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Stock assessment of cockles on Snake Bank, Whangarei Harbour, 1999

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EXECUTIVE SUMMARY

Morrison, M. 2000: Stock assessment of cockles on Snake Bank, Whangarei Harbour, 1999. ***New Zealand Fisheries Assessment Report 2000/26.*** **13 p.**

To assess potential current available yield (CAY) from the Snake Bank cockle fishery, a stratified random biomass survey was undertaken in May 1999. Historical data from previous surveys were used to divide Snake Bank into appropriate density strata. A recruited biomass estimate of 1321 t (based on cockles less than 30 mm) was derived, with a coefficient of variation of 14%. Using $F_{0.1}$ and F_{max} values determined previously for this fishery (0.41 and 0.62 respectively), and with M = 0.30, estimates of constant annual yield (CAY) were 388 t ($F_{0.1}$) and 535 t (F_{max}). Estimates of maximum constant yield (MCY) were 196 t ($F_{0.1}$) and 296 t (F_{max}), and remain unchanged from the 1996 assessment.

A brief tidal height survey was also carried out on Snake Bank to define the boundaries of the bank better, and to allow for examination of possible effects of tidal height on abundance and average size. Year, tidal elevation, and density all exerted interactive effects on average cockle size. However, cockle densities were unaffected by year or tidal elevation.

1. INTRODUCTION

1.1 Overview

There has been a commercial fishery for cockles on Snake Bank since at least the early 1970s, though reported landings before 1982 were small. Reported landings increased from about 150 t to 450 t between 1982 and 1991, and have remained around this level since. Recruited (greater than 30 mm) biomass fell by about two-thirds between 1982 and 1991, to about one-third of probable virgin level. The proportion of very large (greater than 35 mm) cockles decreased to less than 10% of the likely virgin level.

Both growth rate and recruitment of cockles appear to have increased during this time, although recruitment has been variable (σ_R = 0.31) since the fishery has been considered to be fully developed (Cryer 1997). Estimates of $F_{0.1}$ and F_{max} were made in 1996 (Cryer 1997) and 1998 (Morrison & Cryer 1998) using a quarterly yield per recruit (YPR) model based on critical sizes rather than assumed rates of vulnerability by age. Using these reference fishing mortalities and estimates of abundance from surveys, current yield estimates were MCY = 200–300 t and CAY = 388–535 t (1998 survey data), which in general are less than recent average landings (500 t).

The Ministry of Fisheries is considering new controls to ensure the sustainable use of this fishery. Given the recruitment variability and rapid growth of cockles in this fishery, a management strategy based on CAY is likely to be favoured. Such an approach requires frequent (preferably annual) estimates of biomass. This document reports the most recent biomass survey for Snake Bank (April 1999). The specific objective for this project was;

"To estimate the absolute biomass and Current Annual Yield (CAY) for cockles on Snake Bank during the 1998/99 fishing year. The target coefficient of variation (*c.v.*) of the estimate of absolute recruited biomass is 20 %."

1.2 Description of the fishery

Commercial picking on Snake Bank in Whangarei Harbour began in the early 1980s and is undertaken year round, with no particular seasonality. Catch statistics are unreliable before 1986, although 165 t of Snake Bank cockles were exported to the United States in 1982 (Martin 1984). There was probably some under-reporting of landings before 1986, and this may have continued since. There are eight permit holders, each allowed a maximum of 200 kg (greenweight) per day by hand-gathering. If all permit holders took their quota every day, a maximum of 584 t could be taken in a 365 day year. Landings increased rapidly from less than 200 t before the 1988–89 fishing year to exceed 90% of the theoretical maximum in all years since 1991–92, other than 1992–93 when the fishery was closed during the summer because of high levels ofbiotoxins.

1.3 Literature review

Cryer (1997) summarised information on cockles in New Zealand, and no new information has become available since.

2. REVIEW OF THE FISHERY

2.1 Catch limits and landings

Reported landings for Snake Bank from Licensed Fish Receiver Returns (LFRRs) are shown in Table 1. Reported landings before 1986–87 were less than 50 t (J. Holdsworth, pers. comm., ex-technical offer, MAF), but the fishery (anecdotally) supported up to six full-time pickers in some years, suggesting that there was probably some under-reporting of landings. Effort and catch information for this fishery has not been adequately reported in the past, and there are problems interpreting the information that is available. Landed weights reported on Catch Effort and Landing Returns (CELRs) summed to only 50–90% of weights reported on LFRRs during 1989–90 to 1992–93, although more recent data match more closely. In addition, reported landing weights are based on an assumed sack weight of 28 kg, whereas actual measured weights are closer to 30 kg. Landings are therefore estimated using LFRRs where these are available.

Table 1: Reported landings (t, greenweight) from Licensed Fish Receiver Returns for the Snake Bank cockle fishery. The Snake Bank fishery has, since its inception, been limited by a daily limit of 200 kg per permit which equates to an annual aggregate catch of 584 t in a 365 day year (586 t in a leap year). *, landings in 1992–93 constrained by an extended closure due to biotoxin contamination, **, the estimated landings of 566 t in 1993–94 may be unreliable

Fishing Year	Landings (t)	Sum of daily limits (t)
1986–87	114	584
1987–88	128	586
1988–89	255	584
1989–90	426	584
1990–91	396	584
1991–92	537	586
1992–93	*316	584
1993–94	**566	584
1994–95	501	584
1995–96	495	584
1996–97	457	584
1997–98	439	584
1998–99	473	584

For several years, landings in the Snake Bank fishery were not apparently limited by the daily catch limit of 200 kg per permit. However, since the 1991–92 fishing year, reported landings have been close to the theoretical maximum imposed by the daily limit. The aggregate limit of 584–586 t was not based on research information or yield estimates.

2.2 Non-commercial fisheries

Cockles, in common with many other intertidal shellfish, are important to Maori as a traditional food source. They are also taken by amateurs. Non-commercial harvesters prefer relatively large cockles, a length of about 30 mm or greater being acceptable. Accurate estimates of cockle harvest for amateur fishers are not available for areas as small as Snake Bank, but about 50–60 t were taken by amateurs throughout the Auckland Fishery Management Area during the 1994 regional telephone and diary survey (T. Sylvester, MFish, pers. comm.). The proportion of these cockles taken from Whangarei Harbour (probably Snake Bank) was only about 2% of the whole, indicating that amateur harvest was insignificant (about 1 t) compared with commercial landings (about 500 t).

