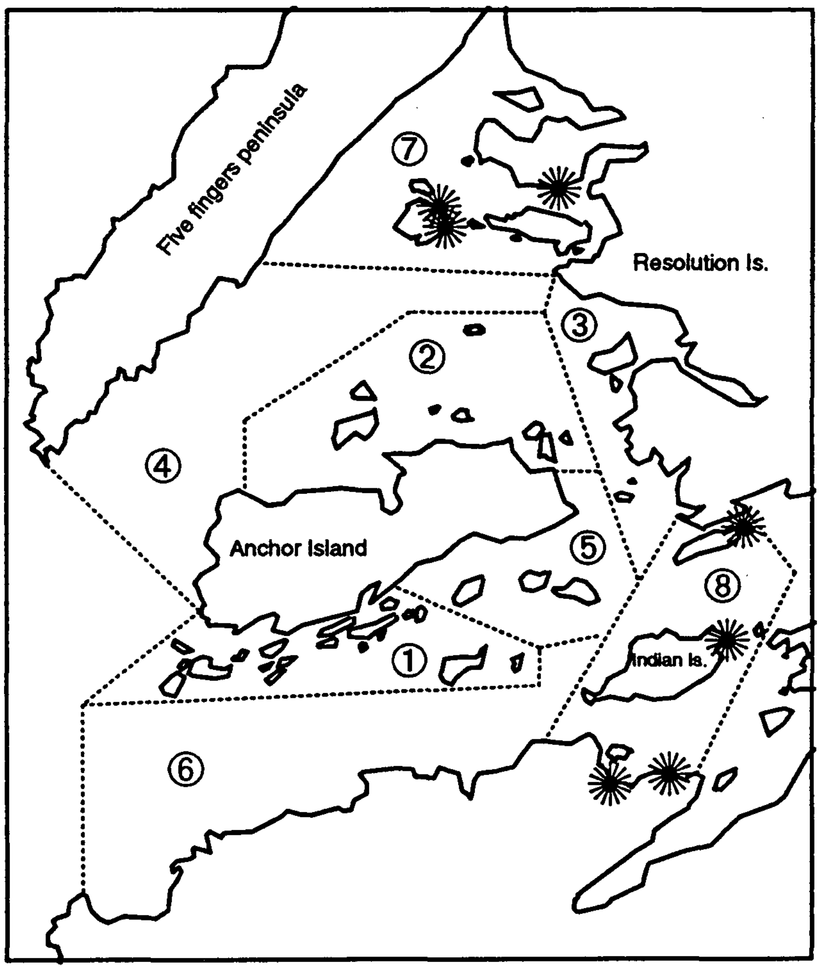

Figure 1. Map of Dusky Sound showing sample strata (numbers in circles) and locations of tag-recapture studies (*).

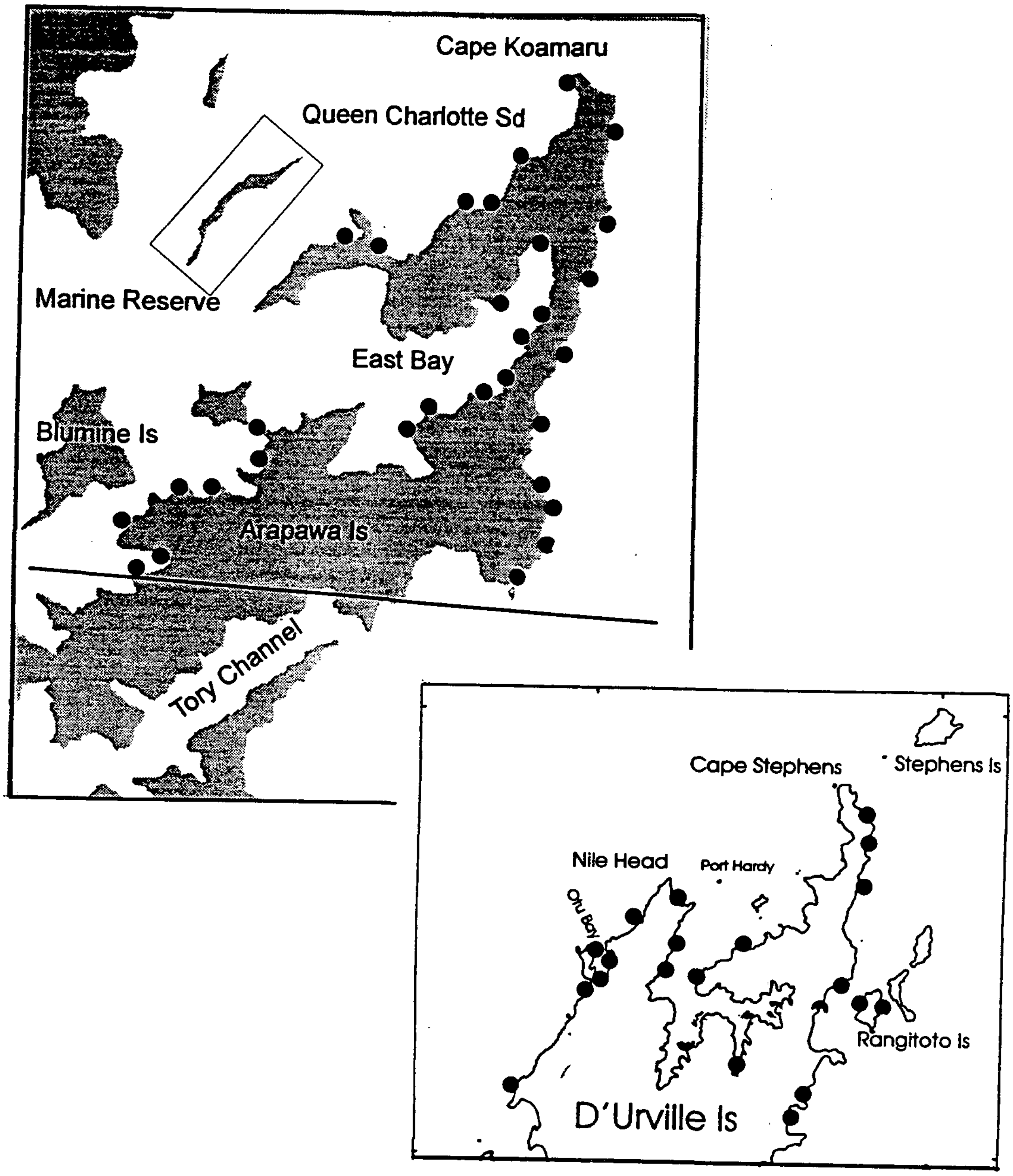

Figure 2. Sample site locations, D'Urville Island and Arapawa Island.

Table 2: Classification of the relative colour and volume of the gonad of kina.

Index	Colour	Volume
1	Dark brown, black or grey	coarse grain, low volume
2	Dark to light brown	coarse grain, low to medium volume
3	Light brown to dull orange	coarse grain, any volume
4	Orange to yellow, bright colour	medium grain, any volume
5	Bright orange or yellow	fine grain, high volume

4.1.3 Reproduction

4.1.3.1 Gametogenic staging

Gonad samples were taken from stratum 1 in Dusky Sound in July and October 1993 and in January 1994. Kina in each of the following five size classes were collected: < 70, 70–90, 90–110, 110–130 and > 130 mm. The gonads were removed from each animal and stored in Davidson's fluid before histological treatment.

Within 4 days of collection, the samples were transferred to 70% ethanol. Transverse sections from each of the gonads in each sample were taken by cutting the gonad midway along its length with a razor blade. The tissue blocks were then embedded in paraffin wax, sectioned at 5 µm, and stained with haematoxylin and eosin (H&E). The completed sections were examined under a compound microscope in an attempt to gain an understanding of the developmental sequence and to compare the development of kina with that of other echinoid species.

4.1.3.2 Oocyte density and size frequency

The mean number of oocytes of different stages per millimetre of tubule wall was calculated by taking 10 replicate counts of cells from each kina over a measured distance of tubule wall. These counts were then converted to a mean number of cells per mm^2 of tubule wall (Gonor 1973a). The data were analysed by ANOVA to test for differences in oocyte densities between individual kina and among size classes.

Oocyte and ovum size frequencies were constructed by measuring the cells with an eyepiece graticule calibrated against a stage micrometer. Each section was traversed twice with the directions at right angles to each other to overcome the problem of non-random size distribution of oocytes within a section of gonad (Gonor 1973b). All cells passing through the central part of the graticule were measured to the nearest 5 µm. As the cells were rarely circular in cross-section, they were measured at their largest diameter. This method gave about 120 to 200 measurements from each section. The data were subjected to 1-way ANOVA to test for differences in mean oocyte size among animals in different size classes.

4.1.3.3 Fertilisation success

Six kina in each of four different size classes (< 80, 80–100, 100–120, and >120 mm) were collected from Dusky Sound in January 1994. Spawning was induced by injecting 1 ml of a 0.5M KCl solution into each of the five gonads. One ml of eggs was collected from a female and diluted in 200 ml of 300 µm filtered sea water and one drop of sperm was diluted in 50 ml of filtered seawater. One ml of the diluted sperm mixture was then added to the egg suspension and allowed to stand for 20 min. The upper 150 ml was then decanted from the beaker and 10 ml of a 10% formalin in sea water solution was added. The first 100 eggs encountered under a compound microscope were checked for the presence of a fertilisation membrane.

4.1.3.4 Sex ratio

The ratio of males to females in Dusky Sound was assessed in July and October by counting the numbers of each sex collected for gametogenic staging. In January 1994, we found that kina can be reliably sexed by eye, and this was routinely applied to all the kina which were collected from then on.

4.1.4 Growth and survival

Trials in aquaria showed that the antibiotic tetracycline was effective in staining the jaws and test of kina. During successive surveys (October 1993 and January 1994), 1575 kina were injected with tetracycline at seven sites, four in stratum 7 and three in stratum 8 (*see* Figure 1).

Sites selected had a good size range of kina (smaller animals in particular being well represented), plenty of available food and space, and were located in areas well defined by natural boundaries. Sites were marked by bolting a line with a subsurface float to the centre of the area to which the kina were returned, and by hanging a marker on a nearby tree.

At each selected site, divers about 250 kina from an area and marked the site. Sometimes divers would search adjacent areas when a particular size class was poorly represented in the sample.

Kina were injected through the peristomial membrane with tetracycline ranging in dose from 2.5 to 20 mg, depending on size, then carefully replaced by hand, ensuring that more vulnerable, smaller kina were placed in the protection of a crevice or rock. Appropriate dosages were determined from aquaria trials (Ebert 1977, Russell 1987, Gage 1992).

In January 1994 a sample of kina was taken from two of the tagging sites established in the October 1993 survey to determine the effectiveness of the methods and the stain. As injected kina cannot be distinguished from uninjected kina without an ultraviolet light source, it was important to determine the effects of migration, emigration, and mortality on the recoverability of tagged kina.

