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An appraisal of an in-season depletion method of estimating biomass and yield in the Coromandel scallop fishery

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EXECUTIVE SUMMARY

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Catch and effort data from Ministry of Fisheries Catch, Effort, & Landing (CELR) forms from the Coromandel scallop fishery were analysed to assess the extent to which "in-season" depletion analysis might be used as a cost-effective means of estimating recruited biomass and yield.

Although catch rates in the Coromandel fishery typically decline throughout the season, these declines are inconsistent, and factors other than the total recruited biomass probably affect dredge catch rates. In half of the 8 years examined for each of the two main beds there was no significant decline in catch rate, precluding the use of depletion methods. Biomass estimates made using depletion methods are not significantly correlated with pre-season surveys, whether these surveys were made primarily by diver (Whitianga beds) or by dredge (Little Barrier beds). This conclusion is robust to the inclusion or exclusion of statistically non-significant depletion regressions, and to restriction of survey biomass estimates to the "commercial available" fraction. In addition, a marginally significant relationship between catch rate during the first calendar month of fishing and recruited biomass has little predictive power and would be sensitive to changes in fishing practice or reporting.

In-season depletion analysis is not a dependable method for estimating biomass in the Coromandel scallop fishery. Depletion estimates of biomass are, on the evidence of catch and effort data from 1991–98 under two different size limits, likely to be available only for the main beds (Whitianga and Little Barrier Island) in about half of all seasons, and the biomass estimates generated are likely to be imprecise and unreliable. The performance of this method for other, less consistently fished beds is likely to be worse. Depletion analysis is unsuitable for estimating current annual yield, CAY.

1.   INTRODUCTION

1.1   Biology

The New Zealand scallop (*Pecten novaezelandiae*) is one of several species of "fan shell" molluscs found in New Zealand waters. They have a characteristic round shell with a flat upper valve marked with radial ridges, and a deeply concave lower valve. Scallops inhabit waters to about 60 m deep (to 85 m at the Chatham Islands), but are more common in depths of 10 to 45 m on substrates of shell gravel, sand or, in some cases, silt. Growth rates are variable and growth to the minimum legal size can take from 1.5 to more than 4 years (Cryer & Parkinson 1999a).

Scallops are functional hermaphrodites, and become sexually mature at a size of about 60 mm shell length (usually some time in their second year). They are extremely fecund and may spawn several times each year. Fertilisation is external and larval development lasts for about 3 weeks. Initial settlement occurs when the larva attaches by a byssus thread to filamentous material or dead shells on or close to the seabed. The major settlement of spat in northern fisheries usually takes place in early January. After growth to about 5 mm, the young scallop detaches the byssus and takes up the adult mode of life. The very high fecundity of this species, and likely variability in the mortality of larval and pre-recruits, leads to great variability in annual recruitment. This, combined with variable mortality of adults, leads to scallop populations being highly variable from one year to the next, especially in areas of rapid growth where the fishery may be supported by only one or two year classes. This variability is characteristic of scallop populations world-wide, and often occurs independently of fishing pressure (Shumway & Sandifer 1991).

1.2   Fisheries

Scallops support two regionally important commercial fisheries off the northeast coast of the North Island, the Northland and Coromandel fisheries being separated by a line running from Cape Rodney to the northernmost point of Great Barrier Island. All commercial fishing is by dredge, fishers in both northern fisheries preferring self-tipping "box" dredges to the ring bag designs in common use in southern fisheries. Until 1994, the minimum legal size for scallops taken commercially in northern scallop fisheries was 100 mm shell length. In 1995, a new limit of 90 mm shell length was applied in the Coromandel fishery as part of a management plan comprising several new measures. The commercial season runs from 15 July to 21 December in the Coromandel fishery. Commercial landings were summarised by Cryer (1999).

Recreational fishing for scallops is undertaken by diving or dredging in suitable areas throughout the fishery, more especially in enclosed bays and harbours, many of which are closed to commercial fishing. In the 1993–94 year, the recreational harvest was estimated as 60–70 t (greenweight), about 13–15% of the total harvest. Scallops were undoubtedly used as food by Maori, although quantitative information on the level of Maori customary take is not available.

1.3   Recent history of the fishery

The bed at Whitianga has been one of the mainstays of the Coromandel fishery since its inception. Biomass has varied by a factor of almost five, with seemingly little link to fishing pressure (Cryer 1994, 1999). Recent years have been relatively poor (six of the seven lowest estimates in the history of the fishery were between 1993 and 1998), and the 1999 survey indicated the smallest population since surveys began (Cryer & Parkinson 1999b).

Historically, the second most important bed in the Coromandel fishery was at Waiheke Island in the Hauraki Gulf. This population declined rapidly in the late 1980s and was essentially unfished between 1993 and 1996. The biomass appeared to increase in 1997 (although the precision of the estimate was poor) and a very similar result (with better precision) in 1998 strengthened the inference that this population was recovering. Unfortunately, the biomass estimate for 1999 was very low.

The bed at Little Barrier Island was highly productive in the mid 1990s, but the two most recent surveys have shown lower biomass. Low biomass at this site was preceded by marked changes to length frequency distributions, with abundant cohorts of small animals essentially disappearing in 1997. The 1999 biomass was the smallest on record (Cryer & Parkinson 1999b).

1.4 Methods of estimating biomass and yield

After a method by Cryer (1994), provisional yield, PY, has been calculated for the Coromandel fishery since 1992. PY is defined as the lower limit of a 95% confidence distribution for the predicted start-of-season recruited biomass in surveyed beds plus an additional (conservative) amount for unsurveyed beds (Cryer 1994). Fishery performance (in terms of the absolute catch rate and its rate of decline) was reviewed part way through each season to refine the estimate of yield.

Historical records for persistent scallop beds which had been subjected to heavy fishing pressure (e.g., $F_{est} \sim 1.0$ at Whitianga, Cryer 1994, 2001) seemed to indicate that standard yield estimates, such as CAY calculated using the Baranov equation, were conservative for the Coromandel fishery. Heavy fishing seemed to have had little impact on subsequent biomass. A more recent modelling approach (Cryer & Morrison 1997) incorporating experimental estimates of incidental mortality and impacts on growth suggests that there are likely to be negative implications of heavy fishing when incidental impacts, especially on mortality, are non-trivial. Stochastic population models (Cryer & Morrison 1997) suggest that catch limits based on PY (which will probably lead to fishing mortality rates of $F_{est} \sim 1.0$) will lead to long term average catches about 50% lower than would be possible at lower fishing mortality. Yield in 1998 and 1999 was estimated using Cryer & Morrison's (1997) reference fishing mortality rates and a modified version of the Baranov catch equation.

Whatever the exact method of estimation, the Ministry of Fisheries has indicated that it prefers a CAY approach to estimating yield and the Shellfish Fishery Assessment Working Group has agreed that MCY for the Coromandel fishery should be zero. A CAY strategy requires annual estimates of recruited biomass and, in the past, these have been generated using fishery independent surveys. Diver surveys of the Whitianga beds were carried out almost annually between 1978 and 1997 but were replaced in 1998 and 1999 with (cheaper) dredge surveys. Other beds within the Coromandel fishery were surveyed only sporadically, mostly by dredge, until 1994, since when dredge and/or diver surveys have covered most commercially exploited beds each year (Cryer & Parkinson 1999a). Where dredges are used in surveys, absolute biomass must be estimated by correcting for the efficiency of the dredge in use. This is effected by comparing dredge counts with diver counts in experimental areas (Cryer & Parkinson 1999a). Surveys typically produce estimates of absolute recruited biomass with a c.v. of about 20%, including measurable uncertainty in average dredge efficiency, but excluding other uncertainty over the representativeness of experimental estimates of dredge efficiency.

Unfortunately, surveys are expensive, and it has been suggested that "depletion analysis" of catch and effort data could be used to estimate biomass "in season", and may provide an alternative means of assessing biomass and/or yield. Such an approach to assessment and management might involve starting each season with conservative catch limits which could be increased during the season based on an analysis of catch rates conducted part way through the season. The trajectory of catch rate with respect to catch already removed can be used in the so-called "depletion methodology" to estimate initial biomass (see Ricker 1975 for a review). A reliable in-season estimate of biomass could be used

to assess yield and to revise catch limits, and could be more cost-effective than the current approach based on surveys. This report summarises work to assess that proposition.

The following objectives were specified for this work by the Ministry of Fisheries:

Overall (project) objective:

To carry out a stock assessment of scallops (*Pecten novaezelandiae*) in the Coromandel fishery, including estimating abundance and sustainable yields.

Objective specific to this report (Objective 4 for 1998–99):

To use a depletion analysis method to assess CAY and evaluate this method as a cost-effective alternative management tool for this fishery.

2. METHODS

2.1 Source of data

Data were requested from the Ministry of Fisheries catch and effort database. The following fields were extracted from the "effort section" of all records having a fishing method of "D" (dredge) and a declared target species of "SCA" (scallop):

Vessel identifier
Date of fishing
Statistical Reporting Area
Hours fishing
Number of tows
Width of dredge
Estimated catch of scallops (kg greenweight)
Total catch (kg greenweight)
Fisher Identification Number of Permit Holder
Page number

This resulted in 48 518 records from the 1990–91 to 1997–98 fishing years. These data will be called the "effort data".

The following fields were extracted from the "landed section" of all records having a fishstock species of "SCA", other than those with a fishstock of SCA 4 or SCA 7 (being the Chatham Island and Southern (Challenger) scallop fisheries, respectively):

Landing date
Port of landing
Species code
Fishstock
Number of containers
Container type
Average container weight (kg greenweight)
Quota Registration Number against which the catch was recorded
Destination (i.e., whether landed or transshipped)
"Greenweight" (for scallops only, this field contains actual meatweight, kg)
Page number

This resulted in 27 835 records from the 1990–91 to 1997–98 fishing years. These data will be called the "landed data".