3. RESEARCH

3.1 Recruited biomass for 1999

3.1.1 Survey methods

Grid surveys have been used in previous surveys because of ease of location of sampling sites, good coverage of the entire bank, and to allow iterative increase in the sampled area during sampling until the periphery of the cockle "stock" had been reached. Such surveys, using a grid spacing of 50 * 50 m and about 190 sites, achieved a *c.v.* of 7–10% (Cryer 1997) assuming that sampling points were randomly distributed. This assumption was clearly erroneous, although such an assumption is usually reasonable (e.g., Milne 1959, Ripley 1981). Circumstances where the assumption is not reasonable include those where there is spatial correlation of density (where the variance tends to be biased (Wolter 1984)) or patchiness on a scale "in phase" with the sampling grid (where the biomass estimate itself can be biased). In some conditions, the level of these biases can be very high (Payandeh 1970, Dunn & Harrison 1993). Several alternative variance estimators have been developed specifically for systematic surveys (e.g., Dunn & Harrison 1993, Millar & Olsen 1995), although there is no consensus as to the most appropriate. All are approximate and pragmatic solutions to a difficult problem.

Because of these difficulties with systematic sampling, a stratified random approach to the estimation of recruited biomass was adopted for the 1998 and the present (May 1999) surveys. Simple random sampling would have been possible for earlier surveys, but good stratification would have been very difficult due to a lack of information on spatial distribution and its consistency among surveys. Analysis of historical records revealed a consistent pattern of two major centres of high cockle density separated by a sinuous bank of slightly higher elevation and lower cockle density (the "snake") and surrounded by areas of lower density at or about the low tide mark. This basic pattern was consistent among surveys, but the location of the "snake" and the edges of the bank change slightly among years.

The stratification for 1998–99 was as follows for Snake Bank (*see* also Figure 1, Table 2).

- The two high density areas were sampled separately, and the larger of the two split into two strata to ensure a good coverage of stations. Thus there were three high density strata (H1, H2, H3).
- The medium density areas surrounding the high density areas, and throughout the "snake", were assigned to a single medium density stratum (M1).
- The peripheral (low tide) area formed a single large low density stratum (L1).

Stations were allocated to strata using simulation. All available historical data were pooled, and a bootstrapping procedure was used to estimate the minimum number of stations needed to achieve the target *c.v.* of 20%. A minimum of five stations was allocated per stratum.

Table 2: Sampling design for Snake Bank cockles to estimate absolute recruited (≥ 30 mm shell length) cockle biomass

Stratum	Area (m^2)	Number of stations
High 1	129 196	11
High 2	187 988	13
High 3	118 378	14
Medium	302 567	12
Low 1	825 500	5
Total	1 563 629	55

Sites were located from bearings on excellent navigational landmarks to determine position using a compass and laser rangefinder. At each site, a square quadrat of 0.5 * 0.5 m (0.25 m^2) was thrown haphazardly onto the bank. All sediment beneath the quadrat was excavated by hand, including those animals directly under the south- and west-facing sides (this accounted for any possible "edge effects"). Cockles were extracted from the sediment using a metal sieve of5 mm square aperture, agitated in water. The aggregate weight of all cockles in each of three size classes (less than 30 mm, 30–34 mm, and greater than or equal to 35 mm) was measured directly for each site.

The recruited biomass of cockles on Snake Bank was estimated using the weighted average of the five stratum estimates of recruited biomass, weights being proportional to the relative size of each stratum.

$$\bar{x} = \sum_{i=1}^{5} W_i \bar{x}_i$$

where $\bar{x}$ is the estimated biomass, W_i is the area, and $\bar{x}_i$ the estimated recruited biomass in stratum i. The variance for this mean was calculated as:

$$s^2 = \sum_{i=1}^{5} W_i^2 s_i^2 / n_i$$

Where s^2 is the variance of the estimated recruited biomass, s_i^2 is the variance, and n_i the number of samples taken within stratum i (Snedecor & Cochran 1989). No finite correction term was applied because the sampling fraction was negligible (much less than 1% of the total available area).

A sample of up to 100 cockles from each quadrat was measured to the next whole millimetre down using vernier callipers, and all unmeasured cockles were counted. Where subsampling was undertaken, an estimate of the sample length frequency was made by scaling each count within a stratum by the inverse of its sampling fraction. Estimated stratum length frequency distributions were derived by weighted averaging of all (estimated) length frequency samples taken within each stratum, weights being proportional to the estimated total density of cockles at each site. Stratum length frequency distributions were scaled to the estimated total abundance of cockles within each stratum using the overall fraction sampled. A fully scaled length frequency distribution for the whole of the survey area was then derived by addition of stratum length frequency distributions. The total number of cockles present within the surveyed areas was derived by summing the scaled length frequency distributions.

A sample of about 100 animals from the lagoon and mid-tide areas of Snake Bank were also measured and animals weighed individually to determine length-weight relationships.

3.1.2. Survey results and discussion

The estimated recruited biomass of cockles on Snake Bank was 1321 t with a *c.v.* of 14% (Table 3). This is higher than the 1998 estimate of 880 t (*c.v.* of 18%), and 1996 estimate of 796 t (*c.v.* of 8%), and possibly indicates the recruitment into the population of a strong year class (or year classes). However, the 1998 and 1999 biomass estimates were not statistically different.

The scaled length frequency distribution for Snake Bank showed a broad, uni-modal length frequency distribution (Figure 2), almost certainly composed of multiple age classes.

The proportion of biomass in the "fishable" portion of the stock (shell length greater than 29 mm) was about 38%, which is effectively the same as in the 1996 survey (36%). This contrasts with about 90% in the first two surveys. The proportion of cockles of shell length 35 mm or greater is now about 5%, compared to about 70% in the initial surveys. Figure 3 shows historical trends in estimated biomass.

Currently 9% of the population falls within the size range of less than 21 mm. Historical values have ranged from 14 to 38% back to 1991; before this the range was only 5–10% (for the first two surveys, where most of the population consisted of relatively large individuals). This relatively low proportion of small cockles is potentially of concern for recruitment into the stock over the next 2–3 years.