At sites 1 and 2 a small sample of kina, representing a broad range of sizes, was collected. The kina were measured, and the jaws removed and bleached (5% $NaHClO_3$). When clean, the jaws were examined under ultraviolet light to check for fluorescing marks. On 12 of 18 kina in site 1 and 15 of 17 kina in site 2, jaws showed clear tetracycline stains.

The use of jaws for examining growth has two major advantages. First, aside from bleaching, jaws require no treatments such as grinding, sectioning, and slide mounting to see the fluorescing marks and measure the growth increment. Second, our concurrent work examining compensatory growth in jaw length (McShane *et al.* 1993a) has given us good estimates of the relationship between jaw length and test diameter in all areas of Dusky Sound.

The jaws were measured with vernier calipers, taking the mean of three measurements, and then examined under a dissecting microscope set up with an external light source fitted with an ultraviolet transmittent filter. The growth increment was measured as the distance from the fluorescing mark to the growing edge of the jaw, again taking the mean of three measurements.

The von Bertalanffy growth parameters K and L_∞ were estimated from tag-recapture studies using the maximum likelihood growth estimation programme GROTAG, (Francis 1988). A non-seasonal model was fitted with growth variability explained according to Francis' equation 5 and measurement error mean and standard deviation allowed to vary.

$$D_t = D_\infty(1 - e^{kt})$$

where
t = age
D_t = test diameter at age t
D_∞ = asymptotic test diameter
k = slope constant

Length at age was confirmed by sequential examination of putative year classes in size frequency distributions. Modes were separated using MIX (MacDonald & Green 1988). The programme fits a series of normal curves to a multimodal size-frequency distribution estimating the mean and standard error of each component distribution.

The survival of kina can be described by the equation:

$$N_t = N_0 e^{-Zt}$$

[N_t = numbers surviving at time t, N_0 =initial number]

If recruitment is assumed constant, the number of kina in successive age classes is a function of growth and mortality only (Ricker 1975). The instantaneous rate of total mortality (Z) can be estimated from size frequency and age data by the application of a linearised age-structured catch curve where the number of survivors of each year class is plotted against their corresponding age so that:

$$\ln N_t = \ln N_{Tr} + zt$$

[Tr = age at recruitment]

In an unfished population, Z is the instantaneous rate of natural mortality and is obtained by regressing ln *Nt* against estimated age in years. We used sequential size frequency data and estimates of growth rate to separate year classes. Thus size frequency data were converted to age frequency data using the inverse von Bertalanffy equation:

$$t_{(L)} = t_0 - 1/K \ln(1 - L/L_\infty)$$

4.1.5 Fishery development, Dusky Sound

All fishers are required to submit records of the location (to the nearest 100 m) and total landings (to the nearest kilogram) of each dive for kina. These data were used for examination of the spatial development of the fishery and trends in catch per unit effort (CPUE). Samples of the catch of individual fishers were taken on several occasions: generally about 200 individuals from the catch of each fisher were measured for test diameter to the nearest millimetre.

4.2 Results

4.2.1 Population surveys

A significant decrease in the density of kina in Dusky Sound has occurred since April 1993 (Figure 3). In comparing densities among strata, the interaction between time and stratum was not significant, indicating that experimental fishing was not associated with the decline in density (Table 3). Indeed, the unfished "Control" strata showed a similar decline in kina density as the fished strata (Figure 3). Temporal variation in the density of kina from fished or unfished strata was not significant after July 1993 (Figure 3).

Kina were abundant off D'Urville Island and Arapawa Island. The mean densities of kina were similar in the two study areas (about 1 per square metre), but the mean test diameter differed greatly between the areas (76 mm for D'Urville Island, 49 mm for Arapawa Island) (Figure 4). As in Dusky Sound, the density of kina from D'Urville Island and Arapawa Island varied independently of depth ($r^2 = 0.05$, $P > 0.3$). Kina from Arapawa Island were, on average, one-third of the weight of kina sampled from D'Urville Island.

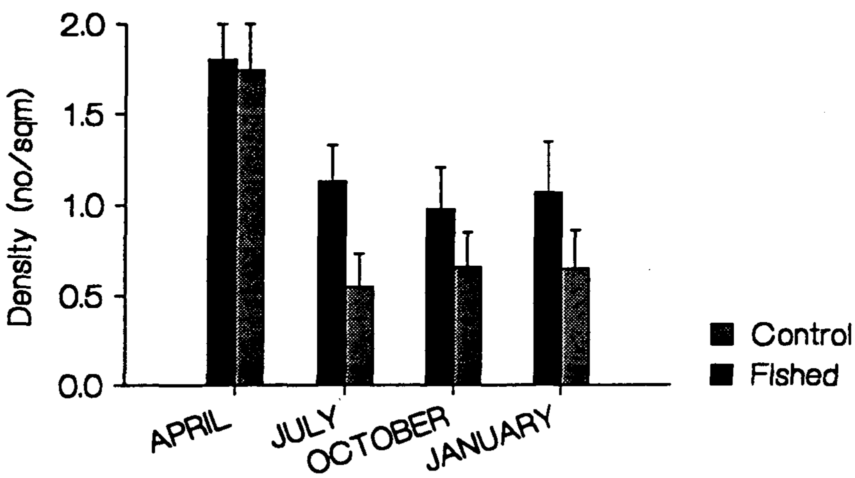

Figure 3. Seasonal variation in the density of kina in fished (stratum 1) and control (stratum 7) strata in Dusky Sound. Data are means with *s.e.*

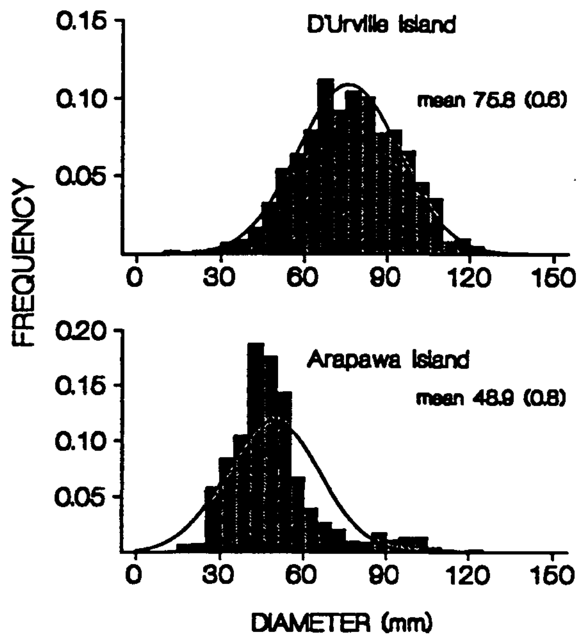

Figure 4. Comparison of the size frequency distributions of kina sampled from D'Urville Island and Arapawa Island. Means are shown with *s.e.*

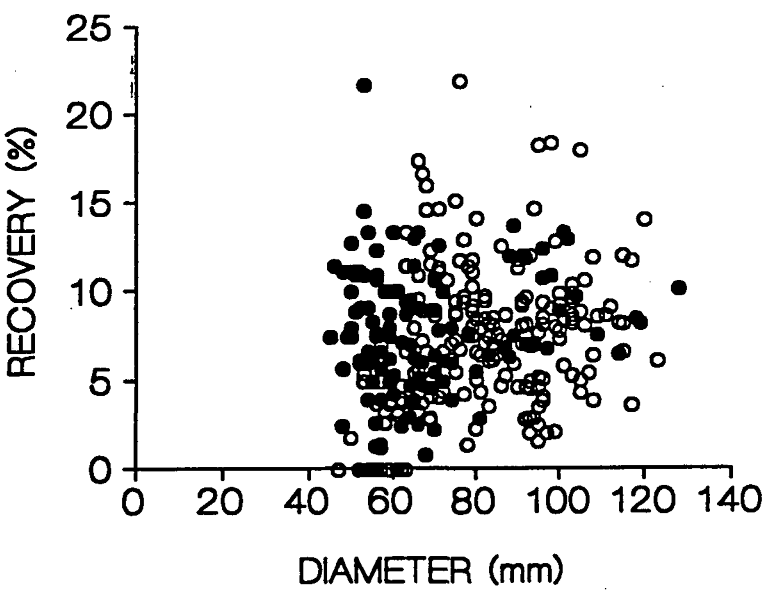

Figure 5. Variation in the recovery of roe (gonad weight as percent of total weight) with diameter of kina from D'Urville Island (open circles) and Arapawa Island (solid circles).

Table 3. Analysis of variance: kina density, Dusky Sound. Data were transformed (ln x + 1) to homogenise variances. (n.s. = not significant, * = P < 0.05, ** = P < 0.01)

Source of variation	SS	d.f.	MS	F	
Stratum	1.73	1	1.73	8.08	*
Time	4.24	3	1.41	4.40	*
Site{stratum}	3.85	18	0.21	1.83	*
Stratum x Time	0.18	3	0.06	0.19	n.s.
Time x site{stratum}	17.37	54	0.32	2.75	**
Residual	9.34	80	0.17		
Total	36.72	159			

The recovery of roe (gonad weight as percent of total weight) was similar between Arapawa Island and D'Urville Island (about 7.5%) and the colour of the roe on average was about 3 (*see* Table 2) for both areas. However, the size at first maturity evidently differed between the two areas with kina from Arapawa Island maturing at a smaller test diameter than those from D'Urville Island (Figure 5).

The surveys showed few small kina (less than 20 mm diameter) in both areas (Figure 4) a result similar to that shown for January samples of kina from Dusky Sound (Figure 6). The size distribution of kina from Dusky Sound show similar mean test diameter but differences in the modal structure among strata (Figure 6). In stratum 3, most kina are above 90 mm diameter, whereas in stratum 7 most kina were below that size.

In Dusky Sound, the gonad index followed a seasonal cycle with spawning evident during summer (significant decrease in the mean gonad index) (Figure 7). However, more recently, differences in the mean gonad index were apparent with significant differences in mean values among strata during January 1994. Off Wellington, the seasonal pattern was less distinct (Figure 8). Mean gonad indices for kina off Wellington were similar throughout 1993, but showed a sharp decrease from December 1993 to April 1994.

