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Characterisation of the Northland scallop fishery (SCA 1), 1989–90 to 2010–11

New Zealand Fisheries Assessment Report 2014/26

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There has been a commercial dredge fishery for scallops off eastern northland since the early 1970s; primarily in Rangaunu Bay, Bream Bay, and Spirits Bay, with lesser harvests taken elsewhere up until the mid-1990s. The fishery was initially only loosely constrained by a 100 mm (4 inch) size limit and a ban on fishing outside of daylight hours (6 am to 6 pm). Daily bag limits were introduced in 1989, but seasonal catch limits were not introduced until 1992, when the first pre-season biomass survey was conducted, to determine a catch limit for the coming season. Pre-season biomass surveys were conducted annually until 1998, although a highly productive bed off Spirits Bay was not surveyed until 1996. Annual landings between the mid-1980s and mid-1990s were in the order of 100 t to 200 t meatweight, with over 30 vessels participating in the fishery.

Legal challenges by Māori delayed the introduction of scallops into the QMS until 1 April 1997, and an initial TACC was set based on the results of a pre-season biomass survey in 1997. The introduction of scallops into the QMS resulted in a sudden reduction of the size of the scallop fleet to 10 vessels, which coincided with a decline in catch rates at the time of an outbreak of "black gill" disease and the invasion of the tube worm *Chaetopterus* spp. The TACC was substantially under caught, and rapid and voluntary downward adjustments were made to catch limits at this time. Since 2001 the fishery has been managed on Schedule 2 of the Fisheries Act 1996, with a "base" TACC of 40 t, and the possibility of an in-season increase to the TACC based on the result of a pre-season biomass survey, if requested by industry (Northland Scallop Enhancement Company). Only six pre-season surveys have been conducted since 1998. In recent years the performance of the fishery has been poor, and concern about the future of the fishery has led to this review.

Catch effort data provided by commercial fishers since 1991 have been used to generate standardised CPUE indices which are used to infer trends in scallop abundance for the three most commonly fished statistical areas: Rangaunu Bay (1D), Bream Bay (1R), and Spirits Bay (9A). In most years only one or two of these areas have been fished, and although the spatial coverage of these indices is patchy, broadly similar trends are evident across all three areas. Catch rates were relatively steady between 1991 and 1997, declined over the next two seasons, then rebuilt, followed by a decline to the current all-time low.

Pre-season biomass surveys have also been conducted intermittently since 1992, and although some of the trends apparent in this time series are loosely similar to those seen in the CPUE indices, some differences are also evident. Neither the spatially patchy standardised CPUE indices nor the temporally sporadic time series of biomass estimates provided by the pre-season surveys adequately describe trends for the main scallop beds in SCA 1, and any assessment of the performance of the fishery and current management measures is problematic.

The main limitation of these data sources is that currently they provide little insight into the state of the stock when abundances are low, and the resource is most vulnerable to overfishing, such as now. A cost effective approach to regularly monitoring scallop abundance is proposed, that could improve the value and utility of both CPUE and pre-season biomass survey data. We also suggest that although some previous management strategy evaluation (MSE) studies have explored alternative management scenarios, further work in this area is warranted to investigate a more comprehensive range of options that could be applied to scallop fisheries managed under Schedule 2 of the Fisheries Act 1996.

1. INTRODUCTION

Scallops (*Pecten novaezelandiae*) support regionally important and valued commercial, recreational, and customary fisheries in various parts of New Zealand, including Northland. The Northland scallop fishery area (SCA 1) is bounded by Reef Point (near Ahipara) on the west coast and Cape Rodney (near Leigh) on the east coast (Figure 1). Commercial scallop fishing in SCA 1 has historically taken place within discrete beds in Spirits Bay, Tom Bowling Bay, Great Exhibition Bay, Rangaunu Bay, Doubtless Bay, Stevenson's Island, the Cavalli Passage, Bream Bay, and along the coast between Mangawhai and Pakiri (Williams 2008). All commercial catches are taken by self-tipping box dredges.

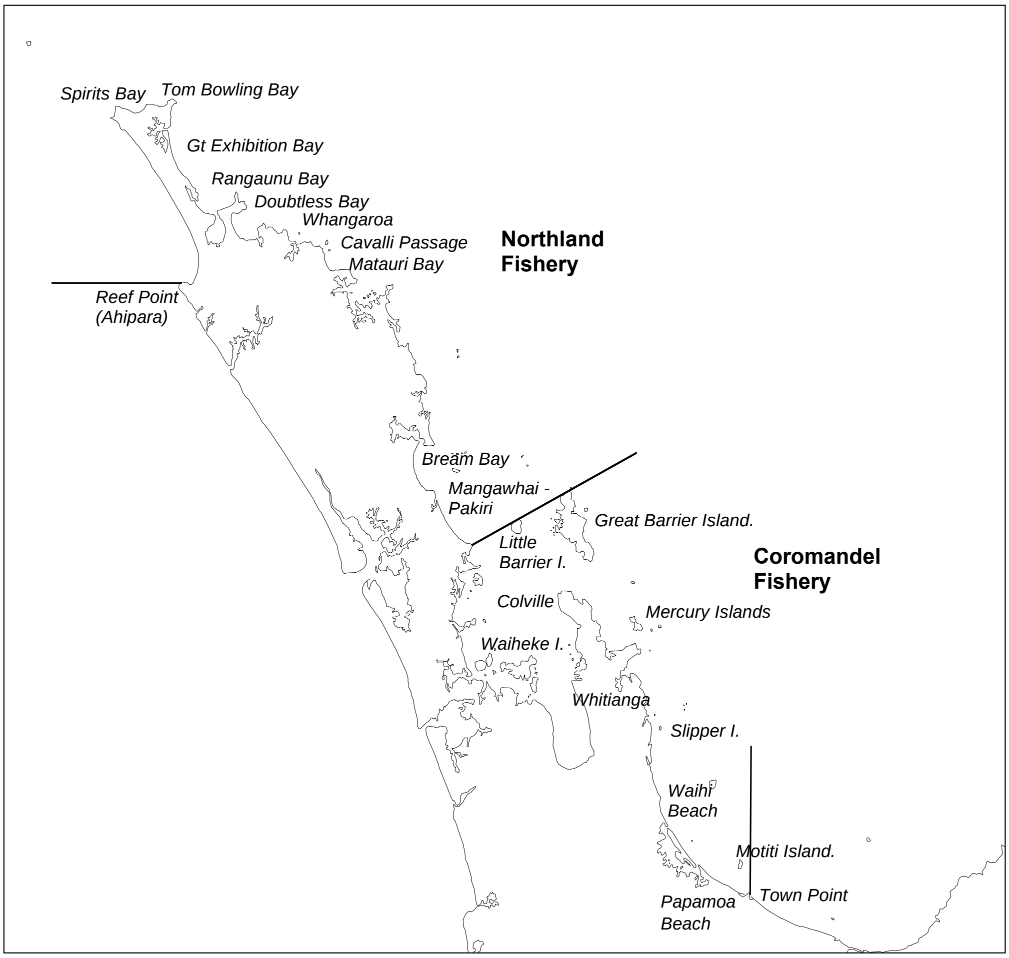

Figure 1: Geographic distribution of the two northern scallop fisheries and the names of locations mentioned in the text. After Cryer & Parkinson (2006).

Commercial scallop fishing in Northland started in about 1970. Since the mid 1980s, when the fishery is considered to have been fully developed, annual landings have averaged just under 100 t meatweight (muscle plus attached roe), but have varied considerably from over 200 t to 1 t (Ministry of Fisheries 2010). Annual landings from SCA 1 were relatively low (17 to 40 t) between 1998 and early 2005, but increased to a peak of 69 t in 2005–06, in response to a substantial increase in biomass, mainly at the Bream Bay and Mangawhai-Pakiri beds (Cryer & Parkinson 2006). Biomass and landings have since declined, to reach an all-time low of 1 t in 2010–11.

The last biomass survey and stock assessment for SCA 1 was in 2007 (Williams 2008). Low catch rates in recent years provided little incentive for industry (Northland Scallop Enhancement Company, NSEC) and the Ministry of Fisheries to commission research surveys and assessments, but the lack of recent information means that the current status of the stock is unknown. Minimal fishing, confined solely to Rangaunu Bay, was conducted in the Northland 2010–11 season, and reports were that catch rates and meatweight condition were very low.

There is increasing concern about the status of the SCA 1 stock, but the cost of a biomass survey and any associated assessment is likely to be high relative to the value of any resulting catch. This report provides a characterisation that summarises the spatial nature and extent of the fishery's catch and effort history, as well as standardised catch per unit effort (CPUE) indices for the three main scallop beds in SCA 1 (Rangaunu Bay, Bream Bay, and Spirits Bay). The information gained through this work has been used to assess the likely current status of the stock.

The overall objective for this project was to characterise the Northland scallop fishery. There were two specific objectives: 1) to review and summarise existing catch and effort data for SCA 1, and 2) to produce a CPUE indices series for SCA 1.

2. FISHERY CHARACTERISATION

2.1 Data sources

Landings data

This characterisation of the Northland scallop fishery was based on catch, effort and landings data provided by the Ministry of Fisheries, for the period 1 October 1985 to 30 September 2010. The sources of the data considered were Quota Management Returns (QMRs), Monthly Harvest Returns (MHRs), and Catch Effort and Landings Returns (CELRs). Scallop fishery CELR data are far less complicated than CELR data derived from finfish fisheries because all fishers usually use the same fishing method (dredge), target and land a single species only (scallops), and mostly record a single day's fishing only on each form. Data from Licensed Fish Receiver Returns (LFRRs) were also initially considered, but catch processers who report on these forms are required to record species codes only, and not Fisheries Management Area (FMA) codes, so there is no reliable way of assigning reported weights to specific fishstocks, such as SCA 1.

Catch effort data were requested for all trips where landings were reported against the FMA codes SCA 1 (Northland scallops) or SCA CS (Coromandel scallops). The reason why data were extracted from both fisheries was that Coromandel fishers also reported their catch against the FMA code SCA 1 until 1995–96, after which a separate FMA code for SCA CS was introduced. An examination of all available data from both fisheries was required, therefore, to determine which trips were attributable to the Northland fishery. Recorded statistical reporting areas (Figure 2) were used to assign trips to their respective fisheries. Some fishers often used non-standard area codes, and in these cases their catch and effort was assigned to a fishery based on their recent reporting history and ports of landing. Some reported statistical areas were recoded when there was an obvious alternative that appeared more plausible (e.g., when a fisher reported fishing in area 2D when they landed their catch at Houhora and had usually fished off Northland, the area code was changed to 1D). Most boats appear only to have fished in either the Northland or the Coromandel fishery, but not both.

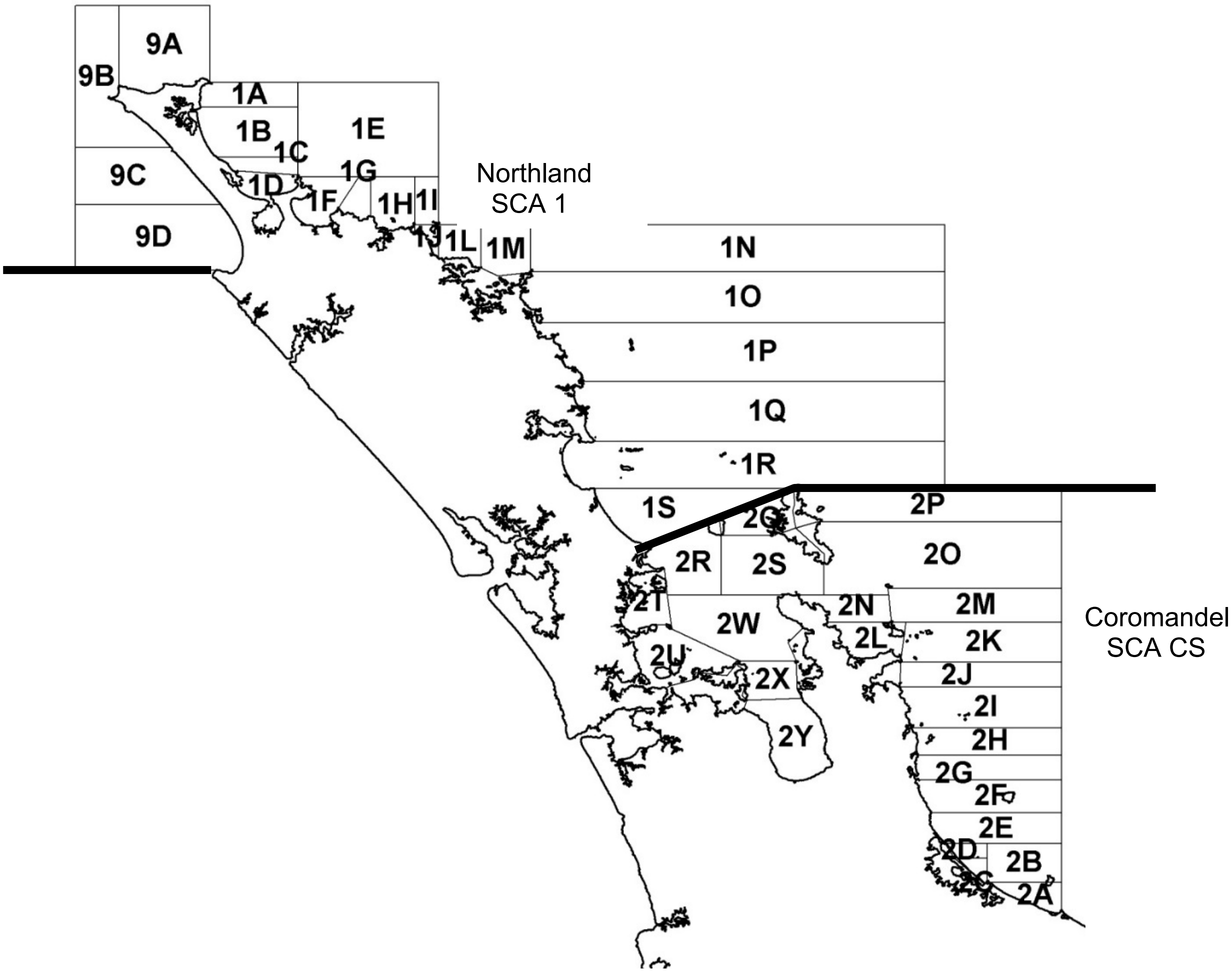

Figure 2: Scallop statistical reporting areas.

The reliability of the catch data was initially assessed by comparing annual landing weight totals reported on CELRs against tonnages reported on QMRs (up until 30 September 2001) and MHRs (since 1 October 2001). Monthly QMR/MHR data are considered to be the most reliable source of information on total landings by fishstock because these data are routinely audited, with annual landing totals usually matching Total Allowable Commercial Catch limits. Annual CELR catch totals closely matched QMR/MHR totals for recent fishing years, but substantial differences were evident in earlier years between 1985–86 and 1991–92 (Figure 3). These differences were largely attributable to confusion over whether fishers were required to report landed weights in terms of greenweight or meatweight. A regulation was introduced in 1990 to clarify reporting requirements:

> *"Section 19(c) – All scallop weight shall be recorded as meatweight being the weight of the scallop after the shell has been removed and discarded."*

This regulation was revised in 2001 to provide further clarity:

> *"Section 36 (3) (b) all scallop weights must be recorded in meatweight, being the weight of scallops remaining when the shell, skirt, and gut has been removed and discarded."*

Many of the discrepancies between annual QMR/MHR and CELR totals were resolved by identifying fishers who had reported greenweights instead of meatweights, and in these cases the greenweights were divided by 8, to convert them to approximate meatweights. Instances of reporting by greenweight were inferred from associated trip-by-trip effort and catch rate estimates, and comparing these with concurrent values reported by the rest of the fleet. Simple data punching errors were also clearly evident in some instances.

This grooming process resulted in a marked improvement between annual QMR/MHR and CELR landed catch weight totals, but substantial differences were still apparent between aggregate weights for 1989–90 and 1990–91, and data for these fishing years were dropped from all subsequent analyses. No CELR data are available before 1989–90.

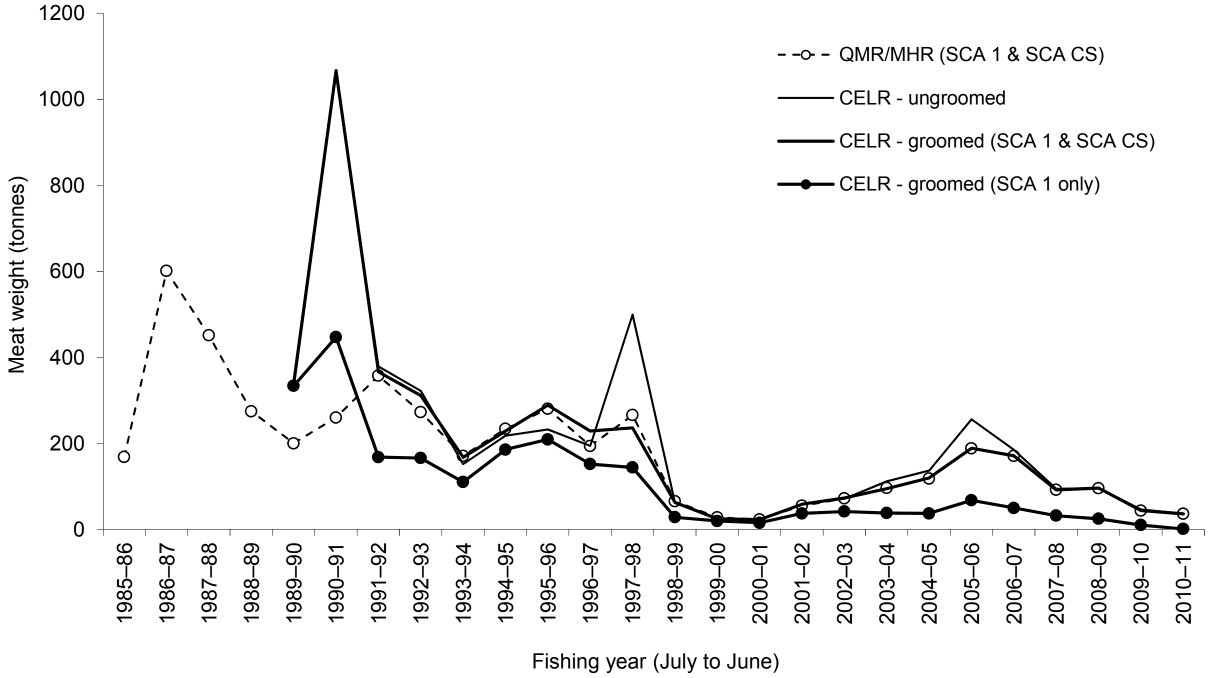

Figure 3: Comparison of annual catch totals derived from ungroomed and groomed Catch Effort Landing Return (CELR) data relative to totals derived from Quota Management Returns (QMRs) and Monthly Harvest Returns (MHRs).

Estimated weights derived from the 'effort' section of the CELR form were also groomed. Estimates of catch weight provided by a fisher for a day's fishing can be very unreliable because they are estimated and not measured, and because some fishers report estimated meatweights on the effort part of the form, whereas others record their catch as estimated greenweight. Estimated catch weights (greenweights or meatweights) were therefore replaced with meatweights reported on the landed section of the form, which we had already groomed as described above.

Most CELR returns provided catch and effort data for a single day's fishing in a single statistical reporting area, and in these cases the estimated catch weight from the effort section of the CELR was replaced with the meatweight from the landed section of the form. When multiple lines of effort were reported on a form, the meatweight from the landed section was prorated across effort events reported on the same form, given the relative estimated weight of scallops associated with each event.