Table 3: Biomass estimates (t) by shell length size classes for cockles on Snake and McDonald Banks. Approximate coefficients of variation (percentage) are given in parentheses for recent biomass estimates. N, the number of samples in each survey. Estimates for 1985 and 1991 corrected assuming measured density and sampling area as in 1982

Year	N	Total	*c.v.* (%)	< 30 mm	*c.v.* (%)	≥ 30 mm	*c.v.* (%)	≥ 35 mm	*c.v.* (%)
Snake Bank									
1982	199	2 556		216		2 340		1 825	
1983	187	2 509		321		2 188		1 700	
1985	136	2 009	(8)	347		1 662	(8)	1 174	
1991	158	1 447	(9)	686	(10)	761	(10)	197	(12)
1992	191	1 642	(8)	862	(10)	780	(8)	172	(11)
1995	181	2 480	(7)	1 002	(9)	1 478	(7)	317	(12)
1996	193	1 755	(7)	959	(9)	796	(8)	157	(11)

1998	55	2 401	(18)	1 520	(20)	880	(17)	114	(20)
1999	47	3 486	(12)	2 165	(12)	1 321	(14)	194	(32)
McDonald Bank									
1998	33	6 939	(19)	5 261	(18)	1 678	(31)	128	(41)

3.1.3 Revised length – weight relationships

Two new length–weight relationships were estimated (Table 4).

Table 4: Length weight regressions ($W = aL^b$) for cockles on Snake Bank (weight in grams, length in mm). Locations relate to the area on Snake Bank from which the cockles were collected

Year	Location	a	b	n	Reference
1992	Random	0.00110	2.721	607	Cryer & Holdsworth (1993)
1995	Random	0.00015	3.285	226	Annala & Sullivan (1996)
1996	Mid-tide	0.00018	3.253	240	Cryer (1997)
1996	Lagoon	0.00037	3.060	204	Cryer (1997)
1998	Mid-tide	0.00018	3.275	103	Cryer & Morrison (1999)
1999	Lagoon	0.00009	3.450	114	This FARD
1999	Mid-tide	0.00010	3.445	122	This FARD

3.1.4 Examination of tidal height and density effects

Data was collected to examine possible interactions between cockle densities, average cockle size in a quadrat, tidal elevation, and year. Tidal elevation data were collected during the 1999 survey period using a hand deployed RTK unit (a high accuracy DGPS) to measure tidal height. All elevations were corrected to chart datum, and a simple digital elevation map constructed (10 cm resolution) (Figure 4). Historical grid data coordinates were overlain on this model to estimate a tidal height value for each quadrat sampled. It was assumed that the bathymetry of Snake Bank has not changed greatly over the period 1983 to 1996. General linear models were run on all data from 1983–96 (all grid based data, with generally more than 150 data points per survey). All density data were logged to improve GLM assumptions of normality. Two separate models were run.

For the model regressing average size per quadrat against log (density), tidal elevation, and year (Table 5a), all interaction terms were significant, suggesting that all play some synergistic role in affecting average cockle size in a quadrat (Figures 5, 6). Additional unexplained variation was likely to be present from variable recruitment, the effects of removals by harvesting, and other factors.

Evidence of density dependent effects on average size were most apparent for the earliest surveys (Figure 5; 1983, 1985); these effects reduced to lower levels in later surveys, perhaps as a result of possible reductions in high biomass areas through removal of the older age classes of the stock. Such density dependence suggests an upper limit to the carrying capacity of cockle biomass on areas of the bank.

For the model regressing log (density) against datum and year (Table 5b), no significant effects were detected.

Table 5: GLMs for historical data series, for a) average size per quadrat vs. log (density), tide datum and year, and b) log (density) vs. tide datum and year

a)

$R^2 = 0.60$

Source	DF	Type III SS	Mean square	F value	Pr > F
LDEN	1	17.5	17.59	1.1	0.2861
YEAR	6	1302.7	217.1	14.1	0.0001
LDEN*YEAR	6	704.2	117.3	7.6	0.0001
DATUM	1	479.1	479.1	31.0	0.0001
LDEN*DATUM	1	301.2	301.2	19.5	0.0001
DATUM*YEAR	6	817.9	136.3	8.83	0.0001
LDEN*DATUM*YEAR	6	524.2	87.37	5.66	0.0001

b)

$R^2 = 0.00$

Source	DF	Type III SS	Mean square	F value	Pr > F
DATUM	1	1399.6	1399.6	0.32	0.5730
YEAR	6	11504.2	1917.4	0.44	0.8553
DATUM*YEAR	6	3764.5	627.4	0.14	0.9905

3.1.5. Snake Bank boundaries and stratification

One of the benefits of the previously used grid based sampling scheme was that sampling could be extended spatially until the boundaries of the stock were located. This is not possible with the currently used stratified random approach. In the current work, the spatial extent of Snake Bank was more precisely defined than before through the use of a RTK unit (DGPS) (these data are now available to generate strata for future surveys if required). However, most of the intertidal/subtidal boundary of Snake Bank falls within the low density stratum "Low 1". This stratum contains only 6% of the cockle biomass on Snake Bank, but covers 53% of the total survey area. Therefore, any impacts on cockle biomass estimates from inaccuracies in defining the intertidal boundaries of the bank are likely to be modest.

Of greater potential importance was the presence of tidal height effects on average cockle size (presumably through an influence on growth rates). Such effects have implications for the productivity of the stock if cockle numbers are not relatively constant from year to year across tidal heights.

3.2 Yield estimates

3.2.1 Estimation of maximum constant yield

MCY was calculated using the equation

$$MCY = 0.50 * F_{ref} * B_{av}$$

where F_{ref} is a reference fishing mortality and B_{av} is the average recruited biomass during a time when the fishery is thought to have been fully exploited (Method 2, Annala & Sullivan 1996). Average recruited biomass was estimated as the mean of all survey estimates from 1991 to 1996 (during which time the fishery is thought to have been fully exploited) and was 954t with a standard error of 175 t (*c.v.* = 18%). $F_{0.1}$ = 0.41 and F_{max} = 0.62 were selected as alternative reference fishing mortality rates (Cryer 1997).

For $F_{0.1}$, $MCY = 0.50 * 0.41 * 954 = 196$ t (rounded to 200 t), or

For F_{max}, $MCY = 0.50 * 0.62 * 954 = 296$ t (rounded to 300 t)

The level of risk to the stock by harvesting the population at either of the estimated MCY values cannot be determined, but would be greater for the F_{max} option. Both estimates of MCY would have an associated *c.v.* of at least 18% (that associated with the estimate of average biomass). Additional error sources would include components from the estimation of M, growth, and the length:weight relationship.