4.2.3 Community composition of macroalgae

In Dusky Sound, sites had similar densities of macroalgae (*Ecklonia radiata* and *Carpophyllum flexuosum*) within a stratum (by ANOVA non-significant site{stratum} effect, $P < 0.05$) and subsites were pooled for comparison of densities among strata over time (Table 4). Significant differences were shown for the density of juvenile brown seaweeds (*E. radiata* and *C. flexuosum* combined), percent cover of crustose and articulate coralline algae, and flat red seaweeds among strata. Significant temporal variation ($P < 0.05$) was shown for *C. flexuosum* and juvenile browns (Figure 9) and in the percent cover of articulate coralline (Figure 10) filamentous reds, and flat reds (Figure 11). There was obvious seasonal variation in the percent cover of annual species *Spatoglossum chapmanii*, *Asparogopsis armata*, and *Ulva lactuca* (Fig 12). The percent cover of these latter species was highest in October and January relative to the other samples, but for any month, there were no differences among strata except for *A. armata* in January 1994 which varied in percent cover among strata. The percent cover of barren ground was similar among strata and over time (*see* Figure 11). Stratum, time interactions were not significant ($P > 0.1$) except for filamentous reds.

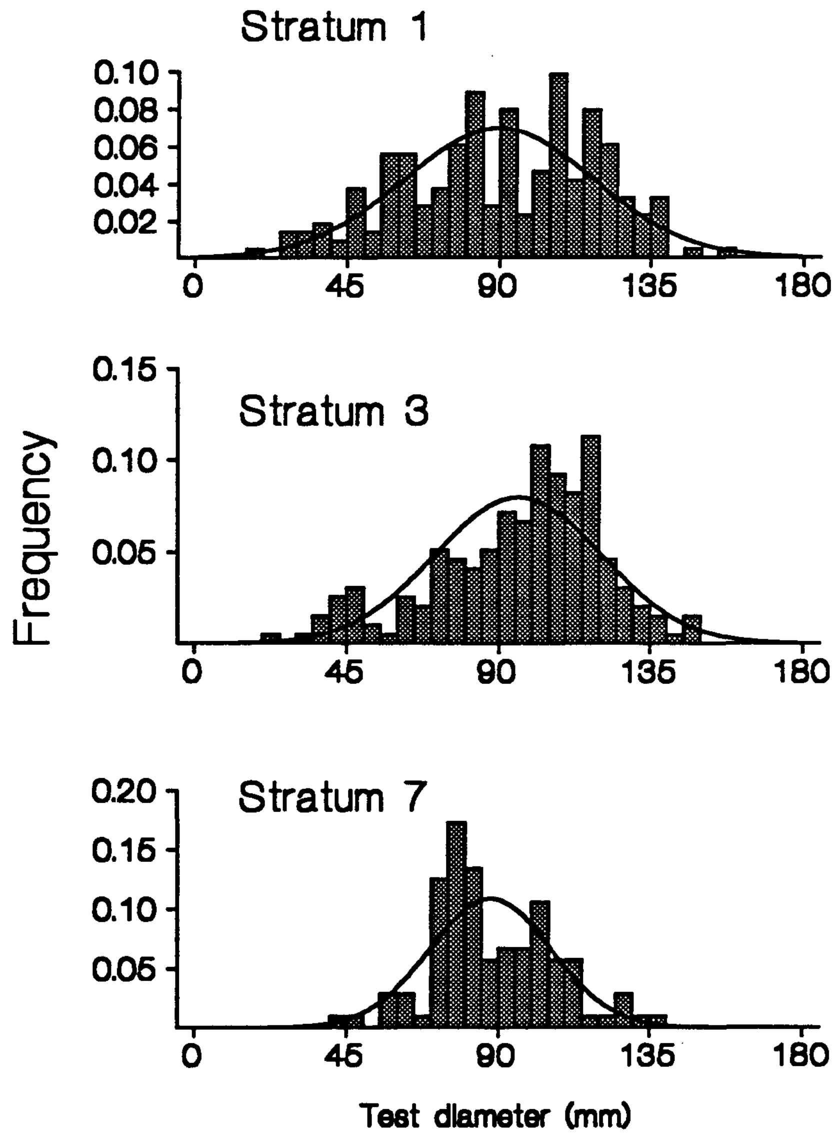

Figure 6. Comparison of the size frequency of kina sampled from three strata in Dusky Sound during January 1994.

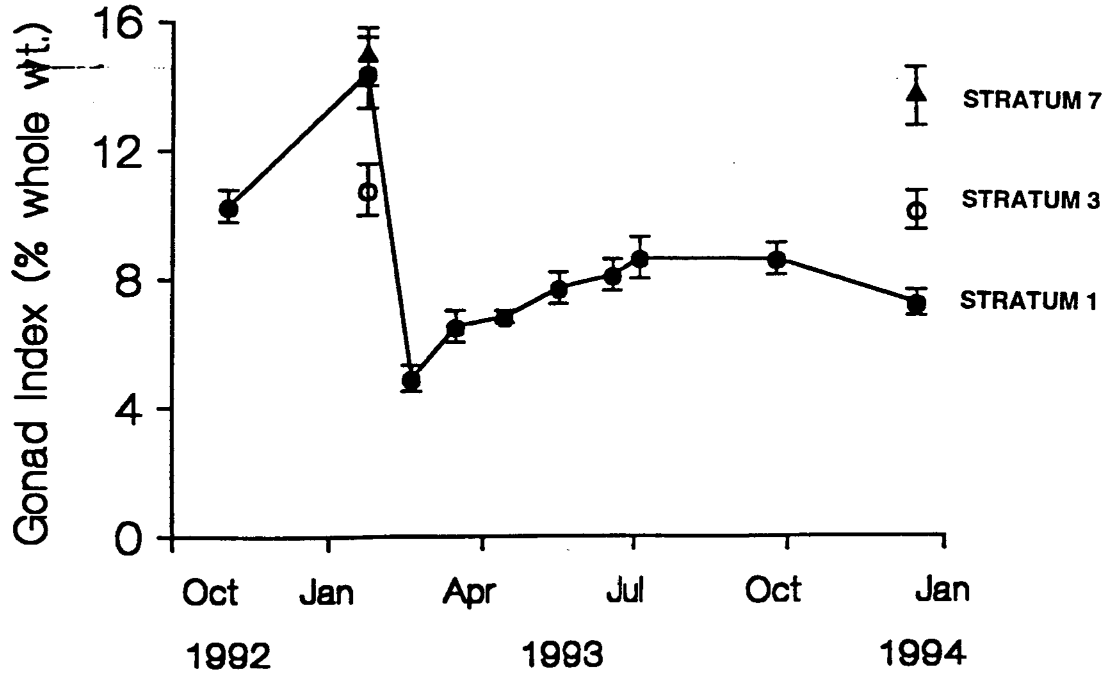

Figure 7. Seasonal variation in the gonad index of kina sampled from three strata in Dusky Sound. Most data are for stratum 1 (filled symbols). Data are means with *s.e.*

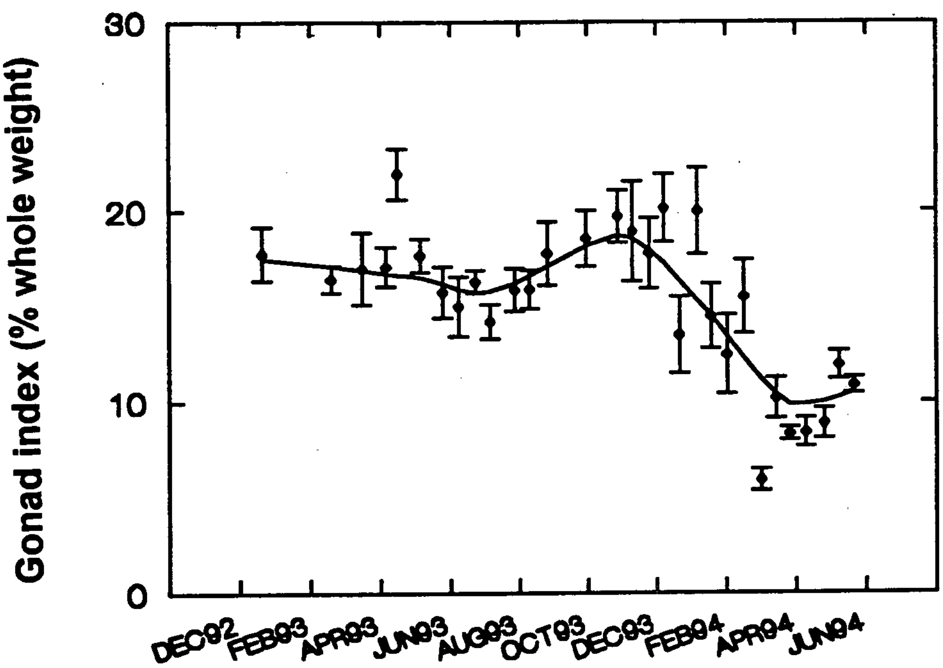

Figure 8. Seasonal variation in the gonad index of kina sampled from Wellington's south coast. Data are means with *s.e.*