Effort data

Scallop fishers report three measures of effort on the effort section of the CELR form: 1) the total tow time for which the dredge is at the target depth for tows completed on the day; 2) the number of tows completed per day; and 3) the width of the dredge used. Anecdotal reports suggest that there has been some confusion about the reporting of total hours fished in a day, as some fishers may have reported the time that the vessel was away from port, rather than the time it spent actually fishing. Tow durations can vary depending on catch rates, and this meant there was no independent measure that could be used to assess the validity of a report of the time spent fishing on a day. Fishing duration values were disregarded if they exceeded 12 hours per day. The choice of this threshold was partially determined by a regulation that was introduced in 1986:

> *"Section 22(5) – No commercial fisher shall take any scallops from any waters of Quota Management Area 1 or Quota Management Area 9 that are not waters within the Coromandel Scallop Fishery other than between the hours of 6am and 6pm on any day."*

Examination of the data showed that almost all reported daily fishing durations were less than 12 hours (Figure 4). Many of the vessels that reported fishing durations greater than 12 hours were dropped from the dataset used to derive standardised CPUE indices because these vessels only participated in the fishery for a small number of years, in the early 1990s.

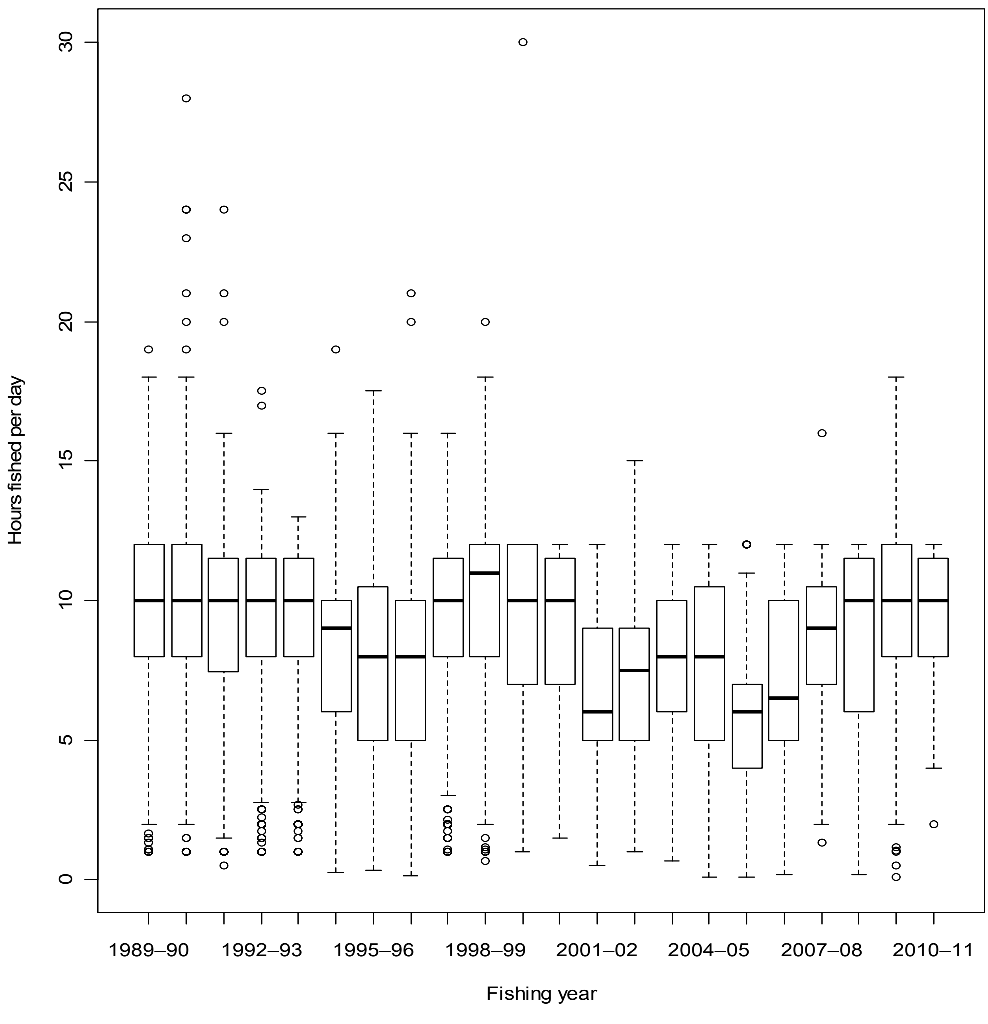

Figure 4: The distribution of reported estimates of the number of hours fished per day, by fishing year.

The number of tows that fishers reported for each day also varied considerably, and values greater than 48 tows per day were considered implausible (Figure 5). Discussions with two SCA 1 commercial fishers suggested that tow durations can vary between 10 and 30 minutes depending on catch rates, but they are usually in the order of 15 to 20 minutes.

Reported dredge widths for individual vessels were generally consistent from year to year, and this measure of effort was regarded as a proxy vessel effect, and these data were neither groomed nor used in any further analysis.

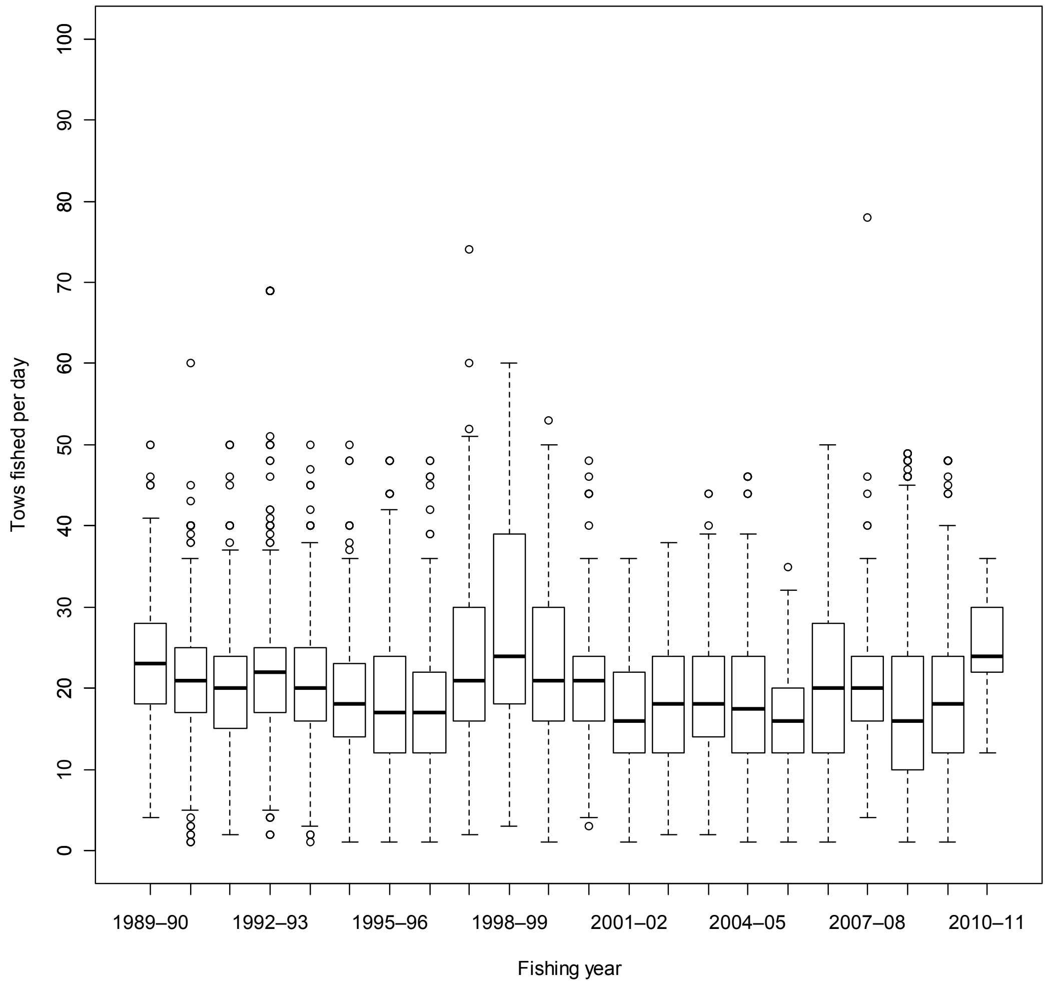

Figure 5: The distribution of the number of tows reported for each day's fishing, by fishing year.

2.2 Catch and effort history

Commercial fishing for scallops in Northland started in the early 1970s after a local fisherman brought back plans for a box dredge from Australia (see Appendix A for a commercial fisher's narrative of the history of the fishery). Scallop dredging first took place in Rangaunu Bay and by the mid 1970s, several vessels were targeting scallops. Market demand for scallops increased, with scallop boats operating out of most Northland ports by 1980, at which time there were 12 active licences. Permits were issued for two fisheries at that time: the Northern fishery (Reef Point to Cape Brett) and the Whangarei fishery (Cape Brett to Cape Rodney). The Spirits Bay area was not included in either of these fisheries, and for many years fishers working in that area reported their effort against the codes "North Cape" or "Area 1". The Northern and Whangarei fisheries were combined in the mid 1980s, involving 24 active licences and many more inactive licences.

The Northland scallop fishery was initially unconstrained by catch limits, and there are anecdotal reports of fishers working day and night at times, until they had about 30 bags of scallops to unload. In 1986 a regulation was introduced to limit the hours of fishing from 6 am to 6 pm, and daily bag limits were introduced in 1989.

Annual catch limits between 1992–93 and 1996–97 were based on information obtained from pre-season biomass surveys. Legal challenges by Māori delayed the introduction of scallops into the Quota Management System (QMS) until 1 April 1997, when an initial TACC of 188 tonnes was set, based on reported fishing histories in recent years. There was a dramatic reduction in the size of the Northland scallop fleet at that time. The TACC for the fishery was reduced to 106 t meatweight for the following 1998–99 season, given the results of a pre-season survey. Catches in this season were much lower than predicted, however, probably at least partially because of an outbreak of "black gill" syndrome (Diggles et al. 2000) and an invasion of the filter-feeding tubeworm *Chaetopterus* sp. on many beds (Cryer & Parkinson 2002). These low catches meant that financial returns from the fishery were correspondingly low and the Minister agreed to defer the 1999 and 2000 surveys to reduce cost recovery levies for the period 1 April 1999 to 30 September 2001. Quota owners agreed to limit their catch for 1999–00 to a voluntary limit 40 t. In 2000–01 the TACC was further reduced to 60 t, and the voluntary limit was reset to 30 t. The Northland Scallop Enhancement Company (NSEC) achieved these limits by leasing back quota off quota holders so that it was not available to cover landed catches for those years. A pre-season survey in 2001 predicted low levels of yield for the coming season (Cryer & Parkinson 2002).

In 2002 the SCA 1 fishery was introduced to Schedule 2 of the Fisheries Act (1996) which specifies that, for certain "highly variable" stocks, the Annual Catch Entitlement (ACE) can be increased within a fishing season. The TACC remains static under this process, but in-season increases are made to catch limits based on pre-season research surveys, that provide projected estimates of biomass and yield for the coming season. The ACE reverts to the "base" level of the TACC at the end of each season. A TAC of 75 t was set, with a TACC of 40 t and allowances of 7.5 t for recreational fisheries, 7.5 t for customary fisheries, and 20 t for other sources of mortality (values all in meatweight). The "base" TACC has remained static since 2002, and pre-season biomass surveys have been conducted since then in the years 2002, 2003, and 2005–07. These surveys resulted in in-season increases for only two of these years, in 2005–06 and 2006–07. NSEC decides whether it wants to commission a pre-season survey each year, to facilitate an in-season increase in the TACC.

The fishing year applicable to this fishery is from 1 April to 31 March, but the actual Northland commercial scallop season runs from 15 July to 14 February. The minimum legal size (MLS) is 100 mm.

Annual landed catch weight totals are available from 1980 onwards (Table 1, Figure 6). Although landings have fluctuated considerably, tonnages landed in the 1980s and 1990s were usually far greater than those landed in more recent years. Only 1143 kg of scallops were landed in 2010–11, which was taken mostly by a single vessel fishing in Rangaunu Bay.

Table 1: Catch limits and landings (t meatweight or greenweight) from the Northland fishery since 1980. Data in this table are taken from the 2010 Working Group report, but the MHR totals since 1989–90 and CELR meatweight totals since 1991–92 are derived from database extracts groomed as part of the present study. Data before 1986 are from Fisheries Statistics Unit (FSU) forms. Landed catch figures come from Quota Management Returns (QMRs), Monthly Harvest Returns (MHRs) forms, Licensed Fish Receiver Returns (LFRRs), and from the landed section of Catch Effort and Landing Returns (CELRs), whereas estimated catch figures come from the effort section of CELRs and are pro-rated to sum to the total CELR greenweight. Catch limits for 1996 were specified on permits as meatweights, and, since 1997, were specified as a formal TACC in meatweight (Green1 assumes the gazetted meatweight recovery conversion factor of 12.5% and probably overestimates the actual greenweight taken in most years). In seasons starting in 1999 and 2000, voluntary catch limits were set at 40 and 30 t, respectively.

			Landings (t)			
	Catch limits (t)		QMR/ MHR	LFRR	CELR & FSU	
Season	Meat	Green[1]	Meat	Meat	Meat	Green
1980–81	–	–	–	–	–	238
1981–82	–	–	–	–	–	560
1982–83	–	–	–	–	–	790
1983–84	–	–	–	–	–	1 171
1984–85	–	–	–	–	–	541
1985–86	–	–	–	–	–	343
1986–87	–	–	–	114	–	675
1987–88	–	–	–	183	–	1 625
1988–89	–	–	–	171	–	1 121
1989–90	–	–	–	164	–	781
1990–91	–	–	–	115	–	519
1991–92	–	–	–	158	168	854
1992–93	–	–	–	135	166	741
1993–94	–	–	–	114	110	862
1994–95	–	–	–	205	186	1 634
1995–96	–	–	–	208	209	1 469
1996–97	188	1 504	–	129	152	954
1997–98	188	1 504	–	136	144	877
1998–99	106	848	28	31	29	233
1999–00	106	785	22	18	20	132
2000–01	60	444	15	17	16	128
2001–02	40	320	38	38	37	291
2002–03	40	320	40	40	42	296
2003–04	40	320	38	39	38	309
2004–05	40	320	40	40	37	319
2005–06	70	560	69	69	68	560
2006–07	70	560	53	53	50	405
2007–08	40	320	33	33	32	242
2008–09	40	320	25	25	25	197
2009–10	40	320	10	10	10	80
2010–11	40	320	1	1	1	8

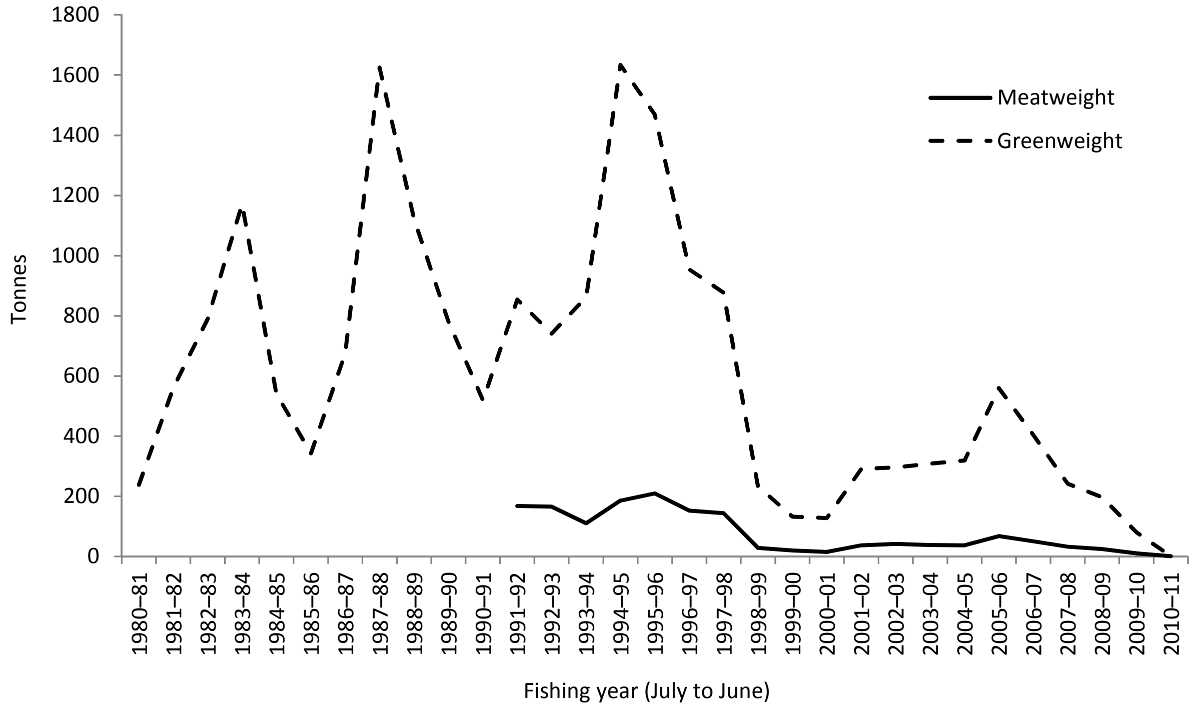

Figure 6: Tonnage of scallops landed annually from the Northland fishery since 1980–81. Annual catch totals given are derived from Fisheries Statistics Unit (FSU) data up until 1988–90, and subsequently from CELR landed weight data.

Detailed catch effort data are available from 1 October 1989, following the introduction of the CELR system. The Northland commercial scallop season runs from 15 July to 14 February the following year, and the definition of the fishing year used in this report is 1 July to 30 June, so that the first month coincides with the beginning of the commercial fishing season. Commercial fishing for scallops has taken place throughout the fishing season in all years since 1989–90, and there is only slight evidence of declining landings as each season progresses (Figure 7). The degree of interannual variability in landings is far greater than that seen within individual seasons.