3.2.2 Estimation of current annual yield

CAY can be estimated using the Baranov catch equation because fishing is carried out year round and natural and fishing mortality act simultaneously (Annala & Sullivan 1996).

$$CAY = \frac{F_{ref}}{F_{ref} + M}\left(1 - e^{-(F_{ref}+M)}\right)B_{beg}$$

where F_{ref} is a reference fishing mortality, M is natural mortality, and B_{beg} is the start of season recruited biomass. Using the estimates of $F_{0.1}$ = 0.41 and F_{max} = 0.62 (Cryer 1997) as alternatives for F_{ref}, the estimate of M = 0.30 from Cryer & Holdsworth (1993) and the latest estimate of recruited (30 mm or greater) biomass, therefore:

For $F_{0.1}$, $CAY = 0.5775 * 0.5084 * 1321\ t = 388\ t$

For F_{max}, $CAY = 0.6739 * 0.6015 * 1321\ t = 535\ t$

The level of risk to the stock by harvesting the population at either of the estimated CAY values cannot be determined. Both estimates of CAY would have an associated *c.v.* of 14% (that associated with the estimate of current absolute biomass). Additional error sources would include components from the estimation of M, growth, and the length:weight relationship

However, it should be noted that because M and F_{ref} values are quite high, assuming that the survey estimate is a beginning-of-season value (B_{beg}) has quite a large effect. (C. Francis, pers. Comm, NIWA, Wellington). If the estimate is treated as a mid-season value (B_{mid}), and C_{99} and F_{99} are the catch and fishing mortality in the 1998–99 fishing year, then:

$$C_{99} = \frac{F_{99}}{F_{99} + M}\left(1 - e^{-(F_{99}+M)}\right) B_{beg}$$

and

$$B_{mid} = B_{beg}\, e^{-0.5(F_{99}+M)}$$

Setting C_{99} to 505 t (the average of the last 4 years catches) and B_{mid} to 1321 t, solving the above equations results in $F_{99} = 0.38$ y^{-1} and $B_{beg} = 1851$ t. This leads to estimated CAYs of 540 t and 750 t, which are very different from those presented above. Assuming the survey was an end-of-season biomass estimate leads to estimates of $B_{beg} = 2\,364$ t and CAY estimates of 690 t and
960 t. (C. Francis, pers. comm,), again substantially different.

It is suggested that this issue needs to be referred back to the Shellfish Working Group. The current length-based model being constructed for this stock should also provide for insights into this issue.

4. DISCUSSION

Catch continues to exceed estimates of MCY and CAY, but despite this the recruitedbiomass has remained remarkably consistent at 700–900 t since 1991 (with the exception of 1995 and 1999). Some recruitment appears to have occurred since 1996.

Examination of nearby McDonald Bank in 1998 indicated a sizeable recruited cockle biomass, exceeding that estimated for the Snake Bank fishery, and this additional area could perhaps be opened for commercial harvesting in the future to reduce harvesting pressure on Snake Bank. However, this apparently unexploited population contains a much higher proportion of smaller cockles than has been found on any of the Snake Bank surveys. Reasons for this difference are unknown, but there may be some difference in population dynamics between the two areas.

5. Acknowledgments

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6. References

Annala, J.H. & Sullivan, K.J. (Comps.) 1996: Report from the Fishery Assessment Plenary, April–May 1996: stock assessments and yield estimates. 308 p. (Unpublished report held in NIWA library, Wellington)

Cryer, M. & Holdsworth, J. 1993: Productivity estimates for Snake Bank cockles, August 1992 to August 1993. MAF Fisheries Northern Fisheries Region Internal Report, Auckland. (Draft report held at NIWA, Auckland)

Cryer, M. 1997: Assessment of cockles on Snake Bank, Whangarei Harbour, for 1996. N.Z. Fisheries Assessment Research Document 97/2 29 p. (Draft report held in NIWA library, Wellington.

Dunn, R. & Harrison, A.R. 1993: Two dimensional systematic sampling of land use. *Applied Statistics 42:* 585–601.

Holdsworth, J. & Cryer, M. 1991: Assessment of the cockle, *Chione stutchburyi*, resource and its associated fishery in Whangarei Harbour. (Unpublished report held at NIWA, Auckland)

Martin, N.D. 1984: *Chione stutchburyi* population responses to exploitation. Unpublished MSc thesis, University of Auckland, N.Z.

Millar, R.B. & Olsen, D. 1995: Abundance of large toheroa (*Paphies ventricosa* Gray) at Oreti Beach, 1971–90, estimated from two dimensional systematic samples. *N.Z. Journal of Marine and Freshwater Research 29:* 93–99.

Milne, A. 1959: The centric systematic area-sample treated as a random sample. *Biometrics* 15: 270–297.

Morrison, M., & Cryer, M. (1999):

Payandeh, B. 1970: Relative efficiency of two dimensional systematic sampling. *Forest Science* 16: 271–276.

Ripley, B.D. 1981: Spatial statistics. Wiley, New York. 252 p.

Snedecor, G.W. & Cochran, W.C. 1989: Statistical methods. 8th ed. Iowa State University Press, Ames, Iowa, USA.

Wolter, K.M. 1984: An investigation of some estimators of variance for systematic sampling. *Journal of the American Statistical Association 79*: 781–790.