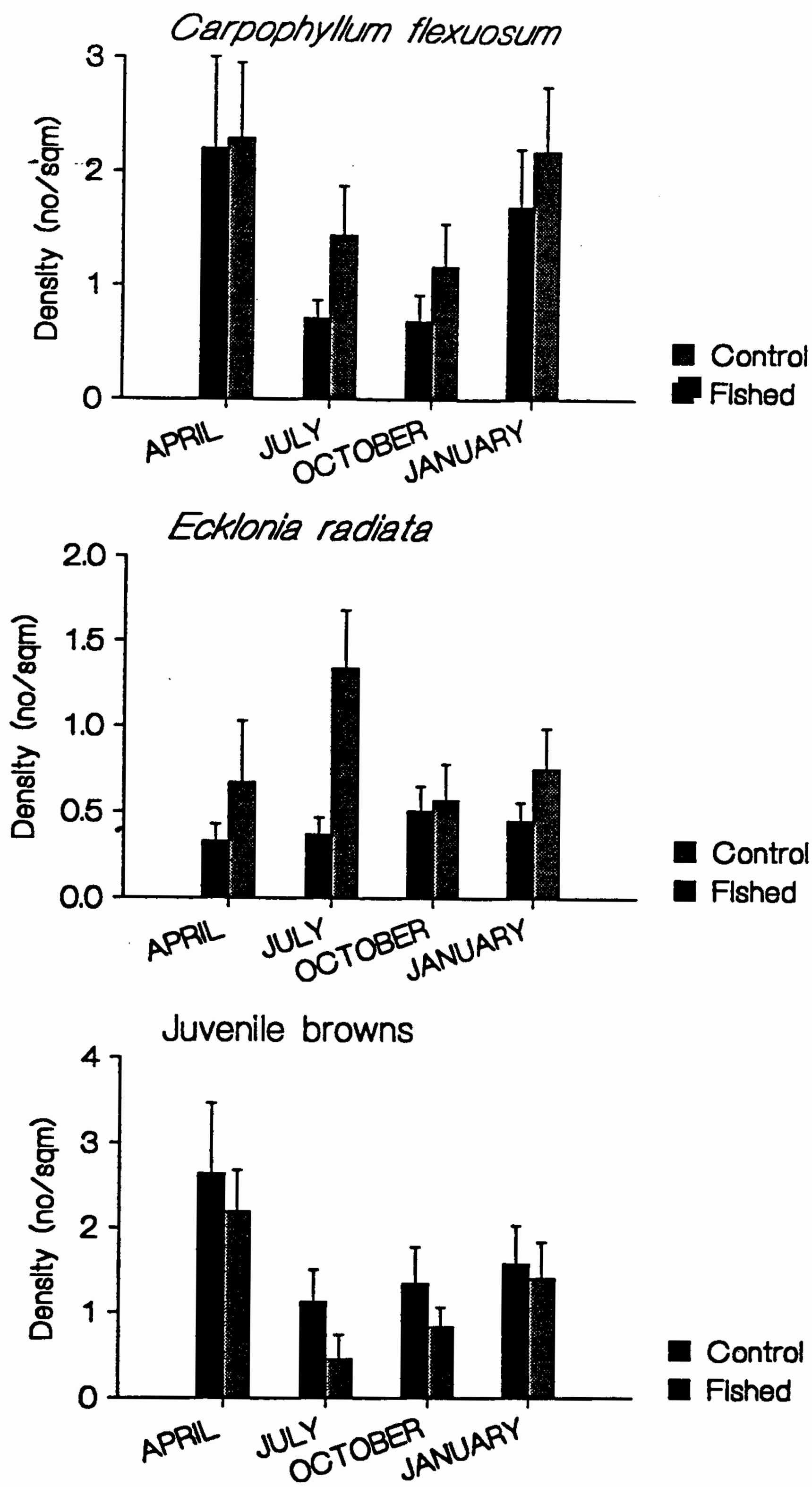

Figure 9. Seasonal variation in the density of *Carpophyllum flexuosum, Ecklonia radiata,* and juveniles of both species (combined values). Data are means with *s.e.*

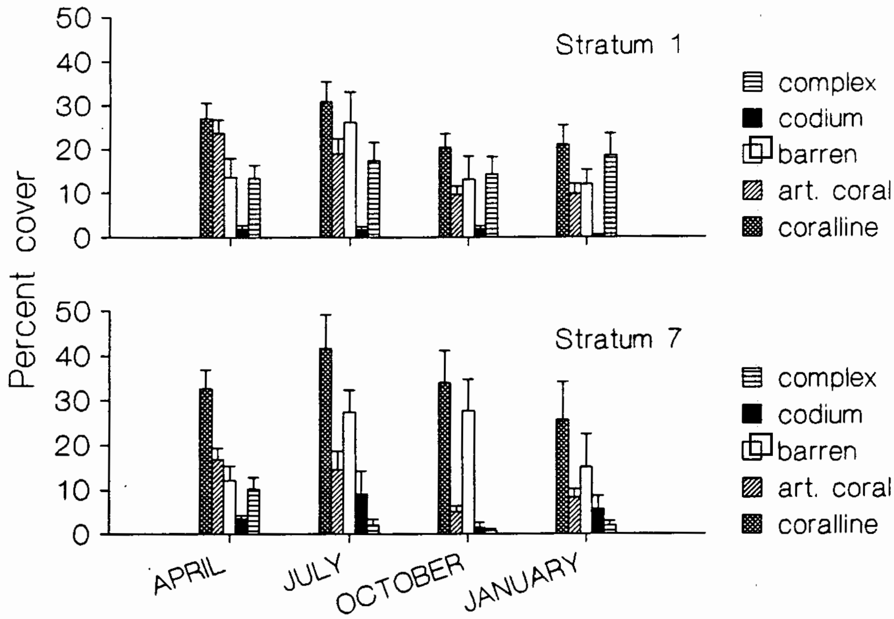

Figure 10 Seasonal variation in the percent cover of encrusting biota (complex = unidentified mixture of coralline; codium = *Codium* spp.; barren = bare substratum; art. coral = articulated coralline; coralline = crustose coralline) and barren ground among strata in Dusky Sound. Data are means with s.e

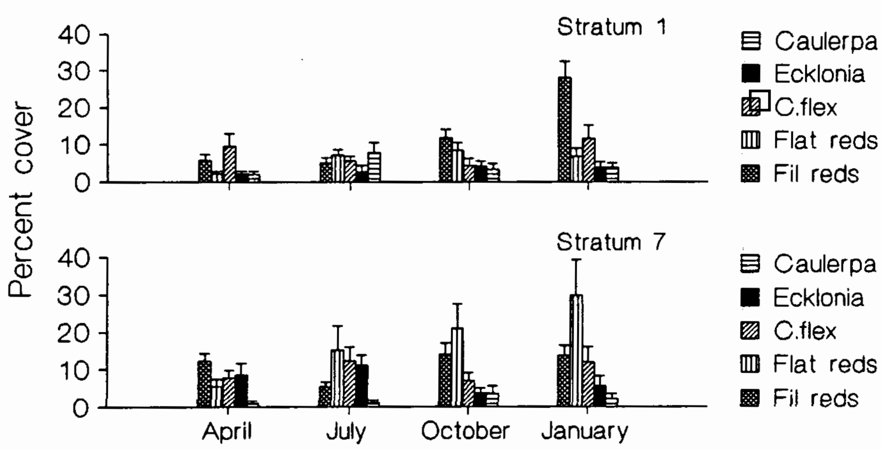

Figure 11 Seasonal variation in the percent cover of canopy forming seaweeds in Dusky Sound among strata (Caulerpa = *Caulerpa* spp.; Ecklonia = *E. radiata*; C. flex = *C. flexuosum*; Flat reds= red macroalgae with flat laminae; Fil reds = red macroalgae with filamentous laminae). Data are means with *s.e.*

Table 4 Analysis of variance of components of the subtidal communities in Dusky Sound. Factors assessed are stratum (1 and 7, d.f. = 1), time (April, July, October 1993, January 1994; d.f. = 3) and their interaction (d.f. = 3) against a residual (d.f = 152). Significance values are shown: n.s. = not significant, * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$).

Effect	Transform	Source of variation		
		Stratum	Time	Stratum x Time
Kina density	$\ln x + 1$	**	***	n.s.
C. flexuosum density	$\ln x + 1$	n.s.	*	n.s.
E. radiata density	$\ln x + 1$	n.s.	n.s.	n.s.
Density of juvenile browns	$\ln x + 1$	*	***	n.s.
Crustose coralline (% cover)	none	*	n.s.	n.s.
Articulate coralline (% cover)	$\ln x + 1$	**	***	n.s.
Filamentous reds (% cover)	$\ln x + 1$	n.s.	***	**
Flat reds (% cover)	$\ln x + 1$	**	***	n.s.
Barren ground	$\ln x + 1$	n.s.	n.s.	n.s.

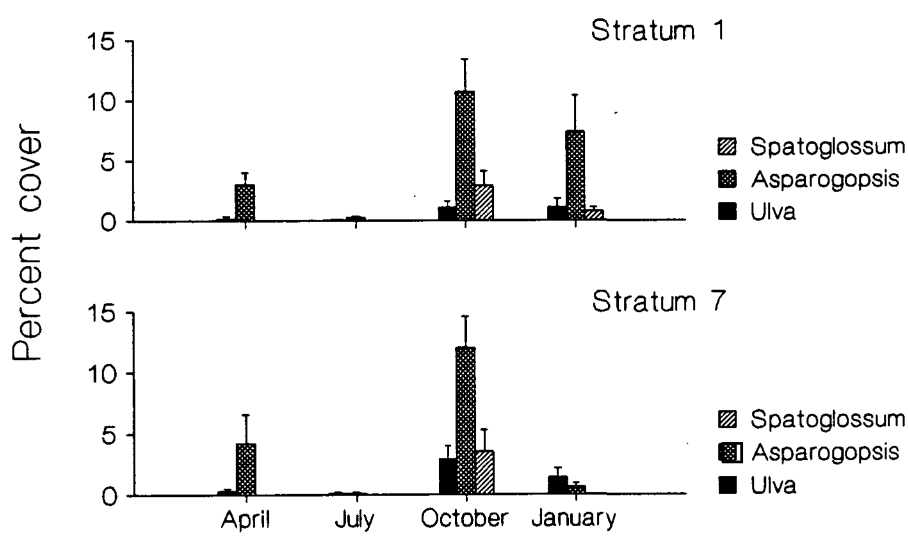

Figure 12 Seasonal variation in the percent cover of annual seaweeds, Dusky Sound (Spatoglossum = *Spatoglossum chapmanii*; Asparogopsis = *Asparogopsis armata*; Ulva = *Ulva lactuca*). Data are means with *s.e.*

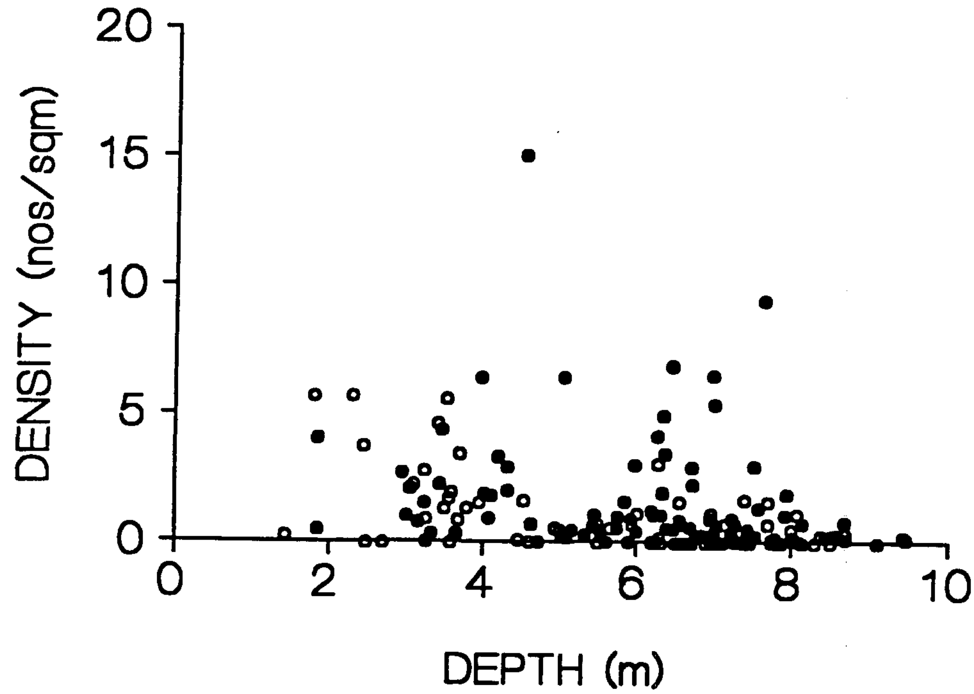

Figure 13. Comparison of the density of *Carpophyllum flexuosum* (solid symbols) and *C. maschalocarpum* (open symbols) with depth off D'Urville Island.

