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Estimating CAY for northern commercial scallop fisheries – a technique based on estimates of biomass and catch from the Whitianga bed

Martin Cryer
MAF Fisheries North
P.O. Box 3437
Auckland

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MAF Fisheries, N.Z. Ministry of Agriculture and Fisheries

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1. EXECUTIVE SUMMARY

Commercial scallop fisheries have existed in northern New Zealand since the late 1970s: amateur fisheries for much longer. Amateur and commercial fisheries are largely, but not completely, separated spatially. A minimum legal size of 100 mm applies to both fisheries.

The most consistently fished bed within the Coromandel controlled (commercial) fishery is at Whitianga. This has been fished with varying intensity since the start of the fishery. Resource surveys have been conducted almost annually since that time. Estimated recruited biomass has ranged from 370 to 1600 t and absolute fishing mortality from 28 to 95%.

Empirical analysis of correlation between fishing pressure and subsequent population and fishery performance indicates no significant relationships between fishing pressure and biomass or commercial landings in subsequent years. There do not appear to be any adverse effects of heavy fishing above a size limit of 100 mm, nor any benefits of low fishing mortality.

A method of estimating Current Annual Yield (CAY) for the commercial fishery areas only is developed based on these empirical analyses. Yield ("CAY") is defined as the lower bound of a two-tailed 95% confidence range for the estimated total recruited biomass for all surveyed beds. A (conservative) addition to commercial allocations can be made based on the average commercial landings from unsurveyed beds in recent years. A two-stage allocation process is proposed whereby allocations to commercial fishers in this fishery can be refined part way through each season.

2. OVERVIEW

Scallops support valuable commercial and non-commercial fisheries throughout New Zealand. Recruited biomass has been found to be relatively easy to measure using dive or dredge surveys, but variable recruitment, growth, and the condition of meat and roe have made the estimation of yield difficult. A new and largely empirical method of calculating Current Annual Yield (CAY) for northern scallops is presented here based on data from the most intensively studied beds of the Coromandel fishery.

3. BACKGROUND

3.1 Biology

The New Zealand scallop 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 and a deeply concave lower valve. Scallops inhabit waters of up to about 60 m deep, but are more common in depths of 10 to 30 m. Growth rates are variable: in the Hauraki Gulf scallops grow to the minimum legal size of 100 mm in about 18 months whereas off the eastern Coromandel Peninsula this can take 3 years. The maximum age of scallops is thought to be about 6 years.

Scallops are hermaphrodite, and become sexually mature at a size of about 60 mm. They are extremely fecund and can spawn several times each year. Larval development lasts for about 3 weeks. The characteristic scallop shell does not develop until a few days after the spat settles to the sea-bed.

The very high fecundity of this species, together with considerable variability in the mortality of the early life stages, leads to great variability in recruitment from one year to the next. This leads to fluctuations in recruited biomass, especially in areas of rapid growth where there may only be one or two recruited year classes. This variability is characteristic of scallop populations worldwide, and can occur independent of fishing pressure (Shumway & Sandifer 1991).

3.2 Fisheries

The eastern coastline of the Auckland Fishery Management Area (AFMA) supports regionally important commercial fisheries, and an intense non-commercial interest in scallops. Commercial fishing for scallops is entirely by dredge, whereas non-commercial fishers take scallops by diving, dredging and, in some areas, by hand gathering. There has been an attempt to separate spatially the commercial and non-commercial fisheries for scallops in the AFMA. This has been effected largely by closing areas of high non-commercial interest to commercial dredging, but some areas of contention still exist.

Commercial fishing for scallops started in 1974 in the Coromandel and Bay of Plenty (Area 2, Figure 1), and in about 1980 in Northland (Area 1). Since the mid 1980s, effort has been relatively stable, and a moratorium on the issue of new permits has been in place since 1988. The Northland fishery now supports 38 vessels and the Coromandel fishery 22. The Coromandel fishery (including the Hauraki Gulf and eastern Bay of Plenty) now constitutes a Controlled Fishery under which licences to fish are granted by the Fisheries Authority (a body independent of MAF Fisheries). Statistical reporting areas for commercial scallop fishing are shown in Appendix 1. In addition to limitations on entry, there are numerous controls on scallop fishing defined in regulation, or imposed by permit conditions. Annual commercial landings of scallops since 1980 have been about 2000 t (greenweight), with more being taken from Coromandel than from Northland (Table 1). Amateur catches are not known, but are probably quite high.

Table 1. Landings (t greenweight) from the Coromandel Controlled Scallop Fishery (Scallop Return Area 2; 2X = Waiheke bed and 2L = Whitianga bed) and Northland Scallop Fishery (Scallop Return Area 1;) since 1980. -, data by area not available.

	Coromandel				Northland		
	Total	2X	2L	Other	Total	Whangarei	Far North
1980	1005	249	690	66	238	-	-
1981	1170	332	743	95	560	-	-
1982	1072	687	385	0	790	-	-
1983	1553	687	715	151	1171	78	1093
1984	1123	524	525	74	541	183	358
1985	877	518	277	82	343	214	129
1986	1035	135	576	324	675	583	92
1987	1431	676	556	199	1625	985	640
1988	1167	19	911	237	1121	1071	50
1989	360	24	253	83	781	131	650
1990	903	132	731	40	519	341	178
1991	1400	99	691	610	854	599	255
1992	1102	3	828	271	741	447	294

3.3 Estimation of yield

Estimation of yield for wild (unenhanced) scallop populations is complicated by the fluctuating biomass (where estimates are available) and landings. There is also a lack of up to date information on the growth and mortality rates of scallops, and how this might vary within and between years.

Maximum Constant Yield (MCY) can be estimated using standard MAF Fisheries methods (Cryer & Parkinson 1992a, 1992b, Annala 1993a), but the results seem to be very conservative. This is perhaps not surprising as a fluctuating resource is likely to be able to support only a relatively low yield using a constant catch strategy. The Mid-Year Fishery Assessment Plenary in November 1993 (Annala 1993b) concluded that MCY was not an appropriate reference point for scallops, and should no longer be estimated. Given the productivity information currently available, standard estimates of CAY for the Coromandel fishery have also been found to be conservative.

Because of the unnecessary conservatism of the standard yield estimates when applied to scallops and the ability to separate commercial and non-commercial fisheries, a new, empirical technique for calculating CAY for commercial areas only has been developed. This technique is based on dive surveys and reported commercial landings for the beds close to Whitianga (Scallop Return Area 2L).

4. WHITIANGA BED SURVEYS AND LANDINGS 1978 TO 1992

4.1 Causes of fluctuations in landings from constituent beds

Both northern scallop fisheries have shown fluctuations in the level and distribution of catches from their beds in recent years. These fluctuations cannot be explained for the Northland fishery as biomass estimates are not available. However, resource surveys within the Coromandel fishery since 1978 allow an empirical examination of fishing pressure on these beds.

The main beds of the Coromandel fishery are found (in descending order of historical importance) north of Whitianga (Area 2L), east of Waiheke Island in the Hauraki Gulf (Area 2X), around Little Barrier Island (Area 2R), and in the Bay of Plenty (principally off Waihi, and around Motiti and Slipper Islands; Areas 2A to 2H). Typically, fishing occurs at the start of each season close to Whitianga where most of the vessels are based. As the season progresses, fishing may be conducted in the Hauraki Gulf and the Bay of Plenty, depending on catch rates close to Whitianga, the condition of the scallops, the nature of seabed conditions and bycatch of "trash," and the preferences of the skippers. Low or moderate landings from particular beds in a given year may not, therefore, necessarily be the result of low biomass. Alternatives could be difficult fishing conditions caused by corrugations in the sea bed or the small average size of scallops, better catch rates or meat recovery fractions from other beds, or consistently unfavourable weather.