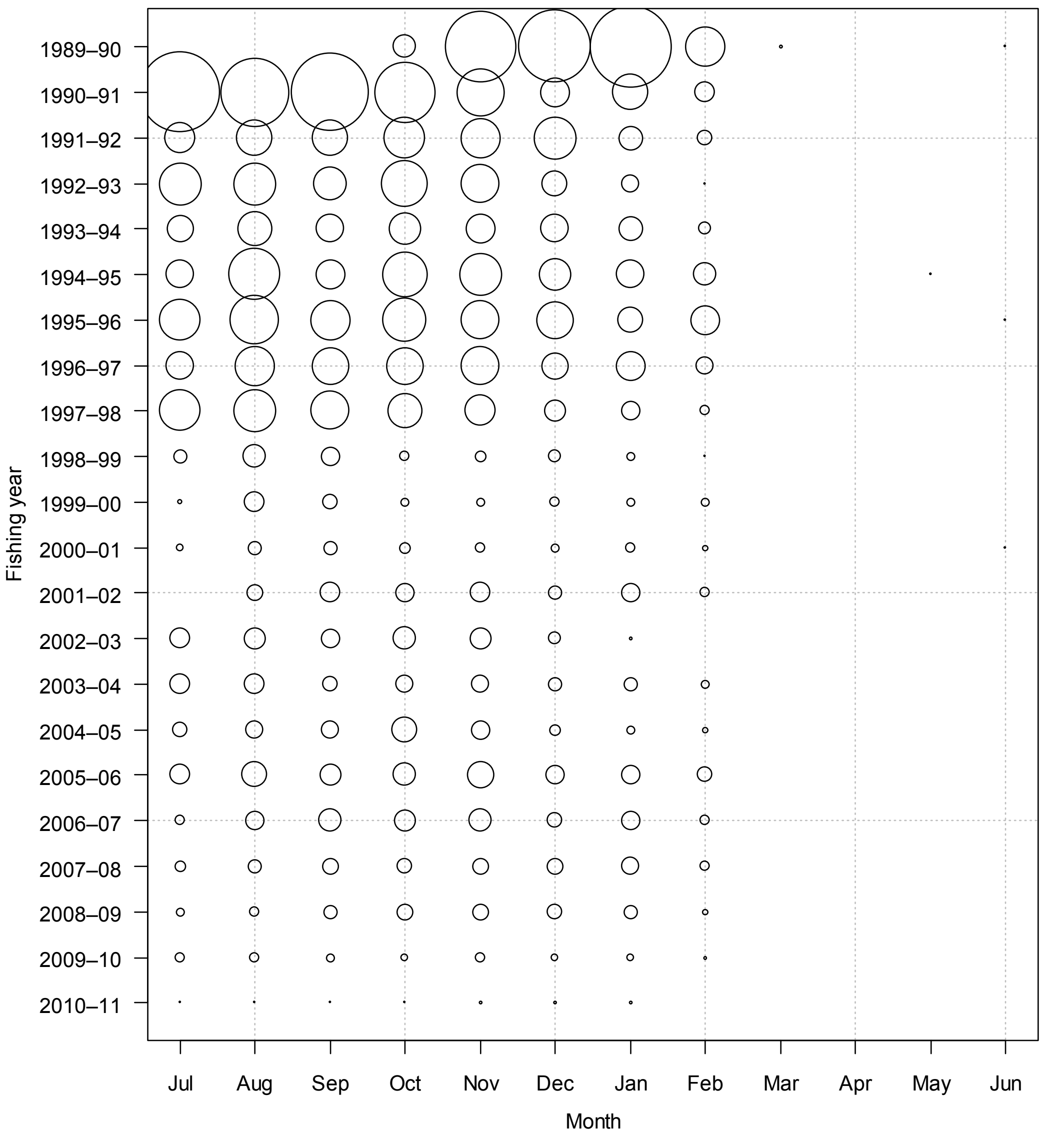

Figure 7: Meatweight tonnages landed by month by fishing year since 1989–90. Data for the first two years of the CELR system (1989–90 and 1990–91) are overestimates, as some fishers were still reporting greenweights instead of meatweights at that time. The area of the largest circle represents 32 t.

The number of vessels participating in the fishery peaked in 1995–96, but the size of the fleet subsequently declined substantially (Figure 8) following the introduction of SCA 1 into the QMS, and large scale mortality events associated with black gill disease and toxic algal blooms. Landings declined sharply, and by the late 1990s, many fishers and processors had left the fishery.

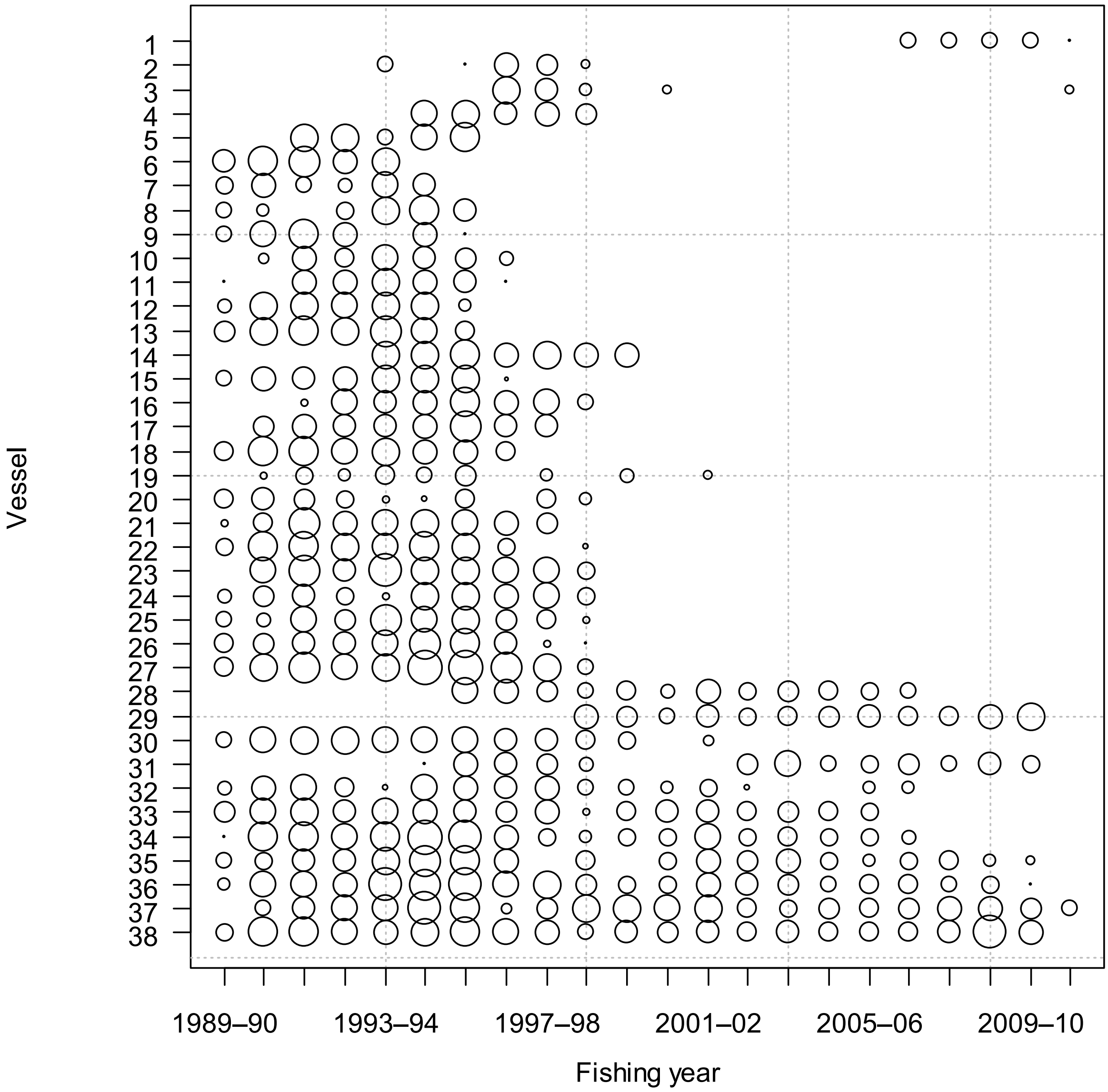

Figure 8: Days fished by vessel (encrypted vessel id) by fishing year since 1989–90. The area of the largest circle represents 146 days fished within a season.

The Northland fishery is divided into 20 scallop statistical reporting areas and most of the catch landed from SCA 1 since 1989–90 has been taken from the three most frequently fished beds: Rangaunu Bay – 1D, Bream Bay – 1R, and Spirits Bay – 9A (Figure 9). Most of the catch landed in any given year was taken from one, or occasionally, two beds. Landings from Rangaunu Bay were larger in the 1990s until 1997–98 compared with the years since then. Landings from Bream Bay were notable only in the early to mid 1990s and in 2005–07, and for Spirits Bay were largest in the period 1995–98.

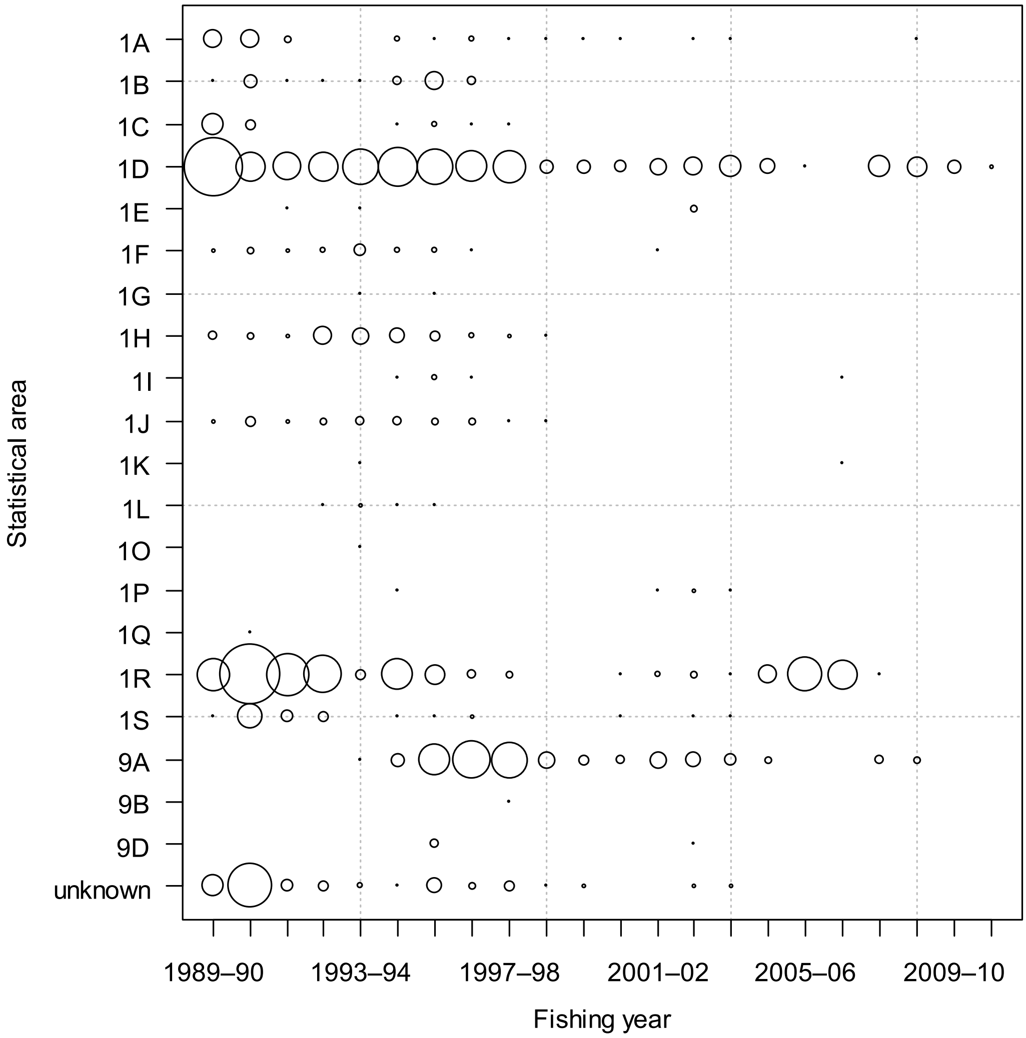

Figure 9: Meatweight tonnages landed by scallop statistical reporting area by fishing year since 1989–90. Data for the first two years of the CELR system (1989–90 and 1990–91) are overestimates, as some fishers were still reporting greenweights instead of meatweights at that time. The area of the largest circle represents 200 t.

3. STANDARDISED CPUE INDICES

3.1 Standardisation methods

Separate standardised CPUE indices were generated for the three most commonly fished areas of SCA 1: Rangaunu Bay – 1D, Bream Bay – 1R, and Spirits Bay – 9A.

Generalised linear modeling was used to predict the reported daily catch (log-transformed) of a vessel in a statistical area given the year and month fished, a measure of effort, and the identity of the vessel (Table 2). The two effort variables "Fishing duration" and "Number of tows" were both initially offered to the model to determine which would be selected first. The less informative effort variable was then removed and the model was re-run. This was necessary because the number of hours fished in a day will be correlated with the number of tows that took place on that day which violates the assumption of non-colinearity. The variable "Number of tows" was selected first in all cases. Both effort variables were offered to the model as third order polynomials, to allow for a non-linear relationship between catch and effort.

The same predictor variables (Table 2) were offered to all catch rate standardisation models. A forward stepwise procedure was used to select the predictor variable that explained most of the unexplained variance at each stage. Predictor variables were accepted only if they improved the R^2 statistic by at least 1%. The variable "Fishing year" was forced in the first iteration of this stepwise procedure, because the purpose of these analyses was to produce annual indices of relative abundance, and catch rate predictions were therefore required for each year.

Table 2: Predictor variables used in catch rate standardisations. Continuous variables were offered as third order polynomials.

Variable	Type	Description
Fishing year	Categorical	Fishing year (forced)
Month	Categorical	Month of calendar year
Vessel	Categorical	Vessel (core vessels only)
Fishing duration	Continuous	Number of hours fished per day
Number of tows	Continuous	Number of tows conducted per day

The marked reduction in the size of the scallop fleet in the late 1990s meant that only 12 vessels had participated in the fishery for at least 10 days in at least 10 fishing years, and catch effort data were considered from these vessels only. These 12 vessels accounted for 30% of the reported days fished and 33% of the meatweight landed by all vessels since 1991–92. Almost all of the catch and effort associated with the remaining 26 vessels took place in the early to mid-1990s (see Figure 8).

Catch effort data from 1989–90 and 1990–91 were dropped from all analyses, because some fishers reported greenweights rather than meatweights in these years, and there was no reliable means of detecting when this had occurred with any certainty. Catch effort data for a further 10 days were also dropped from the analysis, as fishers reported zero catches on these days, which cannot be fitted in a log-linear model.

3.2 Rangaunu Bay – area 1D

The most consistently fished bed in the Northland fishery is in Rangaunu Bay, where scallops have been taken in all but one year (2005–06) since 1989–90 (see Figure 9). Data from 2006–07 were also dropped from the analysis, as only six days of fishing occurred in Rangaunu Bay in this season.
All four explanatory variables were selected by the model, which explained 63% of the variance (Table 3). Both the standardised and unstandardised catch rate indices for area 1D fluctuated markedly over the long term, although there is some evidence of progressive changes in catch rates over three to four consecutive years (Figure 10). Catch rates were relatively stable in the early to mid-1990s, declined sharply between 1997–98 and 1998–99, and then recovered briefly in 2002–03 and again in 2007–08. Catch rates have since declined steadily, with very little fishing effort taking place in 2010–11. The low level of effort in 2005–06 and 2006–07, despite potentially viable catch rates, is probably due to higher catch rates in Bream Bay at that time.

Diagnostic plots for the catch rate standardisation are given in Appendix B. The distribution of the number of tows undertaken per day has remained relatively static since 1991–92 (Figure B2). Predicted catches increase as the number of tows undertaken per day increases, although there is relatively little gain in catch for high effort days, which is probably an artifact attributable to misreporting. Some vessels have generally higher catch rates, in Rangaunu Bay, and throughout the fishery (Figure B3). Catch rates decline after the first month's fishing, and again toward the end of the fishing season (Figure B4).

Table 3: Order in which predictor variables were selected by a lognormal stepwise linear regression of daily catch data for the scallop fishery in Rangaunu Bay, and the improvement in the R^2 statistic which resulted from their inclusion at each step. The variable "Fishing year" was forced in the first iteration of the stepwise procedure. Variables accepted by the model are denoted with an * superscript.

Variable	1	2	3	4
Fishing year*	0.269			
Number of tows*		0.517		
Vessel*		0.389	0.609	
Month*		0.299	0.551	0.632

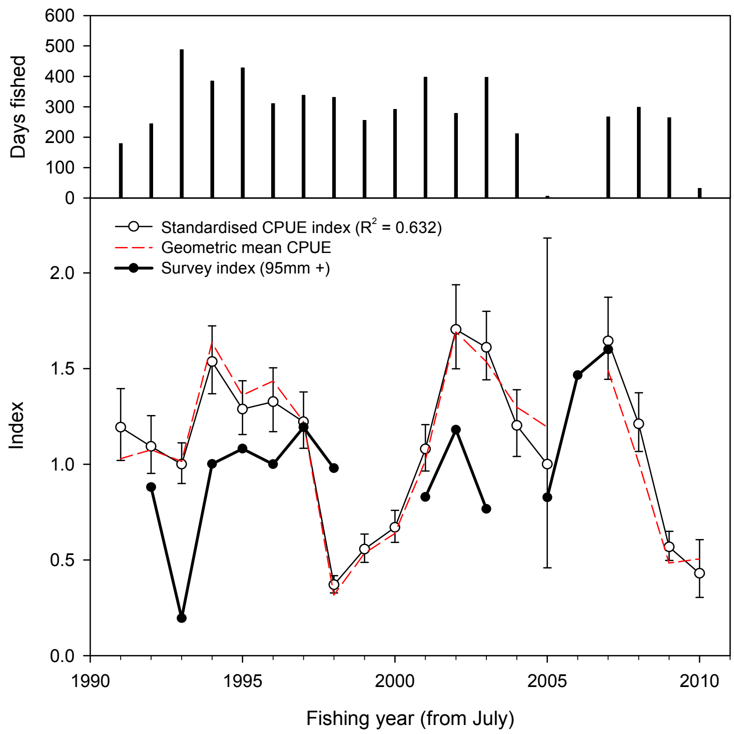

Figure 10: Standardised (lognormal) and unstandardised (geometric mean) scallop catch rate indices for a core set of vessels that dredged in Rangaunu Bay on at least 10 days a year in at least 10 years between 1991–92 and 2010–11. Error bars denote 95% confidence intervals. A relative survey based index of biomass estimates for 95 mm+ scallops in Rangaunu Bay is also given for comparative purposes.

Although there appears to be some similarity in the trends seen between catch rate based and biomass survey based indices of abundance, any comparison should consider the fact that the Northland commercial fishery is subject to a 100 mm minimum legal size limit, whereas survey biomass indices are currently based on scallops greater than 95mm in width. Note also that the biomass estimate for 1993–94 is biased low, because the deeper waters of Rangaunu Bay were not surveyed in this year.

3.3 Bream Bay – area 1R

Substantial harvests have been taken from Bream Bay in the early to mid-1990s and mid-2000s; small tonnages have also been landed in other years (see Figure 9). All four of the explanatory variables offered to the model were selected, and explained 70% of the variance (Table 4). Catch rates in Bream Bay were relatively stable in the 1990s until 1997–98, although the level of effort (days fished) showed an overall downturn during that period, after which there was no fishing until 2000–01. During 2000–03 effort was low but catch rates gradually improved, and, following a year of no fishing in 2003–04, catch rates reached very high levels in 2004–06, and subsequently declined in 2006–08 (Figure 11). Daily catches increased as the number of tows undertaken increased (Appendix C, Figure C2) and the relative efficiency of vessels fishing in Bream Bay (Figure C3) was similar to that seen in Rangaunu Bay (Figure B3). Catch rates usually declined towards the end of the fishing season (Figure C4).

Table 4: Order in which predictor variables were selected by a lognormal stepwise linear regression of daily catch data for the scallop fishery in Bream Bay, and the improvement in the R^2 statistic which resulted from their inclusion at each step. The variable "Fishing year" was forced in the first iteration of the stepwise procedure. Variables accepted by the model are denoted with an * superscript.