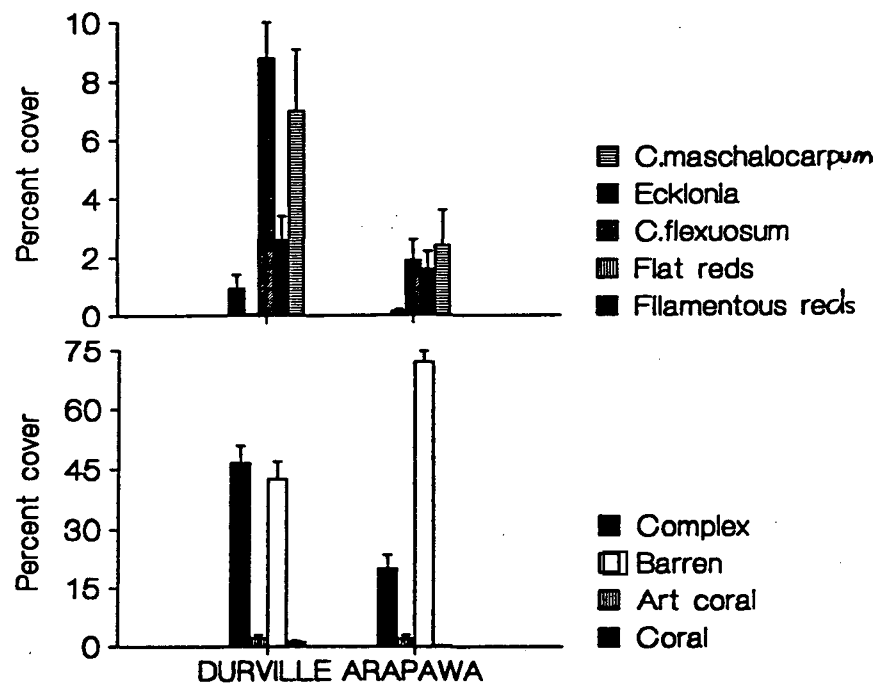

Figure 14. Comparison of the percent cover of seaweeds sampled from D'Urville Island and Arapawa Island (species names are defined except for Ecklonia = *E. radiata*; flat and filamentous reds refer to red macroalgae with flat and filamentous laminae respectively). Data are means with *s.e.*

Seaweeds were abundant off Arapawa Island and D'Urville Island but not as diverse as those from Dusky Sound. The seaweeds were dominated by *C. flexuosum* and *C. maschalocarpum* which were partitioned by depth. *C. maschalocarpum* occupied mainly shallow habitat whereas *C. flexuosum* was more dense in deep habitat (Figure 13). The percent cover of flat and filamentous reds was relatively low (Figure 14) compared with that for Dusky Sound (*see* Figure 11).

4.2.4 Reproduction

4.2.4.1 Gametogenic staging

The sequence of gametogenesis in kina appears to be very similar to that of *Heliocidaris erythrogramma* as detailed by Dix (1970). The recognisable stages are as follows:

Females

Ripe: mature ova free in acini with thin germinal epithelium containing early oocytes (Figure 15 a).
Spent: acini contain no or only relict ova. No nutritive material in germinal epithelium but early oocytes present (Figure 15 b).
Recovering: relict ova in acini showing signs of degradation; abundant eosinophilic phagocytes, early to mid-staged oocytes present in germinal epithelium (Figure 15 c).
Regenerating: progressive reduction in nutritive material with all stages in oocyte development present. No ovum degeneration visible (Figure 15 d).

Males

Ripe: active spermatogenesis still occurs with little eosinophilic nutritive material apparent. Spermatozoa fill the acini (Figure 15 e).
Spent: spermatogenesis absent or minimal with the acini empty or containing only relict spermatozoa. No nutritive material giving the cytoplasm a 'net-like' appearance (Figure 15 f).
Recovering: the acini progressively fill with eosinophilic material with few spermatozoa present and minimal spermatogenesis (Figure 15 g).
Regenerating: gradual reduction in nutritive material and progressive filling of acini as spermatogenesis continues (Figure 15 h).

All of the above stages have been identified in the Dusky Sound samples taken so far, though few spent individuals of either sex have been collected.

In both sexes it was difficult to distinguish between ripe and spent as partial spawning occurs giving rise to sections in which some acini contain gametes which are obviously ripe while others are obviously spent. Similarly with gonads which were in the recovering and regenerating phases. As development is a continuous process, it is sometimes difficult to stage the animals confidently. In addition to the four stages listed above, a further two stages were recognised in the samples from Dusky Sound. The first occurred in very small animals which could not be sexed reliably as the gonad was not developed sufficiently. These were termed 'undeveloped'. The other stage was termed 'immature' where the sex could be determined but mature gametes had not yet been produced.

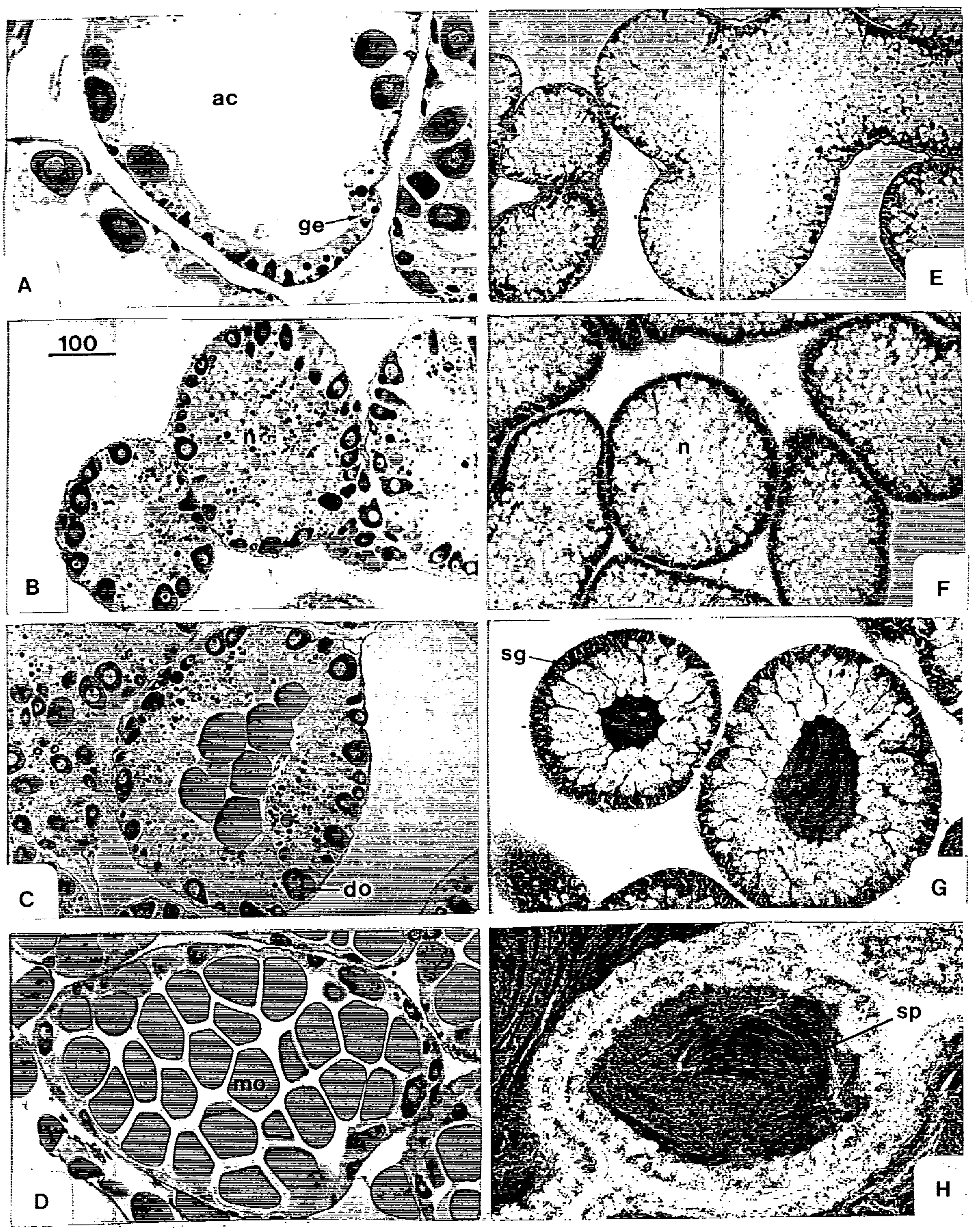

Figure 15. Histological sections of the gonads from female (a–d), and male (e–h) kina. a) spent female showing acini (ac) empty and oocytes in various stages of development in the germinal epithelium (ge), b) recovering stage showing abundant nutritive material (n) in the acini, c) regenerating stage showing developing oocytes (do) in the germinal epithelium and mature ova in the acinus, d) ripe stage with acinus full of mature ova (mo) and little nutritive material, e) spent male showing open net-like acini with little nutritive material and minimal spermatogenesis, f) recovering stage showing buildup of nutritive material in the acinus, and spermatogenesis starting, g) regenerating stage showing active spermatogenesis (sg) and buildup of sperm mass (sp) in the acinus, h) ripe stage with acinus full of mature sperm. Scale is indicated (100 μm).