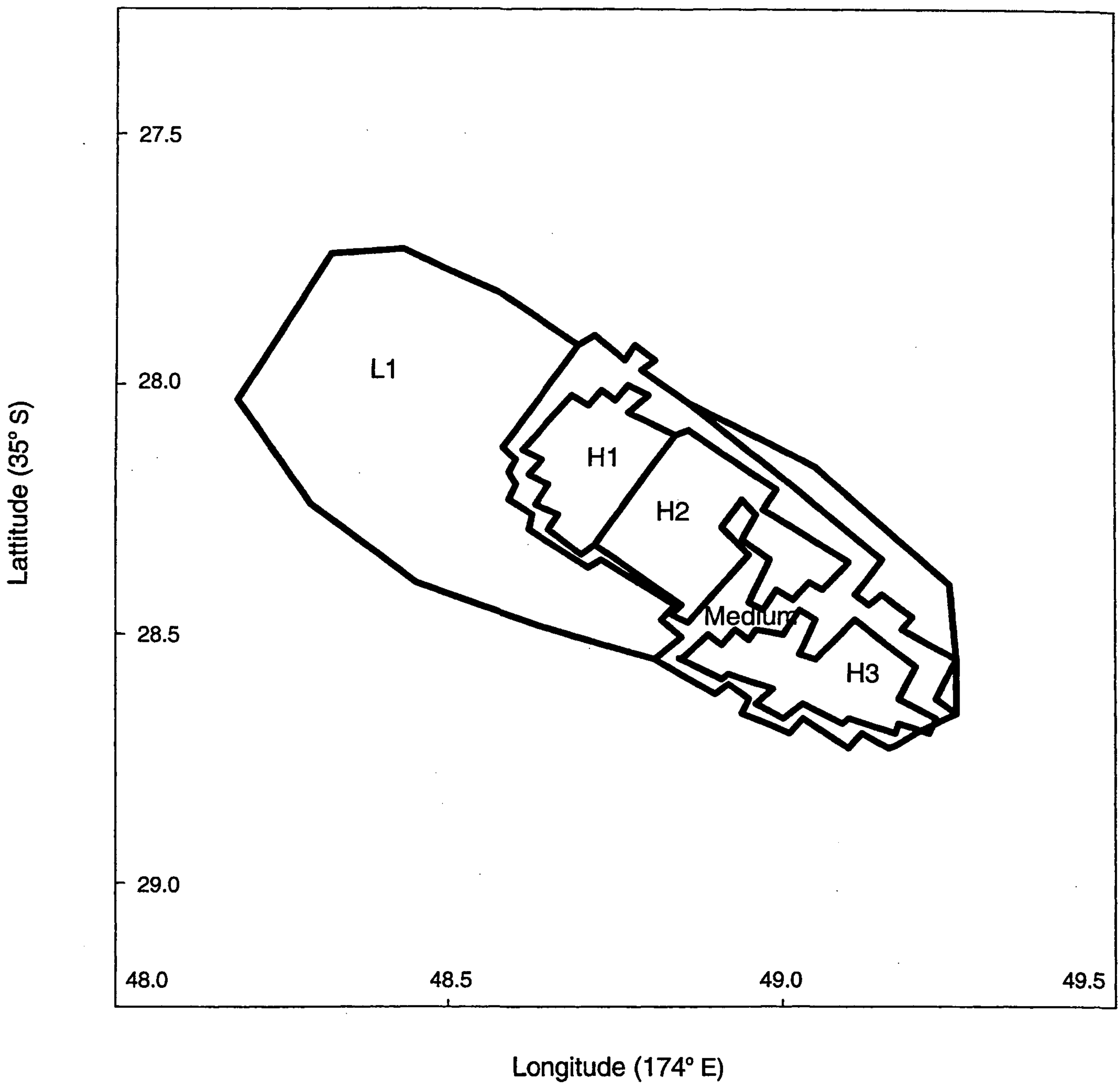

Figure 1: Current stratification of Snake Bank. Codes denote strata identifiers: H, high density; L, low density of cockles

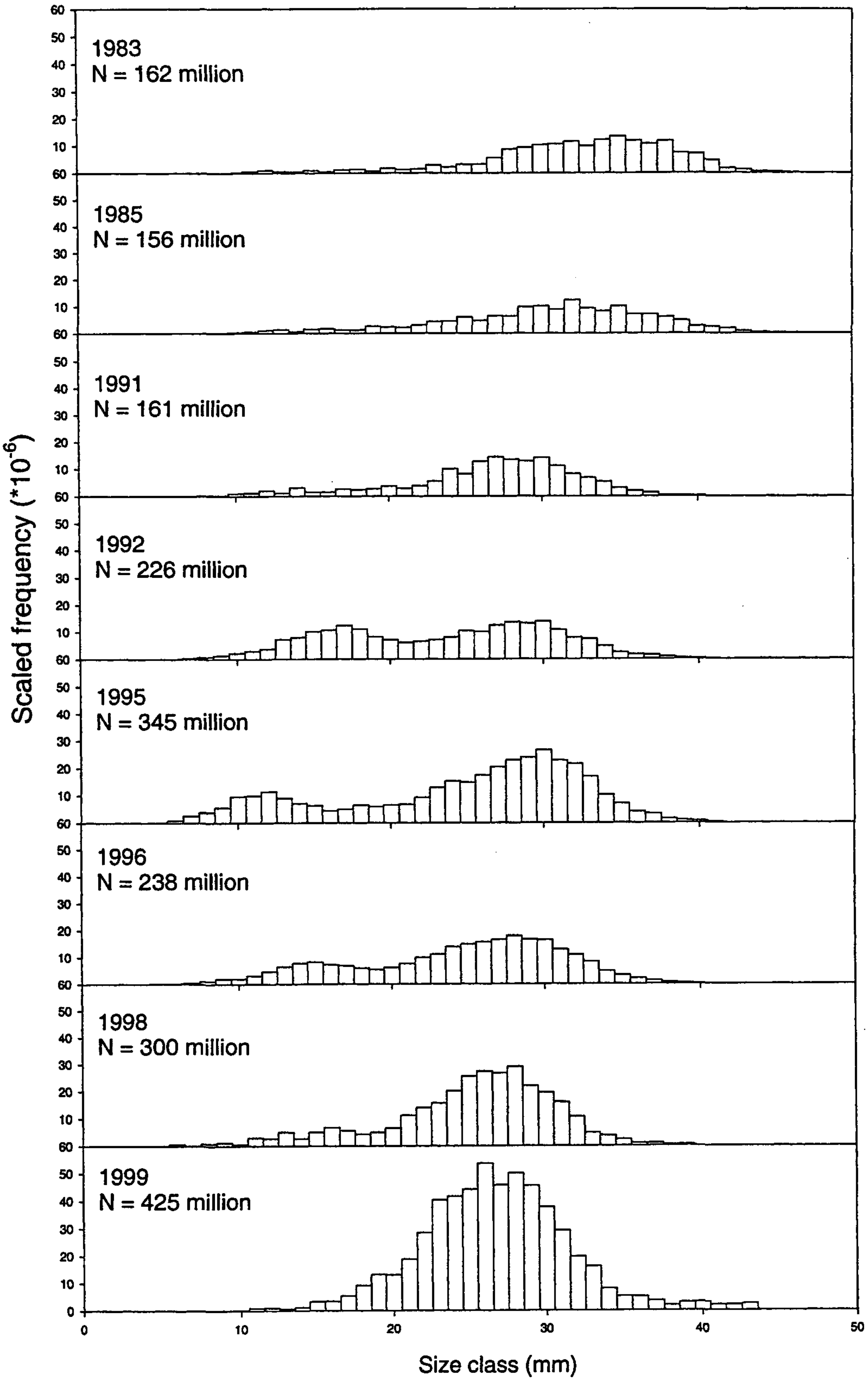

Figure 2: Length frequency distributions, scaled to total population size, for cockles on Snake Bank, Whangarei Harbour, during full biomass surveys, 1983-99. N, total estimated cockles present within the surveyed area.