Variable	1	2	3	4
Fishing year*	0.404			
Number of tows*		0.597		
Vessel*		0.477	0.659	
Month*		0.447	0.644	0.701

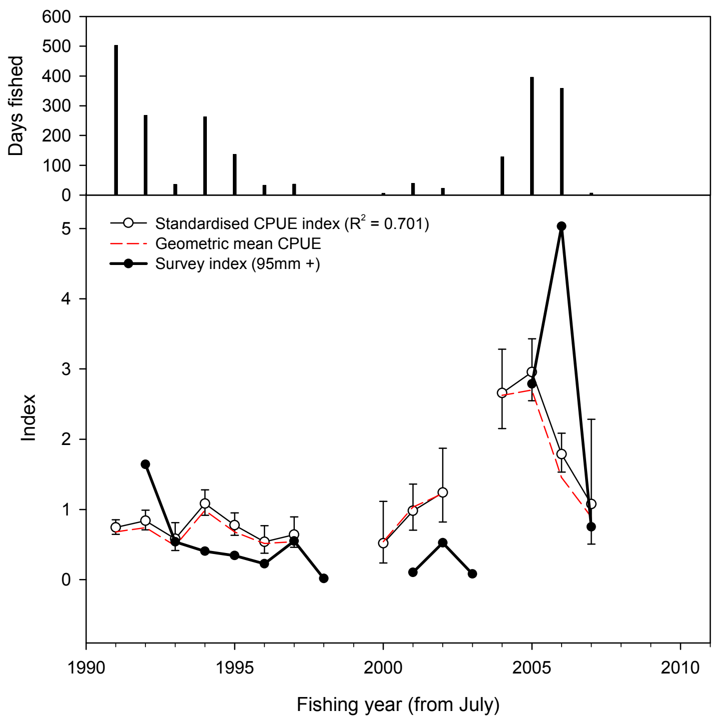

Figure 11: Standardised (lognormal) and unstandardised (geometric mean) scallop catch rate indices for a core set of vessels that dredged in Bream Bay on at least 10 days a year in at least 10 years between 1991–92 and 2010–11. Error bars denote 95% confidence intervals. A relative survey based index of biomass estimates for 95 mm+ scallops in Bream Bay is also given for comparative purposes.

3.4 Spirits Bay – area 9A

Spirits Bay has been fished from 1993–94 to 2004–05, and from 2008–09 to 2009–10 (see Figure 9). All four of the variables offered to the Sprits Bay catch rate standardisation model were selected by the stepwise fitting procedure, and collectively explained 63% if the variance (Table 5). Unstandardised and standardised catch rates peaked in the mid-1990s (Figure 12) when annual harvests were also highest. Catch rates subsequently declined sharply until 1998–89, and then increased slightly to 2000–01. That was followed by a sharp increase to a second peak in 2001–02, and subsequent gradual declines. Annual levels of fishing effort (days fished) have since declined, as the fishery has shifted to areas closer to ports with potentially higher catch rates. Although the overlap between the catch rates based indices and survey based index is limited, similar trends are evident over the time assessed.

As elsewhere, daily catches increased as more tows were completed in a day (Figure D2), with catch rates decreasing as the season progressed from July to February (D4).

Table 5: Order in which predictor variables were selected by a lognormal stepwise linear regression of daily catch data for the scallop fishery in Spirits Bay, and the improvement in the R^2 statistic which resulted from their inclusion at each step. The variable "Fishing year" was forced in the first iteration of the stepwise procedure. Variables accepted by the model are denoted with an * superscript.

Variable	1	2	3	4
Fishing year*	0.232			
Number of tows*		0.506		
Vessel*		0.332	0.602	
Month*		0.266	0.538	0.627

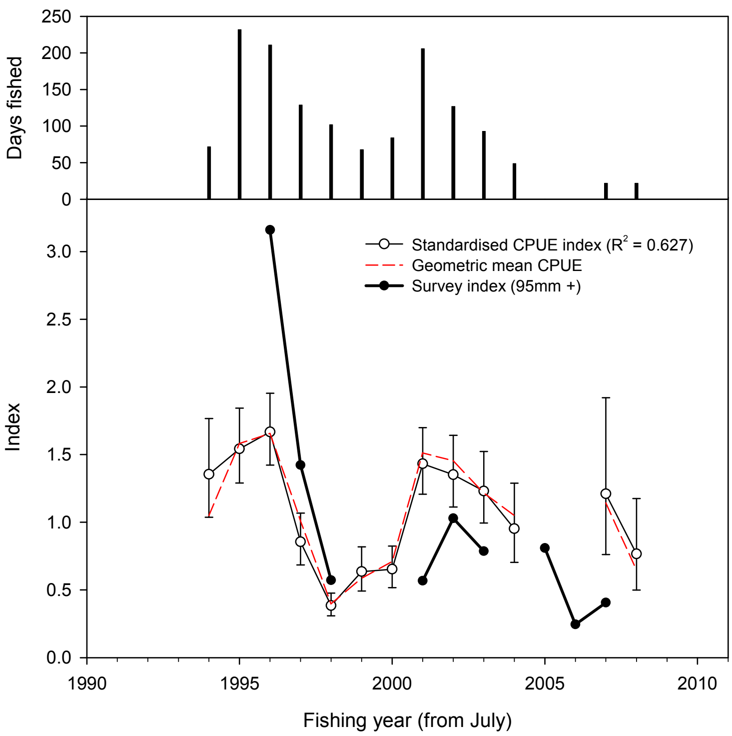

Figure 12: Standardised (lognormal) and unstandardised (geometric mean) scallop catch rate indices for a core set of vessels that dredged in Spirits Bay on at least 10 days a year in at least 10 years between 1991–92 and 2010–11. Error bars denote 95% confidence intervals. A relative survey based index of biomass estimates for 95 mm+ scallops in Spirits Bay is also given for comparative purposes.

3.5 Combined indices for Rangaunu Bay, Bream Bay and Spirits Bay

Data from individual statistical areas were combined to provide a CPUE based index of abundance for the whole SCA 1 fishery. The following analyses should be regarded with some caution, however, because data from individual areas are not weighted together on the basis of their relative biomass, but rather by the amount of data available. This assumes that catch rates throughout the fishery are broadly homogeneous, or that the spatial distribution of fishing effort reflects the relative abundance of scallops in each area. The influence that data from each statistical area have on the standardised catch rate indices varies from year-to-year, as does the distribution of these data (Figure E2). No account is taken of years and areas where no CPUE data are available, which may introduce a bias (Walters 2003).

The interaction between the variables Statistical area and Fishing year was offered to the model, to assess the validity of a combined area analysis, and although this term was selected by the model, it was selected last, and only explained a further 1.4% of the variance (Table 6). This interaction term was ultimately dropped from the model because of the need to generate an index of catch rates by fishing year. The combined area model suggests that the abundance of scallops throughout SCA 1 declined in the late 1990s, and then steadily increased substantially until 2005–06, after which there has been a steady decline (Figure 13).

Table 6: Order in which predictor variables were selected by a lognormal stepwise linear regression of daily catch data for the scallop fishery in Spirits Bay fishery, and the improvement in the R^2 statistic which resulted from their inclusion at each step. The variable "Fishing year" was forced in the first iteration of the stepwise procedure. Variables accepted by the model are denoted with an * superscript.

Variable	1	2	3	4	5
Fishing year*	0.271				
Number of tows*		0.540			
Vessel*		0.348	0.614		
Statistical area		0.307	0.595	0.653	
Month*		0.281	0.551	0.623	0.665

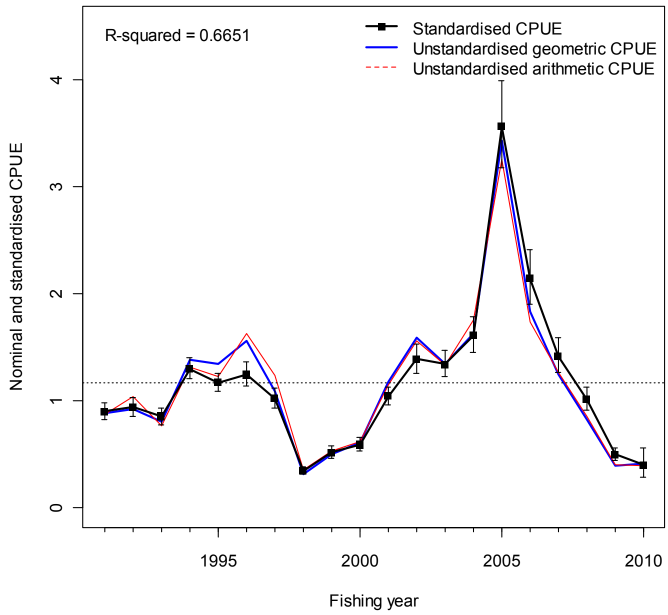

Figure 13: Standardised (lognormal) and unstandardised (geometric mean) scallop catch rate indices for a core set of vessels that dredged in Spirits Bay on at least 10 days a year in at least 10 years between 1991–92 and 2010–11. Error bars denote 95% confidence intervals. A relative survey based index of biomass estimates for 95 mm+ scallops in Spirits Bay is also given for comparative purposes.

3.6 Comparing CPUE indices with biomass survey indices

Area specific and combined area catch rates indices were compared collectively with independent indices based on biomass survey estimates (Figure 14). The degree of similarity between these two sets of abundance indices is low. A marked peak in catch rates in Rangaunu Bay and the three area index occurs in 2005–06, but this spike in assumed abundance is not evident in survey estimates until the following year. This lack of similarity is partially due to: the intermittent nature of the survey time series, the fact that commercial fishers are subject to a minimum legal size of 100 mm whereas the survey estimates are for 95 mm+ scallops, and interannual variability in the spatial distribution of fishing effort and survey strata definitions.

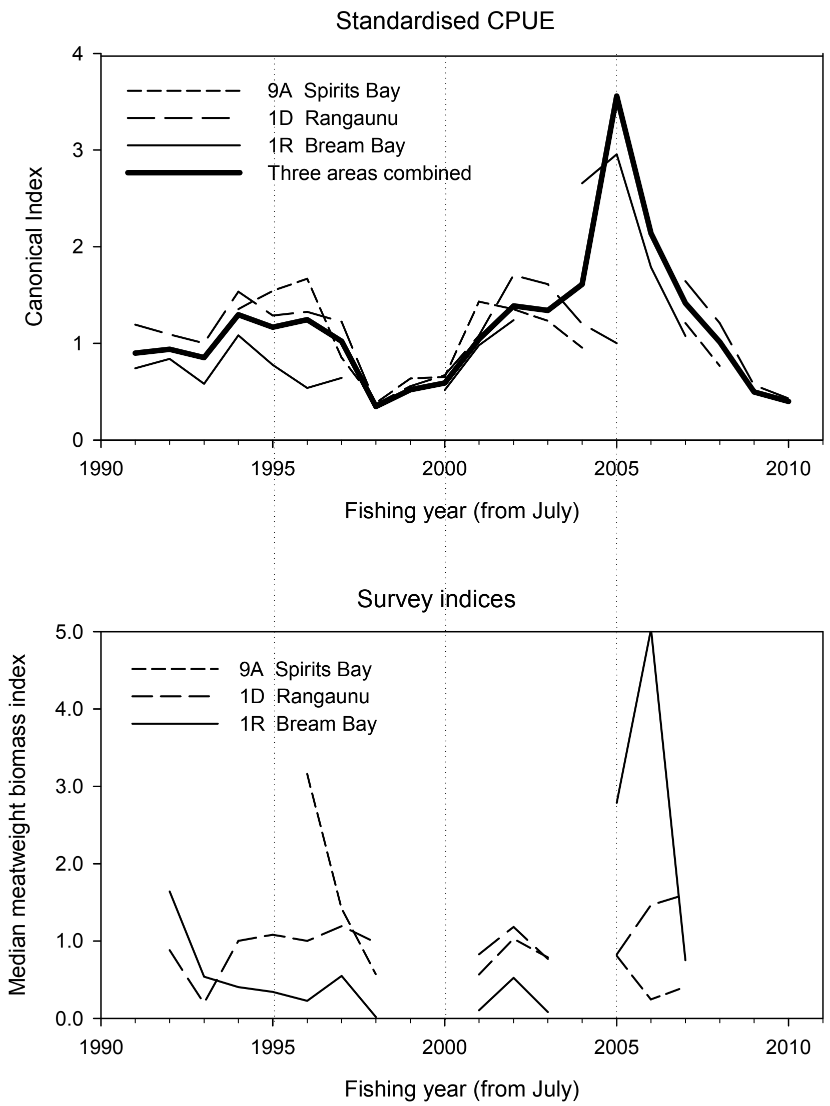

Figure 14: Standardised (lognormal) scallop catch rate indices for the three most commonly fished areas of the Northland scallop fishery and for all three areas combined (upper panel), compared with indices based on biomass survey estimates (lower panel).

4. DISCUSSION

Scallop abundances can vary considerably over time, and much of the research conducted on the SCA 1 fishery to date has focused on short-term perspectives informed by pre-season biomass surveys. This review provides a longer term synthesis of all available sources of information, which suggests that additional data gathering systems and analyses are required to inform the management of the fishery at those times when it is most vulnerable, such as now.

The Northland scallop fishery developed gradually in the 1970s, with over 30 vessels actively fishing between 1985 and early 1997, when the fishery was introduced into the Quota Management System. Fishing effort before 1997 was widespread across the Northland coast, with annual landings of around 100 t to 200 t meatweight. Most of this catch was taken in two to three of the eleven statistical areas commonly fished at that time. Landings declined rapidly in the late 1990s, partially due to a post-QMS reduction of the fleet to 10 vessels, and in part due to an outbreak of "black gill" disease in the mid to late 1990s which coincided with an invasion of the tubeworm *Chaetopterus* spp.

Annual landings in the early QMS years fell far short of the relatively high TACCs set at that time, which did not take the reduction of effort and recent impacts of "black gill" disease and *Chaetopterus* into account. Rapid and voluntary downward adjustments to catch limits were made, but apart from a brief and marked recovery in 2005–06 in Bream Bay, the performance of the fishery has since been poor and landings are currently at a very low level. Although the fishery is managed under Schedule 2 of the Fisheries Act 1996, with a "base" TACC of 40 tonnes, the fishery often fails to catch this initial allocation. One of the most noticeable changes to the fishery is the fact that almost all fishing effort now takes place in only one or two statistical reporting areas, which are consistently fished.

Two sources of independent information have been used to assess the performance of the SCA 1 fishery: catch and effort data reported by commercial fishers on CELRs since 1989, and estimates provided by pre-season biomass surveys conducted by the Ministry of Agriculture and Fisheries (MAF) between 1992 and 1995 and by NIWA since 1996. The indices of abundance derived from these two data sources are only loosely similar, however, and they neither individually nor collectively give a sufficient assessment of the performance of the fishery over time.

Catch and effort data are routinely available at little additional cost because they are required for a variety of management purposes, regardless of any research need. The data submitted by SCA 1 fishers since 1989 provide an uninterrupted record of the level of catch and effort actually experienced in each season. Although these data can be used infer relative trends in abundance over time, there are several reasons why any apparent trends should be interpreted with some caution.

Commercial fishers target their fishing towards those areas that yield the greatest financial return, and catch effort data, therefore, are not necessarily available for areas where scallop densities are low, or for areas further afield when equally good catch rates are experienced closer to port. Catch effort data, therefore, tell us little about the relative performance of areas experiencing low abundance at that time. Only one of the Northland scallop beds has been fished consistently over the past twenty years (Rangaunu Bay) and there is poor agreement between CPUE trends for this area with those seen in the other two less frequently fished beds (Spirits Bay and Bream Bay). Further, the spatial scale at which catch and effort data are reported is coarse, and there are likely to be places within a statistical reporting area which have relatively high localised abundance, that fishers serially target to maintain high catch rates, masking any decline in abundance. Hyperstability, the maintenance of high catch rates despite declining abundance (Hilborn & Walters 1992), can occur both across and within statistical areas, over a range of temporal scales. Fisheries that target sedentary organisms such as scallops are particularly hyperstable (Orensanz et al. 2006). Pre-season surveys and exploratory tows by a commercial fisher can also influence where the fleet fishes in the coming season, but the reported catch effort data do not fully reflect the knowledge that fishers may have about relative abundance at that time. Catch rates during a fishing season will also be maintained to some degree, as sub-legal fish grow through to a harvestable size.

Reported catch weights and catch rates can also change during the season, purely because of changes in scallop condition, and not changes in abundance, so reported weights provide only a very broad predictor of the number of scallops taken. Catch effort data also tell us nothing about the size composition of commercial catches, which could be used to improve our understanding of the population dynamics that underpin productivity. Commercial CPUE data, therefore, provide an incomplete and biased description of trends in abundance over time.

Pre-season biomass surveys overcome many of the problems associated with catch effort data, but this data source also has its limitations in the way it has been implemented for this fishery. All surveys to date have followed standardised randomised scientific methods that should provide a reasonably accurate and unbiased measure of the abundance of scallops in the area surveyed. All three of the most commonly fished statistical reporting areas in SCA 1 have been assessed by all surveys to date, providing some insight into how the less productive unfished areas fared relative to those that were fished in the same year. The length frequency data collected during these surveys have also provided a unique insight into critical processes that drive productivity, such as recruitment. The biomass estimates provided by these surveys were based on counts and estimates of numbers of scallops, rather than measured weights, which are influenced by scallop size and reproductive condition.

However, the cost of these surveys is not insignificant, especially given the scale of the levied fishery. Because the SCA 1 fishery is managed as a Schedule 2 fishery with a base TACC of 40 t, there is little incentive for fishers to commission a survey unless they are reasonably assured of an in-season increase to their seasonal catch limits. This means that surveys are not conducted in years with expected low abundance, and the resulting information gap often coincides with a paucity of catch effort data submitted by commercial fishers for that season.

Although all three of the most productive statistical areas have been assessed by each survey, the spatial extent of the area surveyed in each of these statistical areas has sometimes changed between surveys, based on advice given by commercial fishers when they were asked where they intended to fish in the coming season. This reduces the comparability of survey estimates over time. An obvious problem with this adaptive approach was in 1993, when fishers fished deeper parts of Rangaunu Bay, but only shallow waters were surveyed. This meant that a sizeable catch was taken from the wider bay, despite a low predicted yield based on stations sampled in shallow waters only. Future biomass surveys should consistently survey the entire extent of the area potentially fished in Spirits Bay, Rangaunu Bay, and Bream Bay.

Because the survey is conducted before the start of the season, it is necessary to project survey data forward, to account for growth and mortality. The length of time that will elapse between a survey and the harvest period will vary depending on the timing of the survey and the phasing of fishing effort over the coming season. Some of the previous biomass estimates for SCA 1 are based on the projected abundance of scallops with shell lengths greater than 95 mm. All existing historical biomass estimates should be revised so that they only consider scallops with projected shell lengths greater or equal to the current MLS of 100 mm, to improve the comparability of survey indices with those based on CPUE data (because commercial fishers cannot land scallops smaller than the MLS). These analyses should also incorporate recent improvements in the methods used to adjust survey data for dredge efficiency (Bian et al. 2012).

CPUE and pre-season biomass surveys therefore provide a partial description of the fisheries' performance over the last 20 years, but information is rarely available when abundances are low, when the fishery is at its most vulnerable state and active management is required. Commercial CPUE data provides an incomplete and biased description of trends in abundance over time, and the fishery is unable and unwilling to support comprehensive biomass surveys on an annual basis. All indications are that scallop abundances in SCA 1 are currently at an all-time low, however, and there is little prospect of CPUE and pre-season survey data sufficiently informing the management of this fishery under the current management regime.

One cost effective means of consistently monitoring the performance of the SCA 1 fishery would be for a combination of fisher based sampling and less frequent comprehensive surveys. Pre-season standardised tows can be used as a means of providing an abundance index for all years. The start and finish positions of these tows and their direction could be fixed through time, and the same vessel, dredge, and skipper can be used to undertake the sampling. The skipper can be tasked with recording the number of legal scallops caught in each tow, and asked to measure a limited number of these scallops. The intensity of sampling can be far less than that undertaken during normal pre-season biomass surveys, while retaining the standardisation of methods and consistent surveying of all beds of interest, regardless of prevailing scallop abundance. Fishers often undertake exploratory tows early in the season, and this suggested approach merely formalises that practice and ensures that it provides more useful information that has long term benefits. NSEC, as representative of the SCA 1 commercial scallop fishing industry, has adopted this approach, and the first two of these standardised fisher based sampling surveys were carried out in 2012 and 2013. The intention is for the same vessel and skipper to conduct standardised dredge tows each year before the beginning of the fishing season within the same core locations of SCA 1 (Bream Bay, Rangaunu Bay, Spirits Bay), to provide a cost effective means of monitoring indicative trends in abundance and size structure over the long term.