Because fishing effort is not related directly to scallop biomass on a particular bed, it is likely that all beds are subject to quite variable fishing mortality among years. The availability of several biomass estimates for one bed at Whitianga allows further examination of the consequences of such variability. Summarised information on biomass estimates and reported landings is shown in Figure 2.

4.2 Dive surveys of the Whitianga scallop beds

Dive surveys of the Whitianga scallop beds have been conducted almost annually since 1978. Surveys between 1978 and 1987 were conducted on a 0.5 nautical mile grid design with 120 to 140 stations being allocated. These early surveys were not efficient at targeting sampling effort to areas of high density and variability, and many stations were in areas that rarely held scallops. Many dives were also in deep water, reducing the search time available for each diver. Typically, 13 or 14 divers were employed for 5 days. Nevertheless, these early surveys generated useful information on the geographical boundaries of the beds.

No surveys were conducted before the 1988 and 1989 seasons as it was felt that sufficient information had been gathered to allow landings from the fishery to be managed through in-season analysis of catch and effort returns. However, an unexpected and very poor fishing season in 1989 led to the resumption of surveys in 1990. The 1990 survey was a single-phase stratified random design, with stratum boundaries being derived from the combined results of previous grid surveys. Station allocations were based on previous recorded densities of legal sized scallops, and a total of 99 stations were dived, some being very deep.

Subsequent surveys have used essentially the same strata with the very deep areas removed. They have been two-phase stratified random surveys using about 80 stations. First phase stations are allocated on the basis of the density of undersized scallops in each stratum in the previous year. Second phase allocations are based on the actual variability of counts of scallops likely to recruit in the coming season.

Surveys conducted since 1990 have undoubtedly been more cost-effective than the early designs. A team of 8 or 9 divers for 4 days generates recruited biomass estimates with similar precision to previous methods (relative standard error, sem/mean or, colloquially, coefficient of variation (c.v.) 12 to 14%). The stratified random design also reduces the slight potential for bias inherent in grid sampling non-randomly distributed organisms.

4.2 Variation in fishing mortality and biomass at Whitianga

Given estimates of start of season recruited biomass as well as landed catch, it is possible to build up a picture of the pattern of fishing mortality at Whitianga. Unfortunately, the years when the largest and smallest commercial catches were made from Whitianga are those for which biomass estimates are not available.

From Figures 2 and 3, and Table 2, it is clear that there has been considerable fluctuation in the fraction of scallops taken by the commercial fleet as well as in the biomass and landings. The estimated fraction of scallops taken has varied from about 29% to over 95%. This range is too wide to be explained by error in estimated biomass (c.v. ~12%) or by misreported landings (catches are frequently weighed at the wharf by Surveillance Officers), and it is therefore clear that there has been wide fluctuation in fishing mortality over the period.

The only significant correlation among recruited biomass, landed catch, and the percentage removed by fishing is the negative correlation ($p \approx 0.03$) between recruited biomass and the percentage taken (Figure 4). The lack of any relationship between recruited biomass and catch from Whitianga is not a result of limitation by catch limits, whether daily or seasonal, as the Whitianga bed is only one of several constituent beds of this fishery.

There is no significant autocorrelation in commercial landings, recruited biomass, or estimated fishing mortality (Figure 5). Autocorrelation measures the correlation between an observation and neighbouring observations and can be calculated using any lag or displacement from zero (where, by definition, autocorrelation = 1.0) to n-m-2 (where n is the number of observations, and m is the lag phase). For this analysis, autocorrelation was calculated for time lags of zero to 3 years, and only in one out of nine tests did the correlation coefficient approach the critical value at $p = 0.05$ for a two tailed test. Autocorrelation was least apparent in estimates of recruited biomass, indicating that recruited biomass in a given year is not related to pre-fishing biomass in any of the previous three years.

Table 2. Reported catch, estimated number and biomass of legal sized scallops, percentage caught, and instantaneous fishing mortality (F) for the Whitianga scallop bed (Area 2L). Catch data are from MAF Fisheries databases, and numbers and biomass of scallops estimates from SCUBA diver surveys. Diver efficiency is assumed to be 100% for scallops likely to recruit to the fishery (≥95 mm). Calculations of the percentage of scallops caught and instantaneous fishing mortality, F, exclude any natural mortality, non-commercial or unreported catch, and scallops outside the surveyed areas. -, no survey data available.

	Catch (t)	Number ($*10^{-6}$)	Biomass (t)	Percent caught	Approx. F
1978	729	13.2	1386	52.6	0.75
1979	330	3.5	368	89.8	2.28
1980	690	11.4	1197	57.64	0.86
1981	743	10.4	1092	68.04	1.14
1982	385	6.9	725	53.14	0.76
1983	715	9.5	998	71.68	1.26
1984	525	10.4	1092	48.08	0.66
1985	277	9.2	966	28.67	0.34
1986	576	12.5	1313	43.89	0.58
1987	556	15.5	1628	34.16	0.42
1988	911	-	-	-	-
1989	253	-	-	-	-
1990	731	7.3	767	95.37	3.07
1991	691	10.95	1150	60.09	0.92
1992	828	10.5	1103	75.07	1.39
Mean	596	10.1	1060	59.86	1.11
SD/Mean	0.34	0.30	0.30	0.33	0.70

4.3 Medium term implications for variation in fishing mortality

The short term implications of heavy fishing pressure are that many scallops get caught, and many that are not caught (both juveniles and legal size scallops) have "encounters" with the relatively inefficient gear in use. The impacts of these effects are not known and cannot easily be tested using the information available for scallops in the northern region. However, the high percentage of recruited biomass that can apparently be harvested in a given year would suggest that, as long as survey results are not gross underestimates of biomass and assumed growth rates are reasonable, mortality for uncaught scallops should be modest. Mortality experiments on undersized scallops in the past (cited in Bird 1983) indicate "handling mortalities" of < 5% for gears commonly in use in the Coromandel fishery. In Scottish waters, Chapman *et al.* (1977) showed that mortality for scallops encountered by a dredge was 4-8%, whether such scallops were subsequently captured or not.

Longer term implications of fishing have little relevance to the annual calculation of yield, but might involve modification of the habitat or the genetic constitution of the population. The Coromandel fishery has been in operation for 15 years, but the full implications of habitat or genetic modification would probably take several generations to appear. In addition, statistical degrees of freedom for analyses of impact decrease with increasing time lags, decreasing the power of such tests for long term impacts. The current analysis therefore concentrates on medium term implications that encompass about one or two life cycles for scallops.

The generation time of scallops at Whitianga is thought to be somewhere between 2 and 4 years. Scallops reach sexual maturity at about 60 mm shell width in perhaps 2 years, but population fecundity probably stems mainly from scallops considerably larger than 60 mm. Tagging studies by K.A.R. Walshe (personal communication) in the 1980s suggested that recruitment to the fishery at 100 mm shell width was at age 3 or 4. The proportion of population fecundity originating from any given size class is not known, and is probably variable. However, an examination of the dynamics of the population compared with the performance of the fishery leads to an empirical understanding of the implications of different fishing mortalities. As the generation time is several years, significant adverse impacts of heavy fishing on subsequent spawning or recruitment to the fishery should become apparent with a lag of 2 to 4 years. Immediate significant impacts on growth and survival, especially of pre-recruits, should become apparent with a shorter lag of perhaps 1 year.

When assessing the impact of fishing pressure, absolute fishing mortality is probably a better measure than the instantaneous rate, F. This is because, at high fishing mortalities, small changes in the proportion of fish taken can lead to very large changes in F. Modest error in estimating biomass or catch can lead to very large error in F. The non-linear relationship between absolute and instantaneous rates of fishing mortality also leads to data points using the latter measure being "clustered" close to the origin, with undue statistical leverage being afforded the one or two data points with very high F values, and little leverage to the bulk of the data at low to moderate fishing pressure. The Whitianga scallop bed has frequently been heavily fished, making F a rather unstable measure of fishing mortality (see, for example, Figure 2 where F has a much wider range than the estimated fraction of scallops harvested).