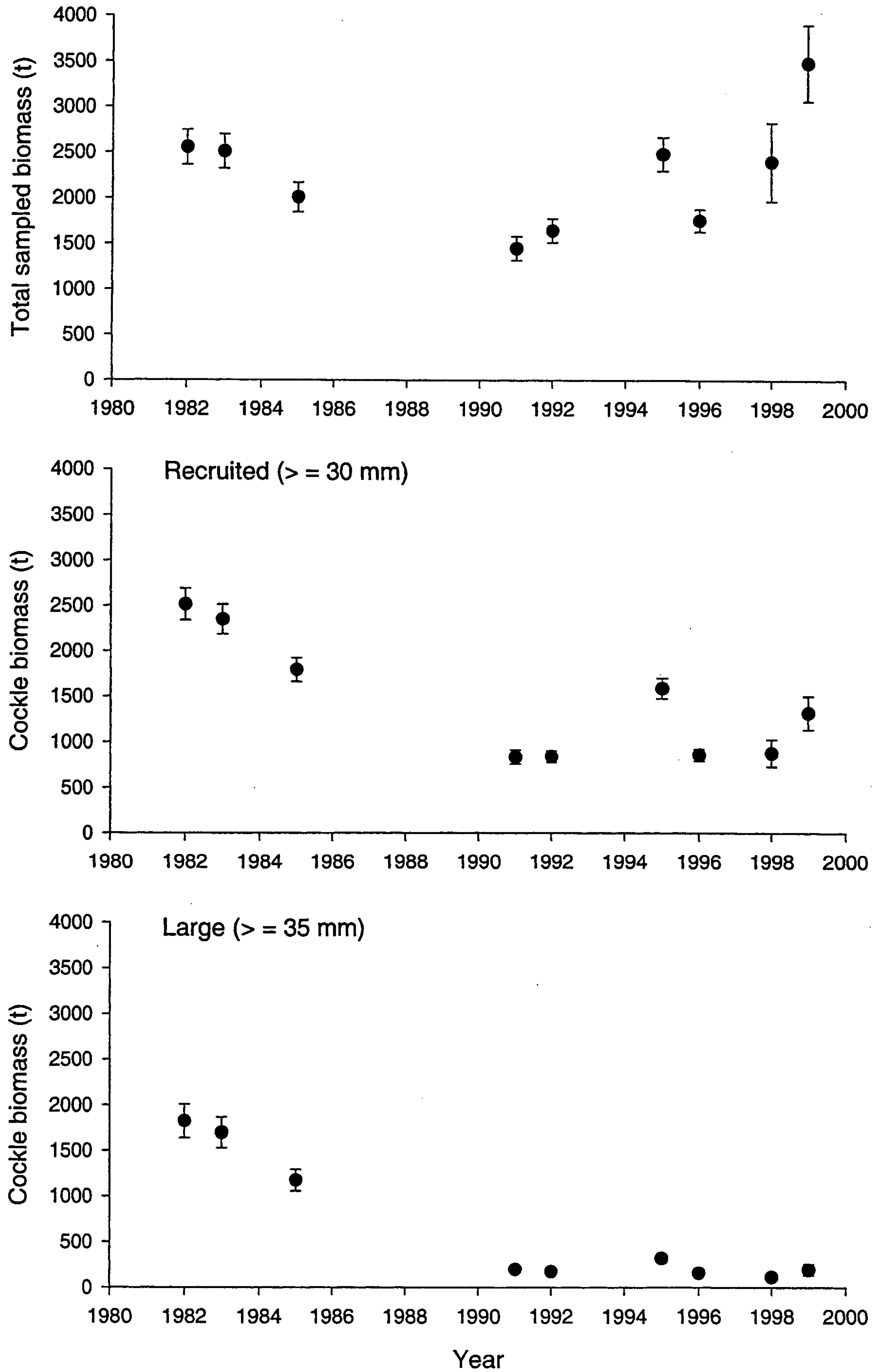

Figure 3: Trajectories (+/- one standard error) of total, recruited (> 30 mm) and large (> 35 mm) cockle biomass on Snake Bank since the inception of the fishery in 1992.