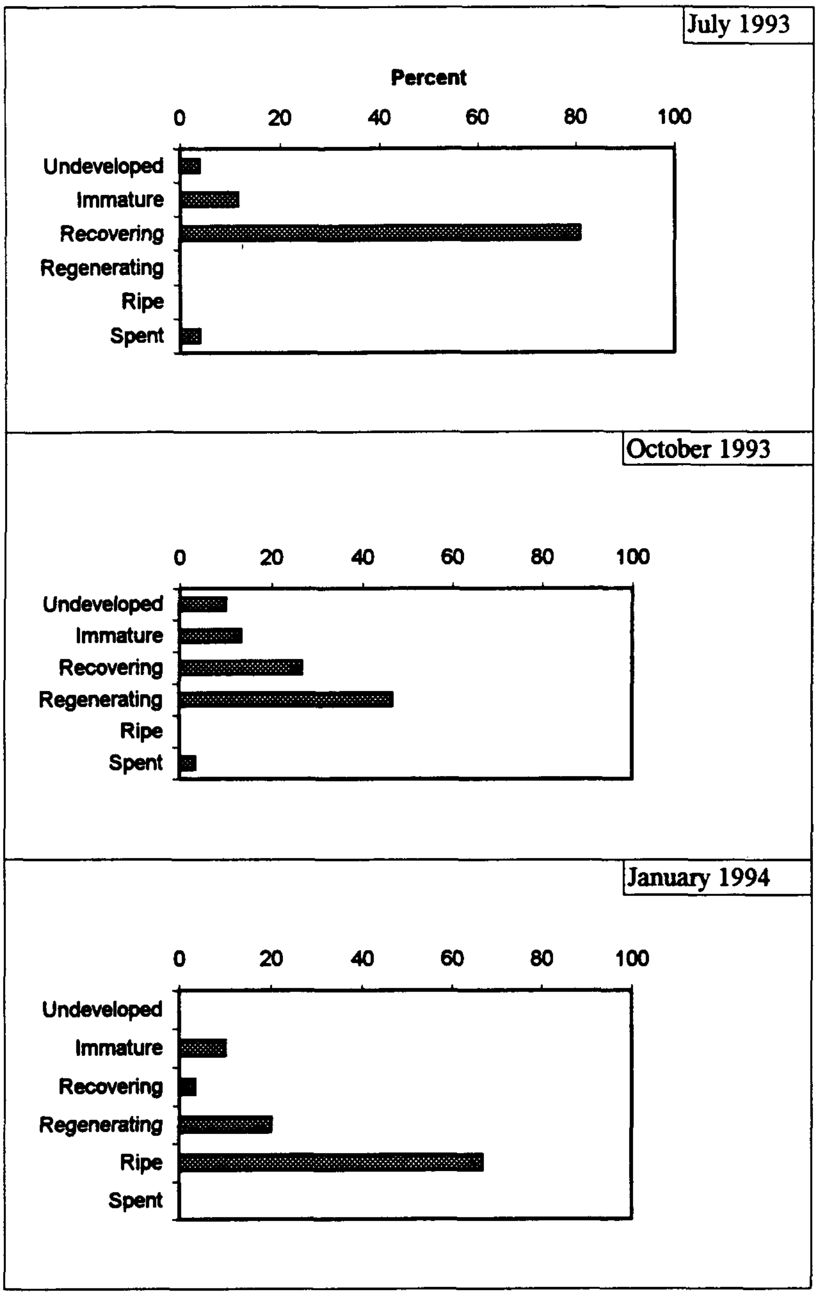

Figure 16. Seasonal variation in the stage of gonad development, Dusky Sound kina. Data are shown as percent of the total sample for both sexes combined (n).

Figure 16 shows a clear progression in gonad development. Of the kina sampled in July 1993, 81% were in the recovering stage and about 4% were spent. None were in the ripe or regenerating phases. In the October sample, almost half were regenerating while almost a third were in recovery and about 3% had recently spawned. In January 1994, two-thirds of the kina were ripe with only 20% still in the regenerating phase. It would appear that the major spawning event, at least for the 1993–94 season, will occur in late summer. Table 5 shows the percent frequencies of the mature kina in each developmental stage from each of the two samples sorted by sex. There were some differences between sexes in the gametogenic cycle. For example, in October, all male kina were regenerating whereas most females were recovering from spawning. However, the sample sizes were small and only three times have been considered.

Table 5. Percent frequencies of *Evechinus chloroticus* in each of the different stages of development by sex for samples taken in July and October 1993 and January 1994 from Stratum 1 in Dusky Sound. n, sample size.

	July, 1993		October, 1993		January, 1994	
Stage	Male	Female	Male	Female	Male	Female
Recovering	90.9	100.0	0.0	63.6	0.0	10.0
Regenerating	0.0	0.0	100.0	27.3	29.4	10.0
Ripe	0.0	0.0	0.0	0.0	70.6	80.0
Spent	9.1	0.0	0.0	9.1	0.0	0.0
n	11	11	11	11	18	12

When the percentages of kina within each of the five size classes are compared (Table 6), the smallest size class (less than 70 mm) was dominated by undeveloped and immature animals in both July and October. The same size class in January 1994 was dominated by animals in the regenerating phase with one being ripe. These kina are probably entering their first breeding season. For all the remaining size classes except those in the 130 mm + group, the July sample comprised animals in stage 2 (recovering). There was one kina in the 130 mm + group which had recently spawned and was in stage 5 (spent). By October these animals had developed further and were either recovering or regenerating. By January 1994 almost all kina in the four larger size classes were ripe. In all size classes there was a progressive development of gametes through time with no evidence of senescence in the larger kina.

Table 6. Percentages of kina in the different stages of gonad development grouped according to size class, sexes combined, n = 10. Stages are as follows: 0 = immature, 1 = undeveloped, 2 = recovering, 3 = regenerating, 4 = ripe, 5 = spent. Kina were collected from Dusky Sound during July and October 1993 and January 1994

	Size Class (mm)														
	< 70			70–90			90–110			110–130			> 130		
Stage	Jul	Oct	Jan	Jul	Oct	Jan	Jul	Oct	Jan	Jul	Oct	Jan	Jul	Oct	Jan
0	25	33	0	0	0	0	0	0	0	0	0	0	0	0	0
1	75	50	33	0	38	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	14	100	67	0	100	43	0	86	33	0
3	0	17	56	100	63	14	0	33	0	0	43	0	0	67	0
4	0	0	11	0	0	71	0	0	100	0	0	100	0	0	100
5	0	0	0	0	0	0	0	0	0	0	13	0	14	0	0

4.2.4.2 Size at Maturity

The smallest kina in which sex could be determined was a female taken in the July sample (53 mm test diameter). One male had recently spawned at a test diameter of 56 mm. The smallest mature female encountered was 67 mm test diameter.

4.2.4.3 Oocyte size-frequencies

Mean oocyte diameters for kina from various size classes are shown in Figure 17. Means $\pm$ *s.e.* ranged from 27.9 ± 0.6 µm to 59.1 ± 1.0 µm. Examination of the residuals showed that the error values were highly correlated with the means and the oocyte measurements were therefore log transformed. Values identified as outliers (SYSTAT, Wilkinson 1990) were removed and a significant difference in the log of oocyte diameter with size class was found ($F_{4, 1958} = 226.7$, $P < 0.001$). A post-hoc Tukey test found significant differences ($P < 0.05$) between all size classes except the two largest (110–130 and 130+ mm).

The regression of oocyte size on test diameter was shown to be significant (ANOVA slopes different from zero, $P < 0.001$).

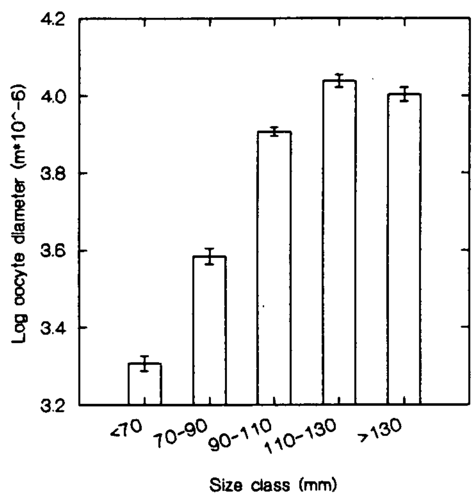

Figure 17. Plot of log oocyte diameter (µm) against size class (mm) for the kina sampled in July. Error bars indicate 1 standard error

4.2.4.4 Oocyte density

There was a significant difference among individuals from the July sample in the number of oocytes per square millimetre of tubule wall: means $\pm$ *s.e.* ranged from 192.4 ± 13.1 to 549.7 ± 41.4 ($F_{10, 98} = 9.13$, $P < 0.001$, Figure 18). Kina with test diameters of 65, 78, 121, and 133 mm had significantly higher numbers of oocytes per square millimetre than those with diameters of 62, 90, 95, 105, 107, 133 or 157 mm.

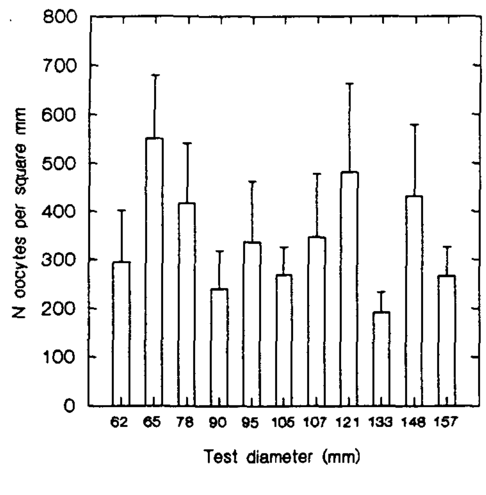

Figure 18. Mean number of oocytes per square millimetre of gonad wall for individual kina taken from Dusky Sound in July 1993. Error bars indicate +/- 1 standard deviation

When the individuals were grouped into size classes (Figure 19), the 90–110 and >130 mm size classes had significantly less oocytes per square millimetre of oocyte wall than the < 70 and the 110–130mm size classes. Means ± standard error ranged from 291.5 ± 24.9 to 481.2 ± 57.

4.2.4.5 Sex ratio

Chi-square tests indicated that there were equal numbers of males and females in samples taken in July 1993 (n = 25), October 1993 (n = 28), and January 1994 (n =118).

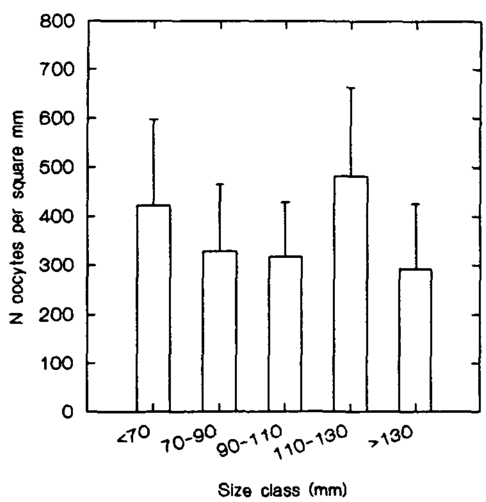

Figure 19. The mean number of oocytes per square millimetre of gonad wall for kina grouped by size class taken from Dusky Sound in July 1993. Error bars indicate ± 1 standard error

4.2.4.6 Fertilisation success

Only one pair of kina failed to produce any fertilised zygotes and these data were ignored in the following analyses. Mean fertilisation rates within the four size classes ranged from 57 to almost 69% (Figure 20). Analysis of variance showed no significant differences in fertilisation rates between the different size classes ($F_{3,17} = 1.05$, $P > 0.4$), though there is some suggestion that the rates for larger animals are slightly lower and more variable than the others.

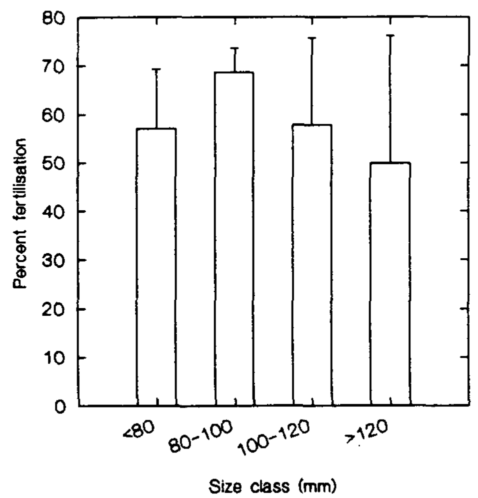

Figure 20 Percent fertilisation rates for kina in four size classes taken from Dusky Sound, January 1994

4.3 Growth and survival

In January 1994, 35 individuals were taken from sites where kina were marked with tetracycline. Most of the kina (78 and 94% from sites 1 and 2, respectively) had jaws which were marked. Some of the larger kina (> 100 mm diameter) which had been marked showed a fluorescing line at the epiphysis of the jaws, or, if present, the fluorescence was faint and on the very edge. Of the kina that showed no fluorescence, most (95%) were over 100 mm test diameter, and few kina over this size have been found with a measurable growth increment. This result may be an indication of the greater mobility of the larger kina which move in and out of the study areas.

Incremental growth of jaws marked with tetracycline was converted to test diameter. A non-linear logistic function provided the best fit to the relationship of jaw length to test diameter (Figure 21). The relationship showed an inflection point about the size at first maturity (McShane *et al.* 1993a). Thus the jaw length (J) can be converted to test diameter (T) by the following:

$J = \alpha/(1 + \beta \exp(-kT))$

$\alpha = 25.54$

$\beta = 7.795$

$k = 0.029$

Because of the small sample sizes, growth increment data from the two sites used in mark-recapture studies were combined. The von Bertalanffy parameters D_∞ and k were estimated to be 117.6 and 0.27 per year respectively. The model seemed to fit the data well (Figure 22) and no trends could be detected in the model residuals. However, due to the small data set and the small size of the increments, this is regarded as a preliminary estimate of growth.

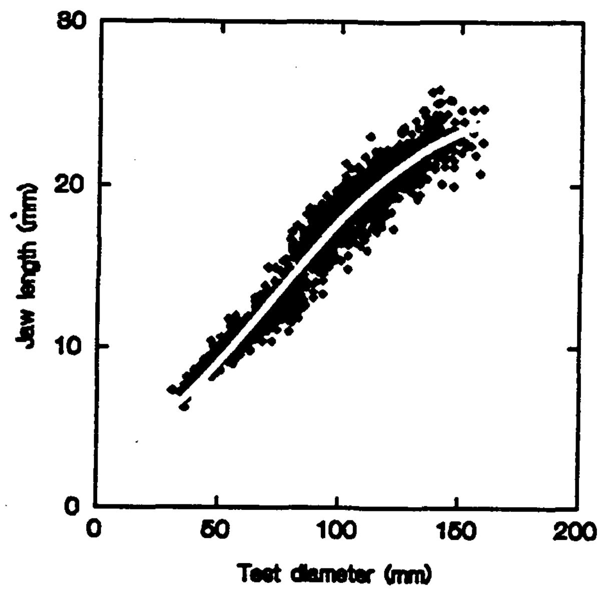

Figure 21. Relationship of jaw length to test diameter. A logistic function has been fitted to the data (see text for details).

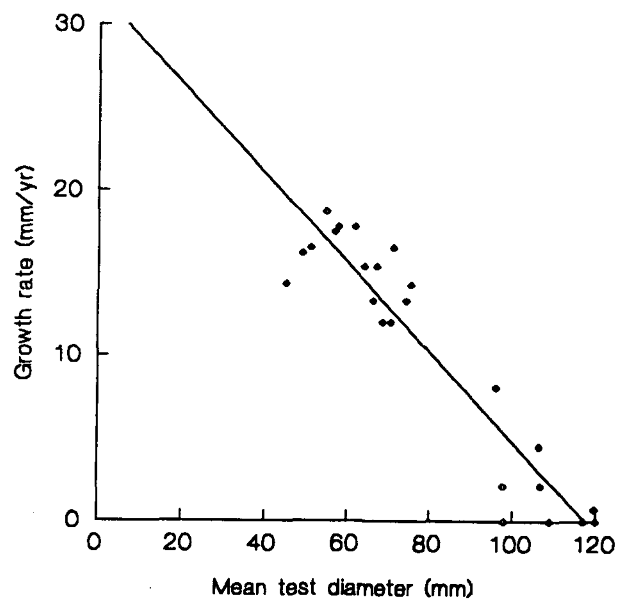

Figure 22 Relationship of growth rate to test diameter showing the fitted growth equation from GROTAG.

Some additional estimates of growth of kina in Dusky Sound have been made by analysis of size frequency data. Using MIX, modes were identified and followed from October 1993 to January 1994 in strata 1,3,7, and 8, and at a separate location "Fixed Head" in stratum 8. By plotting the growth rate for each mode against the mean test diameter (Final mode TD minus Initial mode TD / 2) another estimate of the growth of kina can be made (Figure 23). From the regression of growth rate on test diameter, the von Bertalanffy constants were derived from the results of the modal analysis (Ricker 1975) as K = 0.19, *s.e.* = 0.10, D_∞ = 154 mm.

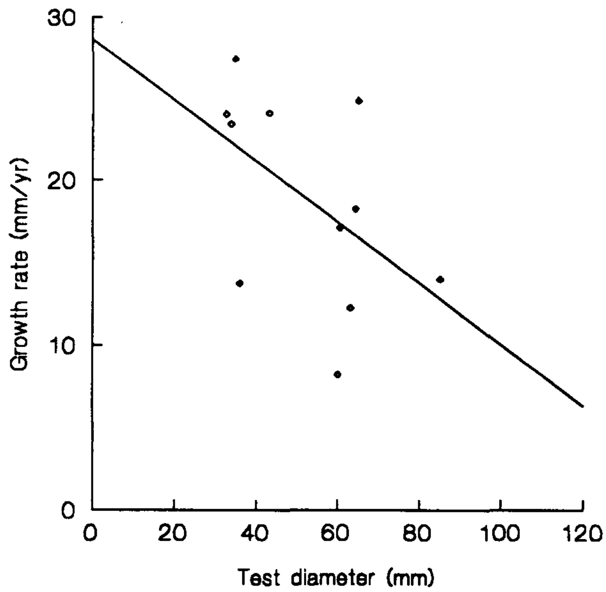

Figure 23. Least squares fitted line for growth rate of kina from MIX analysis of size modes. Each data point represents the growth rate determined from tracking the growth of a single mode.

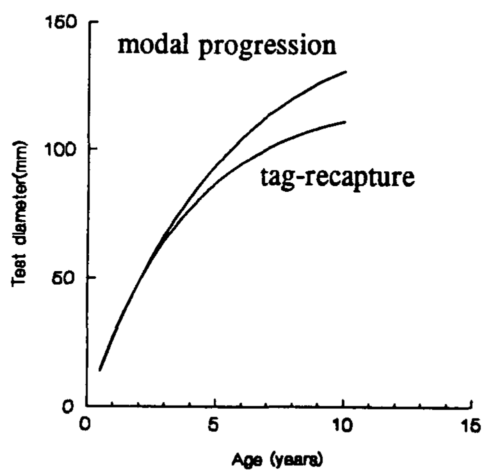

Figure 24 von Bertalanffy growth function fitted to data from tetracycline tagging and from modal progression analysis.

The lengths at age estimated from tagging and modal analysis are different (Figure 24). The maximum test diameter estimated from modal analysis is more consistent with the size distribution of kina than that estimate from tagging.

A second model was fitted to the mark-recapture data. The Tanaka function (Figure 25), (Tanaka 1982, 1988), is a more complex, four parameter model which describes growth slightly differently by allowing continual growth more appropriate for sea urchins (Ebert & Russell 1993). The model incorporates initial slow growth followed by an exponential phase and then a long period of very slow but constant growth.

$$D_t = \frac{1}{\sqrt{f}} \ln \left| 2f(t-c) + 2\sqrt{f^2(t-c)^2 + fa} \right| + d$$

Where D_t is test diameter at age t, t is age, and f, a, d, and c are growth parameters.

$$c = a/E \quad \text{and} \quad E = \exp\left(\sqrt{f}(D_0 - d)\right) \text{ where } D_0 = \text{test diameter at } t = 0$$

Parameters a, d, and f were estimated using non-linear regression (SYSTAT, Wilkinson 1990). Growth rate is shown to increase to a maximum at about 60 mm test diameter and then decrease slowly, possibly accompanying the onset of reproductive maturity.

There are reports of exponential and continuous growth in other sea urchins, e.g. Rowley (1990). Ebert & Russell (1993) used the Tanaka model to describe growth in *Strongylocentrotus franciscanus*. At this stage it is not clear which model kina growth follows most closely as the parameter estimates are based on only a few data points. More information on the growth of very small and very large kina will help to resolve this.

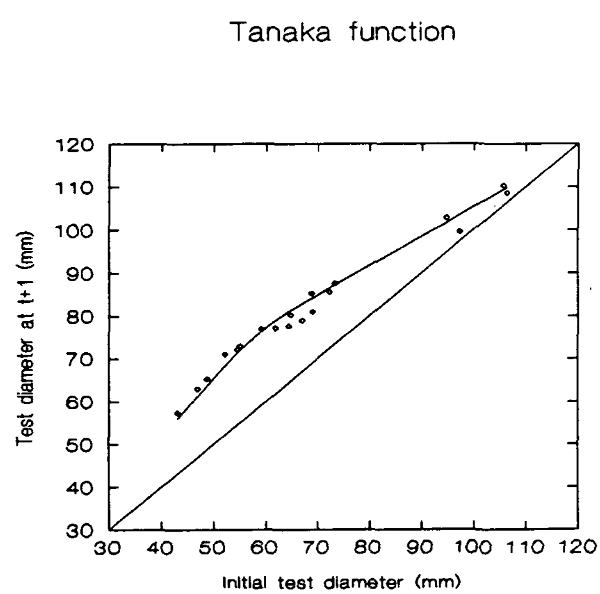

Figure 25. Tanaka ALOG model fitted to Dusky Sound tag data. The straight line at 45° represents zero growth.

Estimates of natural mortality were made separately using estimates of growth derived from sequential length frequency analyses and tag recapture studies. Most fits of the natural log of estimated year class numbers versus age were good (r^2 about 0.9). Estimates of M (means $\pm$ 95% confidence intervals) were 0.39 $\pm$ 0.03 per year for sequential length frequency analysis, and 0.26 $\pm$ 0.02 per year for tag recapture studies.

4.4 Fishery development

The spatial development of the fishery in Dusky Sound is shown in Figure 26. Exploratory fishing is evident from the fishing of areas remote from Anchor Island as the fishery progressed. For example, in July to September 1993, some catches were taken along the Five Fingers peninsula, an exposed coast. The highest catch came from Stratum 1 (Figure 27), but catch per unit effort was similar between strata (about 200 kg/h). Total catches peaked in May after the start of fishing and declined thereafter (Figure 28). Catches ceased after November 1993 because of poor market demand accompanying the prevalence of a bitter taste in the roe of Dusky Sound kina.