2.2 Preliminary data screening

The effort data contained many records from Chatham Island and Southern scallop fisheries, and the first stage of screening was to remove all records which clearly came from one of these fisheries. First, 18 415 records with a reported Statistical Reporting Area of "4x" or "7xx" (where "x" can be any letter of the alphabet) were deleted. These are the correct reporting areas for the Chatham Island and Southern scallop fisheries. Second, 822 records with reported Statistical Reporting Areas of 017, 037, 038, 049, or 050 were deleted as these codes represent the statistical reporting areas for finfish in the areas where the Southern and Chatham Island scallop fisheries are prosecuted. Third, 2025 records between 1 October 1990 and 14 July 1991 were deleted as this database is to be used for analysis of pattern within scallop fishing seasons which start on 15 July each year. These three crude screening tests led to the deletion of 44% of the effort data, leaving 27 185 records. This will be called the "original database".

2.3 Gross data quality

Of the 27 185 records potentially coming from the Northland or Coromandel scallop fisheries, 9.3% had inappropriate Statistical Reporting Areas for a scallop fishery. These records accounted for about 8.9% of reported effort and about 11.6% of reported estimated catch at this stage of data screening. Of a total estimated catch of about 12 000 t (greenweight) since the start of the 1990 season, the Northland and Coromandel fisheries accounted for 6400 t and 4250 t, respectively, and about 1400 t was improperly specified by area.

The records were separated crudely into data from the two fisheries using the Fisher Identification Numbers (Fisher Identification Numbers) of the reported permit holders (all but two permit holders have been authorised to fish only one of the two northern scallop fisheries). Fishers in the Coromandel fishery (as judged by reported Fisher Identification Number) reported inappropriate Statistical Reporting Areas about 15% of the time, compared with less than 5% for fishers in the Northland fishery. There was wide variation in the proportion of inappropriate Statistical Reporting Areas by Fisher Identification Number: the range was 2–31% in the Coromandel fishery and 0–65% in the Northland fishery. These are quite large disparities, and they are likely to have implications for the relative utility of any depletion analysis in the two fisheries.

About 3% of records (765) had a reported Fisher Identification Number which was associated with few (less than 20) or no accurate (scallop) Statistical Reporting Areas. These are likely to be errors associated with mis-punched or mis-reported Fisher Identification Numbers, target species, or fishing method codes. Of the 80 Fisher Identification Numbers in this group, 16 had 1–19 records with admissible (scallop) Statistical Reporting Areas, but the remaining 64 had none.

2.4 Selection of records probably from the Coromandel fishery

Records probably from the Coromandel fishery (the extent of which is shown in Figure 1) were selected from the original database by accepting all records from fishers with permits only for the Coromandel fishery and, for fishers with permits for both fisheries, those records which were more likely than not to have come from the Coromandel fishery. First, all records were accepted which had a reported Fisher Identification Number which was only ever associated with apparently accurate Coromandel scallop fishery Statistical Reporting Areas. Second, the records from two permit holders with access to both fisheries were sorted by vessel ID and date of fishing, and "blocks" of records where vessels were apparently fishing in the Northland fishery were successively deleted. Given the short steaming time between Statistical Reporting Area 2R in the Coromandel fishery and 1S in the Northland fishery, this selection procedure must be at least partly subjective, but the vessels involved

seemed to have patterns of fishing one or other of the fisheries or of moving fairly predictably from one fishery to the other. In all, 8005 records of the former category were selected, and 690 from the latter category. These records accounted for a total of slightly under 5000 t (estimated greenweight). This will be called the "unedited Coromandel database".

2.5 Screening for obvious errors and data editing

Records in the unedited Coromandel database were sorted by vessel, then by date of fishing. The records were then screened manually making the following range checks:

Range check	Criterion
Catch of scallops divided by total catch:	90–115%
Fishing time:	<13 h
Raw catch rate:	>25 kg h^{-1}
Statistical Reporting Area:	Alphanumeric, 2A–2X

Records violating any of these criteria were examined for possible errors. The most common and obvious errors were inappropriate Statistical Reporting Areas, fishing times missing or inflated by an order of magnitude, estimated meatweight reported instead of estimated greenweight (a 7–8 fold difference), and duplicate records. Apparent punch errors were not common (e.g., 600 kg mispunched as 6600 kg or 60 kg).

If an inappropriate Statistical Reporting Area was reported for just one or two records and flanked either side by apparently appropriate Statistical Reporting Areas, then the appropriate Statistical Reporting Area was copied to the record(s) with an inappropriate entry. However, it was common for inappropriate Statistical Reporting Areas to be reported in "blocks", especially at the start of the season. In these instances, inappropriate Statistical Reporting Areas ("002" was the most common) were treated as follows:

Reported Stat area	Action
002, 003	Check port of landing and edit to nearest appropriate Stat Area
005	Check port of landing, but default to 2R (Little Barrier)
007	Check port of landing, but default to 2X (Waiheke Island)
008	Check port of landing, but default to 2L (Whitianga)
22, 23	Edit to 2L (Whitianga) — old 2L subarea codes
L	Edit to 2L (Whitianga)

An aberrant ratio of scallop catch to total catch was most often caused by mis-punched or missing field for the estimated catch of scallops or the total catch. Mis-punches were usually obvious, but missing data had to be resolved by reference to the landed data. The number of bins in the landing and their estimated average content weight were used to estimate greenweight.

Fishing time was sometimes inflated by a factor of 10 and sometimes included "minutes". For example, consecutive records might have 90.0, 80.0, 80.0, 83.0 reported hours of fishing, none of which is possible on a single day. These would be edited to 9.0, 8.0, 8.0, and 8.5 hours of fishing. Where effort data were missing altogether, the average effort for that vessel in adjacent records in the same Statistical Reporting Area was inserted.

Violations in the raw catch rate (estimated greenweight of scallops divided by fishing time) usually indicated an error in one of the source data fields. Most catch rates under 30 kg h^{-1} were checked against data on the landed section of the form, and it was often found that meatweight had apparently been reported in the estimated catch section, which should be greenweight. The "real" greenweight

was estimated using the number of bins in the landing and their estimated average content weight. Where these data were missing, the probable meatweight was estimated by multiplying the estimated greenweight by 7.5. Occasionally, very low catch rates were corroborated by very low bin counts in the landed section of the form and these were left unedited.

The records including these edits were incorporated into the "screened Coromandel database".

2.6 Depletion analysis

The simple depletion analyses described by Leslie & Davis (1939) and DeLury (1947, 1951) can be applied to catch-effort trends where each unit of effort can be assumed to be equivalent. The Leslie regression of CPUE on cumulative catch is usually considered to be more appropriate for fisheries data than the DeLury regression of log(CPUE) on effort because estimates of catch are considered to have less error than estimates of effective fishing effort (Ricker 1975). The Leslie method is summarised in Equation (1):

$$\frac{C_t}{f_t} = qN_0 - qK_t \qquad (1)$$

where C_t/f_t is the total catch divided by the total effort in time period t, q is the average catchability, K_t is the cumulative catch from the population up to the middle of time period t, and N_0 is the original population size or biomass. A linear regression of the form in Equation (1) can be used to estimate initial biomass; when $C_t/f_t = 0$ (or the catch rate has theoretically declined to zero), then $qN_0 = qK_t$, and $N_0 = K_t$. Thus, the intercept of the regression line with the X axis (cumulative catch, K_t) defines the estimate of initial biomass. The confidence limits of the estimate of N_0 can be estimated from the roots of the quadratic function in Equation (2) (after DeLury 1951):

$$N^2 \left(q^2 - t_P^2 s_{yx}^2 \frac{1}{\sum x^2} \right) - 2 \left(q^2 N_0 - t_P^2 s_{yx}^2 \frac{\sum X}{n \sum x^2} \right) + \left(q^2 N_0^2 - t_P^2 s_{yx}^2 \frac{\sum X^2}{n \sum x^2} \right) = 0 \qquad (2)$$

where t_P is the value of Student's t with $(n-2)$ degrees of freedom for a probability p, s_{yx}^2 is the covariance of x on y (CPUE on cumulative catch) in the regression, n is the number of observations, and X and x are, respectively, the individual observed values and their deviations from the mean value of cumulative catch. For reasonably large numbers of observations, this method generates confidence limits very similar to those generated using the upper and lower 95% limits of the slope of the depletion regression, which is computationally simpler.

The development of a depletion methodology for estimating biomass and yield (as an "in-season" estimate of CAY) for a scallop fishery would depend critically on the applicability and precision of such regressions to real catch and effort information. Information from scallop fisheries is complex, and units of effort (hours or days of fishing) are heterogeneous across the fleet. Factors other than scallop density, such as weather, the composition and unevenness of the seabed, scallop condition, factory recovery fractions, changes in vessels or skippers, and large scale mortality events can all affect catch rates. Cryer & Parkinson (1999a) showed that fisher selectivity behaviour varied among fishers and seasons under a 90 mm minimum legal size (MLS). Because the size frequency of landings was measured only in the 1997 and 1998 seasons, it is not known if such variability is common or if it occurred under the 100 mm MLS in force until 1994.

One way of tackling the heterogeneity of catch and effort information is to segregate the data into blocks of fishing effort that are thought to be relatively homogeneous, and to conduct multiple simple

depletion analyses. For example, catch and effort data from a scallop fishery can, and probably should, be segregated by fishing area as different fishing areas often have markedly different seabed types and exposure. This method has been applied to the Coromandel fishery on several occasions (and is repeated here), and the potential impact of some other factors (such as weather and putative seabed unevenness) taken into consideration somewhat subjectively when interpreting the results.

An alternative means of addressing heterogeneity of catch effort information is to conduct a multivariate analysis. General linear modelling was conducted for the 1997 Coromandel season (Cryer 1997). However, interaction effects are common in such models because boats and skippers "specialise" on different areas or bottom types, because bottom unevenness changes with time, and because scallop condition changes with time and according to depth and location. The fleet in the Coromandel fishery typically moves among beds in response to these and other factors throughout the season. Assessing the significance and meaning of the main effects in a linear model is invalid in the presence of significant interaction effects, and great care must be taken in the analysis and in interpreting the results.

Regression slopes and confidence intervals for N_0 assume that there is no error in the independent variable, cumulative catch (K_t) from a particular area. In other words, catch statistics (including effort, location, and catch variables) must, for practical purposes, be completely reliable (Ricker 1975). This requirement will place a great onus on the reporting and interpretation of catch statistics if they are to be used "in season" to estimate yield. Certainly, a great improvement in the timeliness and quality of current reporting for this fishery will be required. Any uncertainty (reporting errors) in catch or statistical reporting areas will lead to an underestimate of catchability, q, and an overestimate of the initial biomass, N_0 (Ricker 1975). Intentional misreporting to mask declines in catch rate would lead to additional bias.

2.7   Assessing "commercially available" recruited biomass

During discussion of the early results of this work, the Ministry of Fisheries Shellfish Fishery Assessment Working Group suggested that depletion estimates of biomass might be better compared with estimates of "commercially available" biomass than with estimates of total recruited biomass. Such estimates have only recently been developed and accepted by the working group as a guide for the Ministry's catch limit setting processes, and most had to be estimated *post hoc*.

The proportion of total recruited biomass (above the MLS in force at the time) which is "commercially available" was estimated by assessing the biomass contained in areas which had an observed density greater than a range of assumed critical densities. In the absence of detailed knowledge of the spatial distribution of legal sized scallops and of the operational and efficiency characteristics of all gear in use in the fishery, any estimate of critical density will be arbitrary. However, reasonable values were used to estimate that a density of 0.08 m^{-2} was likely to lead to a fleet-wide catch rate of over 30 kg h^{-1} for essentially random fishing in "good" areas (Table 1). One might expect that experienced fishers would be able to maintain better catch rates by directing their effort at areas where the returns were better, because of higher dredge efficiency or denser aggregations of scallops.

All surveys between 1991 and 1998 were reanalysed to assess the commercially available biomass in each year. Instead of using the estimated density of (recruited) scallops for each shot, the estimated density above critical density was used in calculations of recruited biomass. Shots where the observed density was less than the critical density were accorded a value of zero. The critical density was varied from 0.02 to 0.08 m^{-2} for each survey to assess the sensitivity of the estimate of commercially available biomass to the assumed critical density.

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Table 1: Assumptions used to estimate the critical density of scallops over which biomass is considered to be "commercially available".

Parameter	Value used	Source
Dredge speed	3.0 kn (1.54 m s^{-1})	Assumed
Average efficiency on sand	41%	Cryer & Parkinson 1999a
Average dredge width	1.84 m	Groomed CELR data 1991–1998
Proportion of time fishing	90%	Assumed
Actual sweep rate	= 1.54 * 3600 * 1.84 * 0.9 = 9180 m^2 h^{-1}	–
Effective sweep rate	= 9180 * 0.41 = 3765 m^2 h^{-1}	–
Average weight of >90 mm scallop	~80 g	Cryer & Parkinson 1999a
Average weight of >100 mm scallop	~100 g	Cryer & Parkinson 1999a
Catch rate (>100 mm) at 0.08 m^{-2}	= 3765 * 0.08 * 100 / 1000 = 30.1 kg h^{-1}	–

3. RESULTS

3.1 Summary of catch and effort in the Coromandel scallop fishery, 1991–98

The reported catches by Scallop Statistical Reporting Area for the years 1991 to 1998 are shown in Table 2. The bed close to Whitianga (Statistical Reporting Area 2L) consistently provided a large proportion of the total estimated catch in these years, and only this bed and those at Little Barrier Island (2R) and Colville (2W) have been fished in all of the eight years. There has been sporadic fishing at Motiti Island (2A), off Waihi Beach (2E, 2F), at Slipper Island (2H), Great Barrier Island (2S), and Waiheke Island (2X) (although it is likely that most of the records for 2X in 1991 were errors and should have indicated 2W, the correct area for "Gerry's Patch").

Biomass estimates are available for Statistical Reporting Areas 2L and 2X in all of the years 1991–1998, for Statistical Reporting Areas 2E and 2F from 1993 onwards, and for all substantive fished Statistical Reporting Areas from 1995 onwards. Those for Statistical Reporting Areas 2L and 2R are presented in Table 3. Some of these estimates have been published previously (Cryer 1999), but others have been generated by re-analysis of historical data using updated estimates of average dredge efficiency and its variance.

For the Whitianga bed, surveying was conducted mostly by divers double counting circular search patterns. This method is assumed to be 100% efficient at retrieving scallops close to the minimum legal size. However, for operational and health and safety reasons, some of the deeper parts of the Whitianga bed have been sampled using dredges since 1992. Biomass estimates by dredge are made using an area swept method, corrected for the estimated average efficiency of the dredge used (e.g., Cryer & Parkinson 1999a). In the 1992 survey, the area sampled by dredge was 13% of the whole, but between 1993 and 1997 the area sampled by dredge was about 26% of the whole. Dredges were used for all Little Barrier Island surveys and for the entire 1998 Whitianga survey. Variance associated with correction for dredge efficiency is incorporated in c.v.s presented here. To ensure comparability of biomass estimates and their variances, a standard multiplier to account for dredge efficiency (2.437 with a c.v. of 10.2%) was applied to all stratum specific biomass estimates where dredges were used.

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Table 2. Estimated catch (t, greenweight) for each scallop statistical reporting area ("Stat" Area), in the Coromandel fishery since 1991. Estimates from the screened Coromandel database derived in 1999 for the assessment of the depletion method, and may differ slightly from estimates in other reports.

Stat	1991	1992	1993	1994	1995	1996	1997	1998
2A	–	11	49	91	39	–	–	–
2B	–	–	4	–	–	–	–	–
2C	–	–	4	–	1	2	12	–
2D	–	–	14	–	–	–	–	–
2E	–	76	55	17	–	–	–	–
2F	–	5	25	2	–	–	–	–
2G	–	–	–	–	–	1	–	–
2H	–	2	28	14	5	7	1	1
2I	–	–	3	1	1	5	–	–
2J	–	–	–	–	–	–	–	–
2K	–	9	2	8	1	–	–	–
2L	704	711	220	131	302	358	505	198
2M	–	–	5	–	–	–	–	1
2N	–	4	6	–	–	–	–	–
2Q	–	–	1	–	–	–	1	–
2R	81	74	77	53	138	172	157	2
2S	–	–	4	2	27	8	3	–
2W	150	75	1	17	22	24	23	1
2X	396	3	1	–	1	–	5	–

Table 3. Recruited biomass estimates (shell length equal to or greater than MLS) for Statistical Reporting Areas 2L and 2R between 1991 and 1998. The MLS was 90 mm for 1991–94, and 100 mm for 1995–98. No surveys were conducted at Little Barrier Island 1991–94. Methods are S, scuba divers; D, dredge; and S/D, a combination of the two methods (where dredge sampling was conducted in 13–26% of the total sampled area).

Year	MLS	Whitianga	c.v.	N sites	Method	Little Barrier	c.v.	N sites	Method
1991	100	783	0.15	80	S	–	–	–	–
1992	100	1 208	0.14	81	S/D	–	–	–	–
1993	100	711	0.12	112	S/D	–	–	–	–
1994	100	457	0.13	103	S/D	–	–	–	–
1995	90	699	0.18	78	S/D	398	0.20	11	D
1996	90	987	0.26	71	S/D	619	0.32	18	D
1997	90	835	0.17	97	S/D	521	0.22	32	D
1998	90	857	0.14	49	D	129	0.21	13	D

Biomass estimates for the Whitianga bed generally have a c.v. of 12–18% (including variance associated with the estimated average dredge efficiency), although the 1996 estimate had a much wider c.v. of 26%. At Little Barrier Island, where fewer samples have been taken, biomass estimates have had a c.v. of 20–32%. Thus, the biomass estimates from the Whitianga bed are considered to be the most reliable in the fishery.

3.2 Simple correlation between biomass and catch rate

For the Whitianga bed (where biomass estimates are probably most reliable), there is a marginally significant correlation between survey estimates of biomass and catch rate averaged over the first calendar month of fishing (Figure 2; $r_6 = 0.71$, $p \sim 0.05$). However, this relationship does not extend to longer periods (e.g., over the first 10 weeks of fishing, $r_6 = 0.55$, $p \sim 0.15$). There are insufficient data to conduct a realistic analysis for the bed at Little Barrier Island.

A regression of start-of-season recruited biomass on catch rate could be used to estimate biomass "in-season". However, the weak nature of the relationship (see Figure 2) means that an estimate of biomass based on catch rates would have poor precision; even at the pivotal point of the regression (where predictive power is greatest), the 95% confidence range for start-of-season biomass is 632–1000 t, covering half of the range of observed values for recruited biomass (450–1200 t). A regression line "forced" through the origin (a model which assumes that catch rate is directly proportional to recruited biomass) generates a similar confidence range of 595–965 t.

3.3 Depletion regression estimates of biomass

3.3.1 General considerations

Catch rates across the whole fishery typically decline as the season progresses (Figure 3), and this pattern suggests that a "depletion" analysis of catch and effort data may provide a cost-effective alternative to pre-season surveys (surveys might cost in the region of five times as much as a CPUE analysis). However, although there is a fairly consistent trend of decreasing catch rate in the early weeks of the season, this is less evident in the second half of each season and, in some seasons, there are rapid increases in fleet average catch rate. These rapid increases are probably caused by movement of fishing vessels from one fishing location to another as news of better catch rates spreads. For this reason, depletion analyses were conducted at the level of single Statistical Reporting Areas, the smallest scale possible with these catch and effort data.

It is possible that the "flattening" of the catch rate trend is a result of more scallops recruiting to the fishable stock as the season progresses. The growth rate of scallops is likely to be much faster in the second half of the season as water temperature rises. For this reason, depletion analysis was conducted using data from the first 8 weeks of fishing (not necessarily the first 8 weeks of the season), as well as with all the available data in each year. For depletion analysis to be of much utility in setting or moderating catch limits in-season, 8 weeks of returns is probably the maximum amount of data that can reasonably be expected to be available.

Because of the consistent catch and the availability of survey biomass estimates for comparison, Statistical Reporting Area 2L at Whitianga was selected for the most complete analysis. Statistical Reporting Area 2R was also examined, but the lack of any biomass estimates for 1991–94 precludes comparison of depletion and survey methods of estimating biomass in these areas for years when the 100 mm MLS was in force. The data from Statistical Reporting Area 2W were not analysed because of the small size of the catch and the inconsistent seasonal and spatial pattern of fishing in this area.

3.3.2 Statistical Reporting Area 2L (Whitianga, Mercury Islands)

Estimates of recruited biomass by depletion analysis are available for seven of the eight years between 1991 and 1998 (Table 4). The MLS was 100 mm for the first four of these years, but was reduced to 90 mm at the start of the 1995 season (for commercial fishers only). Fishery-independent survey estimates of recruited biomass are available for all eight years, from dive surveys (usually with

complementary dredging in deeper strata). The precision of survey and depletion estimates of biomass are broadly similar (10–25%) if only statistically significant depletion estimates are used. Non-significant depletion estimates generate very imprecise lower bounds and intractable upper bounds.

Table 4. Depletion estimates of biomass with upper and lower 95% confidence limits for the Whitianga bed, Statistical Reporting Area 2L. Because the confidence limits generated using this method are asymmetrical, upper and lower equivalent "c.v.s" are given (each being half of the respective 95% confidence interval), together with their average (for approximate comparison with survey c.v.s in Table 3). *, regression slope not significantly different from zero; –, estimate intractable.

Year	Biomass estimate (kg)	Lower 95% limit	Upper 95% limit	Lower "c.v."	Upper "c.v."	Average "c.v."
All data:						
1991	*11 394	2 429	–	0.39	–	–
1992	1 456	1 276	1 728	0.06	0.09	0.08
1993	525	409	809	0.11	0.27	0.19
1994	–	–	–	–	–	–
1995	724	542	1 299	0.13	0.40	0.26
1996	695	559	996	0.10	0.22	0.16
1997	818	714	988	0.06	0.11	0.08
1998	259	217	347	0.08	0.17	0.13
First 8 weeks:						
1991	1 955	1 526	2 788	0.11	0.21	0.16
1992	976	724	1 636	0.13	0.34	0.23
1993	*489	290	–	0.20	–	–
1994	*–	–	–	–	–	–
1995	337	281	448	0.08	0.16	0.12
1996	*459	223	–	0.26	–	–
1997	*696	390	–	0.22	–	–
1998	196	165	254	0.08	0.15	0.11

The 1994 depletion estimates of biomass for the Whitianga bed were essentially intractable because the regression slopes were positive (catch rate increased with cumulative catch). Several other estimates came from regression lines with a slope not significantly different from zero, and this renders the upper 95% confidence limit intractable (as the regression slope becomes positive). Whether or not these "non significant" depletion estimates were included in the analysis, survey estimates of start-of-season recruited biomass were not significantly correlated (with or without "Bonferroni" correction for 15 repeat tests, $p_1 = 0.0033$, Miller 1981) with either of the depletion estimates, with the total catch from this bed in each year, or with mean catch rate over the first 8 weeks of fishing or the whole season (Table 6). There was, however, a large change in the relationship between survey and depletion estimates of biomass when non-significant results were excluded: a negative correlation of -0.10 changed to a positive correlation of +0.72. When depletion estimates were made using data from only the first 8 weeks of fishing (as would be the case in any real assessment application of this technique), the correlation was poor (and quite strongly negative if non-significant results were included). Both patterns suggests that there is no stable relationship between survey and depletion estimates.

Table 5. For Statistical Reporting Area 2L (Whitianga), biomass estimates by pre-season survey (excluding the deep stratum off Opito Bay which was sampled only in 1998), by depletion analysis of catch rates throughout the season, $B_{zero}(a)$, or for the first 8 weeks of the season, $B_{zero}(8)$, whole season catch (t) also expressed as a proportion of the three biomass estimates, and fleet average catch rates for four years when the minimum legal size, MLS, was 100 mm and four years when it was 90 mm. Survey biomass was estimated as the weight of scallops likely to be at or greater than MLS at the regulated start of the season. –, no fishing in July 1993, 1994 or 1995, or depletion estimates of biomass intractable. Non-significant depletion estimates of biomass are underlined.

Year	MLS	Biomass estimate (t) Survey	$B_{zero}(a)$	$B_{zero}(8)$	Catch	Catch as a % of Survey	$B_{zero}(a)$	$B_{zero}(8)$	Catch rate (kg h^{-1}) July	Aug	Sept	8 wk	Season
1991	100	783	11 394	1 955	704	89.9	6.2	36.0	157	145	136	142	142
1992	100	1 208	1 456	976	711	58.9	48.9	72.8	150	117	104	121	102
1993	100	711	525	489	217	30.5	41.3	44.3	–	74	66	67	62
1994	100	457	–	–	131	28.7	–	–	–	44	44	45	47
1995	90	699	724	337	302	43.2	41.7	89.6	–	121	82	90	81
1996	90	987	695	459	358	36.2	51.4	77.8	125	95	89	102	84
1997	90	835	818	696	505	60.4	61.7	72.5	121	103	79	99	76
1998	90	857	259	196	198	23.1	76.4	101.4	90	64	44	68	56

Table 6. Correlation matrix (top, values of r; bottom, values of p) for estimates of biomass, catch, and CPUE for Statistical Reporting Area 2L (for definitions, see Table 5). First three columns estimated using all regression lines from the depletions methods, $B_{zero}(a)$ and $B_{zero}(8)$, middle three columns estimated using only significant regression lines from the depletions methods, last three columns common to both approaches. Significant values of p are boxed (Bonferroni corrected for 15 tests, critical p = 0.0033) (NB, degrees of freedom are not constant due to empty cells in Table 5).

r	Non-significant used Survey	$B_{zero}(a)$	$B_{zero}(8)$	Non-significant deleted Survey	$B_{zero}(a)$	$B_{zero}(8)$	Common results Season catch	8 week CPUE	Season CPUE
Survey	1.0000			1.0000					
$B_{zero}(a)$	-0.1031	1.0000		0.7247	1.0000				
$B_{zero}(8)$	-0.6593	0.9374	1.0000	0.0770	0.9749	1.0000			
Catch	0.6483	0.6314	0.8367	0.6483	0.9505	0.8586	1.0000		
8 wk CPUE	0.6259	0.7637	0.8777	0.6259	0.9051	0.9497	0.9414	1.0000	
S'sn CPUE	0.4250	0.8928	0.9408	0.4250	0.9357	0.9756	0.8857	0.9570	1.0000

p									
Survey	–			–					
$B_{zero}(a)$	0.8120	–		0.0616	–				
$B_{zero}(8)$	0.1648	0.0012	–	0.8674	0.0086	–			
Catch	0.0821	0.1027	0.0134	0.0821	0.0017	0.0546	–		
8 wk CPUE	0.0969	0.0339	0.0065	0.0969	0.0065	0.0176	0.0005	–	
S'sn CPUE	0.2939	0.0047	0.0010	0.2939	0.0029	0.0084	0.0034	0.0002	–

When non-significant results were included (but not when they were excluded) there was a significant correlation between the two depletion estimates. Both depletion estimates tended to be correlated with average catch rate over the whole season, but not with average catch rate over the first 8 weeks of fishing. Catch and average catch rate were highly correlated. There were several significant

correlation coefficients among various monthly mean catch rates and season average catch rates, but these are not very surprising or informative and are not reported in detail.

Depletion regression lines for the Whitianga bed (Figure 4) using data from only the first 8 weeks of fishing were consistently steeper than those using data from the whole season. There are at least two plausible explanations for this trend. First, fishers may first remove a "sub-population" of highly catchable (high q) scallops first before moving onto the wider population which is less catchable (low q). Second, catch rates may be "buoyed" during the latter part of the season by the growth of new scallops into the recruited population and by growth (in weight) of those animals present. It is hard to choose between these two alternatives without modelling the population in some detail.

The 8 week depletion estimate was usually lower than the survey estimate. Again, there are at least two plausible explanations, and a paucity of information to test their relative likelihood. First, fishers may first remove that portion of the recruited biomass which is highly catchable and available at commercially viable catch rates. This proposition was tested approximately (and found wanting; see Section 3.3.4) by replacing the estimate of recruited biomass with an estimate of "commercially available" biomass. Second, incidental damage and mortality caused by dredging may account for the difference between the survey estimate and the depletion estimate. Cryer & Morrison (1997) showed that incidental mortality could be a highly significant factor in the Coromandel fishery, especially at a MLS of 100 mm where a large proportion of scallops greater than 90 mm shell length returned to the water will die.

3.3.3 Statistical Reporting Area 2R (Little Barrier Island)

Statistically significant depletion estimates of biomass are available only for 3 or 4 years because fishing has been less consistent than in Statistical Reporting Area 2L, especially during the first 8 weeks of each season (Table 7). Fishery-independent survey estimates of recruited biomass (by dredge) are available for only the most recent 4 years (under a 90 mm MLS) (Table 8). The precision of the statistically significant depletion estimates is highly variable (5–30%), but comparable with that of dredge surveys (20–30%).

The availability of only four survey estimates of biomass for Little Barrier Island has reduced the statistical degrees of freedom for this analysis to almost unusable levels. There is only one significant correlation (after Bonferroni correction for multiple tests, Miller 1981) among survey estimates of start-of-season recruited biomass, depletion estimates of biomass, total catch from this bed in each year, and monthly mean estimates of catch rate (Table 9). Whether or not non-significant depletion estimates of biomass were included in the analysis, the only significant correlation was between average catch rates calculated over the first 8 weeks of fishing and over the whole season. As the season at Little Barrier Island rarely exceeds 8 weeks, this result is neither informative nor useful.

Relationships between the depletion estimates of biomass and estimates of catch and catch rate tend to be negative when non-significant depletion estimates are included. The exclusion of these non-significant estimates reduces the degrees of freedom and leads to some sign changes (to positive correlation coefficients). This "instability" suggests that modest amounts of additional data are not likely to depict depletion estimates of biomass as reliable.

Perhaps because fishing is less consistent at Little Barrier Island, there is much less consistency in the relationship between the depletion regression lines calculated using data from only the first 8 weeks of fishing compared with those calculated using data from the whole season (Figure 5). In 1992 and 1993, the whole season depletion regression is steeper than the 8 week depletion regression, and in many other years, the two lines are indistinguishable (sometimes because almost all of the fishing took place in an 8 week period). Because survey estimates of biomass are lacking for the first 4 years

of the analysis, statements about the relationship between survey and depletion estimates of biomass cannot be very certain. However, where both types of estimate are possible (in only three years), the depletion estimates are considerably lower than the survey estimates of biomass (see Table 8). The same potential explanations apply as for the Whitianga bed.

Table 7. Depletion estimates of biomass with upper and lower 95% confidence limits for the Little Barrier Island bed, Statistical Reporting Area 2R. Because the confidence limits generated using this method are asymmetrical, upper and lower equivalent "c.v.s" are given (each being half of the respective 95% confidence interval), together with their average (for approximate comparison with survey c.v.s in Table 3). *, regression slope not significantly different from zero; –, estimate intractable.

Year	Biomass estimate (t)	Lower 95% limit	Upper 95% limit	Lower "c.v."	Upper "c.v."	Average "c.v."
All data:						
1991	211	156	378	13.1	39.5	26.3
1992	135	111	181	8.7	17.1	12.9
1993	*1 423	262	–	40.8	–	–
1994	*205	120	952	20.6	–	–
1995	199	152	371	11.7	43.6	27.6
1996	221	203	248	4.1	6.1	5.1
1997	279	236	360	7.7	14.5	11.1
1998	–	–	–	–	–	–
First 8 weeks:						
1991	98	78	138	10.2	20.5	15.4
1992	*–	–	–	–	–	–
1993	*–	–	–	–	–	–
1994	*205	120	952	20.6	–	–
1995	199	152	371	11.7	–	–
1996	215	180	288	8.2	17.0	12.6
1997	273	213	427	11.1	28.1	19.6
1998	–	–	–	–	–	–

Table 8. For Statistical Reporting Area 2R (Little Barrier Island), biomass estimates by pre-season survey (no surveys 1991–94), by depletion analysis of catch rates throughout the season, $B_{zero}(a)$, or for the first eight weeks of the season, $B_{zero}(8)$, catch (t) also expressed as a proportion of the three biomass estimates, and fleet average catch rates for four years when the minimum legal size, MLS, was 100 mm and four years when it was 90 mm. Survey biomass was estimated as the weight of scallops likely to be at or greater than MLS at the regulated start of the season. –, no survey, no fishing, or depletion estimate of biomass intractable. Non significant depletion estimates of biomass are underlined.

		Biomass estimates (t)				Catch as a % of			Catch rates (kg h^{-1})				
Year	MLS	Survey	$B_{zero}(a)$	$B_{zero}(8)$	Catch	Survey	$B_{zero}(a)$	$B_{zero}(8)$	July	Aug	Sept	8 wk	Season
1991	100	–	211	98	81	–	38.2	82.4	180	155	125	144	126
1992	100	–	135	–	71	–	53.0	7.8	116	104	117	115	90
1993	100	–	1 423	–	76	–	5.3	19.1	–	–	66	77	74
1994	100	–	205	205	53	–	25.9	25.9	–	–	–	–	92
1995	90	398	199	199	138	34.7	69.6	69.3	–	235	161	198	197
1996	90	619	221	215	172	27.8	78.0	80.1	225	169	111	157	144
1997	90	521	279	273	157	30.1	56.2	57.5	153	124	58	125	113
1998	90	129	–	–	2	1.9	0.0	0.0	–	–	47	47	47

Table 9. Correlation matrix (top, values of r; bottom, values of p) for estimates of biomass, catch, and CPUE for Statistical Reporting Area 2R (for definitions, see Table 5). First three columns estimated using all regression lines from the depletions methods, $B_{zero}(a)$ and $B_{zero}(8)$, middle three columns estimated using only significant regression lines from the depletions methods, last three columns common to both approaches. Significant values boxed (Bonferroni corrected for 15 tests, critical p = 0.0033) (NB, degrees of freedom are not constant due to empty cells in Table 8).

r	Non-significant used			Non-significant deleted			Common results		
	Survey	$B_{zero}(a)$	$B_{zero}(8)$	Survey	$B_{zero}(a)$	$B_{zero}(8)$	Season catch	8 week CPUE	Season CPUE
Survey	1.0000			1.0000					
$B_{zero}(a)$	0.3328	1.0000		0.3328	1.0000				
$B_{zero}(8)$	0.2756	0.0503	1.0000		0.8349	1.0000			
Catch	0.9660	-0.2363	-0.3136	0.9660	0.6976	0.8833	1.0000		
8 wk CPUE	0.6776	-0.6998	-0.4686	0.6776	0.0616	-0.4307	0.7679	1.0000	
S'sn CPUE	0.5936	-0.4695	-0.4585	0.5936	0.1540	-0.2397	0.7570	0.9820	1.0000
p									
Survey	–			–					
$B_{zero}(a)$	0.7840	–		0.7840	–				
$B_{zero}(8)$	0.7548	0.9618	–	0.3711	–				
Catch	0.0340	0.6911	0.7546	0.0340	0.1903	0.3106	–		
8 wk CPUE	0.3224	0.0936	0.3013	0.3224	0.8989	0.4794	0.0438	–	
S'sn CPUE	0.4064	0.2495	0.2620	0.4064	0.7280	0.6537	0.0296	0.0001	–

3.3.4 Effects of considering commercially available biomass instead of total biomass

For the Whitianga bed, there was a strong relationship between the total recruited biomass of scallops and the biomass which was considered to be "commercially available" (found in patches with a density of $0.02-0.08$ m^{-2} or more, $r_6 = 0.995-0.999$, $p < 0.001$, Figure 6) However, there was also a strong relationship between total biomass and the proportion of that biomass which was considered to be "commercially available" (in patches with a density of 0.08 m^{-2} or more, $r_6 = 0.927$, $p = 0.003$, see lower panel in Figure 6). Thus, the higher the total biomass, the greater the proportion (as well as the tonnage) that fishers might realistically expect to extract before catch rates became unacceptably low. This increases the "contrast" between years of high and low biomass; the ratio of the highest to the lowest biomass estimate increased from 2.6 to 4.0 as the critical density was increased to 0.08 m^{-2}. The commercially available proportion of the total recruited biomass in 1998 was a little lower than it was in 1997; although the total biomass increased slightly on 1997, the commercially available biomass decreased.

Using estimates of commercially available biomass instead of total recruited biomass did not substantially improve the correlation between depletion and survey estimates of biomass (Table 10), nor did it much change the relationship between the depletion estimates and the total catch or average catch rates. This is probably because the total biomass and the commercially available biomass are so highly correlated. De-coupling the total and commercially available biomass estimates would probably require large changes from year to year in the patchiness of legal sized scallops and, hence, in the proportion thought to be commercially catchable. This appears not to be the case. Commercially available biomass is correlated with total recruited biomass and not with depletion estimates of biomass.

Table 10. Estimated correlation coefficients (r, top) and probability values (p, bottom) for relationships between survey biomass and depletion estimates of biomass (Bzero(all) and Bzero(8)). Values are given for separate analyses where all depletion estimates are included (All), or where only those with regression slopes significantly different from zero are included (Sig. only). The effect of restricting the estimate of biomass to that portion which is "commercially available" was assessed by considering critical densities of 0.04 and 0.08 m^{-2}.

	Total biomass		Biomass > 0.04 m^{-2}		Biomass > 0.08 m^{-2}	
	All	Sig. only	All	Sig. only	All	Sig. only
r						
Bzero(all)	-0.1031	0.7247	-0.1105	0.7583	-0.1215	0.7745
Bzero(8)	-0.6593	0.0770	-0.6476	0.0929	-0.6343	0.0779
p						
Bzero(all)	0.8120	0.0616	0.7988	0.0464	0.7793	0.0400
Bzero(8)	0.1648	0.8674	0.1728	0.8405	0.1822	0.8658

4.   DISCUSSION AND CONCLUSIONS

The two beds at Whitianga (2L) and Little Barrier Island (2R) have together provided more than 80% of landings from the Coromandel scallop fishery since 1992, and are likely to remain of critical importance. Any prospective assessment technique for this fishery must be capable of generating biomass estimates with acceptable precision in at least these two areas and, preferably, all other areas.

Depletion analyses based on the Leslie model (Leslie & Davies 1939) were applied to rigorously screened and groomed catch and effort data from these two beds. Such regression estimates were computed using data from the whole season and, to simulate what might be available for an "in-season" review of catch limits, using data from the first 8 weeks of fishing (not necessarily the first 8 weeks of the regulated season). Despite the availability of complete catch and effort data, and the rigorous screening process (removal of outliers), significant depletion estimates of biomass could be generated for only four years out of eight (Table 11), and some were intractable. One of the significant depletion estimates for Statistical Reporting Area 2R was only marginally significant.

Depletion estimates of biomass were not significant for about half of the years examined and those that were significant were not correlated with survey estimates of biomass. For the Whitianga bed, comparing depletion estimates of biomass with "commercially available" recruited biomass instead of with total recruited biomass did not change this conclusion.

In an assessment setting, the performance of the depletion method could be expected to be significantly degraded by slow reporting, poor reporting, punching errors, inadequate screening and error checking (especially by staff not familiar with the fishery), or by deliberate misreporting by fishers who might perceive a short term gain in biasing the assessment. Put simply, the performance of depletion regression methods presented in this report is likely to be optimistic, and worse results should be expected in an "in-season" assessment, especially of beds fished less consistently than those in 2L and 2R.

The only other area for which consistent survey data are available is Statistical Reporting Area 2X, which includes the once-prolific bed east of Waiheke Island. Following the rapid decline of this population in the late 1980s, fishing has been sporadic, and the amount of catch and effort data is currently inadequate for a realistic appraisal of the depletion method. However, there is no reason to suppose that the method would perform better in this area than in the two areas already appraised, and the point is moot unless a substantial fraction of the catch is likely to be taken from this area. Although there have been mildly encouraging signs in recent biomass surveys, the indications are that

the Waiheke Island bed will continue to be of only minor importance. This increases the importance of any assessment based on catch and effort in Statistical Reporting Areas 2L and 2R.

Most depletion estimates of biomass in this study were considerably lower than survey estimates, but some were much larger, probably as a result of data problems (statistical error in catch or effort is most likely to lead to a flattening of the regression line and a positive bias in the biomass estimate). On its own, the lack of correlation between depletion and survey estimates of biomass need not necessarily be taken as an indication that depletion estimates are in some way inferior, especially given that the precision of some recent survey estimates of biomass in the Whitianga and Little Barrier beds has been relatively poor (target precision, as a coefficient of variation (c.v.) for the whole survey, is set by the Ministry at 20%, and some constituent beds are likely to have a c.v. greater than 20%, Cryer & Parkinson 1999a). However, the combination of poor correlation with survey estimates and the lack of significant regression slopes in about half of the cases examined for the most heavily and consistently fished beds using the best possible data, together militate against depletion analysis as a reliable tool for in-season assessment of biomass in this fishery.

Table 11. Summary of relationships between depletion and survey estimates of biomass in the two main beds of the Coromandel fishery, 1991–98 (2L = Whitianga, 2R = Little Barrier Island, * one of the four nominally significant estimates for 2R was only marginally significant). In an "in season" assessment setting, about 8 weeks of catch and effort data would probably be available.

Criterion	Statistical reporting area	
	2L	2R
Models using first 8 weeks catch effort data:		
Number of significant regressions (out of 8)	4	*4
Range of biomass estimates (% of survey, significant B_{zero} estimates only)	23–249%	35–52%
Correlation between survey and depletion estimates (all regressions)	-0.659 (NS)	0.276 (NS)
Correlation between survey and depletion estimates (significant regressions only)	0.077 (NS)	too few data
Models using all catch effort data:		
Number of significant regressions (out of 8)	6	5
Mean biomass estimate (% of survey, significant B_{zero} estimates only)	30–121%	36–54%
Correlation between survey and depletion estimates (all regressions)	-0.103 (NS)	0.333 (NS)
Correlation between survey and depletion estimates (significant regressions only)	0.725 (p ~ 0.08)	0.333 (NS)

Implicit in the management of this fishery using a Current Annual Yield (CAY) regime is the availability of annual estimates of biomass. Such estimates could be generated using pre-season surveys (e.g., Cryer & Parkinson 1999a), by in-season depletion analysis (as appraised here), or by some other survey or modelling approach. The main conclusion that can be drawn from the analyses

presented here is that depletion analysis cannot reliably generate biomass estimates, even for the core areas of the fishery, and should therefore be considered unsuitable as a means of estimating yield.

5. CONCLUSIONS

1. Catch rates in the Coromandel scallop fishery typically decline throughout each season, but these declines are unpredictable. Factors other than recruited biomass probably influence catch rate.

2. For the Whitianga bed, where survey data are likely to be most reliable, there is a marginally significant correlation between survey estimates of biomass and gross catch rate averaged over the first calendar month of fishing, but this relationship is not significant when extended to the first 8 weeks of fishing. This relationship cannot be used to estimate biomass with precision and such estimates would be highly susceptible to changes in fishing practice, changes in gear, or misreporting of catch and/or effort.

3. Catch and effort data from this fishery have a high proportion of reporting and punch errors. Not all such errors can be corrected, and they cannot be excluded from a depletion estimate of biomass without introducing bias. Errors in catch and effort data, including slow reporting (important for an "in-season" assessment), are also likely to bias depletion estimates of biomass.

4. Depletion regressions (after the method of Leslie & Davies 1939) can be used to estimate start of season biomass where there is a significant decline in catch rate with accumulated catch but, for the main beds in this fishery, such regressions are significant in only about half of the seasons examined. Some regressions had a positive slope and biomass cannot be estimated under these circumstances.

5. Where depletion estimates of biomass are tractable and statistically significant, they were not correlated with pre-season survey estimates of biomass. This conclusion is robust to modification of the biomass estimate to take account of only "commercially available" biomass. Using data from the first 8 weeks of fishing in each bed, depletion biomass estimates were 20–250% of the survey estimates. Performance of the method appears to be better for the Little Barrier bed than for the Whitianga bed, but there are too few data (only three direct comparisons between survey and depletion estimates of biomass) to support firm conclusions.

6. Neither simple regression of catch rate on biomass nor "in season" depletion estimates of biomass offer a realistic method of estimating start-of-season biomass and yield in the Coromandel scallop fishery.

6. ACKNOWLEDGMENTS

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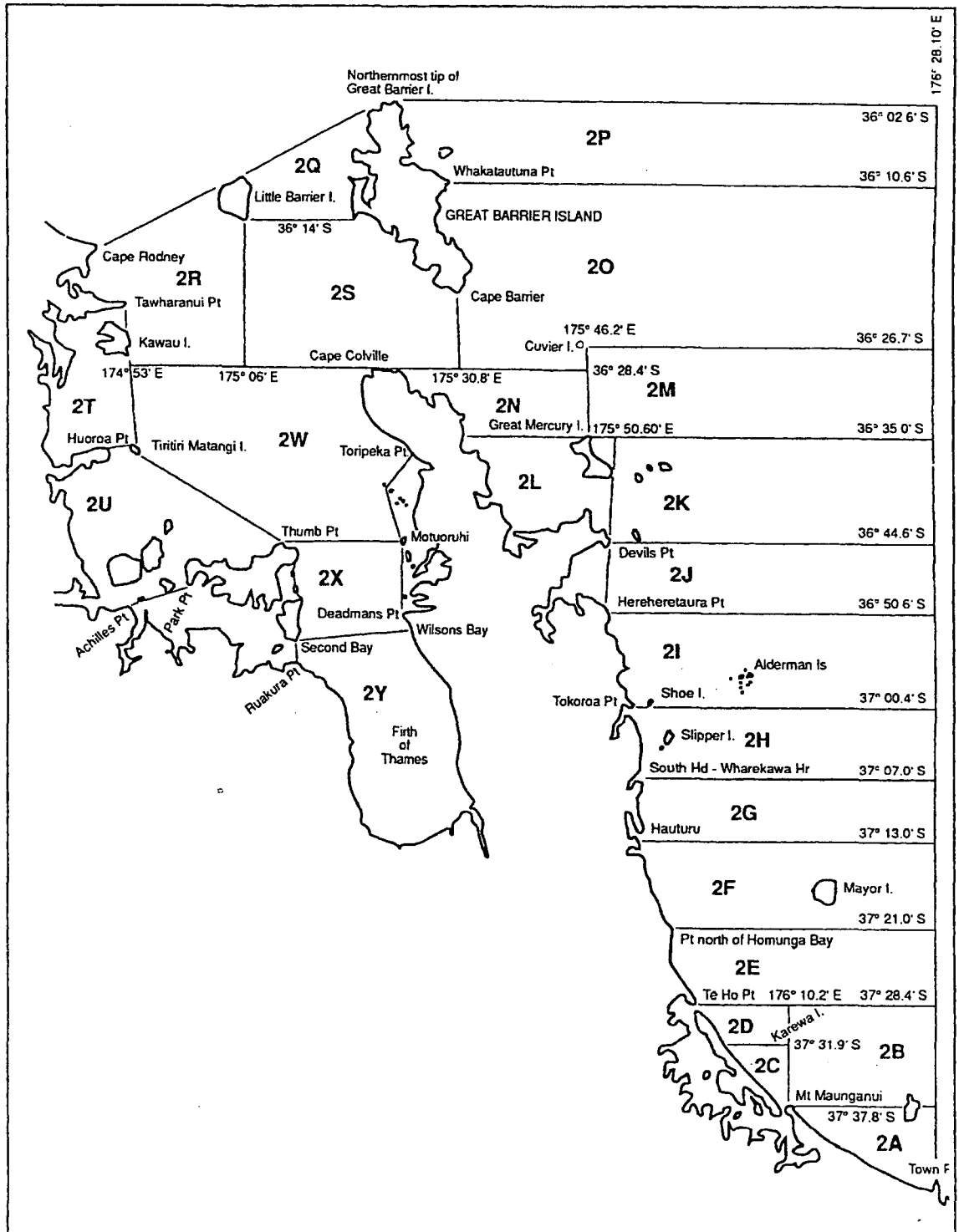
Figure 1. Scallop statistical reporting areas ("Stat Areas") for the Coromandel scallop fishery (after MAF Fisheries certified map #2, September 1991). Lines dividing Statistical Reporting Areas within this fishery and separating this fishery from the Northland scallop fishery are all approximate.
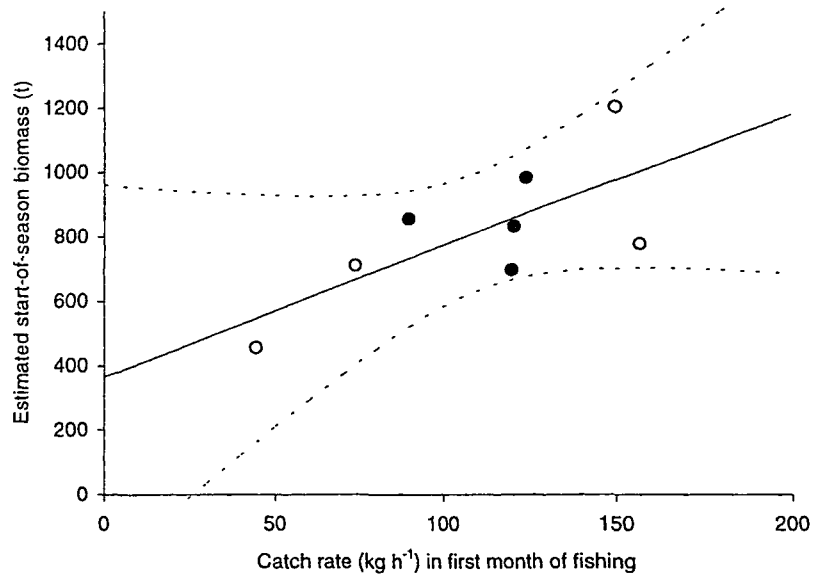
Figure 2. Relationship between catch rate during the first month of fishing in the Whitianga bed and start-of-season biomass (estimated by dive survey), 1991–98. Open circles, minimum legal size (MLS) = 100 mm; closed circles, MLS = 90 mm. The solid line represents a least squares regression, and the dashed lines represent the 95% confidence bounds of estimated values of biomass.
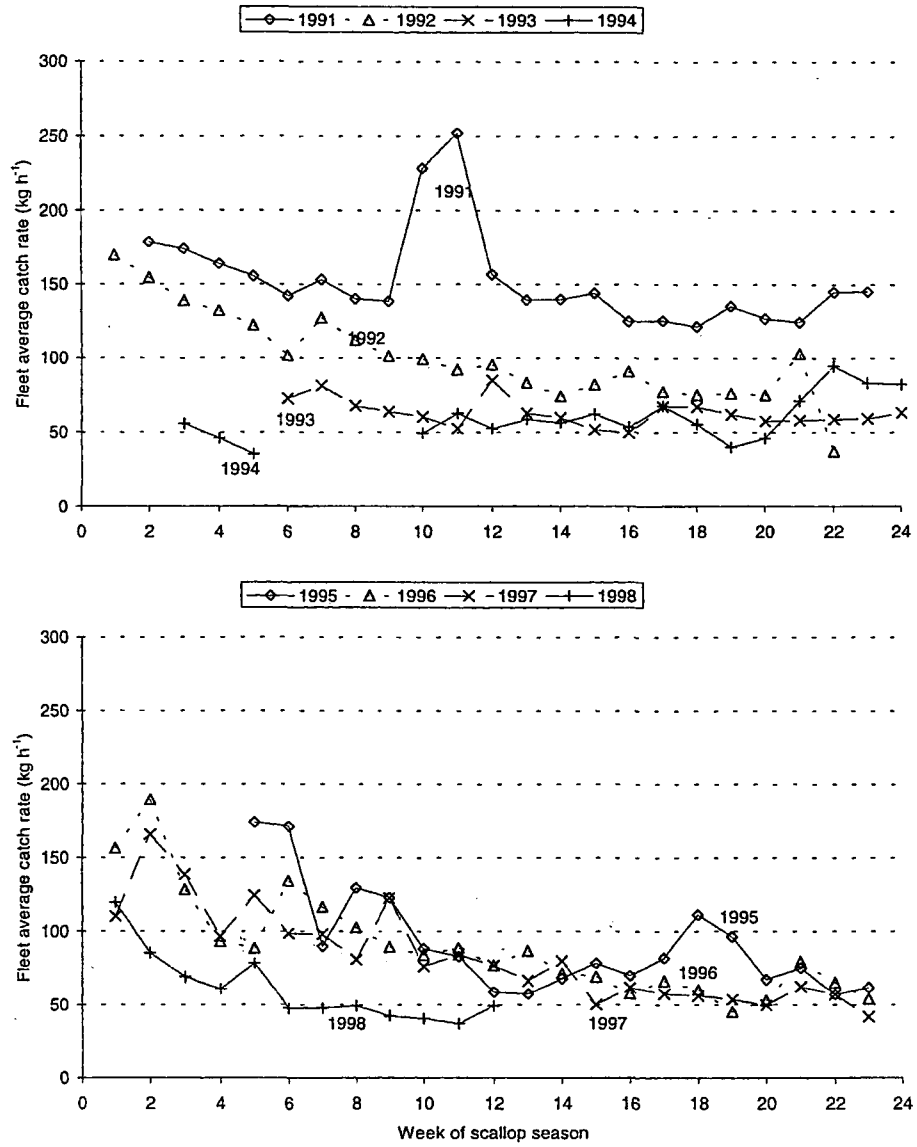
Figure 3. Raw weekly catch rates (greenweight, kg h^{-1}, across the whole Coromandel fishery) for four years under a 100 mm MLS (top) and four years under a 90 mm MLS (bottom).
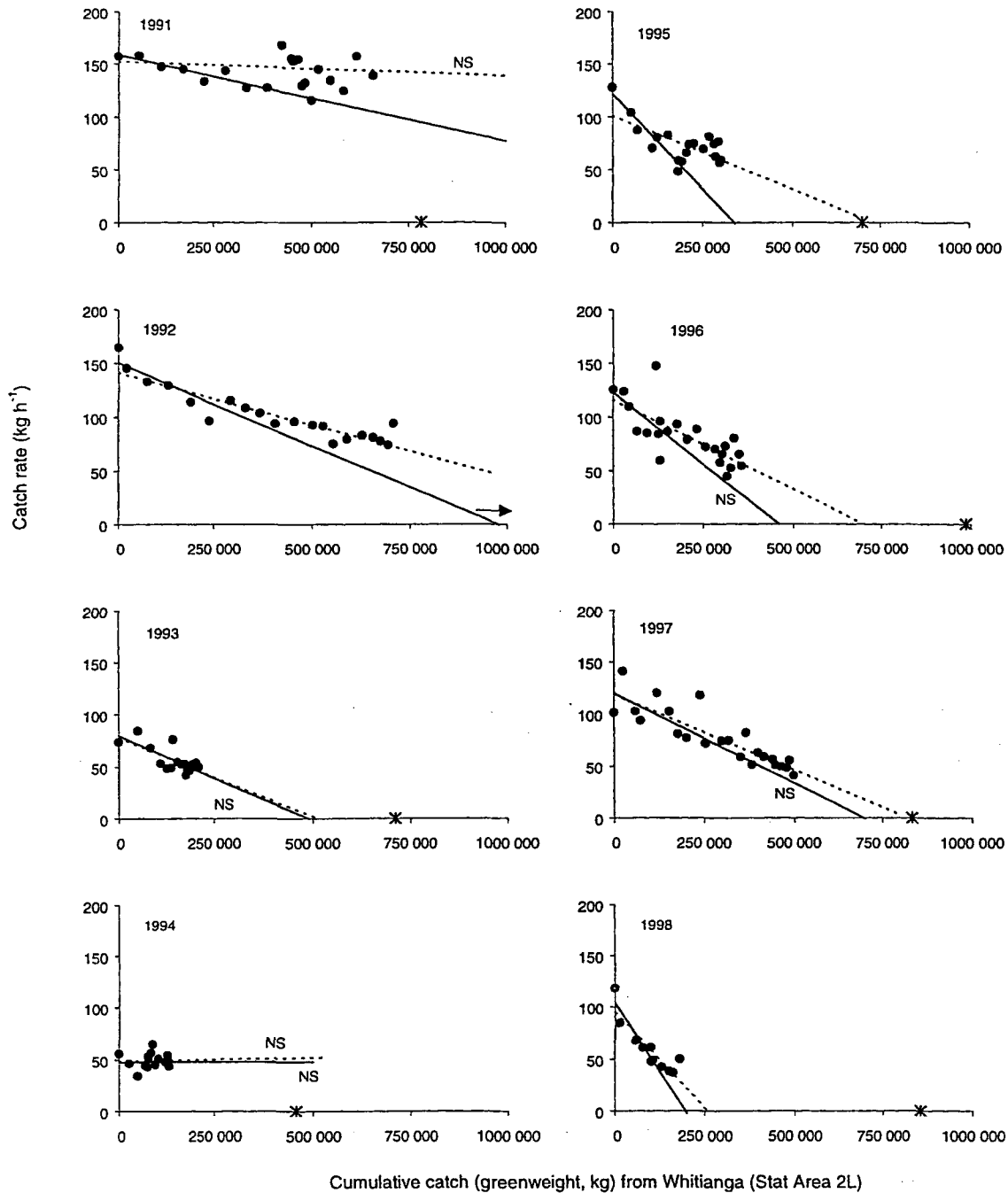
Figure 4. Depletion plots for Statistical Reporting Area 2L when data from only the first 8 weeks of fishing (solid lines) or from the whole season (dotted lines) are included in regression lines. Each data point represents weekly average catch rate for this reporting area. Regression lines are extrapolated beyond the extent of the data to indicate the approximate biomass estimate by the depletion method (where the regression line intercepts the axis of cumulative catch). Stars indicate the recruited biomass estimate from the pre-season survey in each year (which is beyond the scale in 1992, as indicated by the arrow). Regression lines which have a slope not significantly different from zero (p > 0.05, not α corrected for multiple tests) are indicated "NS", below the line for 8 week models and above the line for whole season models.

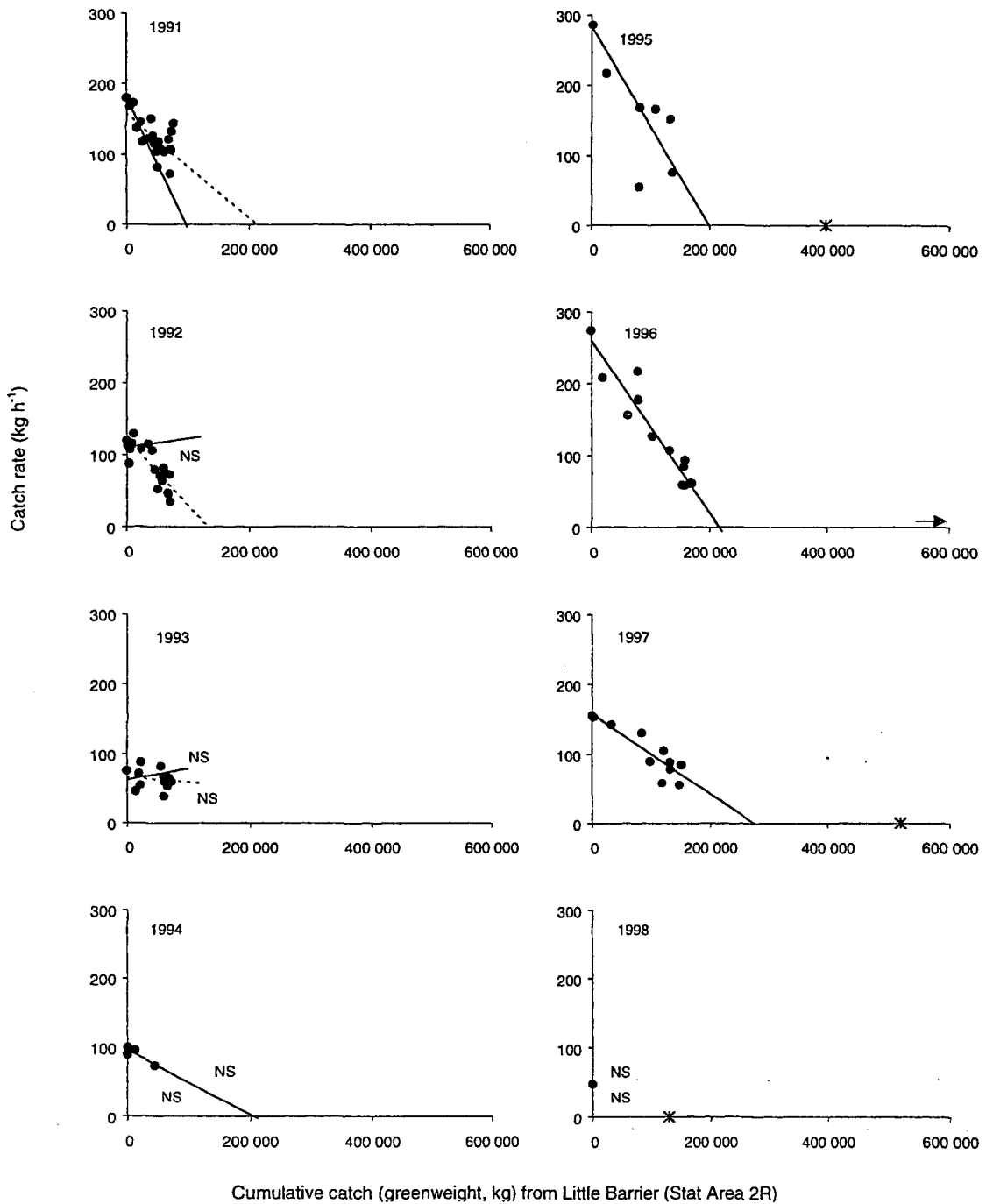Cumulative catch (greenweight, kg) from Little Barrier (Stat Area 2R)

Figure 5. Depletion plots for Statistical Reporting Area 2R when data from only the first 8 weeks of fishing (solid lines) or from the whole season (dotted lines) are included in regression lines. Regressions for whole season models (dotted lines) are not visible for years in which fishing was conducted in eight weeks or less (1994, 1995, 1998), or for years where the two models give almost identical results (1996 and 1997). Regression lines are extrapolated beyond the extent of the data to indicate the approximate biomass estimate by the depletion method. Stars indicate the recruited biomass estimate from the pre-season survey in each year (which is beyond the scale in 1996, as indicated by the arrow). Regression lines which have a slope not significantly different from zero (p > 0.05, not α corrected for multiple tests) are indicated "NS", below the line for 8 week models and above the line for whole season models.
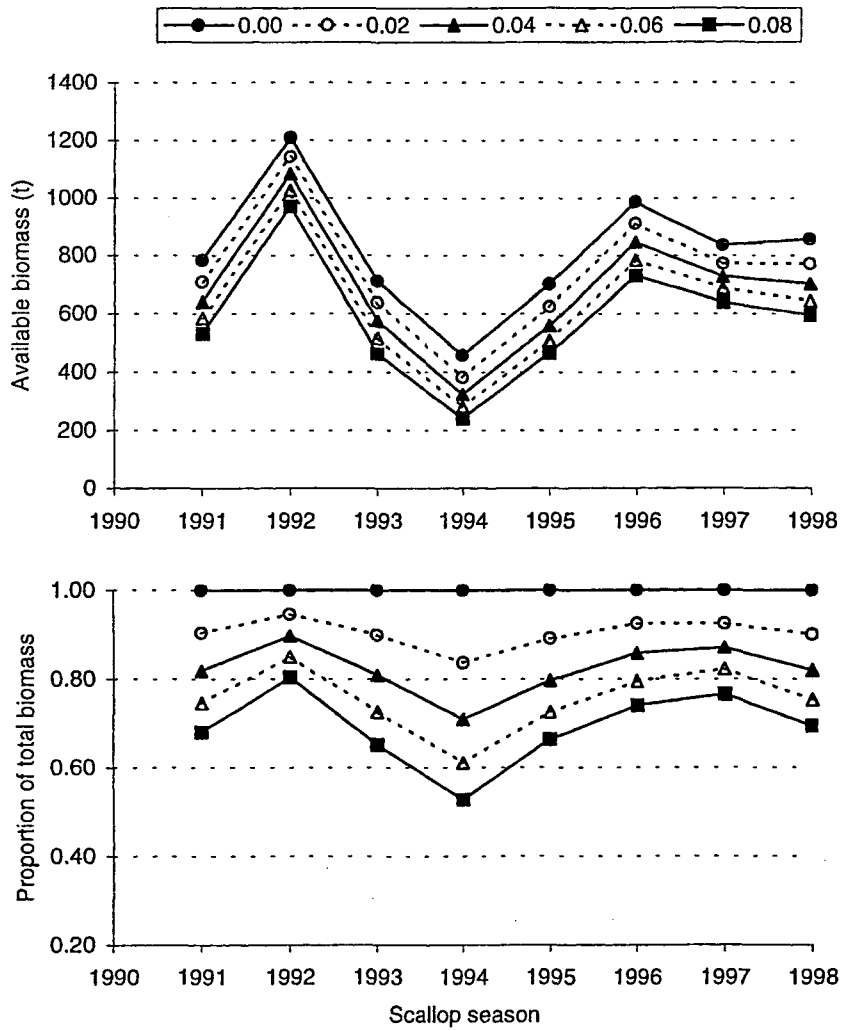
Figure 6: Estimates of "commercially available" recruited biomass (top) and the proportion of total recruited biomass which is commercially available (bottom) for critical densities of 0.02–0.08 m^{-2}, for surveys of the Whitianga bed between 1991 and 1998.