Routine collection of fishery data (catch by size category and effort) at finer spatial resolutions (similar to that undertaken by the Coromandel scallop fishery, SCA CS) during the course of normal fishing operations could also greatly improve the value and utility of the data available to examine changes in stock abundance and patterns of recruitment.

A recent investigation of North Island scallop fisheries suggested that there was potential to predict catches beyond the first season after a survey (Tuck 2011), and incorporating pre-season standardised tows, improved catch composition and effort data, and less frequent (perhaps every two or three years) comprehensive surveys into a spatially explicit length based population model may provide an informative and cost effective assessment package.

This review has posed wider questions, about whether the current management regime is the most appropriate given the spatial population dynamics and scale of the SCA 1 fishery. Although the data sources reviewed here are probably of insufficient resolution and quality to inform a management strategy evaluation (MSE) model for this fishery, much could be learned from modelling of data provided by the more data rich Coromandel scallop fishery (SCA CS). Some management strategies have already been investigated by Cryer et al. (2003), and more recently by Haist & Middleton (2010), but a more comprehensive exploration is warranted of the relative merits of: differing levels of “base” TACC for Schedule 2 fisheries, spatial management with and without bed specific “base” TACCs, the efficacy of in-season adjustments to catch limits based on pre-season surveys and/or early season catch rate data, the frequency of pre-season biomass surveys if they are routinely conducted when a low “base” TACC is set, rotational fishing, alternative minimum legal size limits, the extent to which the maintenance of critical spawning densities in key locations could maintain the longer term productivity of the stock, subdividing existing management areas to allow for management at a finer spatial scale, setting aside parts of existing management areas as reserves to support the ongoing productivity of the wider bed, and the extent to which any of these measures could minimise the incidental effects of fishing. The economic performance of the fishery should also be considered, to ensure that it can support potential management measures such as pre-season biomass surveys and monitoring of catch rates.

5. ACKNOWLEDGMENTS

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APPENDIX A

A commercial fisher's narrative on the history of the SCA 1 fishery, by Tom Hunt

This is a history of the northern commercial scallop fishery from a fisher's personal point of view. Where the word approximately is used it's because dates are from memory and exact times would need to be verified by statistical records. Refer to the SCA 1 draft Fishery Plan, page 21, Fig 6 (Ministry of Fisheries 2007) for some correlation to dates given to history.

Before the late 1960s no commercial scallop fishery existed in Northland, as there was poor demand for the shellfish. By approximately 1970 a then local fisherman had been to Australia and brought back designs for a box dredge to catch scallops. A fisher associate went about having the dredge and a winch built and fitted to his then commercial vessel and proceeded to scallop in Rangaunu Bay. The product was unloaded to the Yovich fish factory at Unahi. By the mid 1970s several more boats had started fishing scallops as market demand increased and by 1980 boats were working from most local ports.

In 1980, I purchased a Scallop business off a then retiring fisherman. At the time there were approximately 12 working permits (but more dormant) in the then northern fishery which covered from Reef Point to Cape Brett. Some fishermen also had separate permits for the Whangarei fishery which covered from Cape Brett to Cape Rodney. An average catch rate at the time was 2 bags an hr (approx. 1 ½ bins). There were no time or bag restrictions but restrictions to areas like Harbours and ½ mile lines. Fishers tended to work day and night until they had approximately 30 Bags to unload. Boats were based in Houhora, Awanui, Mangonui and Whangaroa. The main processors at the time were Hikurangi Fisheries (Yovichs) now Sanfords and Far North Fisheries.

In the 1982–83 season Doubtless Bay had a come alive event (higher than average catch rates) e.g. 6 bags an hr and most boats fished this area. Doubtless Bay continued to be a productive area and tended to be fished for the first two months of the seasons due to winter weather until approximately the mid 1990s.

Rangaunu Bay had always been one of the better Scallop bed areas but in the 1984–85 season there was an in season die off (Black Gill) so most boats ended up fishing Spirits Bay where the catch rate was approximately 6 bags an hour. Spirits Bay had no specific reporting designation so fishers used either North Cape or Area 1 as a reporting code.

About the mid 1980s through discussion with a Mr. Neil Martin of MAF the line was lifted from between the Northern and Whangarei fisheries. This meant there were approximately 24 active boats in the now combined fishery (but many more dormant permits). At this time a line was established at North Cape and Spirits Bay was given a different area code. Only boats from the original area 1 Northern Scallops were allowed to fish this area.

Approximately 1986 through discussion with MAF bag limits and shorter hours were introduced.

Also in 1986 the ITQ system was introduced starting with selected wet fish species. By 1990 Maori had put an injunction on the ITQ process and scallops along with many other species didn't move into the quota system.

In the 1987–88 season Bream Bay and Pakiri had a come a live event with most boats working this area that season. We also had the advent of more boats entering the fishery, some having sold off their wet fish ITQ now activated their scallop permits, others just seeing the opportunity to create a history in the fishery.

The early 1990s saw most boats working in the Northern areas of Whangaroa, Rangaunu, Great Exhibition and Spirits bay. By this time we had a daily catch limit of 600 kg of green shell (16 bins) and daylight hours of 6 am to 6 pm. The line was lifted at North Cape for those that had not previously fished Spirits Bay and area 9 was created for reporting. The season 1990–91, 1991–92, 1992–93 were decided by MAF as the ITQ history years for fishers. Between 1990 and 1996 the boats working in the fishery increased to 36. There were 6 processing sheds, 4 of these exporting (view graph page 22 of plan).

About 1994 meetings were held between fishers, MAF, Seafic and Maori to try to move the fishery into the ITQ system. The Maori injunction was lifted by this time with the 20% allocation agreement and the main stumbling block became the agreement of fishers to pass 20% of their historic catch to Maori at no compensation. Agreement on this and other things like the grandfather clause were negotiated over a two year period and scallops moved into the quota system in 1996–97 with the allocation of 180 tons of scallop meat to fishers in what had historically been a 100 ton fishery.

At this time the NSC was formed to manage the fishery under guidance from MAF and SeaFIC through people like Tom Hollings, Tony Craig, Graeme McGregor. Also the late 1990s saw a series of meetings and the negotiation of the then called 50 m line across Spirits Bay and Tom Bowling Bay which restricted fishers to inside this line. Also about this time a voluntary agreement was negotiated with local iwi through Dover Samuels that NSEC members would not fish the Cavalli Passage and this has been upheld until this day.

The 1998–99 season saw the sharp decline of the fishery (view graph page 22 of fish plan) due I feel to at least two factors e.g. the fishing pattern in the 90s and a pre-season advent of Black Gill causing a large die off of mature scallops. These times of die off seem to occur in years of predominantly easterly weather pattern (La Nina) as in the late 90s and this is the weather pattern we are seeing at the present. About this time we also had the occurrence of toxic bloom scare which caused harvesting shut downs and the regime of product testing which changed the future of fishing patterns with fishers restricted to areas tested and opened at NSEC cost. This is still the case today. 1998 also saw the first trials of spat catching lines by NSEC with mixed results.

1999 saw the quota holdings cut by 76% due to poor survey results and a change in the way the TAC was calculated. This put many fishers and processors out of business and the lack of supply stopped export.

In approximately 2000 the commercial catch was set at 40 tons and has stayed at that until this day except for the 2005–06 and 2006–07 seasons when the commercial catch was lifted to 70 tons by MFish advice due to survey results for those years. There are now 8 boats and 2 processors working in Northland Scallops.

The 2000–2001 season showed an increase in catch rates from the previous two seasons but also the worry of tube worm invasion in both Rangaunu Bay and Bream Bay and many areas could not be fished due to dredge clogging by the worm.

2001–2002–2003 were reasonably good years in both Rangaunu Bay and Spirits Bay with catch rates of about 3 bins per hr.

In the 2004–2005 season Bream bay came alive and continued this way until the end of the 2006–2007 seasons with catch rates between 5 to 8 bins per hr.

The 2007 survey told us that Rangaunu was the best for stock and the season started well at between 6 to 8 bins an hr. But about 4 weeks into season we had a Northerly storm with 7 metre swells which tore the bottom to pieces and deposited a good many of the scallops on the beaches, after this the catch rate was approx. 4 bins an hr. Another big storm towards the end of the season with 5 metre swells made the catch rate even slower. Most of this last season scallops were in mediocre condition due to the continual easterly pattern.

APPENDIX B

Diagnostic plots for CPUE standardisations for the scallop fishery in Rangaunu Bay

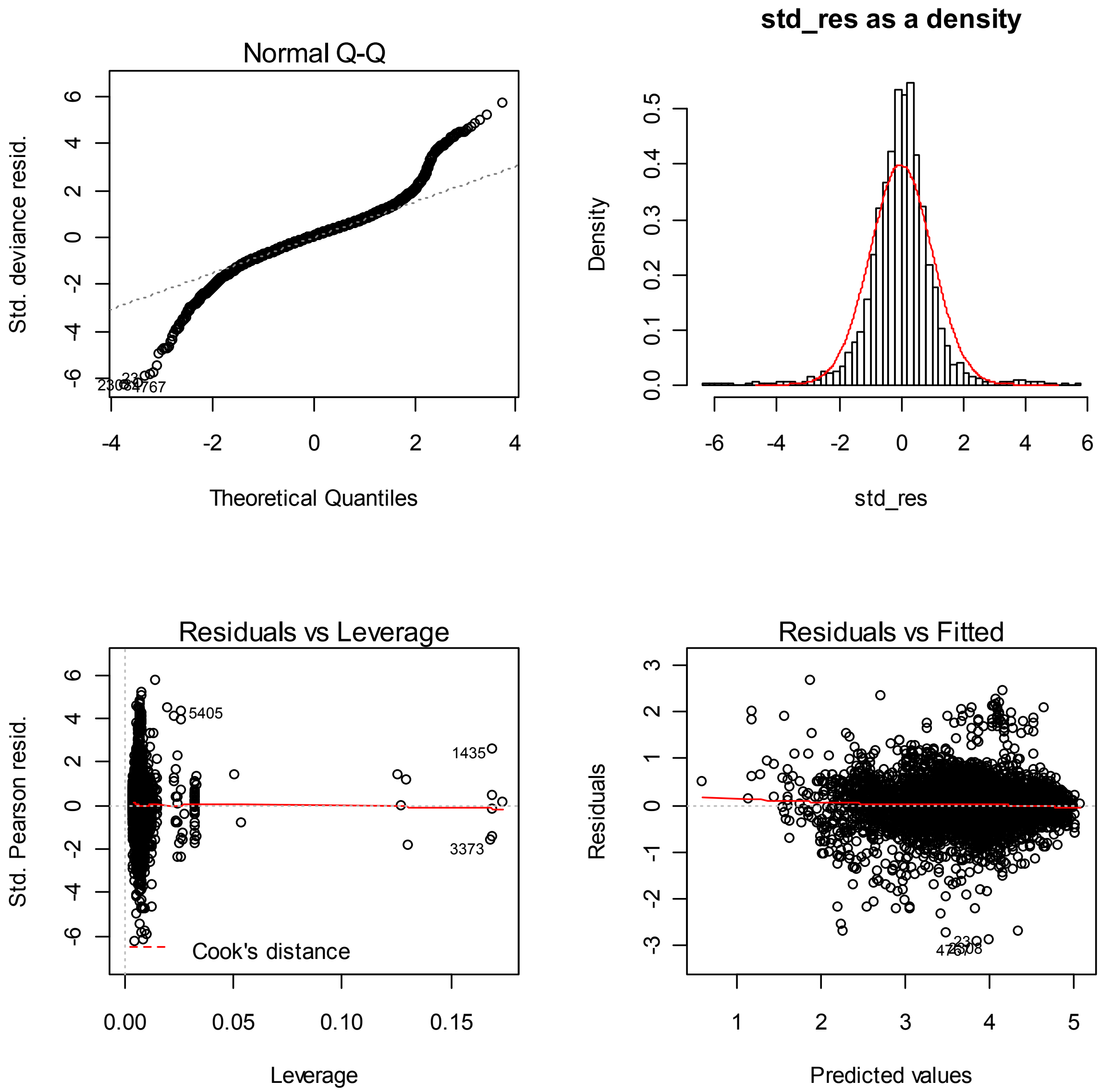

Figure B1: Diagnostic plots describing the fit of a standardised model of scallop catch rates for the Rangaunu Bay scallop fishery. A quantile-quantile plot of standardised residuals [upper left panel]; a histogram of the standardised residuals compared to the distribution predicted from a lognormal distribution [upper right panel]; a plot of standardised residuals against the leverage that each data point has on the modelled relationship between daily catches and explanatory variables [lower left panel]; standardised residuals plotted against predicted daily catches [lower right panel].

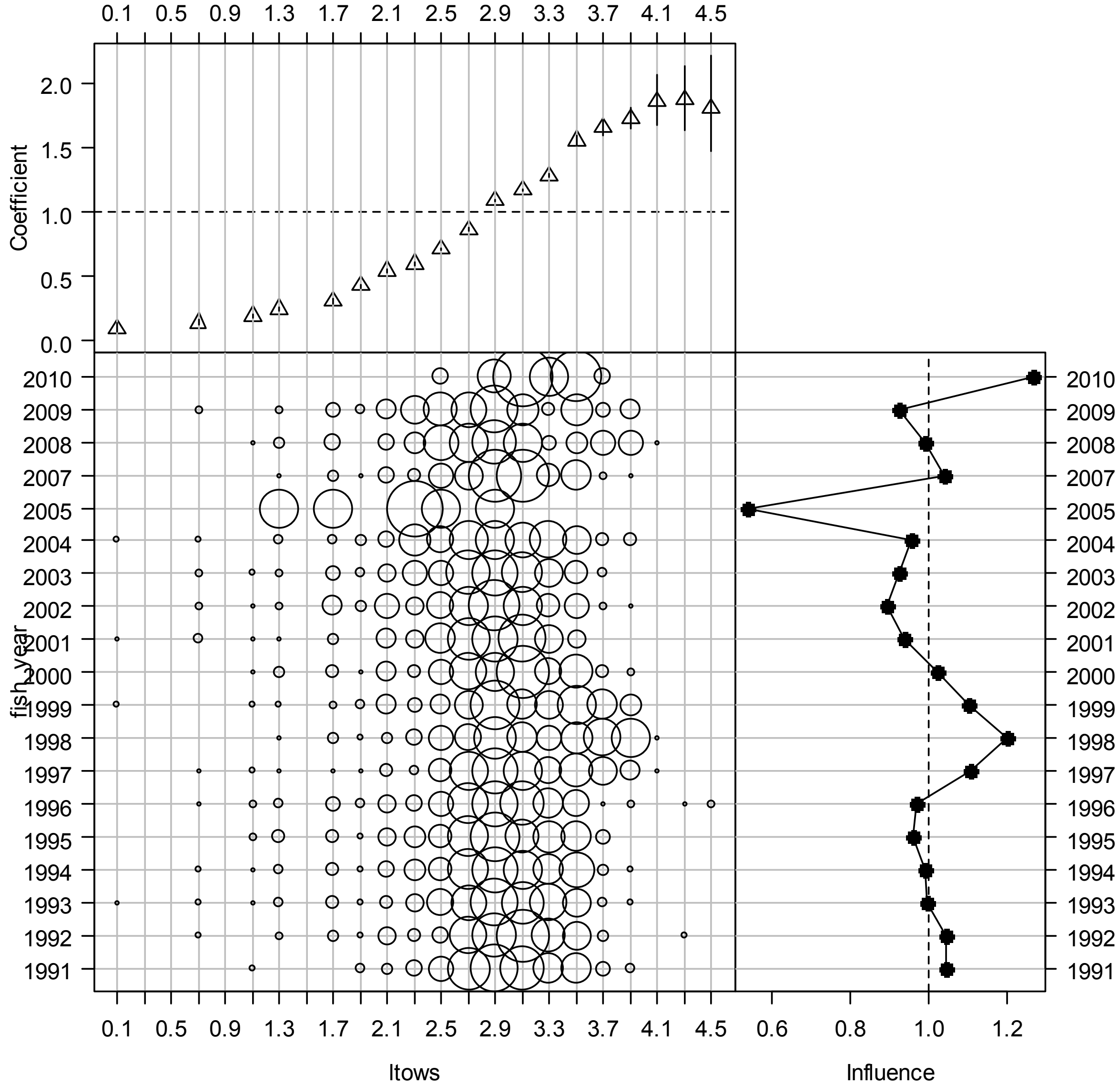

Figure B2: Effect of the logged number of tows (per day) on a lognormal model of daily catches in Rangaunu Bay. Effect by number of tows [upper panel]; Distribution of observations by fishing year [lower left panel]; cumulative effect of the variable number of tows by fishing year [lower right panel].

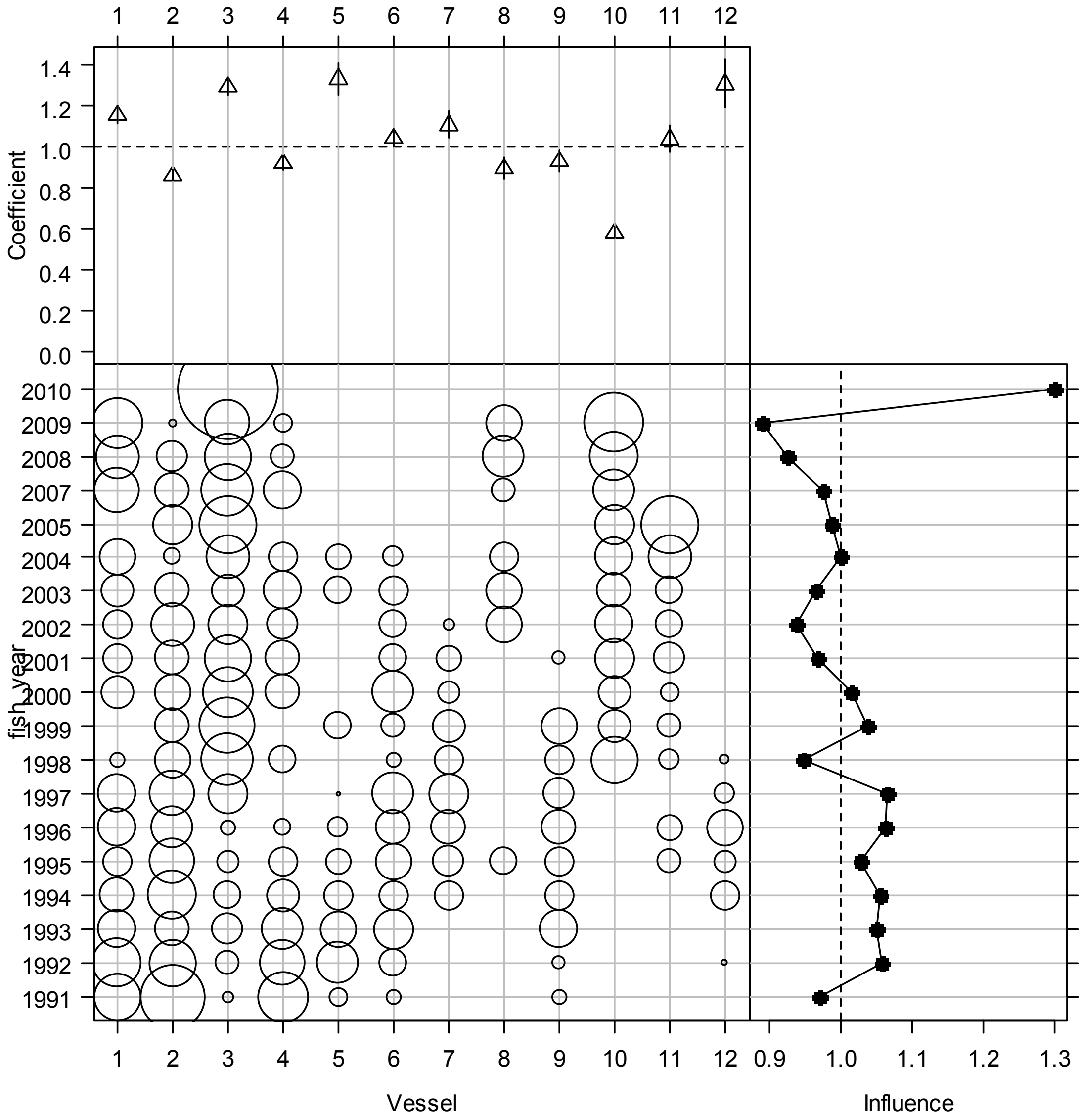

Figure B3: Effect of individual vessels on a lognormal model of daily catches in Rangaunu Bay. Effect by vessel [upper panel]; Distribution of observations by fishing year [lower left panel]; cumulative effect of the variable vessel by fishing year [lower right panel].