In Dusky Sound the fishery targetted a size range of kina (80–120 mm test diameter) in relation to the available kina (Figure 29).

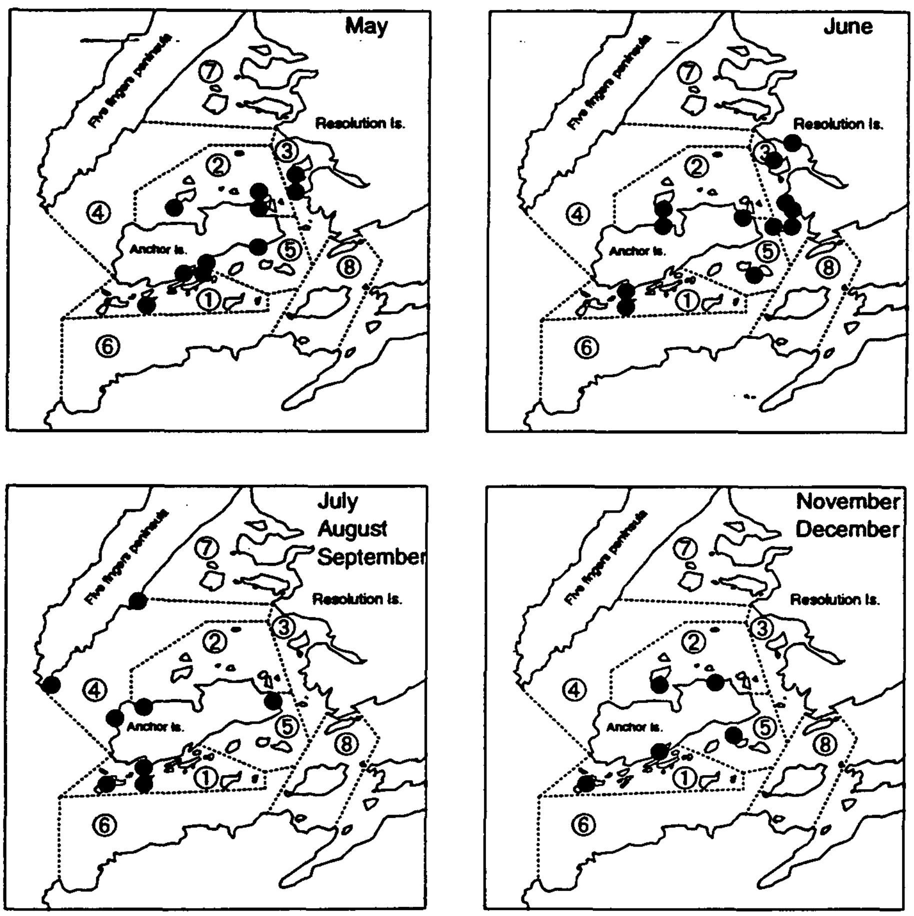

Figure 26. Development of fishing for kina in Dusky Sound. Monthly location of fishing activities is shown as filled circles relative to the sample strata in Dusky Sound.

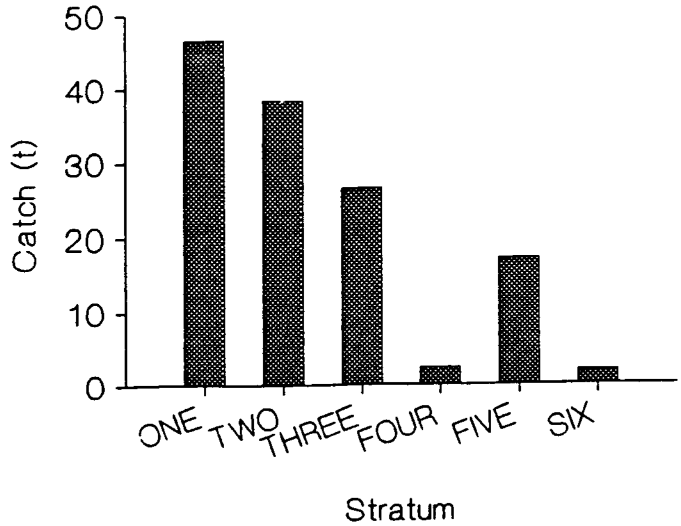

Figure 27. Total catch of kina by stratum in Dusky Sound.

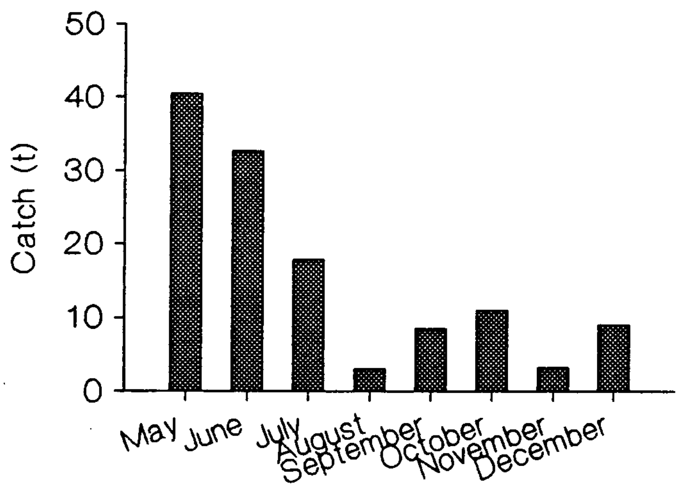

Figure 28. Catch of kina in Dusky Sound by month.

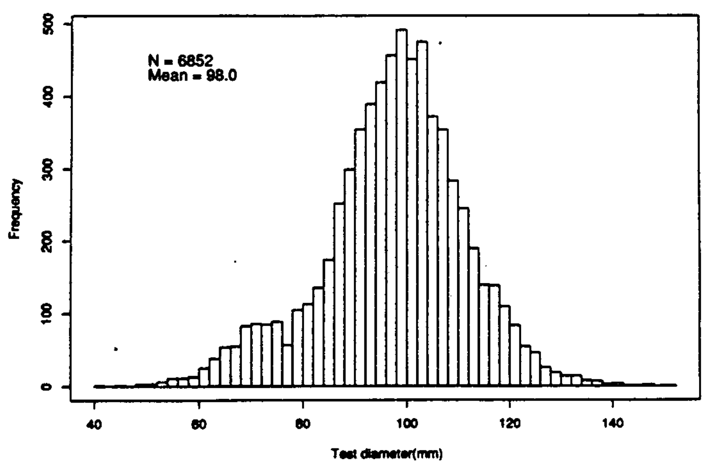

Figure 29. Size composition of the catch of kina from Dusky Sound.

5. DISCUSSION

The harvest of about 130 t of kina from Dusky Sound has been insufficient to cause a measurable change in the density of kina or in the composition of seaweeds. The fishery has not developed to the target of 1000 t per year because of poor market demand due to a bitter taste in the roe which has become prevalent, possibly due to ingestion of a microalga (Parry *et al.* 1989, McShane et al. 1994b). Nonetheless, estimates of biological parameters have been derived for Dusky Sound kina.

The composition of seaweeds varies spatially and temporally in Dusky Sound. Seasonal variation includes the change in abundance of annual species and recruitment of other seaweeds such as *C. flexuosum* and *E. radiata*, the dominant brown macroalgae. Survey results for the main taxa (crustose and articulate coralline, *C. flexuosum*, *E. radiata*, and flat reds) may be considered as prefishing estimates for future comparison once major fishing starts. At the level of replication applied so far, the results for these taxa represent a powerful basis for testing hypotheses of fishing-induced changes.

In the absence of significant fishing, the main results from our studies relate to the general biology of kina. Considerable variation has been shown in the reproductive cycle from interannual and spatial variation in the gonad and from histological examination. Further evidence of wider scale spatial variability in reproduction is evident from the results from Arapawa Island and D'Urville Island and off Wellington's south coast.

Such variation in reproduction could result in variation in recruitment. Recruitment processes are poorly understood for kina, but spatial variation in the number of small kina indicative of recent settlement was shown in Dusky Sound (*see* also McShane *et al.* 1993 a). In measuring recruitment as the density of small kina, mortality and migration acting at earlier stages of the life history of kina may obscure the relationship between reproduction and recruitment. Further research, using settlement collectors at various locations in Dusky Sound, will provide greater insight into settlement processes and provide a more robust correlation between reproduction, settlement, and recruitment.

The relative fecundity of kina declines with size. However, studies of fertilisation rates revealed that gametes from large kina were viable; there was no significant difference in fertilisation rates with size. Kina from the other locations (Arapawa Island and D'Urville Island) were generally smaller than those from Dusky Sound, possibly because of differences in their growth characteristics. The observation of poor quality roe from large kina (dark colour, coarse texture) pertains mainly to Dusky Sound kina. In Dusky Sound, as shown by the fishing so far, large kina are unlikely to be harvested and therefore could provide a residual breeding stock. It is likely that in reaching a large size, such kina require considerable energy in maintenance (Black *et al.* 1982, Ebert 1982, Levitan 1988, Edwards & Ebert 1991). Density dependent growth, reduced by fishing, could be negated by retaining a stock of large individuals. However, little is known of compensatory growth processes in kina or of the comparative energy requirements of small and large individuals. Further studies , accompanying further experimental fishing, will address these processes in more detail.

Preliminary estimates of growth in Dusky Sound are consistent with estimates for kina elsewhere (e.g., Dix 1972). The information presented here will provide a basis for comparison when fishing reaches the prescribed level, but more information is required on sources of variation in growth. For instance, it is likely that the growth rate of kina varies over small distances according to factors such as relative exposure and food availability. Further growth studies will be examining such sources of variation in the growth of kina.

5. IMPLICATIONS FOR MANAGEMENT

The availability of roe from any kina fishery varies seasonally and spatially. Such variation should be considered in managing any kina fishery. Regional variation in roe quality and quantity is considerable and it is likely that kina stocks are much smaller than the present management area boundaries.

It is not yet possible to estimate sustainable harvest levels of the populations of kina considered in this assessment. Estimates of growth and survival are only preliminary and more reliable values will emerge from continuing studies. Such estimates will be used to develop yield per recruit models which will provide information to assess possible size limits. At present, few large kina are harvested because they do not have roe of market quality. Strategies which result in the retention of large kina could provide for a residual breeding stock and obviate the need for size limits.

The experimental fishery planned for Dusky Sound has not achieved its projected catch because of the prevalence of poor quality roe. This may or may not be a permanent limitation to future development. The problems confronting development of a fishery in one area emphasize the need to consider management over smaller areas than of the present management areas.

6. ACKNOWLEDGMENTS

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