Using estimated absolute fishing mortality in a given year as an independent variable and plotting the commercial landings of scallops from Area 2L in subsequent years as a dependent variable leads to an empirical test of the impact of fishing pressure on the fishery (Figure 6). There seems to be very little impact, with none of the relationships being statistically significant ($R^2 = 0.001$ to 0.180 with 8 to 10 df; $P \gg 0.10$ in all cases).

There is no evidence that heavy fishing of the Whitianga bed in a given year leads to low landings in the next year (which might indicate heavy incidental mortality or morbidity on recruited or pre-recruit scallops), or after lags of 2-4 years (when recruitment overfishing might become apparent). Conversely, low fishing mortality does not necessarily lead to high yields in the subsequent year or years.

It has been shown that commercial landings from the Whitianga bed are not directly related to available biomass. For this reason, the biomass remaining at the end of a given year was compared with the estimated recruited biomass in subsequent years. The end of fishing coincides closely with the time of spawning and spat settlement for scallops in the Coromandel fishery, although amateur scallop fishing continues for a further 2 months. This analysis can therefore be thought of as a crude examination of the stock and recruitment relationship for scallops at Whitianga. There is no discernible relationship (Figure 7) between the biomass of legal sized scallops left on the beds and subsequent estimates of recruited biomass for lags of 1-4 years ($R^2 = 0.004$ to 0.102 with 6 to 10 df; $P \gg 0.10$ in all cases).

These analyses, the first being essentially fishery-based (a relationship between fishing mortality and subsequent landings) and the second being population dynamics based (a relationship between uncaught stock and subsequent recruited biomass), both indicate no significant short to medium term implications of heavy fishing pressure on the Whitianga beds. These beds have the longest history of commercial fishing in the northern region, and have probably been fished most heavily. In some years, over 90% of the estimated start of season recruited biomass is reported as being landed from the Whitianga bed.

4.4 Potential confounding factors

4.4.1 Fishery based analysis (relationship between fishing mortality and subsequent landings)

It is possible that the estimates of recruited biomass made by scuba surveys and the landed catches do not come from identical areas. There may be parts of statistical reporting area 2L that are not within the survey bounds. Confusion could also arise from commercial landings that are reported with the wrong statistical reporting area: some fishers inadvertently insert the same reporting area after a shift of location. Mismatch between biomass and catch would tend to introduce imprecision into any analysis of impact and, if the errors were large or numerous, would conceal any relationship between fishing mortality and subsequent performance. The scallop beds in the Coromandel fishery are relatively discrete, however and, in a typical year, most skippers would fish only two or three beds (2L, 2X, and, perhaps, 2R). There should therefore be considerable fidelity in the reporting of areas. In addition, the boundaries of the dive surveys have been determined after several years of extensive surveys with multiple zero catches on the periphery, so the extent of the beds should be well defined. Annual consultation with the fishers has led to minor changes in recent years, but these have not greatly influenced subsequent biomass estimates.

Errors in the estimate of recruited biomass would also have an obscuring effect, although these surveys typically have a relative standard error (colloquially, coefficient of variation or "c.v.") of only 12-14%. Assumed values for growth and mortality are used to predict start of season biomass but, because the surveys are conducted fairly close to the start of the season, even quite large errors in the assumed coefficients should not greatly bias the estimates.

4.4.2 Population dynamics based analysis (relationship between uncaught stock and subsequent recruited biomass)

Perhaps the biggest weakness of this analysis is that the spawning stock may not be well defined by the biomass of legal sized (100 mm) individuals. There is undoubtedly a contribution to spawning by scallops of between 60 and 100 mm shell width, though the extent of this is not known. An egg per recruit or spawning stock biomass per recruit analysis could be conducted to increase our knowledge of the importance of spawning by individuals below the minimum legal size. Unfortunately, scallop "condition" or meatweight varies considerably both within and between years, making a realistic analysis of eggs per recruit difficult. Also, spawning by scallops outside the Whitianga beds may provide some or all recruitment of juveniles to the stock.

Either of the above factors could render the analysis presented here somewhat academic, if the aim was to identify a causal relationship. However, this is an entirely empirical analysis aimed at assessing the dynamics of the Whitianga scallop population and fishery following fishing activity of recent and historical patterns. The lack of a link between heavy fishing mortality and subsequent recruited biomass would remain whether the "new" recruited biomass stemmed from local spat or from spawning outside Area 2L.

Scallops occur in many deepwater areas (>50 m) around Whitianga, sometimes in dense concentrations. However, these beds are rarely fished because catch rates are not usually good, and the scallops do not usually reach legal size in deep water. At present, few of the Whitianga vessels are capable of dredging deeper than about 50 m, and the poor returns of legal sized scallops mean that fishing pressure is unlikely to spread into these areas under the current minimum legal size.

The independence of the broad conclusions of this analysis from poor definition of the spawning stock is dependent on future patterns of fishing mortality not changing markedly. More specifically, if the size limit were to be decreased from 100 mm, then protection afforded to current pre-recruits and uneconomic beds would be lost. Significant changes to the management regime in this regard would necessitate a reassessment of the method of estimating yield for the commercial fishery.

5. AN EMPIRICAL TECHNIQUE FOR ESTIMATING CAY FOR NORTHERN COMMERCIAL SCALLOP FISHERIES

5.1 Factors underpinning the technique

The following technique relies heavily on the following three factors currently prevailing in northern scallop fisheries.

i) Commercial and non-commercial scallop fisheries are essentially separated spatially. Heavy commercial fishing in areas of intense recreational interest would clearly have negative implications for amateur access. Preservation of access for amateur fishers is essential besides ensuring sustainable commercial fishing. Separation is not complete in all areas, but a management review programmed for the 1993-94 year should resolve most of the conflict areas.

ii) A minimum legal size of 100 mm is in force throughout the commercial and amateur fisheries, and this is rigorously enforced.

iii) Heavy commercial fishing pressure on the bed with the longest fishing history has had little demonstrable impact on subsequent fishing, or on the dynamics of recruited biomass on that bed.

The analyses presented here, show that there are no obvious negative effects of heavy fishing pressure on the scallop beds at Whitianga. Moreover, there does not seem to be a positive consequence (increased biomass or available yield in subsequent years) of leaving scallops uncaught at the end of a season. This would suggest that, to achieve the greatest long term commercial yield, scallops in the Whitianga bed, and, by implication in other "commercial" beds in the north, should probably be fished heavily.

Given that there do not seem to be any negative effects of heavy fishing, it would be possible to allow "competitive" fishing of a total quota set at a level which was unlikely to restrict catches, even in good years. Under this type of management, fishers would have little idea in advance of each season of their likely income or profit. It is highly likely that there would be large variability of the proportions of the total catch taken by different fishers. There would be strong incentives for scallop fishing to be highly intensive early in the season, even if recovery rates were poor or the weather was bad. Such an approach is unlikely to lead to the highest possible yield or value from the fishery, and would also be contrary to agreements reached among participants that allocations should be equal. No biomass surveys would, however, be required, making this approach to management relatively inexpensive.

A second approach to managing this fluctuating resource is to estimate yield before each season and divide it equally among the participants who will then have an indication of their expected catch. Under this regime there should be greater incentives for fishers to take their "quota" when it is most profitable to do so, probably when meatweight yields are highest. Annual biomass surveys are required for this type of management, and these are expensive both in sampling time and analysis. The long term average catch and value of the fishery should, however, be greater. A general willingness on the part of the participants to fund surveys would indicate that their value has historically exceeded their cost.

5.2 Calculation of CAY for northern commercial scallop fisheries

The approach outlined above suggests that CAY could be set equal to the estimated start of season recruited biomass of legal sized scallops without compromising the sustainability of the fishery. However, the following factors complicate this simple relationship.

i) Not all beds within the Coromandel or Northland commercial fisheries are surveyed each year, so total standing biomass cannot be estimated.

ii) There is sampling error associated with estimates of scallops thought likely to recruit.

iii) Factors such as mortality, growth, and meatweight content all have sampling error and are subject to variation within and among seasons. This variability introduces further uncertainty in predicting start of season recruited biomass from survey results.

iv) There is no simple means of establishing what might be an "uneconomic density" of scallops for commercial harvesting. Thus the fraction of scallops that can be harvested economically will vary from year to year and cannot be determined in advance. The economics of fishing is subject to a range of factors such as the patchiness of the resource, the skill of the skipper at seeking out good areas and refining the fishing gear, the market value of product, and fixed and variable operating costs. It is not within the expertise of MAF Fisheries to determine a minimum economic density.

Some of these factors could be taken into account using "best guesses," but wrong guesses could lead to quite inappropriate estimates of CAY (and consequent allocations) so an adaptive process has been developed which takes into account some of the uncertainties. CAY based on the philosophy discussed above is first estimated as the lower limit of a two-sided 95% confidence interval for the start of season recruited biomass, and a further amount is added to account for other beds that have not been surveyed.

The "additional" amount for unsurveyed beds could be the MCY estimate for these beds. In the past, MCY has been calculated according to method 4 ($MCY = cY_{av}$) (Annala 1993a) as other methods have been found to give very conservative estimates of likely yield. However, the 1993 Mid-Year Fishery Assessment Plenary concluded that MCY was not an appropriate biological reference point for scallops. Given the variability in scallop recruitment and mortality, it was suggested that MCY be set to zero for this species.

An additional amount over and above the estimate of CAY based only on surveyed beds must therefore be estimated by explicit calculation. It is proposed that the calculation be based on previous methods of estimating MCY. CAY for northern scallop fisheries should be calculated as follows:

$$\mathbf{CAY} = \mathbf{B}_{(surveyed,\ current,\ p=0.975)} + \mathbf{cY}_{av(non\text{-}surveyed)}$$

where $B_{(surveyed,\ current,\ p=0.975)}$ is the lower limit of a two sided 95% confidence interval for the estimated start of season recruited (100 mm) biomass and $cY_{av\ (non\text{-}surveyed)}$ is equal to the constant c (0.6 for scallops) multiplied by average landings over all years since 1980 for those beds not surveyed in the year for which yield is to be estimated.

Calculation of the initial allocation is important since it informs fishers what they can expect for the coming season as well as allocating the available yield equitably. If the initial allocation is set too conservatively, then fishers are given no real guide to the likely quantity and, where the initial allocation is small in absolute terms as well as conservative, a reassessment of yield may be required very shortly after the start of the season. Two revisions of allocations may even be required. If the initial allocation is set too high, then fishers will be misled as to the likely profitability of fishing, may make inappropriate business decisions as a result, and may not be able to take their allocation at economic catch rates, if at all. In effect, optimistic initial allocations will lead to competitive fishing and increasing incentives for fishers to take scallops quickly and not necessarily in good condition.

The consequences of a conservative initial allocation are thus considerably more favourable than the consequences of optimistic initial allocation.

It is strongly recommended that yield be estimated either in greenweight or in numbers of scallops. The average recovery of meat from greenweight (i.e. the inverse of the conversion factor) varies among seasons, among years, and among beds. In the past, this variation has led to fishers changing fishing areas so as to take scallops in the best condition at any given time. However, recent events, such as poor condition throughout all available fishing areas in 1993 and the potential for fishery closure due to dinoflagellate toxins have modified the behaviour of fishers. There now seems to be a greater incentive for fishers to take scallops early, notwithstanding poor condition, when there is a real or perceived threat of closure because of toxins. Estimating yield in meatweight could lead to unrealistic expectations among fishers as poor recovery or closures because of toxins could lower the actual landings. Further analysis of the historical variability of recovery fraction by year, season, and bed should help to estimate the potential magnitude of the differences between predicted and realisable yield in this fishery.

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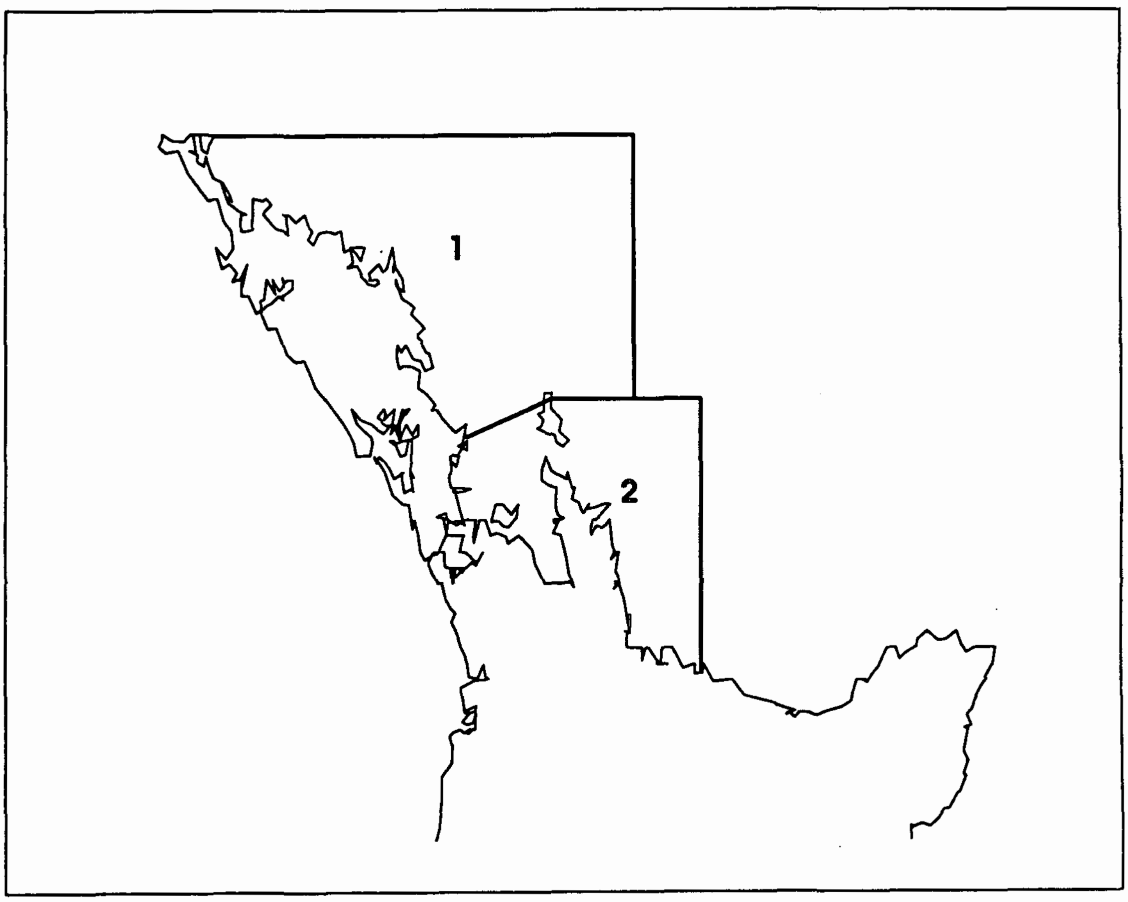

Figure 1: Commercial scallop fishing areas around the east coast of the North Island. Scallop Area 1 is the "Northland" fishery, and Scallop Area 2 is the Coromandel controlled fishery. Statistical reporting areas are shown in Appendix I.

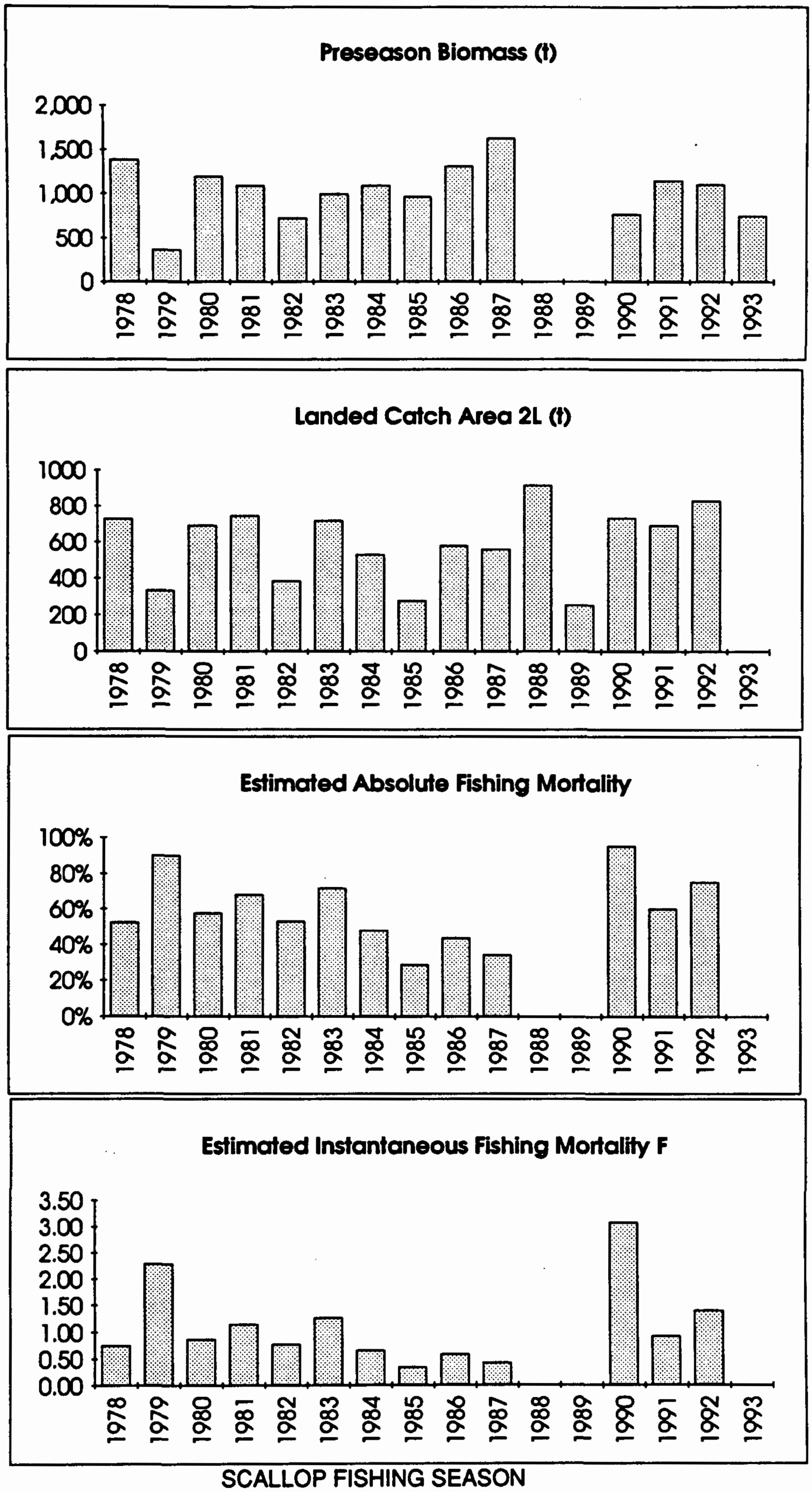

Figure 2: Estimates of biomass, catch, and fishing mortality from the Whitianga scallop bed since surveys began in 1978. No surveys were conducted in 1988 or 1989.

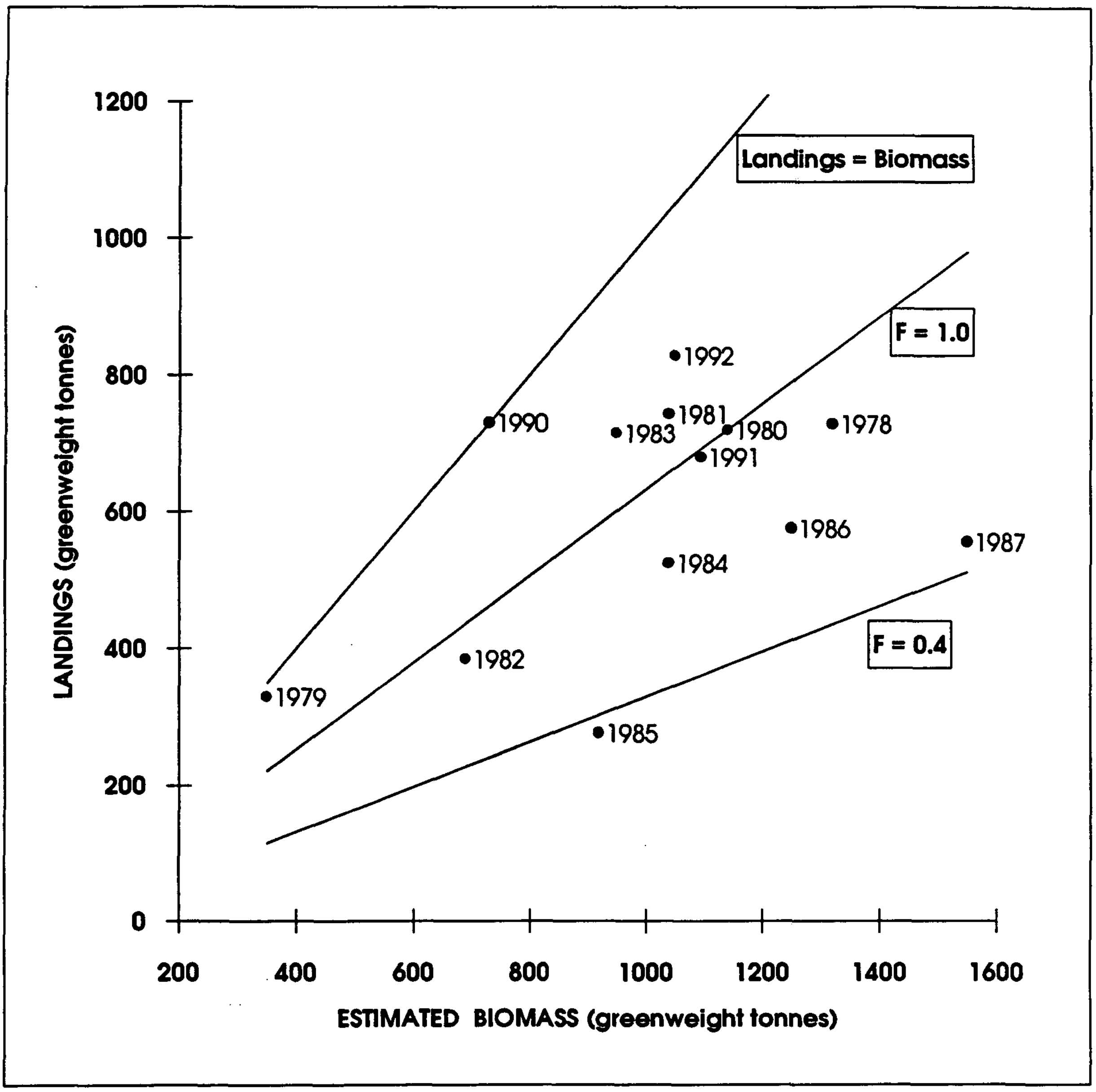

Figure 3: Landings from the Whitianga bed (Area 2L) of the Coromandel scallop fishery compared with estimated start of season recruited (>100 mm) biomass. Predicted landings for fishing mortalities of F = M = 0.40; F = 1.00; and F = infinity (landings = biomass) are indicated as lines.

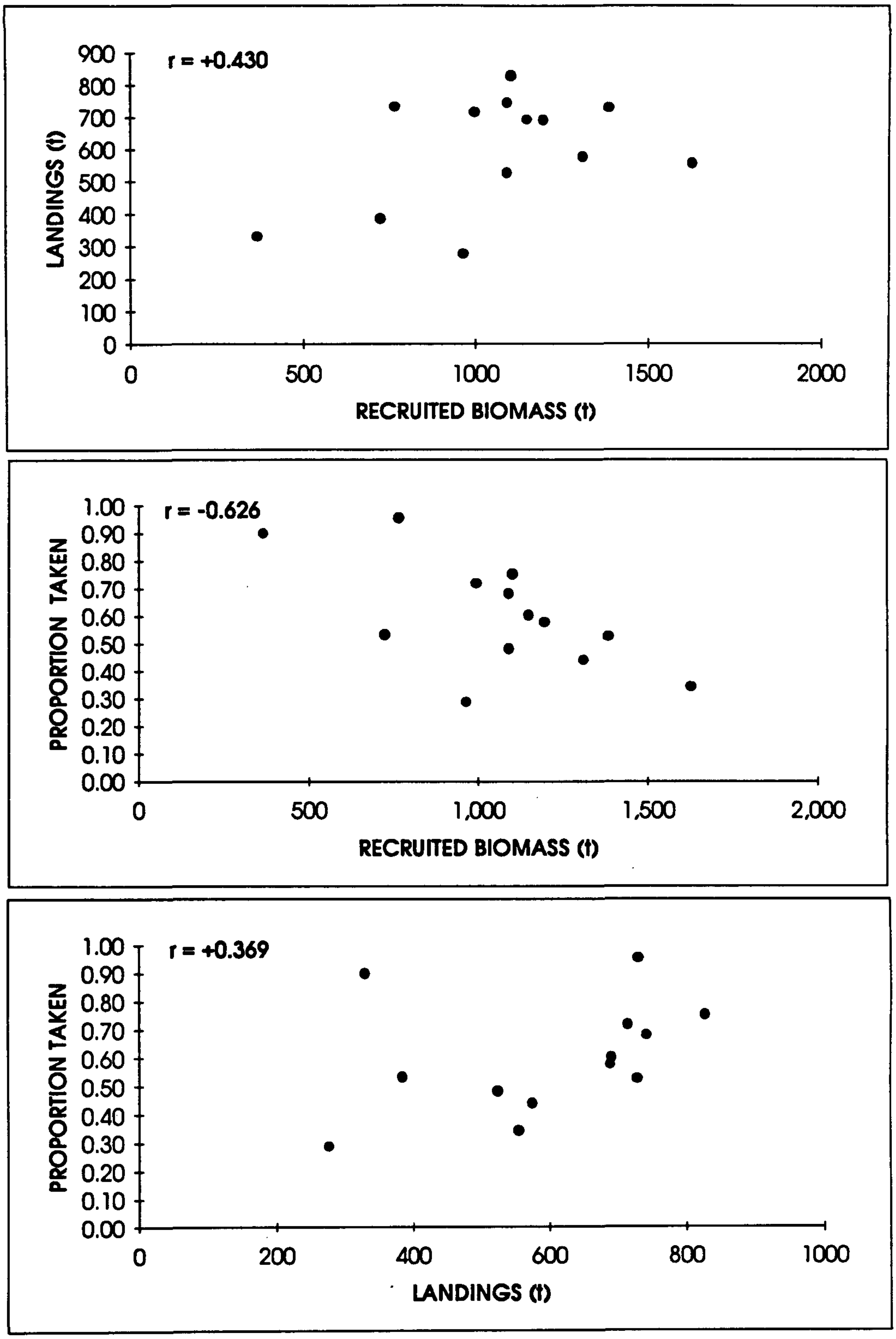

Figure 4: Relationships among estimated recruited biomass, commercial landings, and the percentage of recruited biomass estimated to have been taken in given years in the Whitianga beds of the Coromandel scallop fishery. Simple correlation coefficients are given for each case (11df).

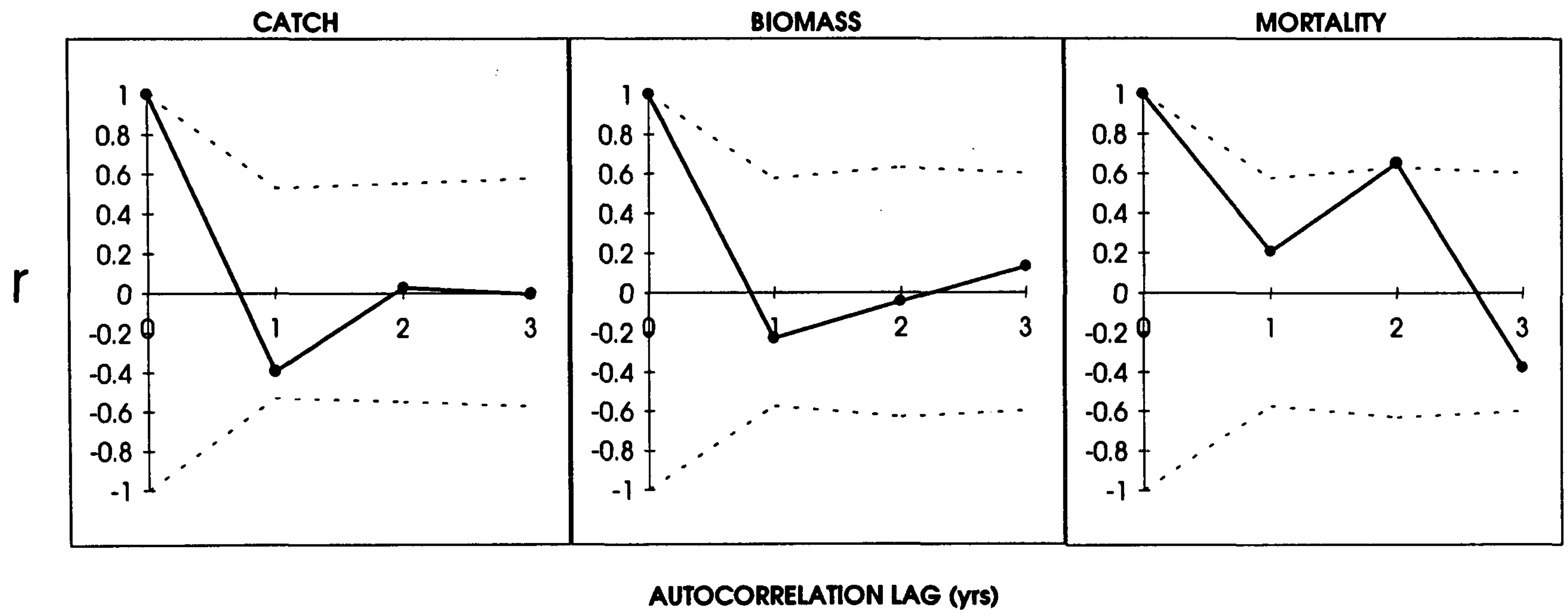

Figure 5: Autocorrelation in commercial landings from the Whitianga bed (Area 2L), recruited biomass, and estimated absolute fishing mortality. In each case, autocorrelation is calculated for lags of 1, 2, and 3 years (circlies, solid line). Critical levels of the correlation coefficient for $p = 0.05$ are shown as dotted lines.

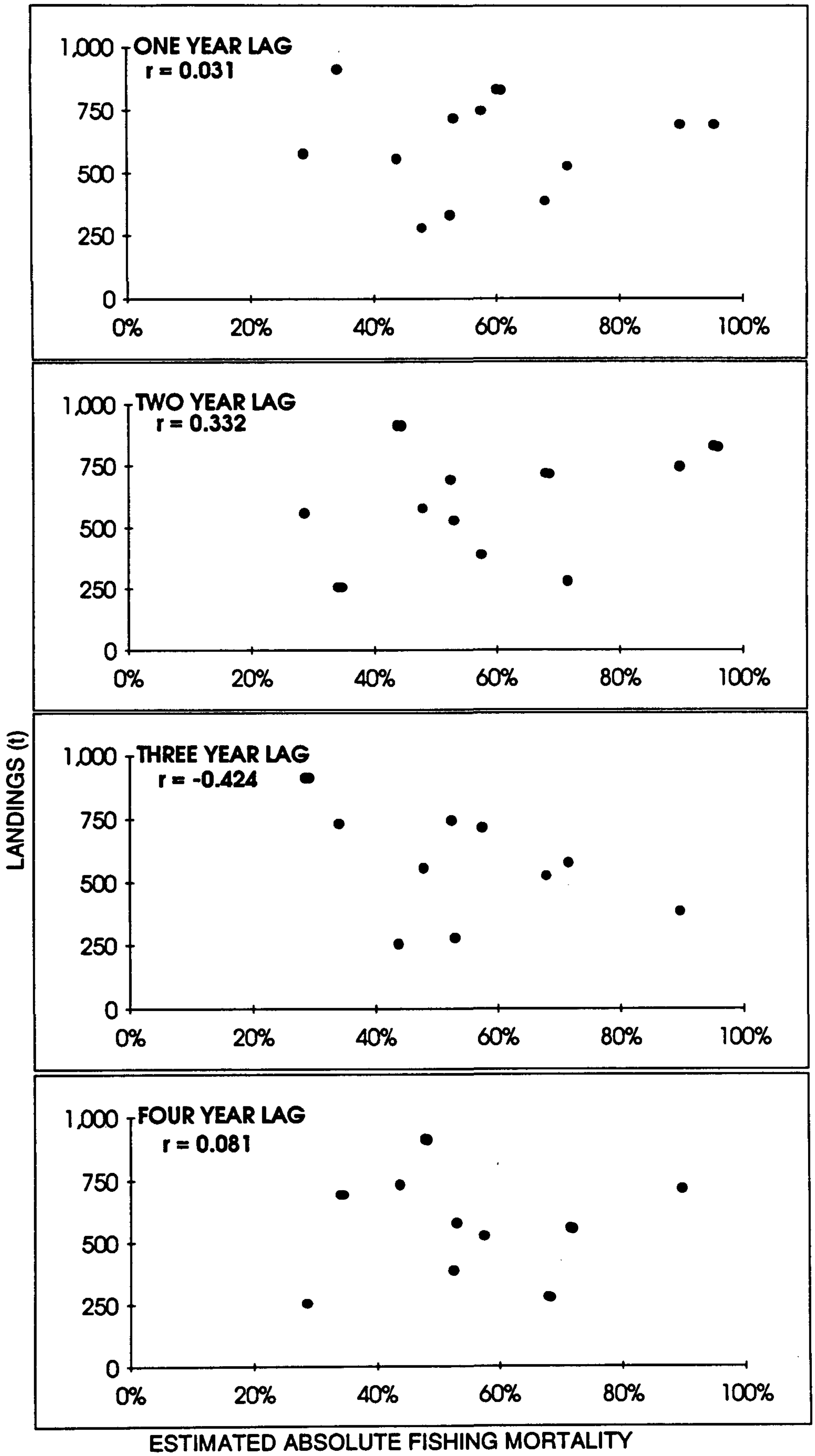

Figure 6: Relationship between the estimated absolute fishing mortality in a season and the landings from the same beds 1, 2, 3, and 4 years hence. Data from Table 2.

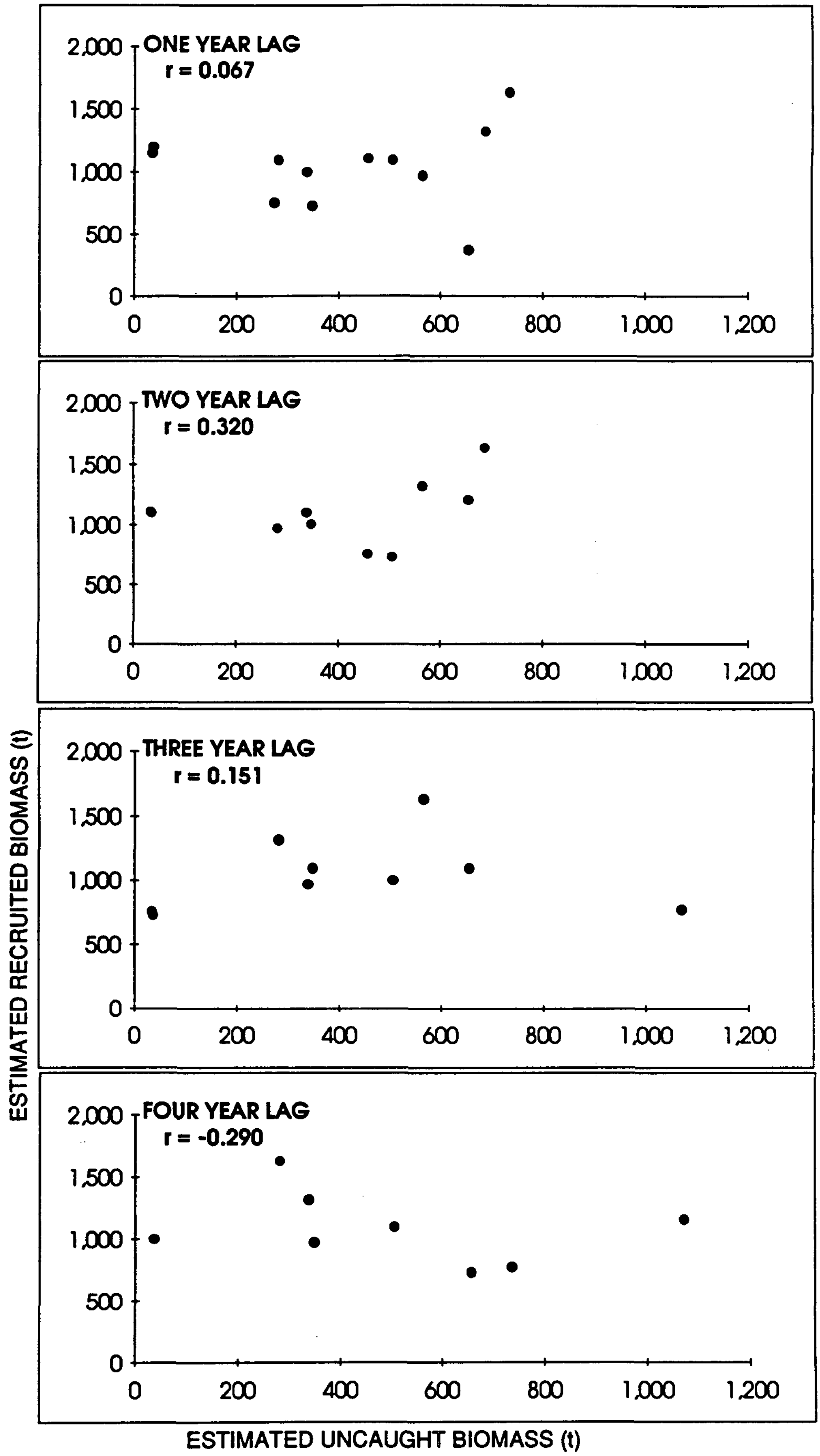

Figure 7: Relationship between the estimated biomass of scallops remaining uncaught at the end of a season and the estimated biomass present in the same scallop beds 1, 2, 3, and 4 years hence. Data from Table 2.

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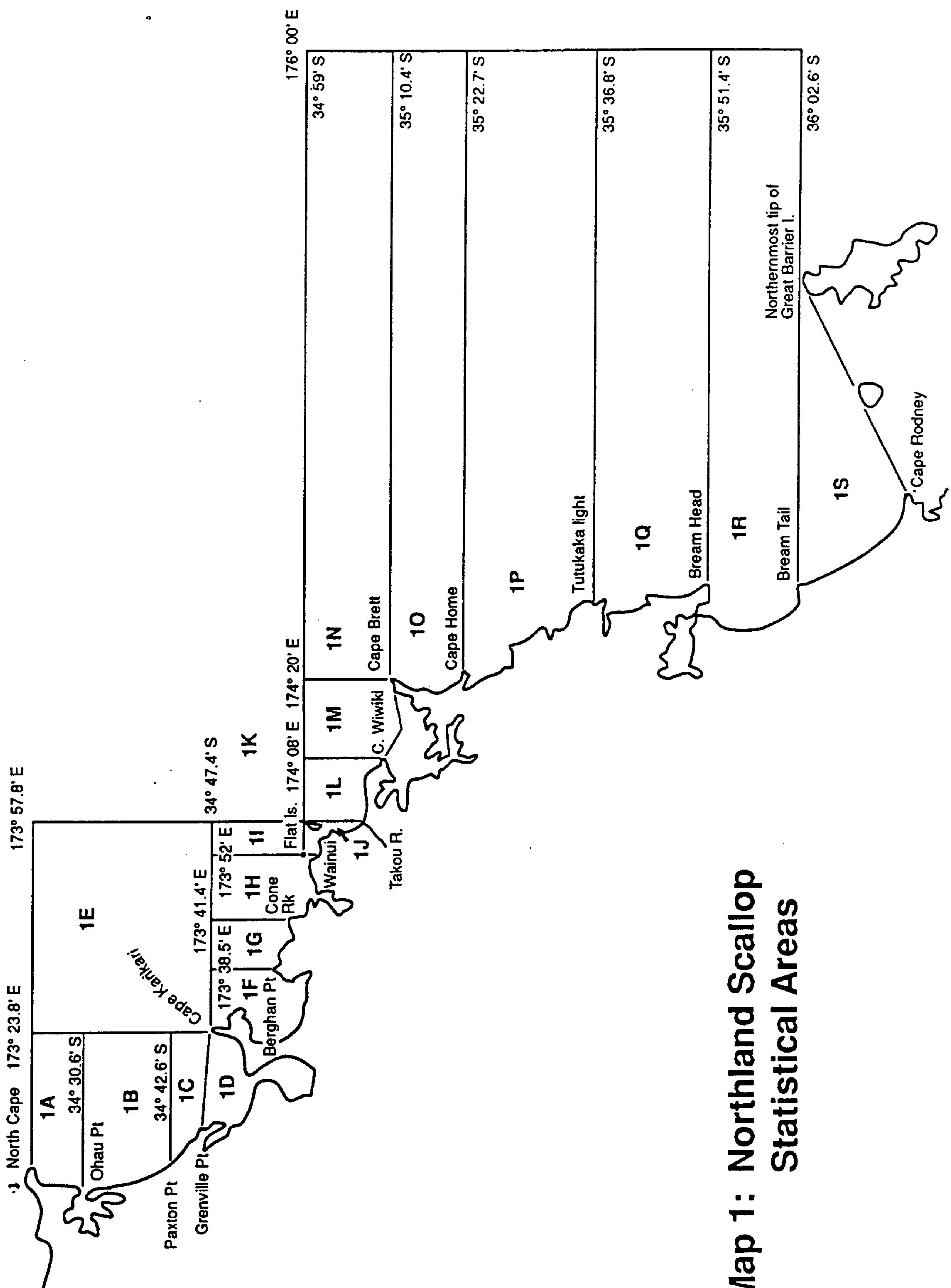
APPENDIX 1.



Map 1: Northland Scallop Statistical Areas

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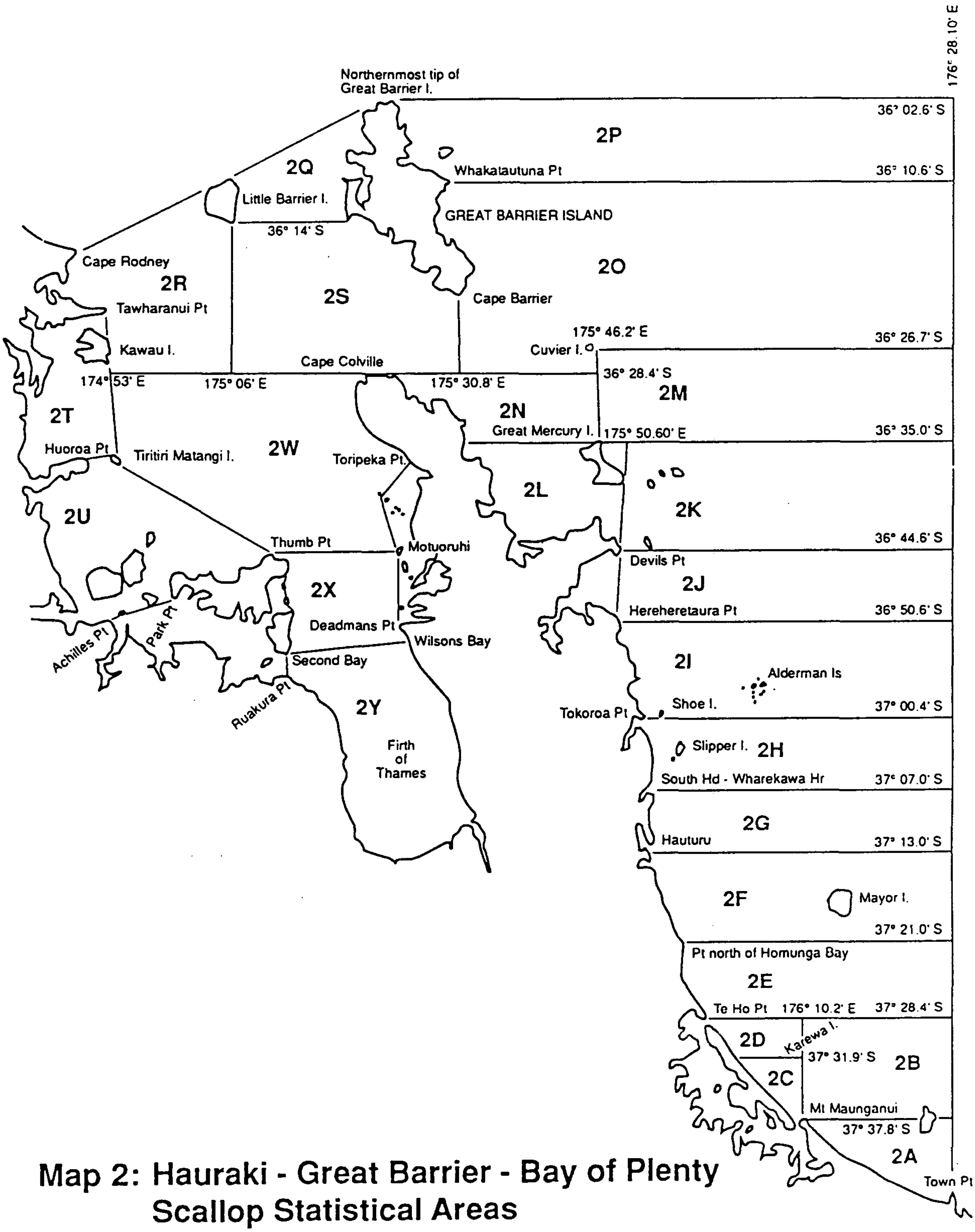
APPENDIX 1.



Map 2: Hauraki - Great Barrier - Bay of Plenty Scallop Statistical Areas

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