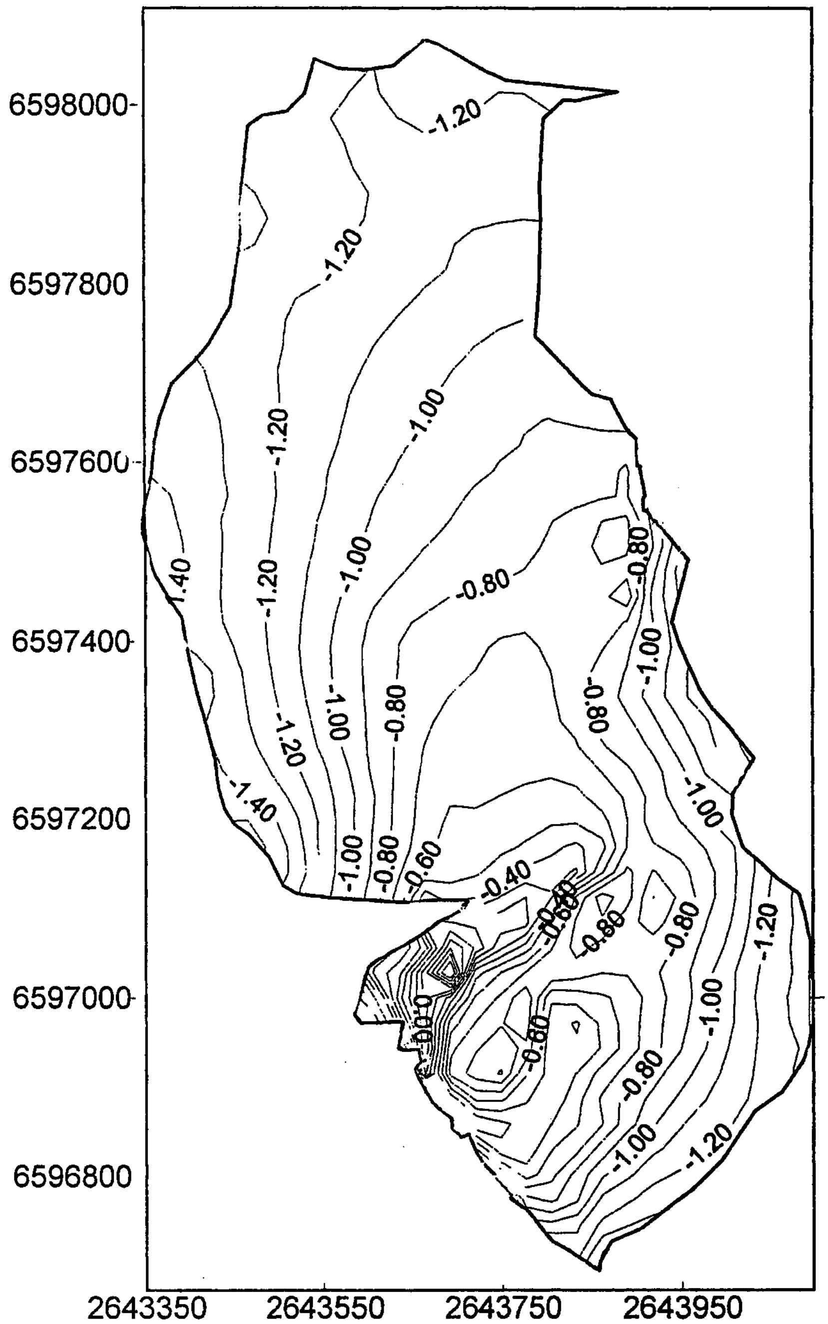

Figure 4: Bathymetric contour plot of Snake Bank. Boundary line denotes extent of RTK measurements. Contour band values are mean sea level units (MSL); spatial coordinates are in New Zealand Map Grid (NZMG).

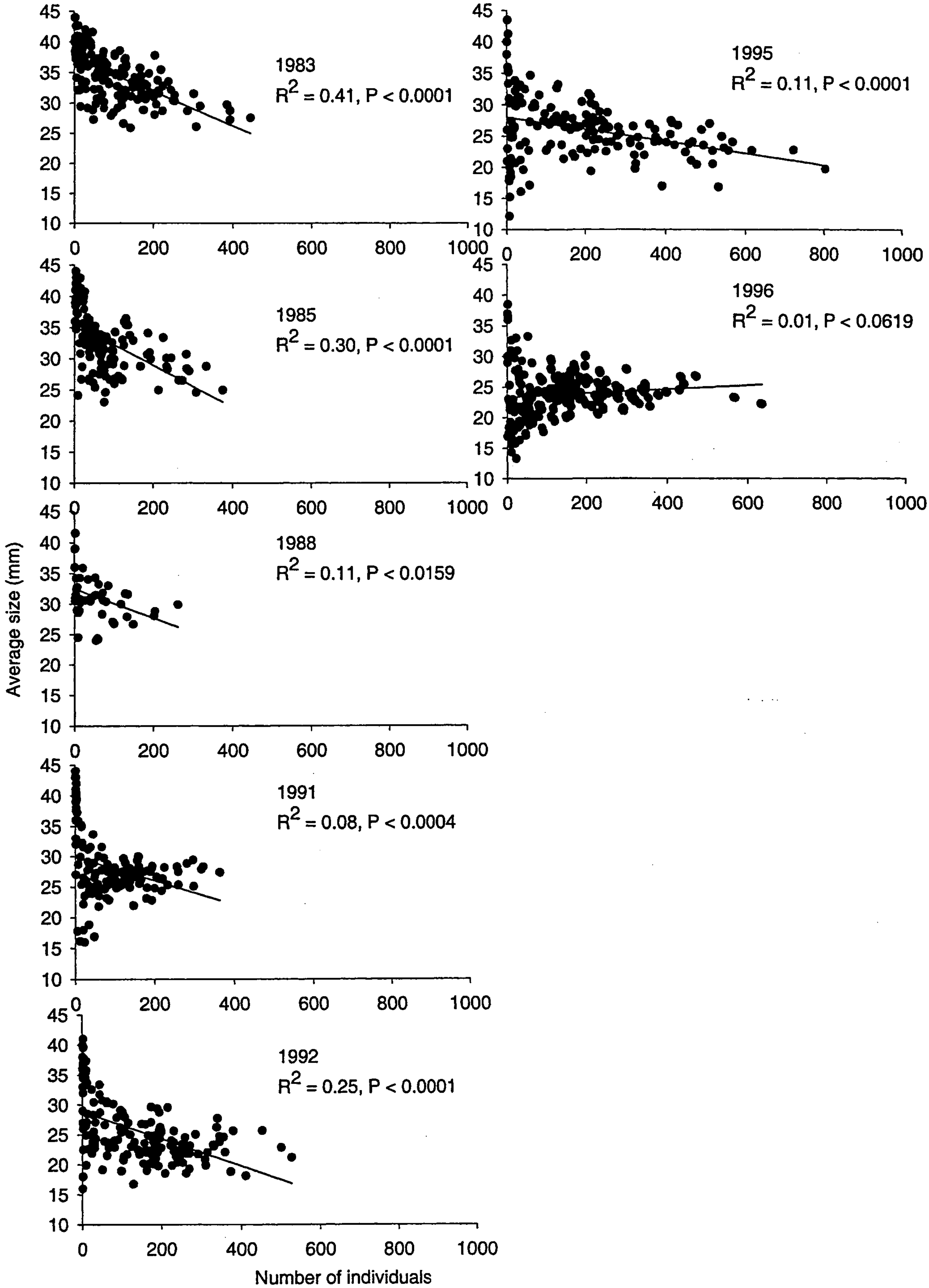

Figure 5: Relationships between cockle density and average size per quadrat for 1983-96 surveys.