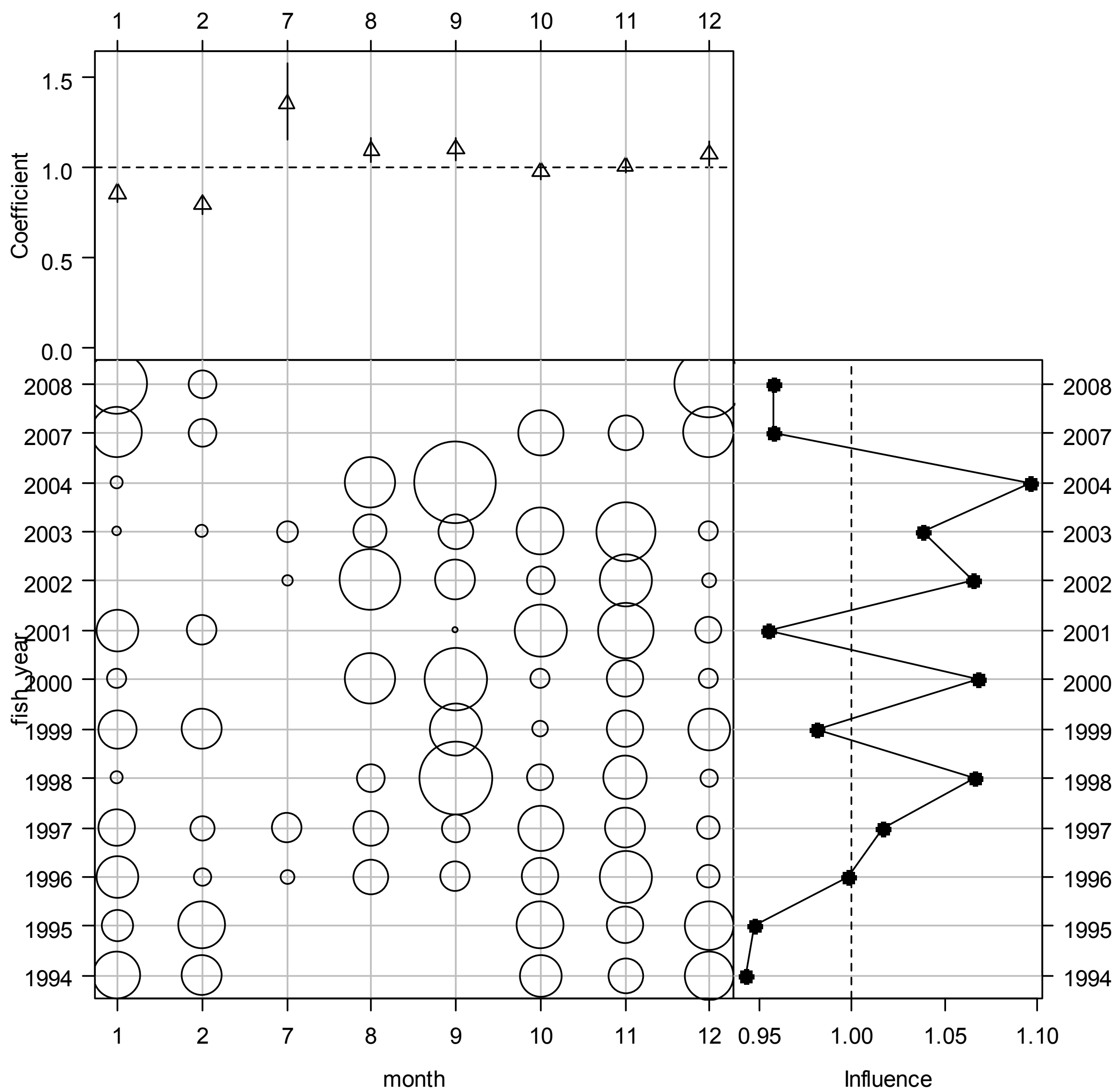

Figure B4: Effect of the variable month on a lognormal model of daily catches in Rangaunu Bay. Effect of each month [upper panel]; Distribution of observations by fishing year [lower left panel]; cumulative effect of the variable month by fishing year [lower right panel]. The scallop season runs from July (month 7) to February in the following year (month 2).

APPENDIX C

Diagnostic plots for CPUE standardisations for the scallop fishery in Bream Bay

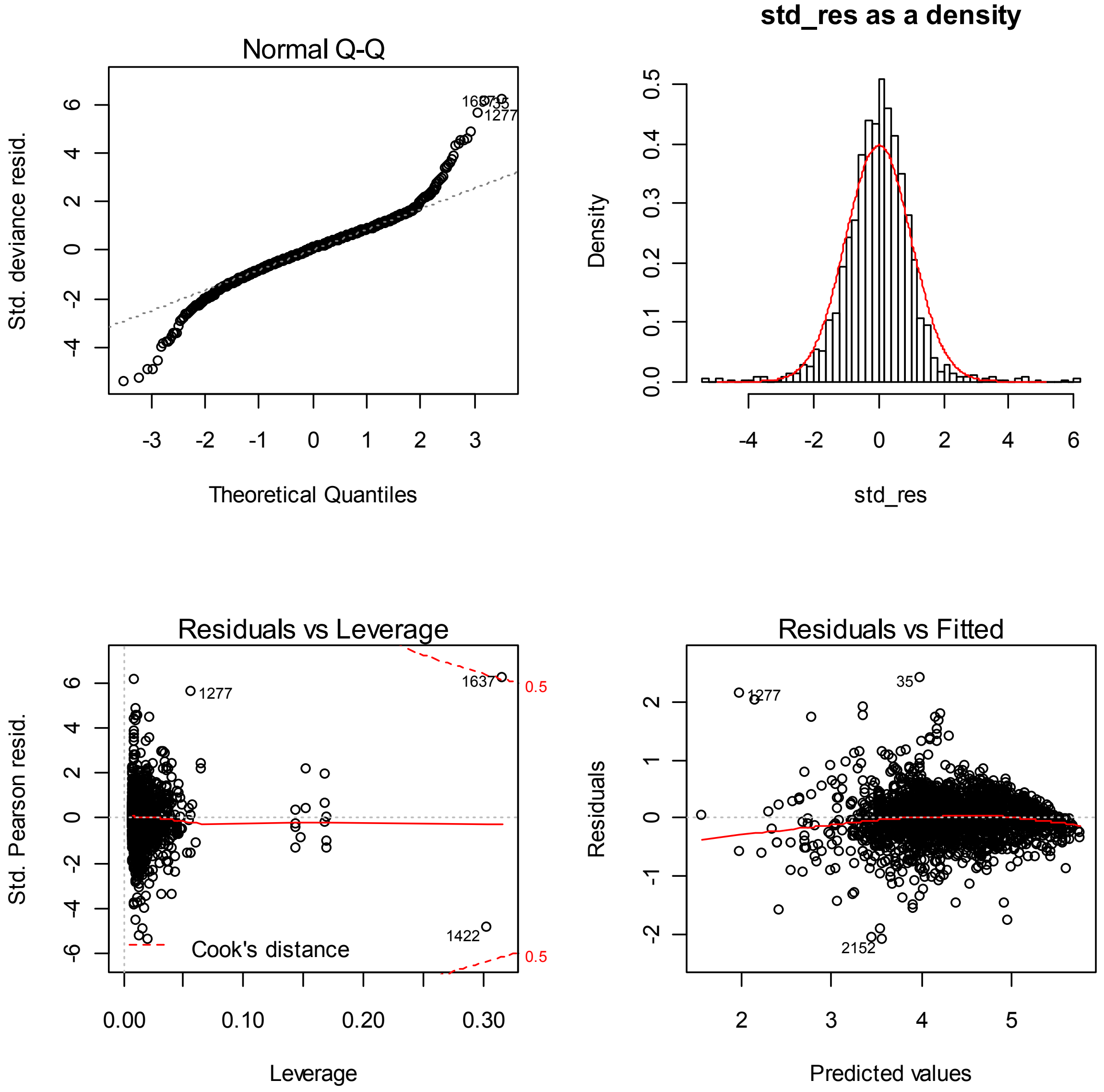

Figure C1: Diagnostic plots describing the fit of a standardised model of scallop catch rates for the Bream Bay scallop fishery. A quantile-quantile plot of standardised residuals [upper left panel]; a histogram of the standardised residuals compared to the distribution predicted from a lognormal distribution [upper right panel]; a plot of standardised residuals against the leverage that each data point has on the modelled relationship between daily catches and explanatory variables [lower left panel]; standardised residuals plotted against predicted daily catches [lower right panel].

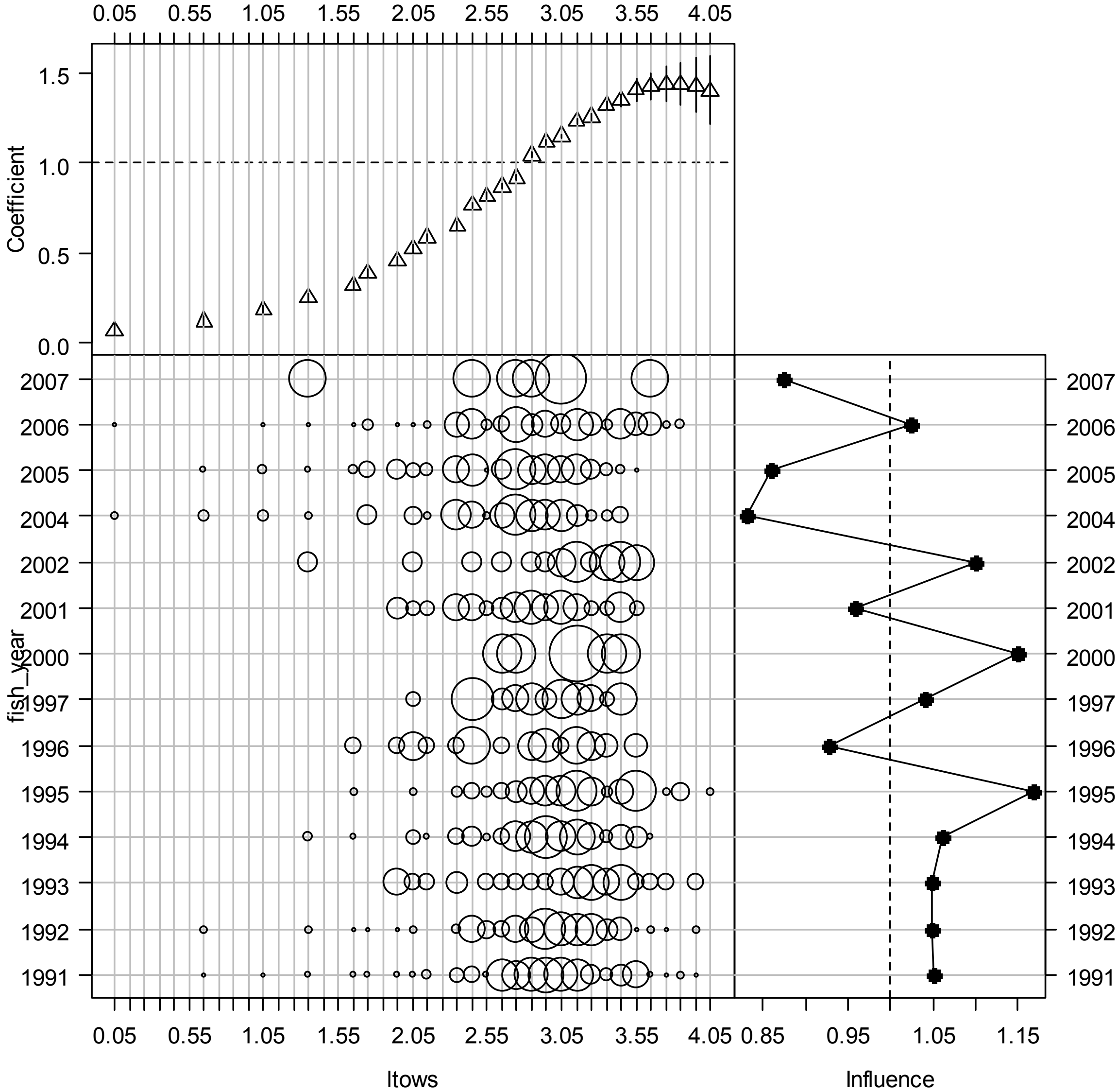

Figure C2: Effect of the logged number of tows (per day) on a lognormal model of daily catches in Bream Bay. Effect by number of tows [upper panel]; Distribution of observations by fishing year [lower left panel]; cumulative effect of the variable number of tows by fishing year [lower right panel].

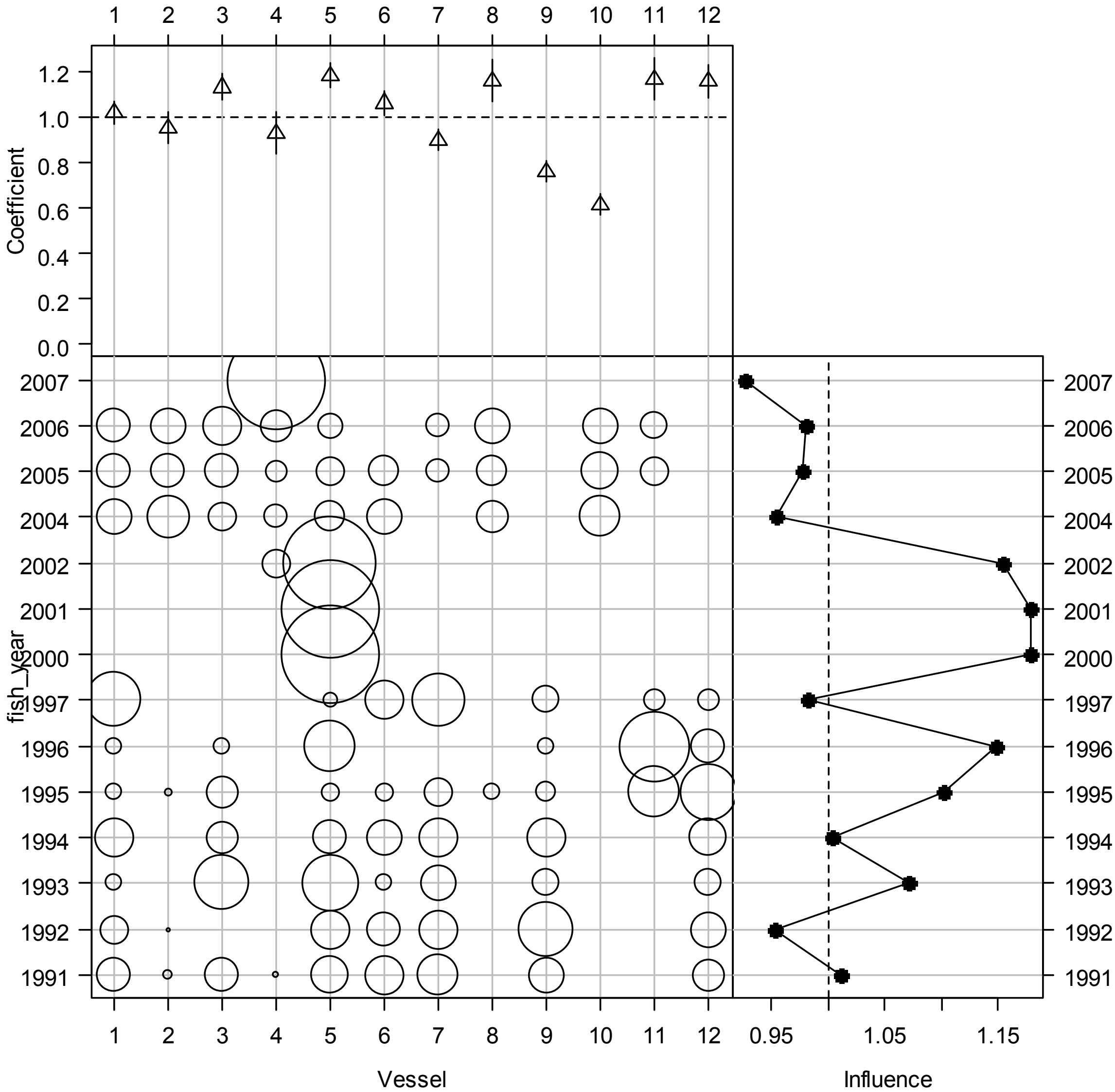

Figure C3: Effect of individual vessels on a lognormal model of daily catches in Bream Bay. Effect by vessel [upper panel]; Distribution of observations by fishing year [lower left panel]; cumulative effect of the variable vessel by fishing year [lower right panel].

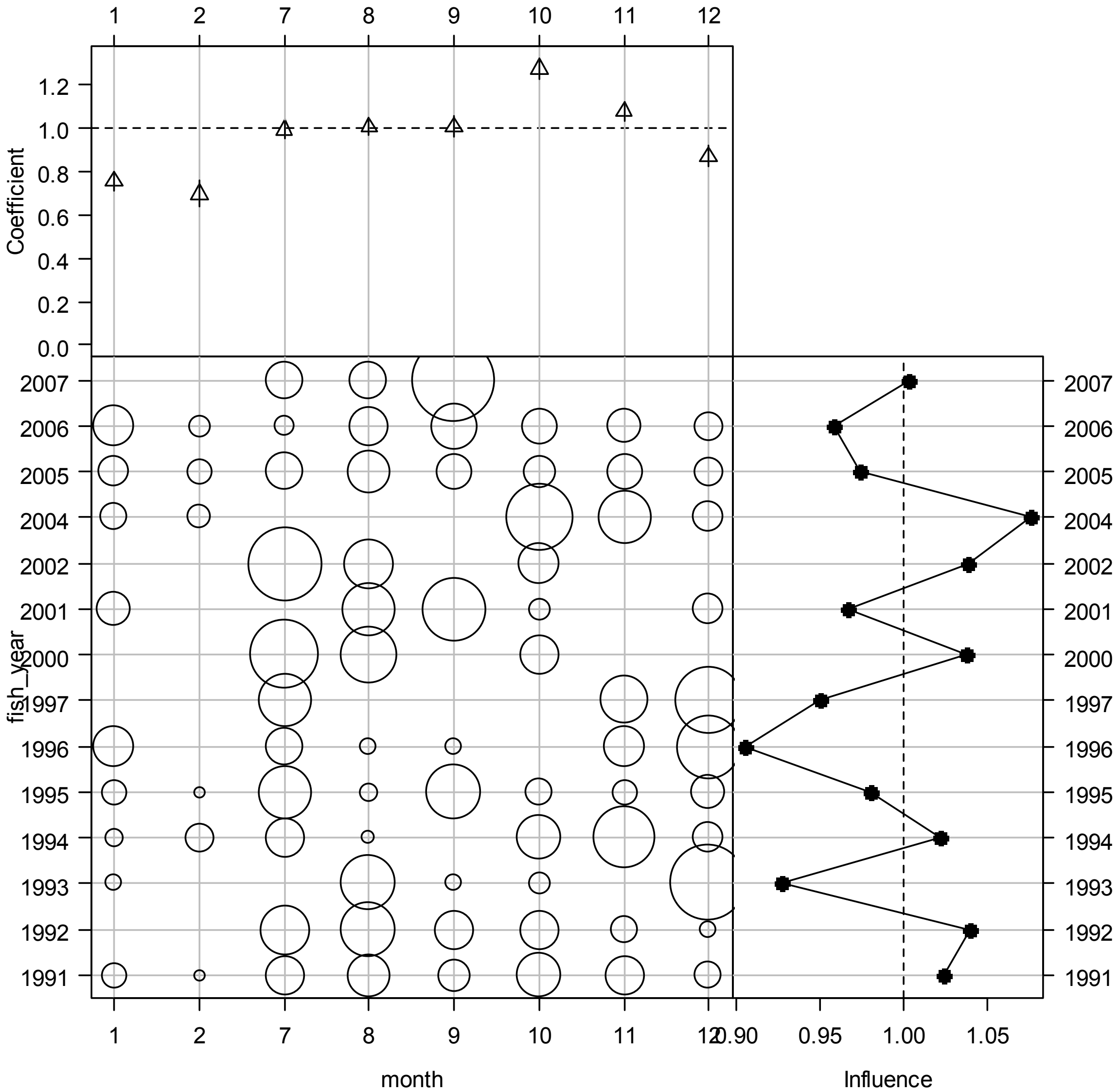

Figure C4: Effect of the variable month on a lognormal model of daily catches in Bream Bay. Effect of each month [upper panel]; Distribution of observations by fishing year [lower left panel]; cumulative effect of the variable month by fishing year [lower right panel]. The scallop season runs from July (month 7) to February in the following year (month 2).

APPENDIX D

Diagnostic plots for CPUE standardisations for the scallop fishery in Spirits Bay

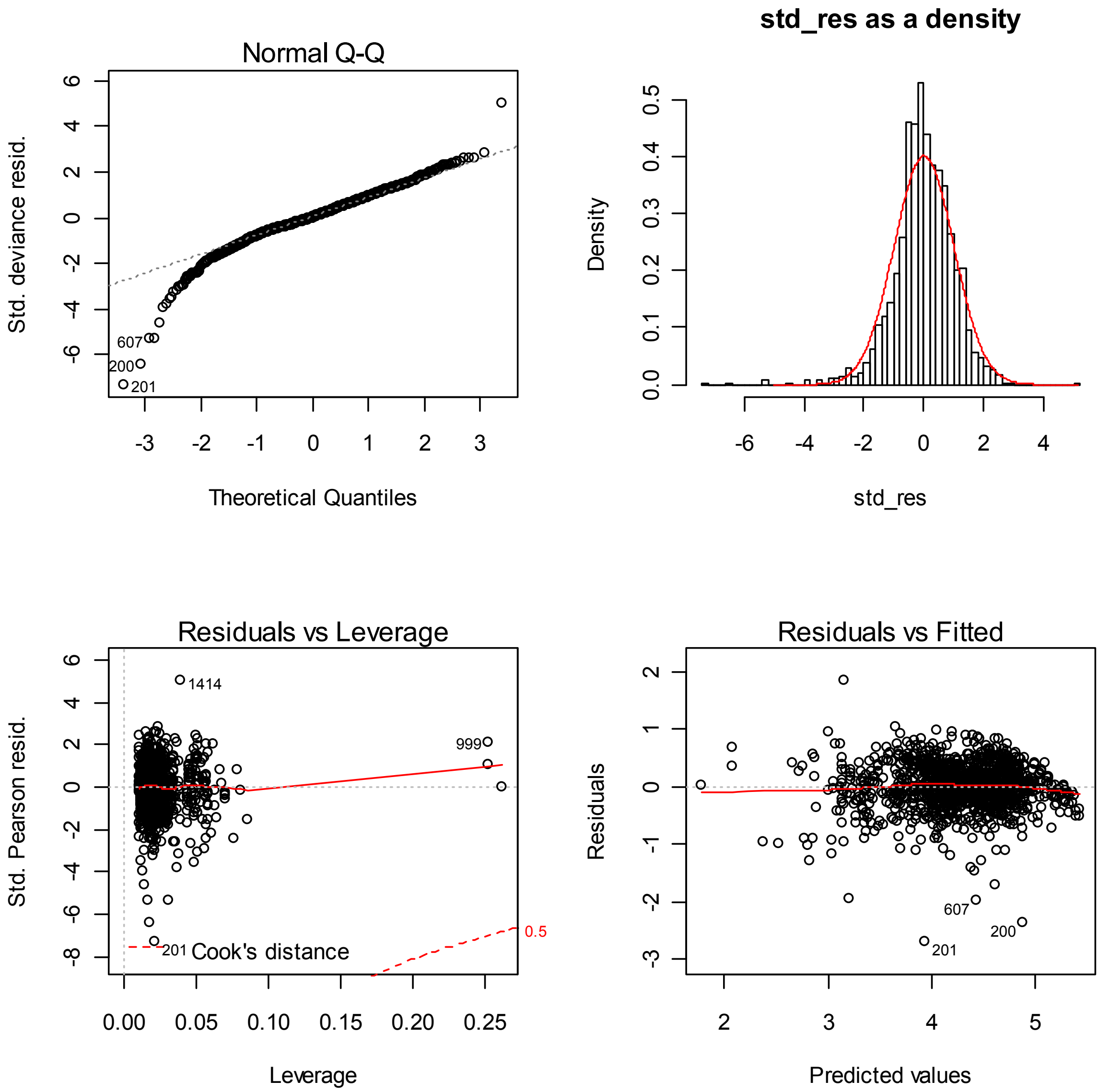

Figure D1: Diagnostic plots describing the fit of a standardised model of scallop catch rates for the Spirits Bay scallop fishery. A quantile-quantile plot of standardised residuals [upper left panel]; a histogram of the standardised residuals compared to the distribution predicted from a lognormal distribution [upper right panel]; a plot of standardised residuals against the leverage that each data point has on the modelled relationship between daily catches and explanatory variables [lower left panel]; standardised residuals plotted against predicted daily catches [lower right panel].

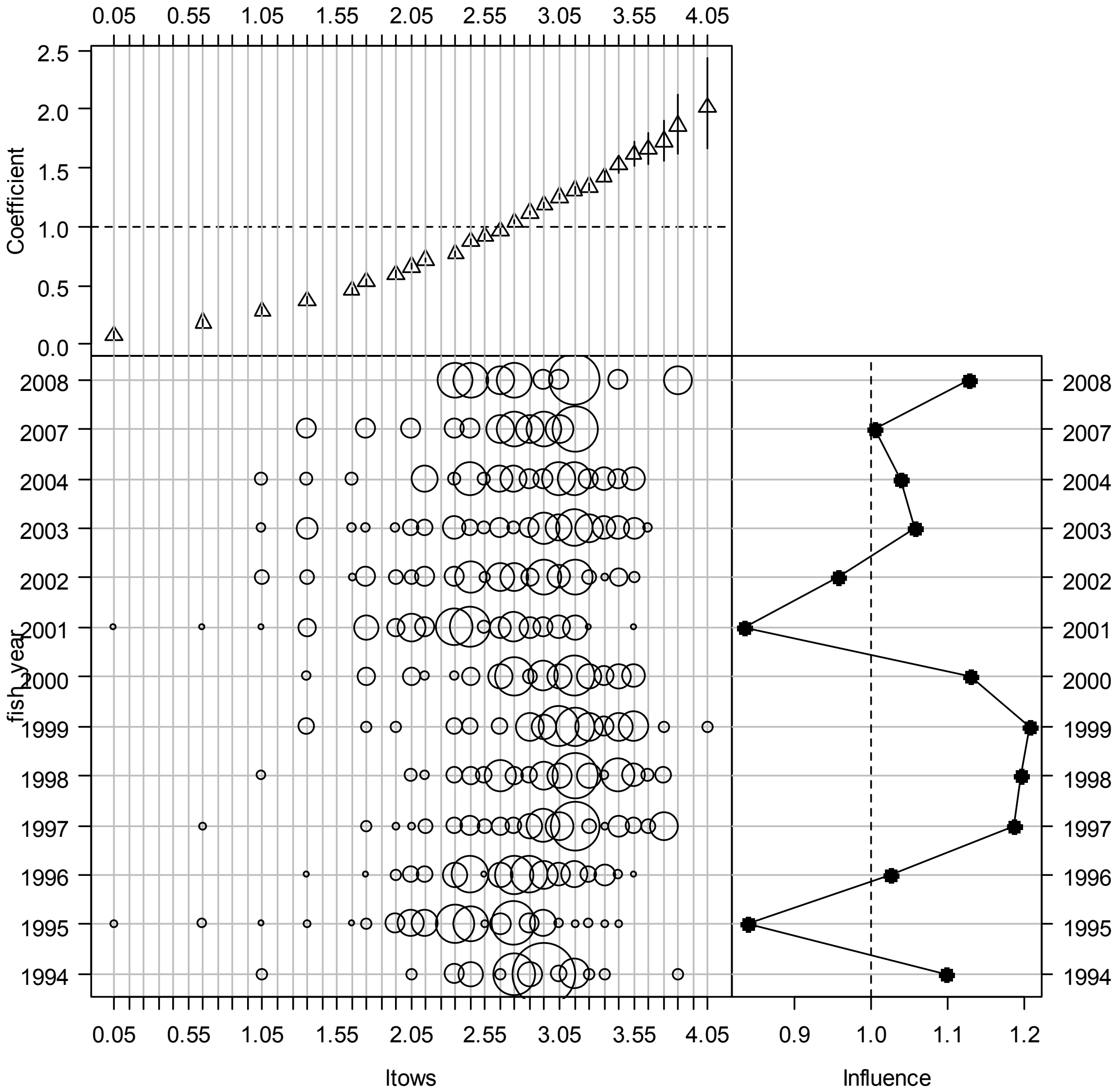

Figure D2: Effect of the logged number of tows (per day) on a lognormal model of daily catches in Spirits Bay. Effect by number of tows [upper panel]; Distribution of observations by fishing year [lower left panel]; cumulative effect of the variable number of tows by fishing year [lower right panel].

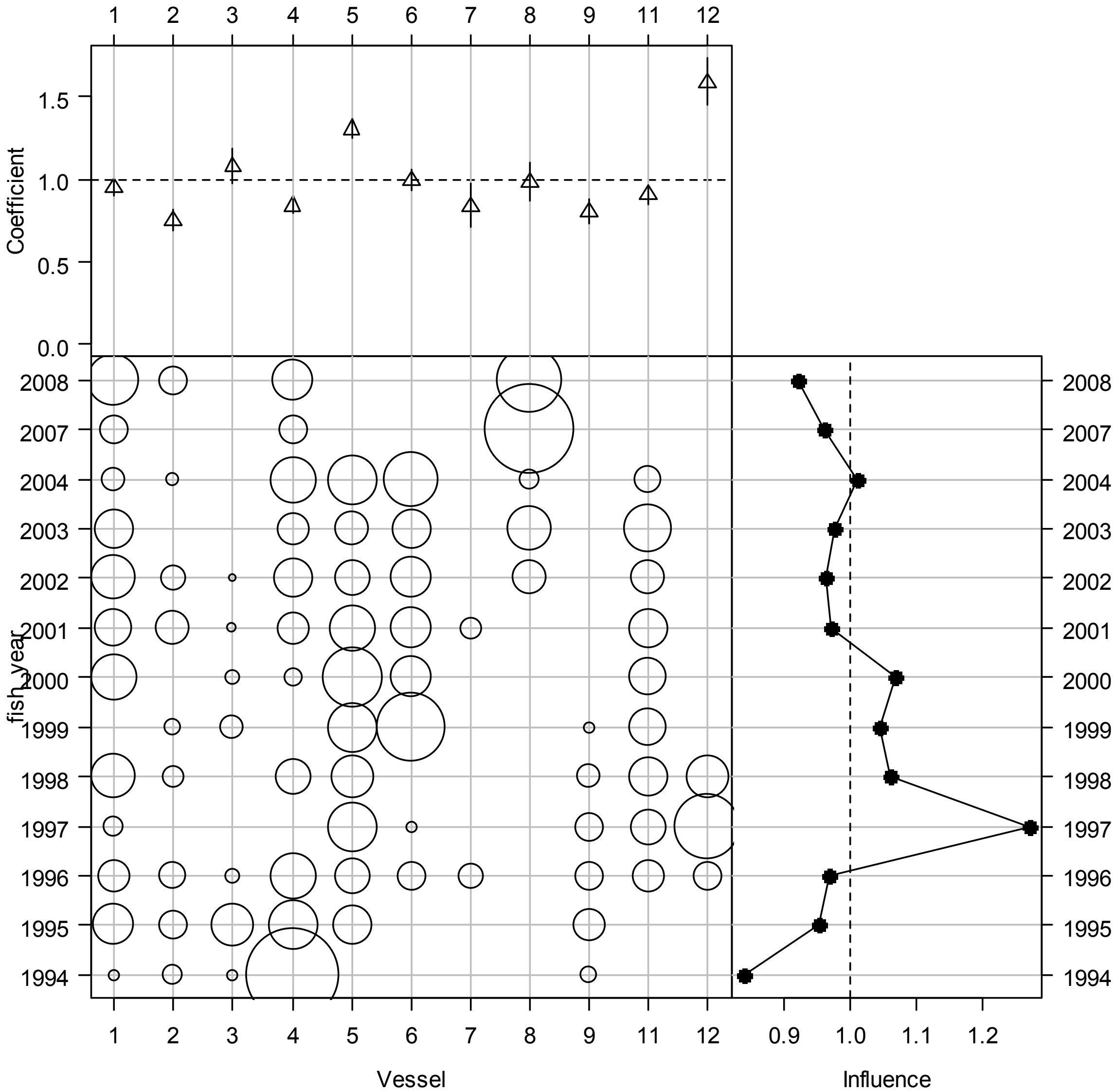

Figure D3: Effect of individual vessels on a lognormal model of daily catches in Spirits Bay. Effect by vessel [upper panel]; Distribution of observations by fishing year [lower left panel]; cumulative effect of the variable vessel by fishing year [lower right panel].

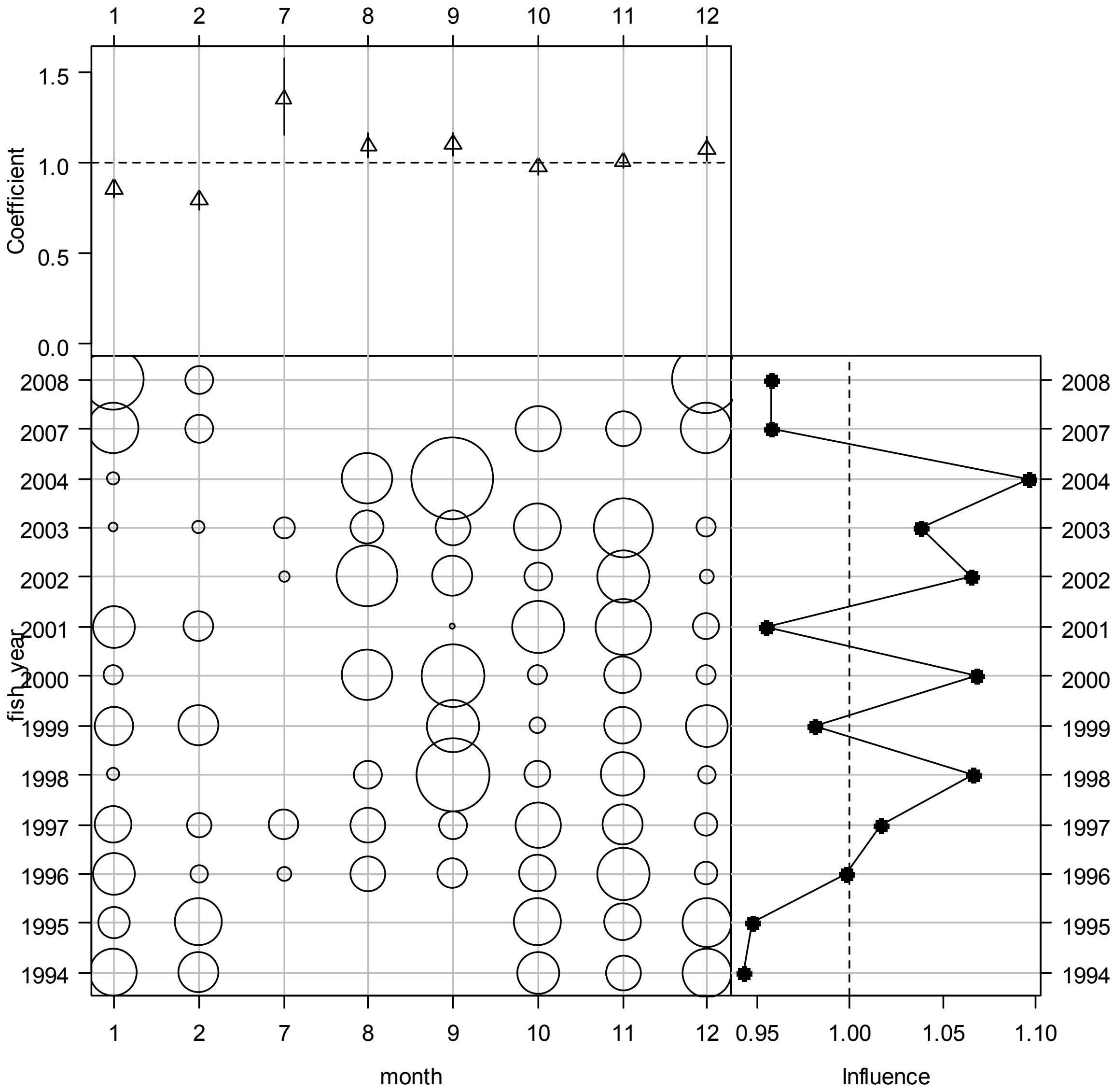

Figure D4: Effect of the variable month on a lognormal model of daily catches in Spirits Bay. Effect of each month [upper panel]; Distribution of observations by fishing year [lower left panel]; cumulative effect of the variable month by fishing year [lower right panel]. The scallop season runs from July (month 7) to February in the following year (month 2).

APPENDIX E

Diagnostic plots for CPUE standardisations for all three areas combined

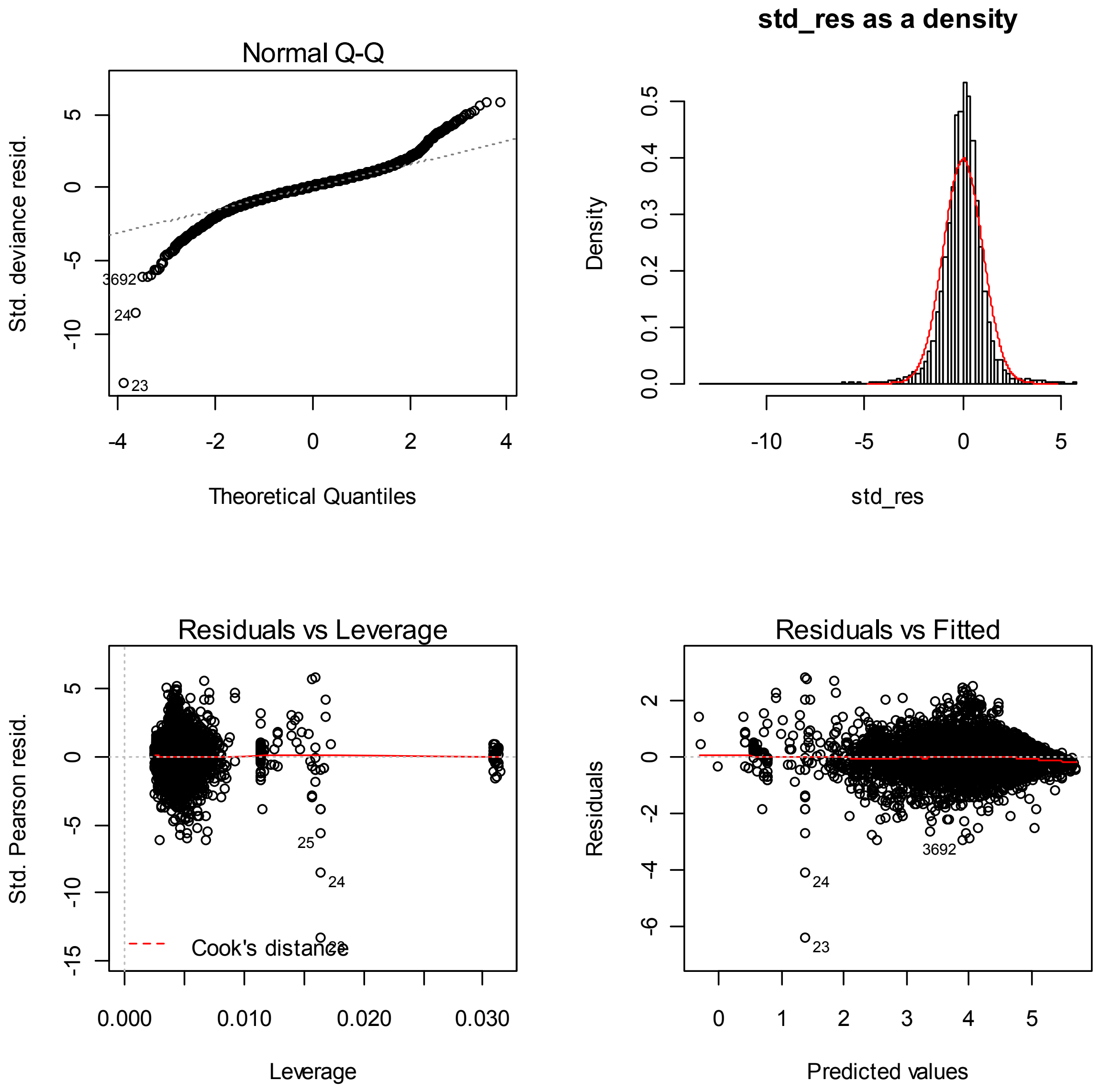

Figure E1: Diagnostic plots describing the fit of a standardised model of scallop catch rates for all three areas combined. A quantile-quantile plot of standardised residuals [upper left panel]; a histogram of the standardised residuals compared to the distribution predicted from a lognormal distribution [upper right panel]; a plot of standardised residuals against the leverage that each data point has on the modelled relationship between daily catches and explanatory variables [lower left panel]; standardised residuals plotted against predicted daily catches [lower right panel].

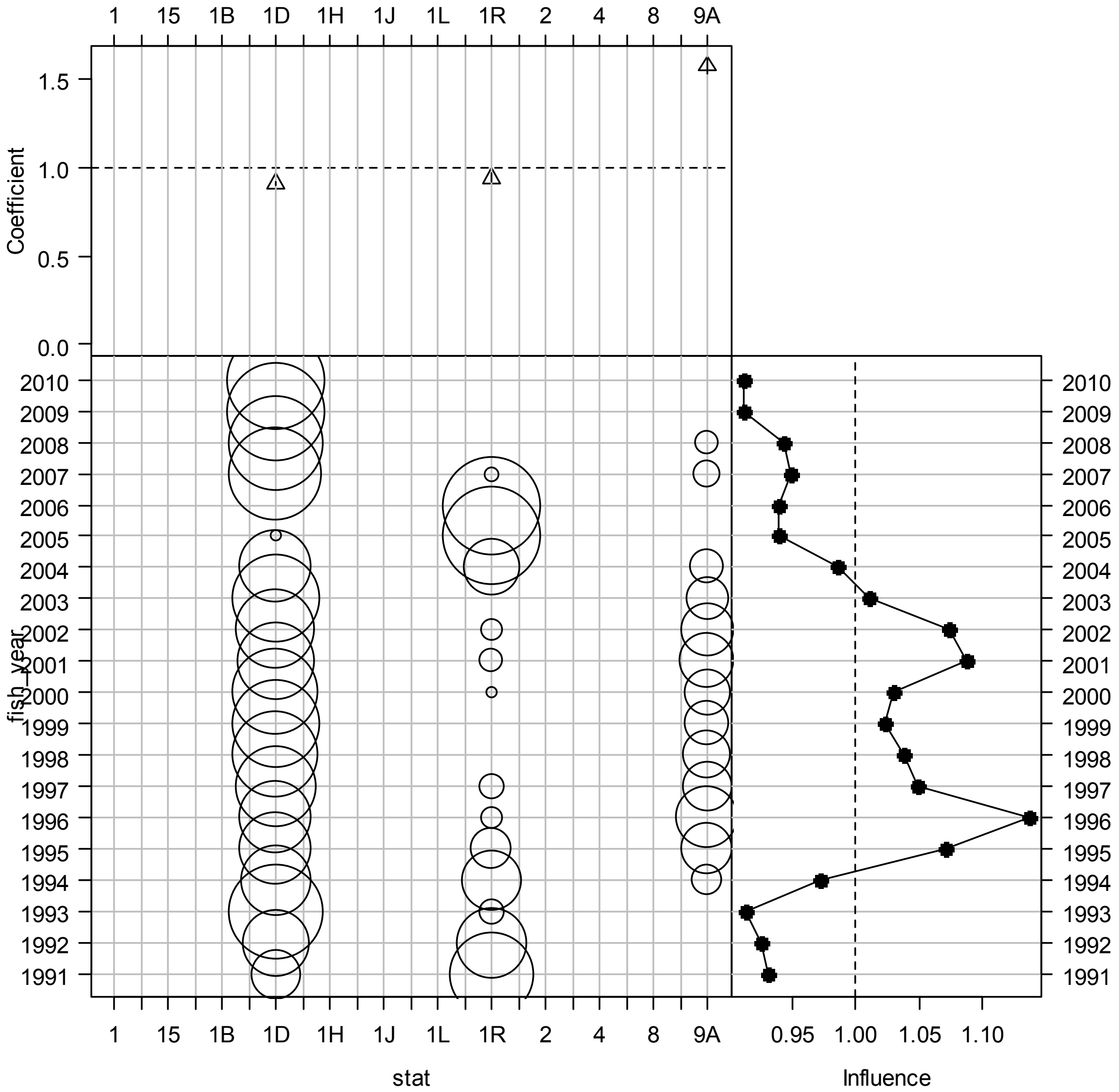

Figure E2: Effect of statistical area on a lognormal model of daily catches across all three areas of SCA 1. Effect by number of tows [upper panel]; Distribution of observations by fishing year [lower left panel]; cumulative effect of the variable number of tows by fishing year [lower right panel].

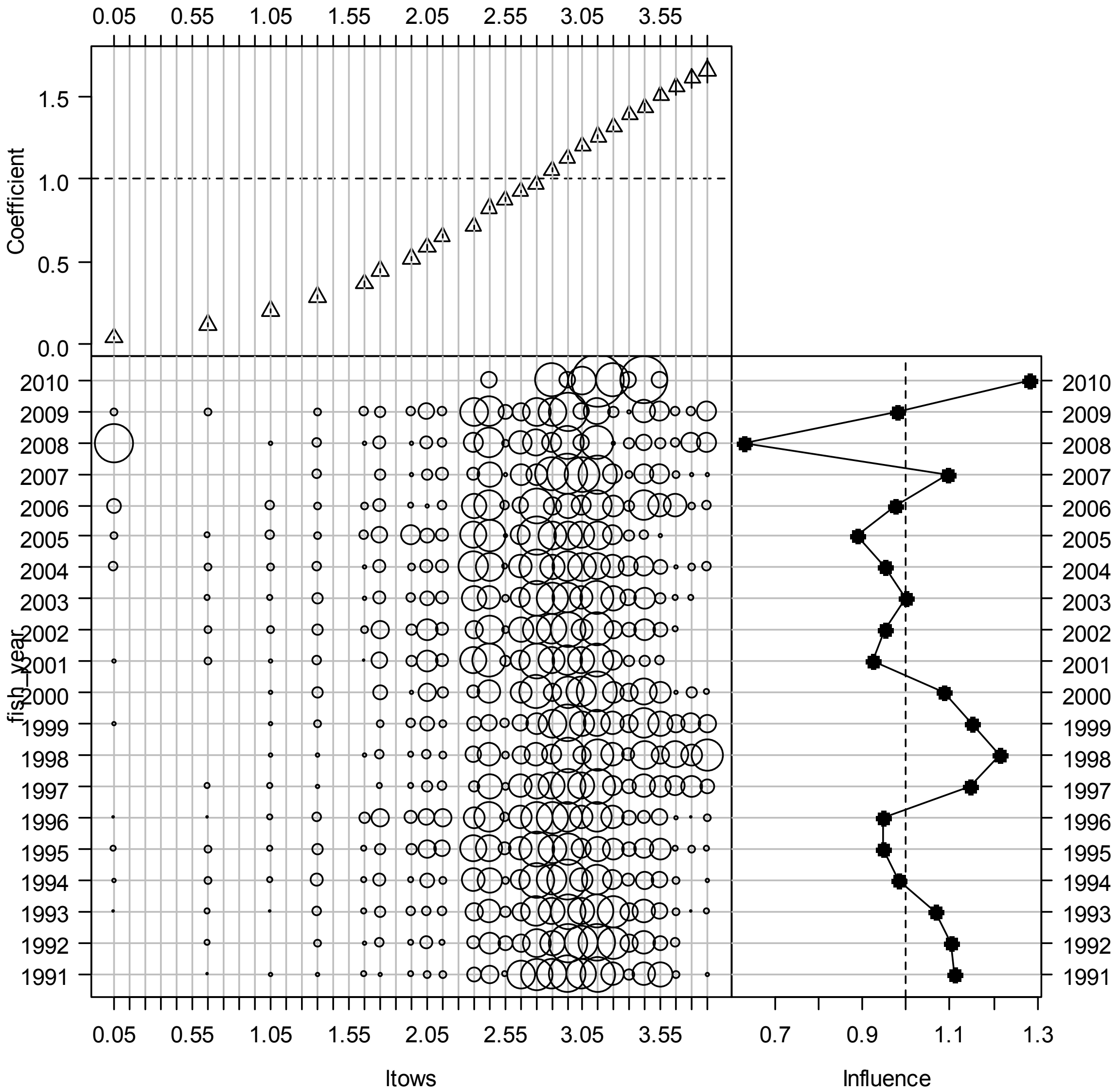

Figure E3: Effect of the logged number of tows (per day) on a lognormal model of daily catches across all three areas of SCA 1. Effect by number of tows [upper panel]; Distribution of observations by fishing year [lower left panel]; cumulative effect of the variable number of tows by fishing year [lower right panel].

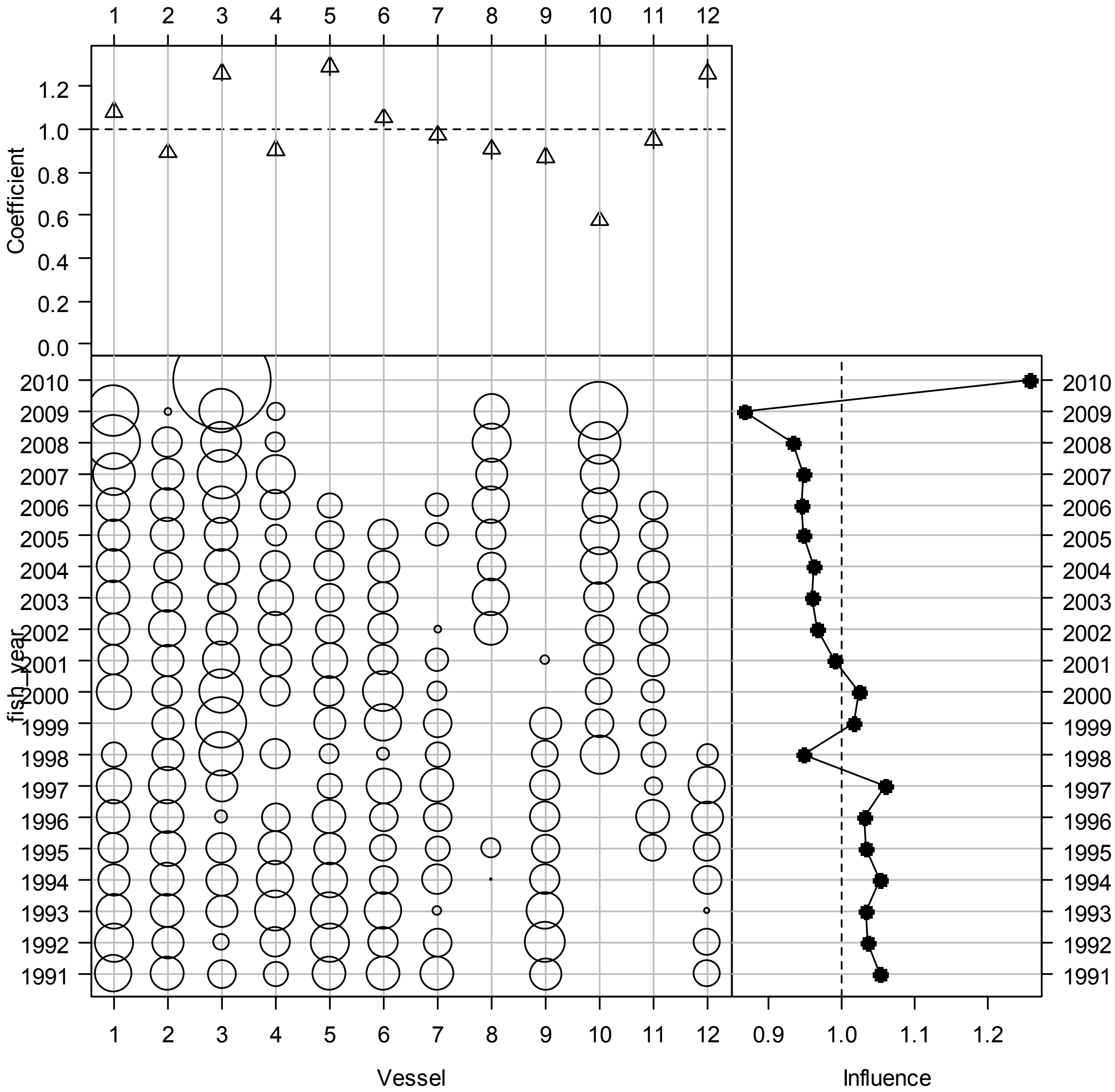

Figure E4: Effect of individual vessels on a lognormal model of daily catches across all three areas of SCA 1. Effect by vessel [upper panel]; Distribution of observations by fishing year [lower left panel]; cumulative effect of the variable vessel by fishing year [lower right panel].

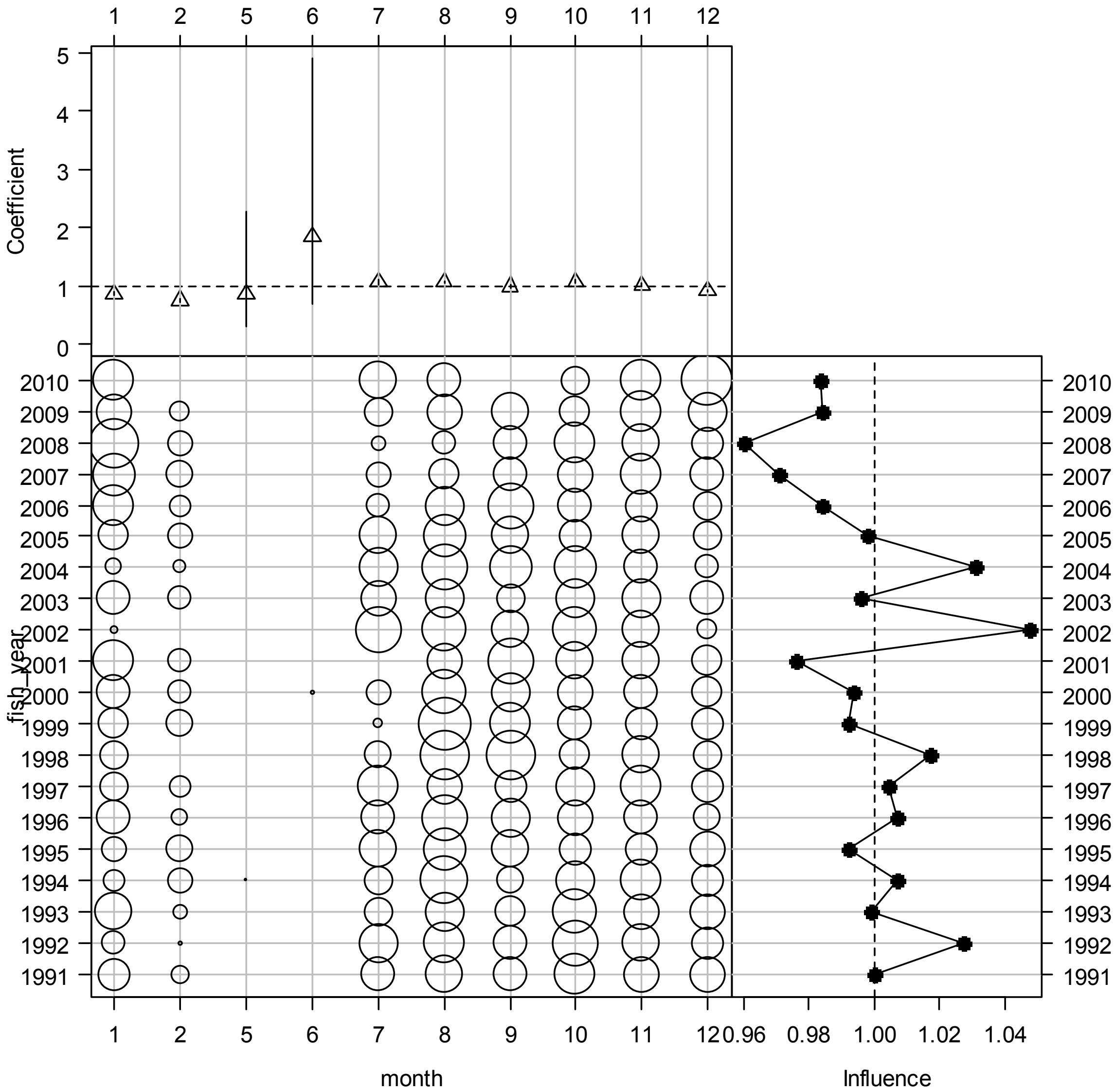

Figure E5: Effect of the variable month on a lognormal model of daily catches across all three areas of SCA 1. Effect of each month [upper panel]; Distribution of observations by fishing year [lower left panel]; cumulative effect of the variable month by fishing year [lower right panel]. The scallop season runs from July (month 7) to February in the following year (month 2).