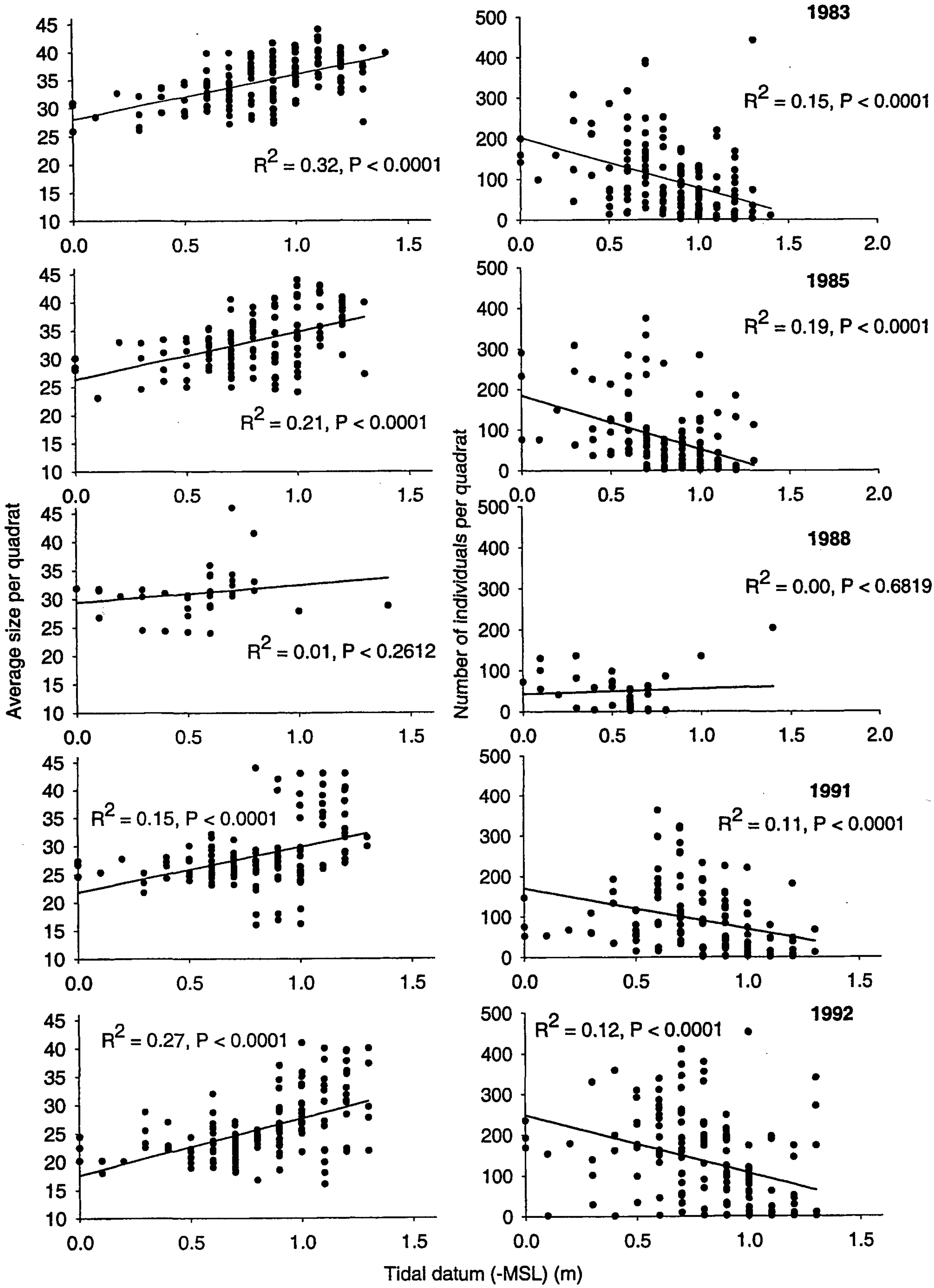

Figure 6: Plots of tidal height versus average cockle size, and density for 1986-96 surveys.

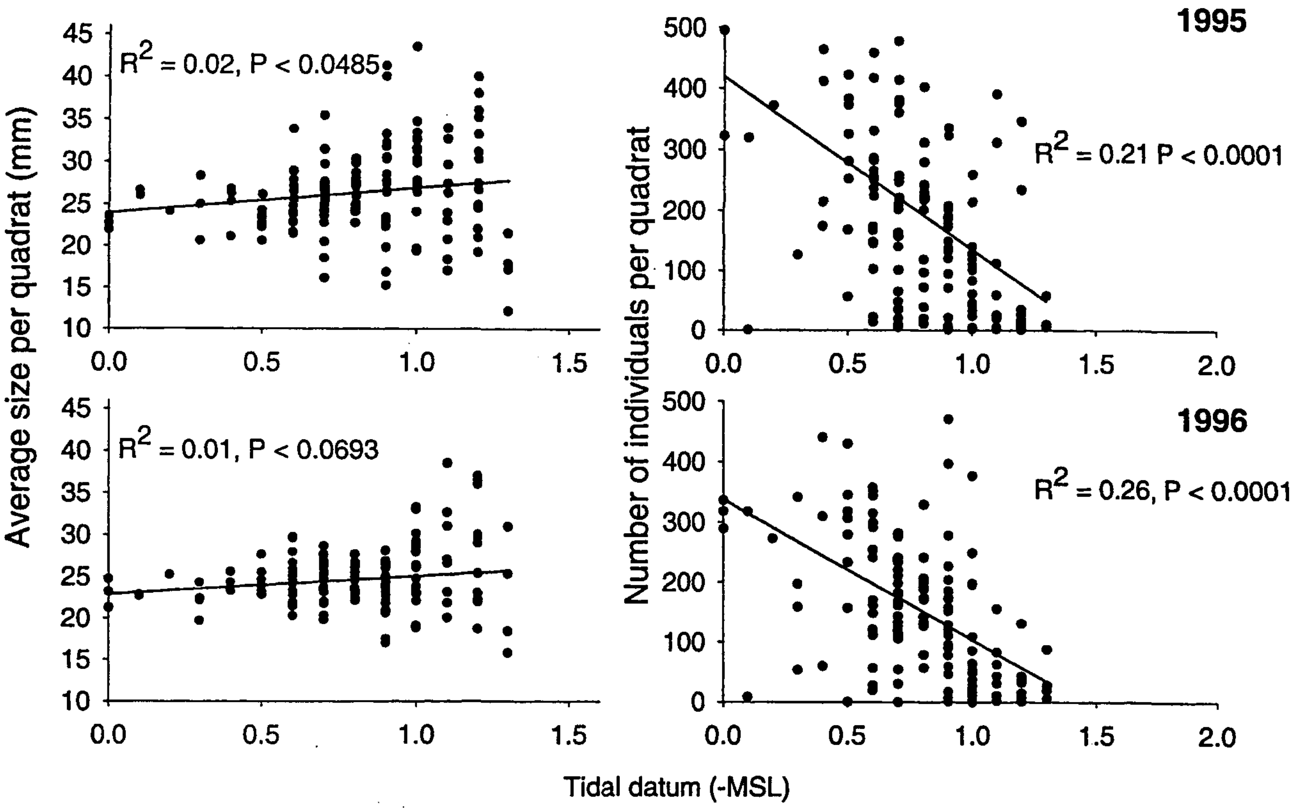

Figure 6 continued: