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Tini a Tangaroa

Indices of albacore abundance from the west coast troll fishery, 1989–90 to 2016–17

New Zealand Fisheries Assessment Report 2021/35

T.H. Kendrick

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Ministry for Primary Industries
PO Box 2526
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This study was contracted as Ministry for Primary Industries (now Fisheries New Zealand) project ALB2017-01 with the specific objective: "To update standardised CPUE for the west coast albacore troll fishery using data up to the end of the 2016–17 fishing year".

Albacore tuna (*Thunnus alalunga*) caught in New Zealand waters are part of a single South Pacific Ocean stock that ranges from the equator to at least 49º S. Albacore are caught by trolling off the west coast of New Zealand during a narrow seasonal window (December to April) after which they become unavailable to that method. The fish taken in this fishery are small, comprising 2–3 cohorts of juvenile fish, and provide some of the only information on recruitment to the wider South Pacific stock.

Catch data are in the form of counts; effectively, the number of fish per vessel-day, and a negative binomial linear model was fitted to all catch data including zero catches. Catches were standardised for variance in the explanatory variables using a forward stepwise multiple regression procedure. Terms were only added to the model if they increased the percent deviance explained by 1%.

The annual CPUE indices fluctuate around unity in a 3–4 year cycle, with small error bars around each point. Analyses repeated on independent subsets of core vessels yield annual indices that resemble each other closely, with little effect of standardisation. Within-year variance is small relative to the interannual variance in catch rates, reflecting the homogeneity of catch rates experienced across the fleet in each year despite any differences in fishing behaviour.

New Zealand is at the extreme range of albacore and the expansion /contraction of the small fish in the stock may be affected by climatic events outside the spatial and temporal scale of the New Zealand troll fishery. The El Niño/Southern Oscillation (ENSO) is the most important coupled ocean-atmosphere phenomenon to cause global climate variability on interannual time scales, and the Multivariate ENSO Index (MEI) roughly coincides with the cyclical pattern of CPUE of troll-caught albacore in New Zealand waters in the most recent two decades, when data are better reported, with peaks in availability coinciding closely with La Niña events.

The conclusion of this study is that CPUE of troll-caught albacore in New Zealand waters is unlikely to be a useful index of abundance. There is probably no recruitment signal in these indices.

1. INTRODUCTION

1.1 The fishery

Two albacore (*Thunnus alalunga*) stocks (North and South Pacific) are recognised in the Pacific Ocean. Albacore tuna caught in New Zealand waters are part of a single South Pacific Ocean stock that is distributed from the coast of Australia and archipelagic waters of Papua New Guinea eastward to the coast of South America and south of the equator to at least 49º S. The New Zealand catches represent about 10% of the total and are predominantly taken in summer by trolling, with most of the balance taken over winter by surface longline.

With the establishment of the Western and Central Pacific Fisheries Commission (WCPFC) in 2004, stock assessments of the South Pacific Ocean (SPO) stock of albacore tuna are now undertaken by the Oceanic Fisheries Programme of the Secretariat of the Pacific Community under contract to WCPFC. No assessment is possible for albacore within New Zealand fisheries waters because the proportion of the greater stock found within New Zealand fisheries waters is unknown and likely varies from year to year. Albacore taken by trolling are juveniles and provide some of the only information on recruitment to the wider South Pacific stock.

Albacore are currently outside the Quota Management System, but, New Zealand, as a member of the WCPFC, has committed to not increasing the number of vessels actively fishing for South Pacific albacore in the Convention Area south of 20° S above "current" (2005) levels or "recent historical" (2000–2004) levels. (Conservation and Management Measure passed at the second annual meeting of the WCPFC).

The earliest known commercial catch of tuna in New Zealand waters (species unknown but probably skipjack tuna, *Katsuwonus pelamis*) was by trolling and was landed in Auckland in the year ending March 1943. Regular commercial catches of tuna, however, were not reported until 1961. Before 1973 the albacore troll fishery was centred off the North Island (Bay of Plenty to Napier and New Plymouth), with the first commercial catches off Greymouth and Westport (54% of the total catch) in 1973. These catches (species unknown but primarily albacore and skipjack with some southern bluefin, *Thunnus maccoyii,* and yellowfin tuna, *T. albacares*, possible) are summarised in Figure 1.

The New Zealand albacore fishery, especially the troll fishery, has been characterised by periodic poor years that have been linked to poor weather or colder than average summer seasons. Despite this variability, albacore landings have steadily increased since the start of commercial fishing in the 1960s. The average catch in the 1960s of 19 t, increased in the 1970s to 705 t, in the 1980s to 2256 t, and in the 1990s averaged 4571 t. Catches peaked at more than 6700 t in 2002–03 due largely to the participation of two chartered longliners that exclusively targeted albacore (longline-caught albacore are more usually a bycatch of fishing for bigeye (*T. obesus*) or southern bluefin tunas). Since then catches have declined to their lowest level since 1988 of less than 2100 t in 2007, with a subsequent increase in 2008 to nearer 3700 t (Table 1).

Albacore taken by trolling are small (averaging about 5 kg each) and are mainly caught off the west coast of New Zealand during a narrow seasonal window each year (December to April) after which they become unavailable to that method. Their subsequent movements are unknown, but they are considered unlikely to be the same fish that are taken by longline through the winter and which average about 10 kg each.

New Zealand has been undertaking annual catch sampling of the troll fishery since 1996–97 and although that programme is useful for evaluating relative strength of the three cohorts commonly present, it is less useful for estimating longer term trends in recruitment without reference to some measure of relative abundance. This was first attempted in 2005 under project TUN2002/03 which used data up to 2004 (Unwin et al. 2005).

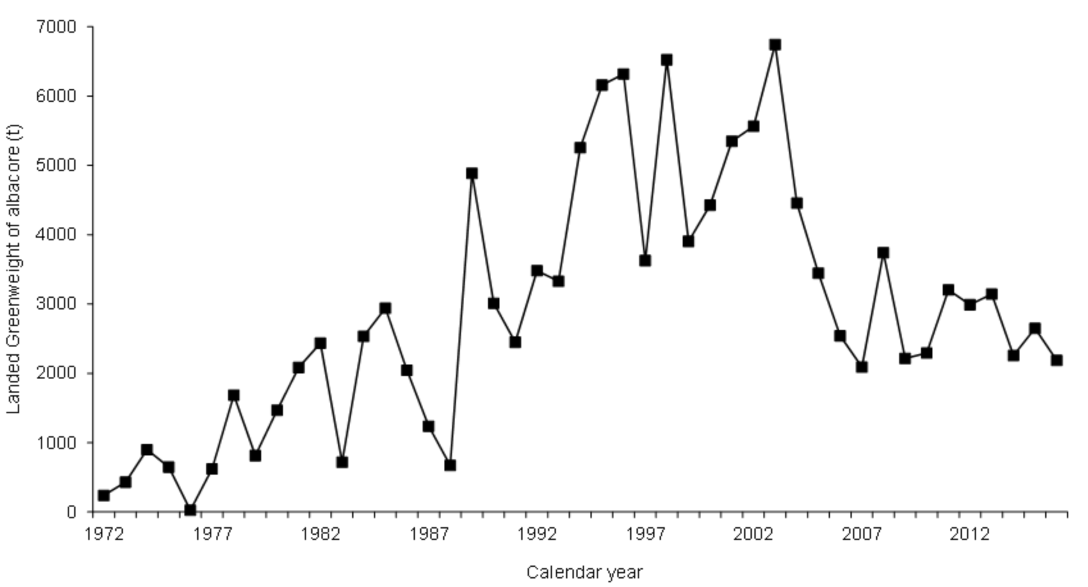

Figure 1: Catch of albacore (t) in New Zealand waters. Source: Ministry of Fisheries Science Group (2008), Ministry for Primary Industries data submissions to WCPFC for subsequent years (up to 2016).

1.2 Previous work

The troll catch-per-unit-effort (CPUE) index from project TUN2002/03 (estimated using a negative binomial generalised linear model and quasi Poisson generalised additive model) was not accepted by the Highly Migratory Species Working Group as an index of abundance because the choice of potential explanatory variables was largely inappropriate, either due to the coarse scale at which catch effort data are captured on the Catch Effort Landing Return (CELR) form type for trolling or for other reasons particular to the fishery such as its mode of operation concentrated in daylight hours and in one quarter of the year (January-March).

Sea surface temperature (SST), and various derivatives thereof, obtained by remote sensing were considered most likely to have explanatory power, but were not available for the area off the west coast between 36° and 40° S. This area accounted for 49% of the troll effort and effectively eliminated those data from the analysis. Quarter year was used as the temporal resolution in the previous study, but most troll effort occurs between January and March (Q2) and the other quarters are relatively unimportant. Longitude was important in that CPUE peaked between 170° and 172° E, but this represents the difference between the west coast (main focus of troll activity) and the east coast which has always been relatively unimportant. Depth was offered and accepted into the model, but how that could be meaningfully associated with position at statistical area resolution is not clear. The measure of effort (number of hooks) used to calculate catch-per-unit-effort was also considered inappropriate.

Unwin et al. (2005) surmised that ocean agitation that determines the depth of the seasonal thermocline may influence the vertical availability of albacore to surface gears, with high agitation increasing thermocline depth, and making age 2 albacore less available at the surface. They concluded that improved spatial resolution at which troll catch and effort data are recorded would be necessary to improve the utility of troll CPUE for an albacore assessment.

Kendrick & Bentley (2010) carried out a lognormal standardisation of successful trips and attempted to address the criticisms of the previous methods with more appropriate explanatory variables and a much simpler model, but the resultant annual indices were similar with little effect of standardisation. That study highlighted the lack of contrast in the data within any one year and concluded that availability of juvenile albacore to this fishery is likely to depend on factors outside the New Zealand EEZ, including wider ecological effects that would be confounded with year effect in any standardised analysis of abundance.

2. METHODS

2.1 Data sources

Tuna fisheries catch and effort data have been collected by the Ministry for Primary Industries (MPI) and its predecessor organisations since at least 1976 (Ministry of Agriculture and Fisheries at that time), but changes to data collection and processing mean that domestic fisheries catch and effort data are not currently available before 1989. CELR data are available beginning with the third quarter of 1989 (start of the 1989–90 October-September fishing year).

Troll-caught albacore are estimated in numbers of fish on CELRs, but the actual weight landed at the end of the trip is available from the bottom of the form and is verifiable from Monthly Harvest Returns (MHRs) that are required to be submitted by permit holders.

The characterisation was done on landed greenweight of albacore allocated to effort records proportionate to the estimated catch (in numbers of fish) using a variation of the Starr methodology (Starr 2007) that does not further amalgamate the data as reported. All troll catch and effort is reported on CELRs so there is no need to combine data across form types and therefore no need to further amalgamate data. Albacore are considered to belong to a single New Zealand stock and this reduces the complexity that is usually associated with the allocation of landed catch to effort in statistical areas that straddle more than one Fishstock.

The CPUE standardisation was done on estimated catch (numbers of fish), as is traditional for tuna, offered to the model as number of albacore per record (at the original CELR resolution). Almost all troll effort is targeted at albacore, so records generally represented one vessel-day except when more than one statistical area was fished in the same day.

2.2 Methods used for grooming and collation of commercial catch and effort data

Catch and effort data were obtained from the MPI data base "*warehou*" using a two-part extract. The first part identified candidate trips by searching for all landings to Fishstock ALB 1 or which fished using troll gear between 01 October 1989 and 30 September 2017. Once trips that satisfied these criteria were identified, all effort and landing records associated with these trips were extracted. All statistical areas are included in ALB 1. The total landed greenweight available from the bottom of the form and obtained in the "*warehou*" extract differs from the total landings of albacore reported by Ministry of Fisheries Science Group (2008) (which in the early years would have been derived from Licensed Fish Receiver Returns) especially in the early part of the time series. This is due to the relatively poorer error checking routines for catch effort data in those years.

Landings, estimated catch, and associated effort were all groomed separately before merging and the resultant annual total landed and estimated catches are compared in Figure 2 and Table 1. Estimated catch could be expected to overlay landed catch perfectly in Figure 3 (given the primary and secondary y-axes scales used) if all albacore were troll caught and weighed about 5 kg. The departure between the two series in the early 2000s reflects the increased proportion of longline catch of larger albacore during that period.

Outlier values in the landing data were identified by finding the trips with very high landings of albacore based on verified maximum values supplied by the MPI Information Management Group. The effort data for these trips were then used to calculate the trip CPUE based on landings and the total estimated catch for the trip was calculated. Trips which had a ratio of landed to estimated catch which exceeded 4 and a CPUE which exceeded two times the 95th percentile of the trip CPUE distribution for the entire dataset were dropped entirely.

Table 1: The effect of grooming on the extract. Verified landed greenweight (t), landed greenweight from the bottom of the CELR form as extracted from "*warehou*" database, landed greenweight after grooming (as used for the characterisation), percent of verified landings, percent of data available in the extract, and estimated catch (thousands of fish) in the groomed dataset (as used for the CPUE analysis).

Fishing year	QMR reported catches (t)	Bottom of form (some edits)	Landed catch for analysis (t)	% analysis catch of landed catch	% analysis catch of QMR	Estimated catch in dataset (thousands fish)
89–90	3 144	2 050	1 990	97	63	481
90–91	2 451	2 295	2 215	96	90	470
91–92	3 434	4 876	354	7	10	700
92–93	3 323	1 715	1 261	74	38	571
93–94	5 315	4 545	1 219	27	23	997
94–95	6 195	4 550	3 899	86	63	1 065
95–96	6 316	5 583	4 835	87	77	877
96–97	3 728	4 167	3 995	96	107	517
97–98	6 525	6 710	6 151	92	94	815
98–99	3 727	3 851	3 731	97	100	405
99–00	4 697	4 918	4 681	95	100	679
00–01	5 509	5 499	5 364	98	97	617
01–02	5 531	5 817	5 679	98	103	622
02–03	6 300	6 582	6 432	98	102	798
03–04	4 969	5 245	5 062	97	102	774
04–05	3 501	3 621	3 580	99	102	518
05–06	2 627	2 798	2 774	99	106	437
06–07	2 069	2 210	2 184	99	106	385
07–08	3 631	3 886	3 737	96	103	687
08–09	2 246	2 323	2 300	99	102	415
09–10	2 186	2 263	2 241	98	103	361
10–11	3 266	3 428	3 394	98	104	662
11–12	3 039	3 125	3 094	98	102	540
12–13	2 927	3 032	3 002	99	103	461
13–14	2 466	2 596	2 570	99	104	409
14–15	2 536	2 708	2 681	97	106	436
15–16	2 218	2 315	2 292	99	103	346
16–17	2 035	2 089	2 068	99	102	288

Almost all albacore were landed green (whole) with a conversion factor of unity used to back-calculate greenweight from landed (processed weight) so that changes over time in conversion factors are not a concern for this species. Most albacore were landed to destination code "L" (landed to a Licensed Fish Receiver in New Zealand), but there were significant landings reported to destination code "R" meaning that they were retained on board for subsequent landing. These fish are not identifiable when subsequently landed and there is therefore a risk of double counting. When destination code "R" was used the entire trip was dropped with the loss of over 8600 t of albacore from the analysis dataset. The loss was most severe in the early 1990s but only affected the characterisation and was not reflected in the CPUE dataset which was based on estimated catch in numbers of fish. The shortfall apparent in landed catch when compared with the annual totals from LFRRs in those years (Figure 3) does suggest that there was in fact no double counting and that the landings coded to destination "R" could have been retained in the dataset.

Occasional outlier values (input errors) in the effort data were identified by comparison with empirical distributions derived from the effort variable (duration or number of sets), and where the values were in the extreme upper and lower tails of the distribution (a multiple of the 95th percentile value), they were replaced with the median value for the effort field for the affected vessel. Missing effort data were treated similarly. Missing values for statistical area, method, or target species within any trip were substituted with the predominant (most frequent) value for that field over all records for the trip. Trips with all fields missing for one of these descriptors were dropped entirely.

The allocation of landed catch to effort, performed for the characterisation section of the report, was done without further amalgamation of the data, by allocating the landed greenweight, declared at the end of the trip, to the effort events in the trip in proportion to the estimated catch. Where there were no estimated catches during the trip, the allocation was proportionate to the amount of effort. In many of these records, there were no estimated catches recorded in the columns for the top five species caught yet there was a positive value reported in the 'total catch' field. It appears that when the entire catch consisted of a single species, some fishers felt that duplicating that value (underestimated catch of individual species) was unnecessary.

This method of using allocated landings retained more than 95% of landed ALB 1 catch for analysis in most years (the exceptions being 1991–92 and 1993–94 when there were several very high landings with the destination code "R", i.e. retained onboard). The allocated landed greenweights were then raised for each record in the dataset to represent, when summed, the QMR annual totals and used to describe the ALB 1 fisheries in the characterisation part of this study.

For the CPUE standardisation part of this study, estimated catches were compared with the allocated landed greenweights for each troll trip to identify catches erroneously reported in weight (Figure 2). Records where the ratio was less than 2 were converted back to numbers of fish using an assumed average weight of 5 kg for troll-caught albacore. In hindsight, however, the dataset remains contaminated with poorly reported catch in the first half of the first decade with the ratio of annual catch to landings in the analysis dataset being considerably lower than in subsequent years and yielding unrealistically small average fish weights.

The data available for each trip included estimated catch of albacore (number of fish), total hours fished, number of days fished, fishing year, statistical area, month of landing, and a unique vessel identifier.

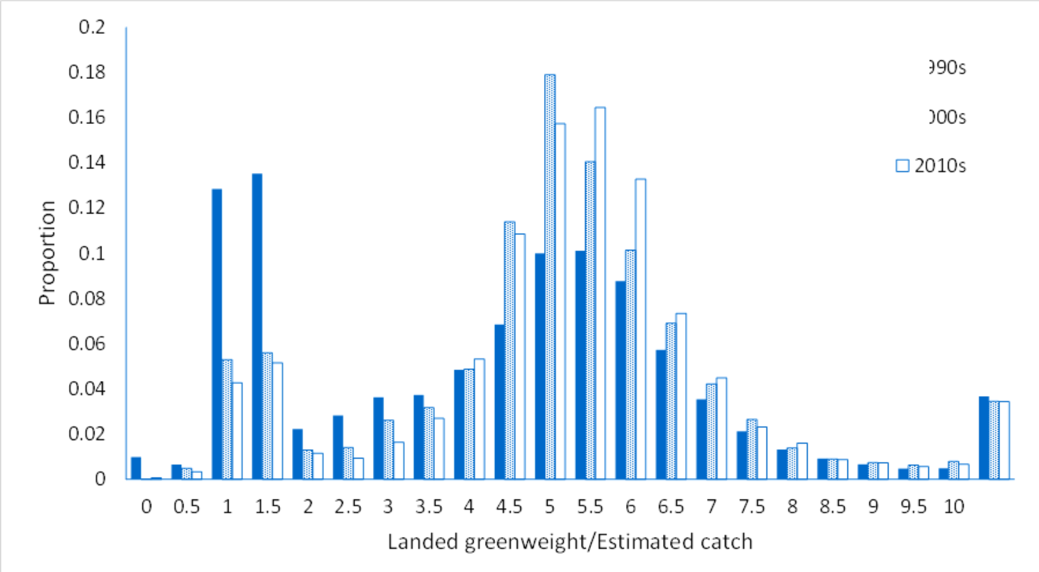

Figure 2: The distribution of values for landed weight / estimated catch for individual troll fishing trips compared across decades, 1990-1999, 2000-2009, and 2010-2017. Trips for which fish are erroneously reported in weight are evident in this plot where they are centred on 1. The threshold below which a trip was deemed to have erroneously recorded estimated catch in weight rather than numbers was set at 2.

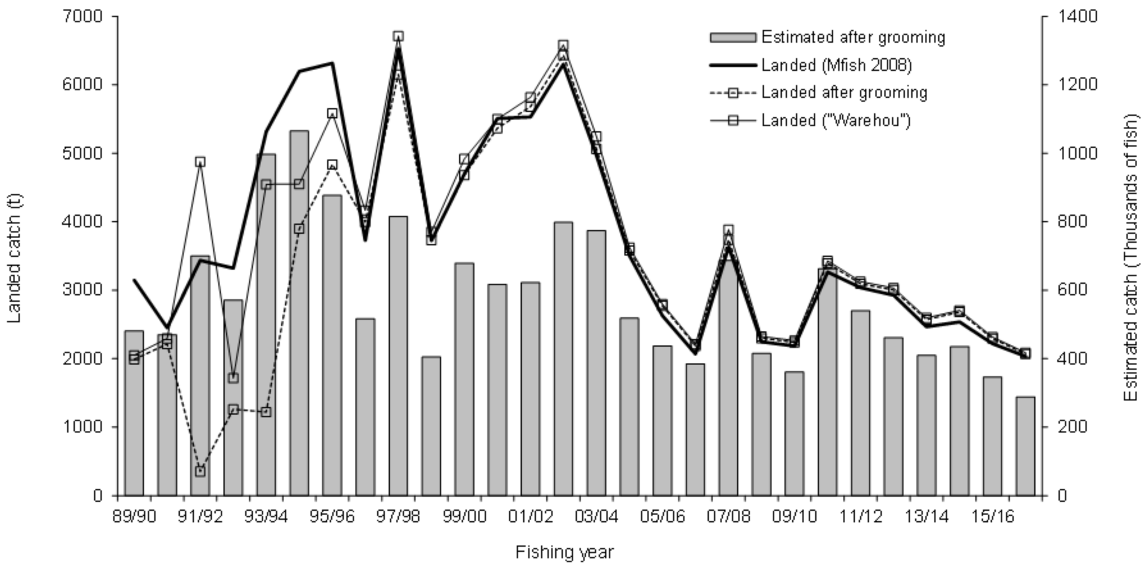

Figure 3: The effect of grooming on the extract. Verified landed greenweight (t) is shown by the bold line; landed greenweight from the bottom of the form as extracted from "*warehou*" database by the solid line; landed greenweight after grooming by the dashed line; and estimated catch (thousands of fish) in the groomed dataset which is indexed on the secondary y-axis.

2.3 Methods used for catch-per-unit-effort analysis

2.3.1 Definition of fisheries

The fishery in which juvenile albacore are monitored uses the troll method, is targeted at albacore, reports on CELRs, and operates in any statistical area off the west coast of either island. Month was restricted to November to May but most catch was taken during December to March in each fishing year.

2.3.2 Core fleet definitions

The data sets used for the standardised CPUE analyses were further restricted to those vessels that participated with some consistency in the defined fishery. Core vessels were selected on the basis of involvement by specifying two variables: the number of trips that determined a qualifying year, and the number of qualifying years that each vessel participated in the fishery.

The core fleet was selected by choosing variable values that resulted in the fewest vessels while maintaining the largest catch of albacore. This selection process generally reduced the number of vessels in the dataset by about 70% and the amount of landed albacore catch by about 20%. Note that the vessels thus selected are not necessarily the top vessels with respect to catching albacore.

2.3.3 Sea surface temperatures

The oceanographic data included in the analysis are from a Pacific Ocean Hindcast data set derived from a model-based ocean analysis system (NOAA NCEP EMC CMB Pacific). These data were available for each month from January 1980 to September 2017 and at a spatial resolution of one degree of latitude and 1.5 degrees of longitude.
(http://iridl.ldeo.columbia.edu/SOURCES/.IGOSS/.nmc/.Reyn_SmithOIv2/.monthly/.dataset_documentation.html).

Sea surface temperature was collated at statistical area/month resolution for the whole time series. A mean monthly temperature based on a 10-year series (1990–1999) was also calculated for each statistical area, and the anomaly from those measures of normality was calculated for each area and month. These anomalies are effectively the SSTs with the strong seasonal pattern (highly correlated with month) removed. A pattern of colder and warmer than usual years is apparent when those monthly anomalies are averaged over a fishing year. The pattern is consistent across statistical areas, though the temperature range is generally greater and the minimum temperatures cooler the further south the statistical area. For clarity and contrast, only two areas are presented as examples (Figure 4).

2.3.4 Statistical area zones

The spatial resolution of troll catch and effort data is determined by New Zealand Fisheries General Statistical Area (Figure 5). For the CPUE standardisation, statistical areas off the west coast were amalgamated into latitudinal bands (statistical area zones) to allow the model to account for the southerly drift of fish and fishers during the season (Table 2). This loses the longitudinal resolution in the data, but it is minimal (inshore/offshore), and of little interest because most activity occurs in the inshore statistical areas.

Unwin et al. (2005) found longitude was important in explaining variance in troll CPUE in that CPUE peaked between 170° and 172° E, but that analysis was not confined to west coast areas, and that result describes the difference between the west coast (main focus of troll activity) and the relatively unimportant east coast.

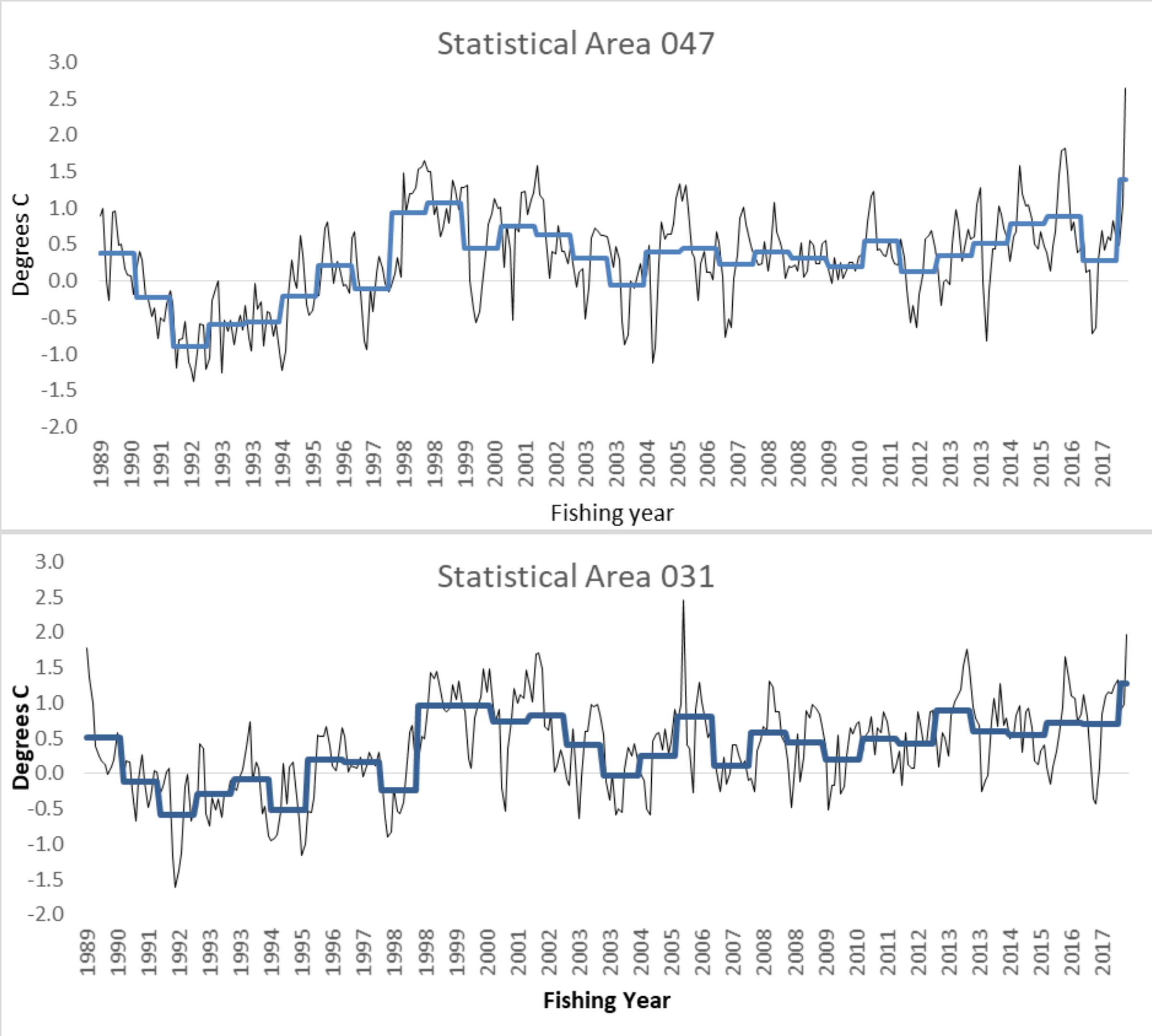

Figure 4: Monthly sea surface temperature anomalies (light line) relative to a ten year (monthly) average, and annual mean anomaly from ten year average (heavy line) for two selected statistical areas, 047 [Upper], and 031 [Lower].

Table 2: General Statistical Area groupings used to define the west coast troll fishery.

Statistical area (zone)	Statistical Areas included
48	048, 104
47	047, 103
46	046, 102
45	045
42	042, 101
41	041, 801, 701
36	036, 037, 038, 040, 703, 702
35	035, 704
34	034, 705
33	033, 706
32	032, 501
31	031, 030, 502
Other	East coast and other

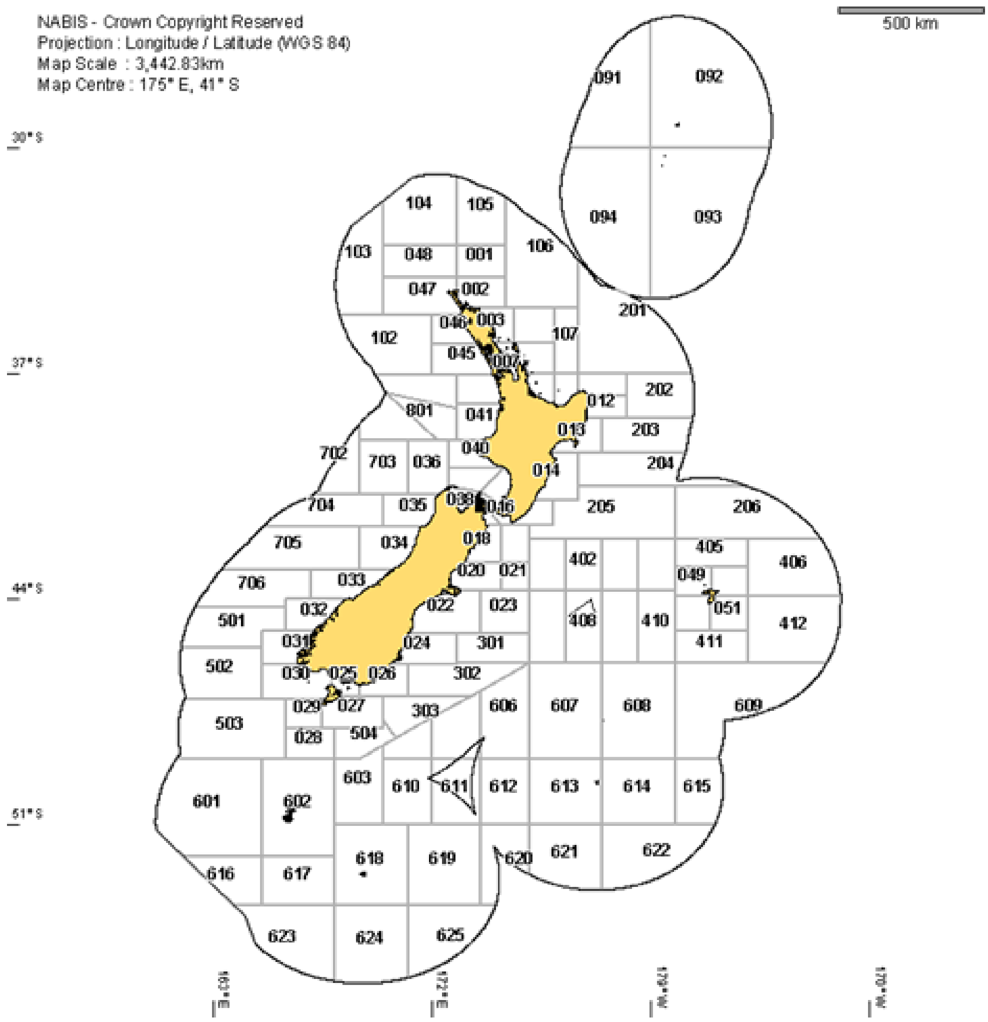

Figure 5: New Zealand General Statistical Areas used for spatial reporting of troll catch and effort.

2.3.5 Models

Catch data are in the form of counts, effectively the number of fish per vessel-day, and were standardised using a negative binomial regression, which is preferable for modelling over-dispersed count outcome variables, i.e., where the conditional variance exceeds the conditional mean. It can be considered as a generalisation of Poisson regression because it has the same mean structure as Poisson regression and it has an extra parameter to model the over-dispersion.

The negative binomial linear model was fitted to all catch data, including zero catches, of ALB 1 using the glm.nb function (with a log link) in R from the MASS package (Venables & Ripley 2001). Catches were standardised for variance in the explanatory variables using a forward stepwise multiple regression procedure made on the basis of the Akaike Information Criterion (AIC). Terms were only added to the model if they increased the percent deviance explained by 1%. The year effects were extracted as canonical coefficients (Francis 1999) so that confidence bounds could be calculated for each year.

The dependent variable for the negative binomial models was the number of albacore per record, where a record represented a vessel-day in most cases. The explanatory variables offered to the model were: *fishing year* (always forced as the first variable), a unique *vessel* identifier, and *month* (of catch), and *Statistical Area (zone)* offered as an interaction term to attempt to account for the observed southerly drift of effort in this fishery during the season. The logs of number of *vessel days* and *duration* were offered as alternative measures of effort to explain catch as a catch rate.

Continuous effort variables were offered as third order polynomials. Environmental variables were also offered as third order polynomials and included sea surface temperature (*SST*), *Monthly SST Anomaly*, and *Annual SST Anomaly*.

The log of the outcome is predicted with a linear combination of the predictors, and the maximal set of model terms offered to the stepwise selection algorithm was

~ fyear + vessel + area:month + poly(log(days), 3) + poly(log(duration), 3) + poly(SST, 3) + poly(MonthlyAnomaly), 3+ poly(AnnualAnomaly, 3)

with the term *fyear* forced into the model.

3. RESULTS

3.1 Characterisation of the ALB 1 fisheries

Albacore are the second most important component of the domestic tuna catch (after skipjack), and are taken mostly by troll gear (54–96% annually since 1989–90) with most of the balance taken by surface longline (Table 3, Figure 6). Troll gear also takes a small amount of skipjack with occasional catches of other tuna species. Longline is mostly targeted at bigeye and southern bluefin tunas, and more recently swordfish, but the greatest part of the catch consists of albacore.

Following the development of domestic longlining in the early 1990s, the domestic tuna fleet operating in New Zealand fisheries waters peaked in 2001 and has subsequently declined. The rapid expansion, particularly in the late 1990s to 2000, arose because tuna fisheries were among the few open access fisheries in New Zealand at that time. In 2002–03 a new longline fishery developed that exclusively targeted albacore and contributed to the peak in albacore catches that year (Kendrick 2006). It centred on two chartered (Philippine-flagged) vessels that have not returned since.

The two fishing methods operate quite differently from each other both seasonally and spatially, although many vessels fish both gear types, switching from troll to longline in time for the start of the bluefin tuna season in April-May. The longline fishery is widespread throughout New Zealand waters but catches most of its albacore in winter off the east coast of the North Island as a bycatch of the southern bluefin tuna fishery. It has expanded in the most recent decade to the west coast of the South Island as domestic vessels have replaced charter vessels in that fishery. The troll fishery is mainly a near-shore activity operating in summer months off the west coast of both islands (Figure 7). The size of fish also differs between methods with troll caught albacore averaging about 5 kg each and not considered likely to be the same cohort that are caught by longline later in the same year but which are usually about twice that size. The longline fishery is not considered in any further detail this study.

Table 3: Distribution of landed albacore by method and by fishing year for ALB 1 in tonnes and in percent of annual landings. Catches are raised to the annual QMR catch (Table 1). Percentages sum to 100 by year. SLL, surface longline.

Fishing	Landed catch (t)			Landed catch (%)		
year	Troll	SLL	Other	Troll	SLL	Other
89–90	3 030	68	46	96.4	2.2	1.5
90–91	2 361	43	48	96.3	1.7	2.0
91–92	2 379	831	225	69.3	24.2	6.5
92–93	2 602	663	58	78.3	19.9	1.8
93–94	3 286	1 959	71	61.8	36.9	1.3
94–95	5 450	713	33	88.0	11.5	0.5
95–96	5 244	989	83	83.0	15.7	1.3
96–97	2 739	953	36	73.5	25.6	1.0
97–98	4 973	1 527	25	76.2	23.4	0.4
98–99	2 028	1 686	13	54.4	45.2	0.3
99–00	3 307	1 365	25	70.4	29.1	0.5
00–01	3 455	2 040	13	62.7	37.0	0.2
01–02	3 294	2 232	7	59.5	40.3	0.1
02–03	4 145	2 162	11	65.6	34.2	0.2
03–04	4 097	853	18	82.5	17.2	0.4
04–05	3 009	481	11	86.0	13.7	0.3
05–06	2 203	418	6	83.9	15.9	0.2
06–07	1 783	280	6	86.2	13.5	0.3
07–08	3 415	201	15	94.1	5.5	0.4
08–09	1 876	369	1	83.5	16.4	0.0
09–10	1 694	492	0	77.5	22.5	0.0
10–11	2 805	461	0	85.9	14.1	0.0
11–12	2 776	264	0	91.3	8.7	0.0
12–13	2 588	336	4	88.4	11.5	0.1
13–14	2 137	322	8	86.6	13.0	0.3
14–15	2 325	212	0	91.6	8.4	0.0
15–16	1 873	251	93	84.4	11.3	4.2
16–17	1 787	204	45	87.8	10.0	2.2

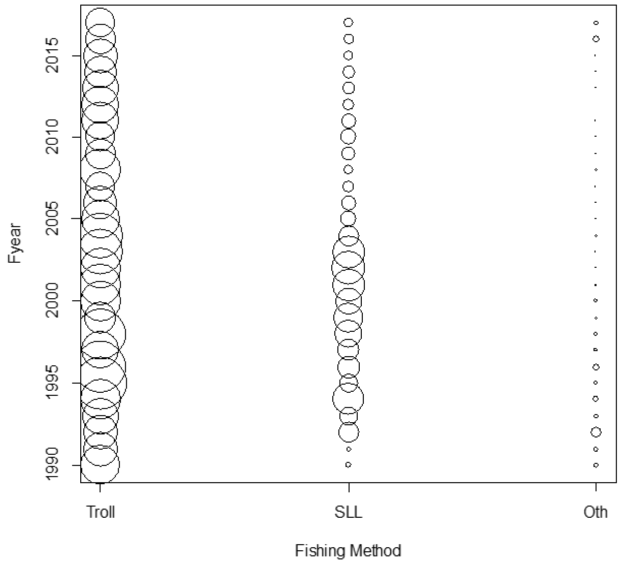

Figure 6: Distribution of landed albacore by method and by fishing year for ALB 1 in tonnes. Percentages sum to 100 by year. SLL, surface longline. Data are given in Table 3.

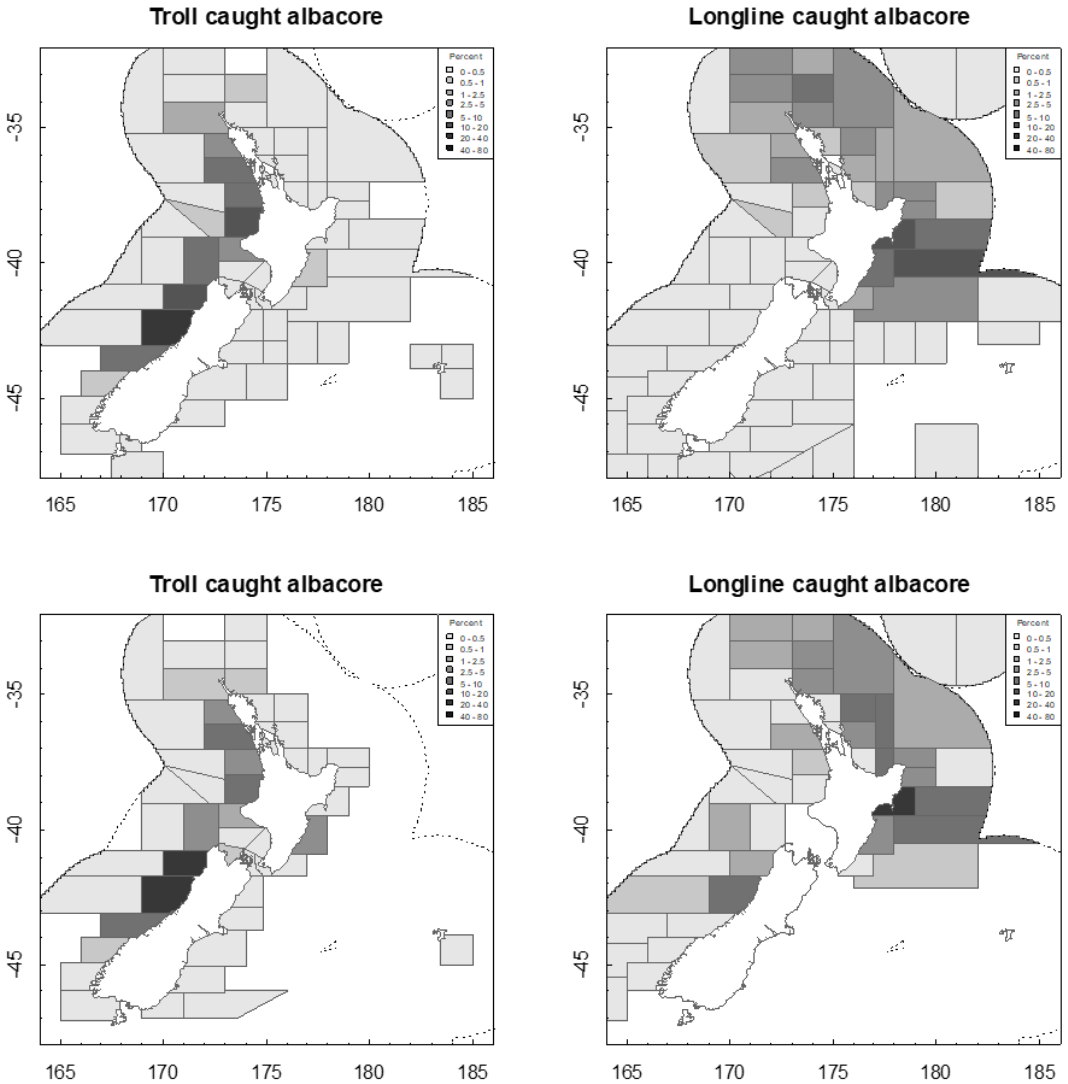

Figure 7: Recent spatial distribution of albacore catches for the two main fishing methods (troll and surface longline) by statistical area: [upper] 2000–01 to 2008–09, [lower] 2009–10 to 2016–17. Plots show percent of total number of fish for method. For statistical area labels see Figure 5.

3.2 Characterisation of the albacore troll fishery

The New Zealand tuna fleet is dominated numerically by about 170 (in 2008) domestically owned and operated vessels (mostly 15 to 25 m length) that fish for tunas using troll and longline gear, some of them switching between gear types by season or operating part of the year in non-tuna fisheries. There has been a significant reduction in the New Zealand tuna fleet since 2001 and most of the reduction has occurred in vessels smaller than 50 GRT (Anon 2009).

The numbers of vessels targeting albacore by troll for each fishing year is shown in Figure 8. The 2007–08 count of 148 troll vessels is just over 51% of the vessels fishing by this method in 2000–01 (288) and about 32% of the peak number of vessels operating in 1993–94 (455). These figures are from the ungroomed dataset and may be greater than other summaries.

Troll catches peaked in the mid 1990s at over 5000 t and again in the early 2000s at nearer 4000 t (Table 3). Catches have declined each year since 2002, consistent with the decline in numbers of vessels operating in this fishery (Figure 8).

The troll fishery in New Zealand waters is almost entirely targeted at albacore (more than 99% in each year since 1989–90) (Table 4). Most of the catch in each year has been taken between January and March with some expansion into the first and third quarters of the fishing year in the mid 1990s and early 2000s (Figure 9).

Before 1973 the albacore troll fishery was centred off the North Island (Bay of Plenty to Napier and New Plymouth), with the first commercial catches off Greymouth and Westport (54% of the total catch) in 1973. In the 1990s there was considerable troll activity in east coast areas (primarily the Bay of Plenty) but that has since declined and the fishery is now focused on the inshore statistical areas off the west coast of both islands with the greatest catches in most years taken from statistical area (zone) 34 (Figure 10).

In 1998–90 and 1999–2000, the effort off the west coast was largely confined to the higher latitudes, south of about 40° S (Kendrick 2006), but since 2000–01, trolling has started in December and January as far north as 35° S, and then shifted south as summer weather conditions allow the fleet of small vessels to operate at higher latitudes off the exposed coast (Figure 11). In the third quarter there is an indication of some troll vessels returning northward; others switch gear to longline in time for the start of the southern bluefin fishery that takes place off the west coast of the South Island starting in May-June.

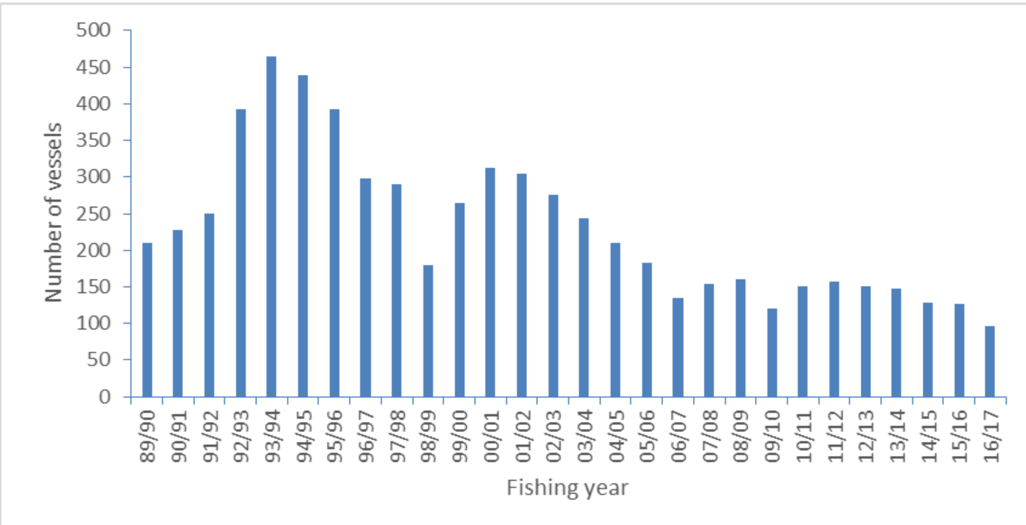

Figure 8: Number of vessels in the ungroomed dataset that used the troll method and targeted albacore, by fishing year.

Table 4: Distribution of landed albacore for troll method, by target species and fishing year, in tonnes and in percent of annual landings. ALB, target species is albacore. Percentages sum to 100 by year.

Fishing	Landed catch (t)		Landed catch (%)	
year	ALB	Other	ALB	Other
89–90	3 021	8.7	99.7	0.3
90–91	2 358	2.6	99.9	0.1
91–92	2 374	5.0	99.8	0.2
92–93	2 595	6.8	99.7	0.3
93–94	3 263	22.9	99.3	0.7
94–95	5 436	13.8	99.7	0.3
95–96	5 241	3.4	99.9	0.1
96–97	2 736	2.5	99.9	0.1
97–98	4 972	1.3	100.0	0.0
98–99	2 027	0.6	100.0	0.0
99–00	3 305	2.1	99.9	0.1
00–01	3 454	1.0	100.0	0.0
01–02	3 292	1.7	99.9	0.1
02–03	4 142	2.9	99.9	0.1
03–04	4 096	0.9	100.0	0.0
04–05	3 009	0.1	100.0	0.0
05–06	2 203	0.4	100.0	0.0
06–07	1 783	0.4	100.0	0.0
07–08	3 415	0.1	100.0	0.0
08–09	1 876	0.2	100.0	0.0
09–10	1 694	0.0	100.0	0.0
10–11	2 804	0.8	100.0	0.0
11–12	2 775	0.7	100.0	0.0
12–13	2 588	0.0	100.0	0.0
13–14	2 136	0.8	100.0	0.0
14–15	2 320	4.8	99.8	0.2
15–16	1 873	0.0	100.0	0.0
16–17	1 787	0.0	100.0	0.0

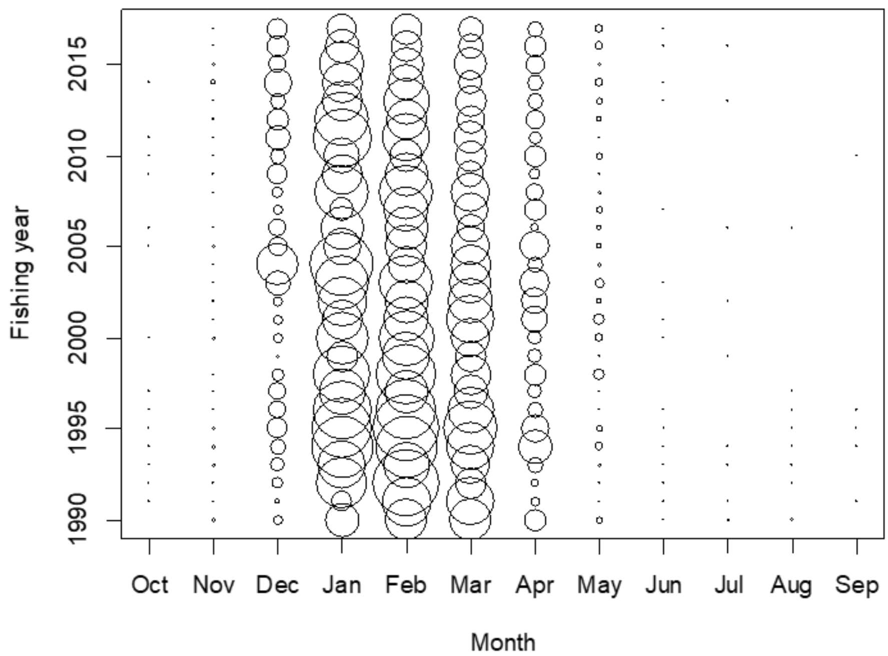

Figure 9: Distribution of targeted troll catch of albacore by month and fishing year. Circle areas are proportional to the annual catch totals for targeted troll given in Table 4. The largest circle equals 1943 t in February 1998.

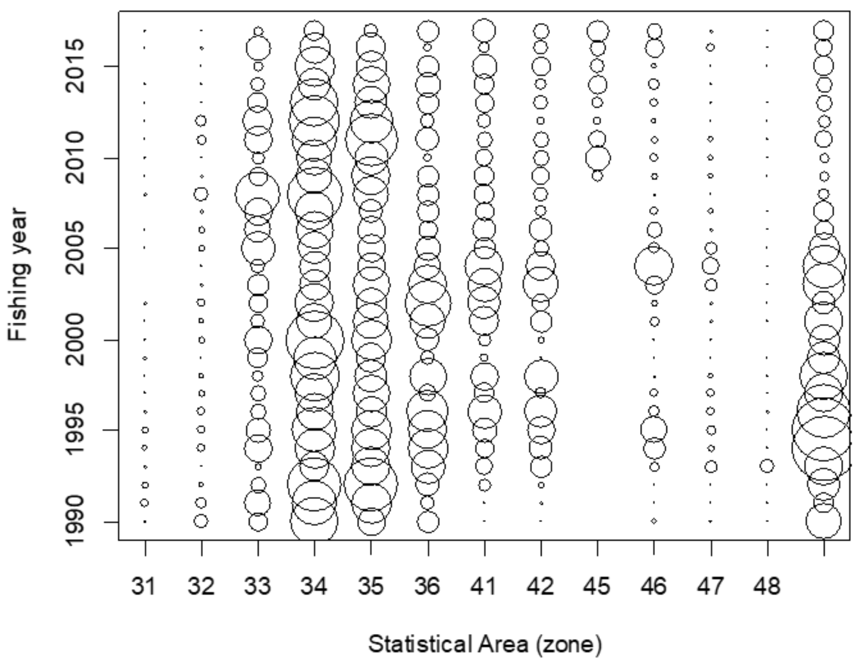

Figure 10: Distribution of targeted troll catch of albacore by statistical area (zone) and by fishing year. Circle areas are proportional to the annual catch totals for targeted troll given in Table 4. The end column is the 'Other' category. The largest circle equals catch weight in statistical area (zone) 34 in 1999–2000.

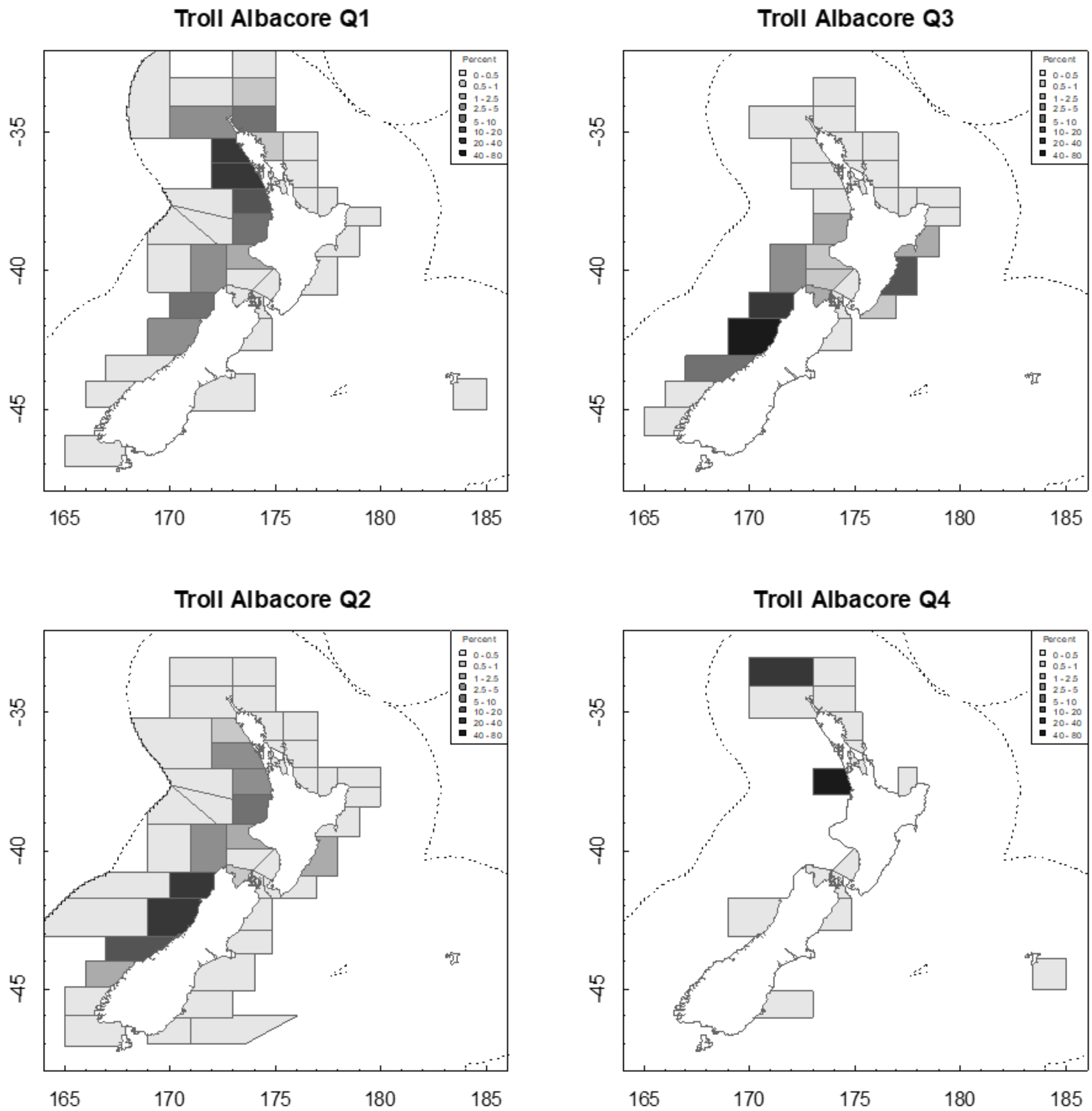

Figure 11: Spatial and seasonal distribution of recent troll catches of albacore (fishing years 2009–10 to 2016–17 combined), by year-quarter and statistical area. Percent of total troll catch. Q1, October -December; Q2, January-March; Q3, April-June; Q4, July-September. For statistical area labels see Figure 5.

3.2.1 Measures of effort for troll

The measures of effort for trolling include number of lines, number of hooks, vessel-day, and duration. Number of sets is not a variable collected for this method. The distribution of values for the number of lines (Figure 12) and number of hooks (Figure 13) confirm that these data are contaminated with badly recorded effort because values greater than 15 are not feasible on boats of this size. Fishers are instructed to record the maximum number of (lines /hooks) in the water at one time, but it appears that they sometimes multiply this by an unknown factor.

The Highly Migratory Species Working Group (HMSWG) has, in the past, expressed a lack of confidence in these data and has also noted that number and experience of the crew (not recorded) is probably more important in determining the number of albacore landed than is the number of lines or hooks (N. Smith, past chair HMSWG, pers. comm.). There is not thought to be much variation in rig among troll vessels, and it was recommended that vessel-day be used as the measure of effort for this method. The distribution of duration fished (Figure 14) seems less prone to misunderstanding and more likely to reflect total hours trolled in a day.

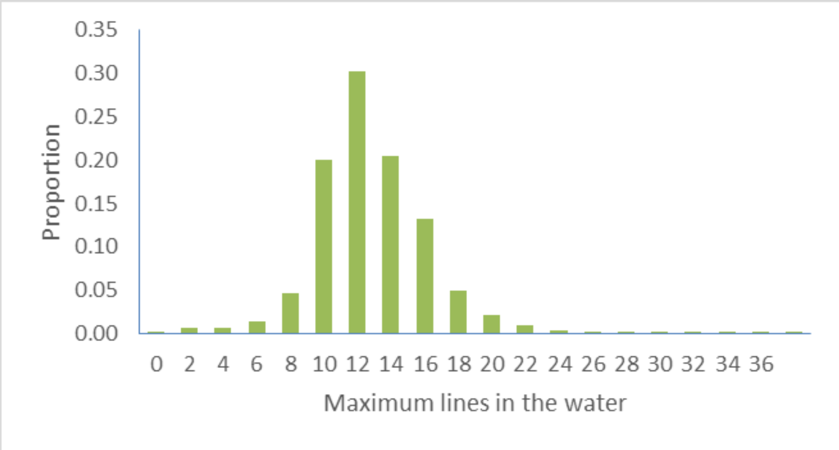

Figure 12: Distribution of the maximum number of lines in the water at any time for troll effort reported on CELRs.

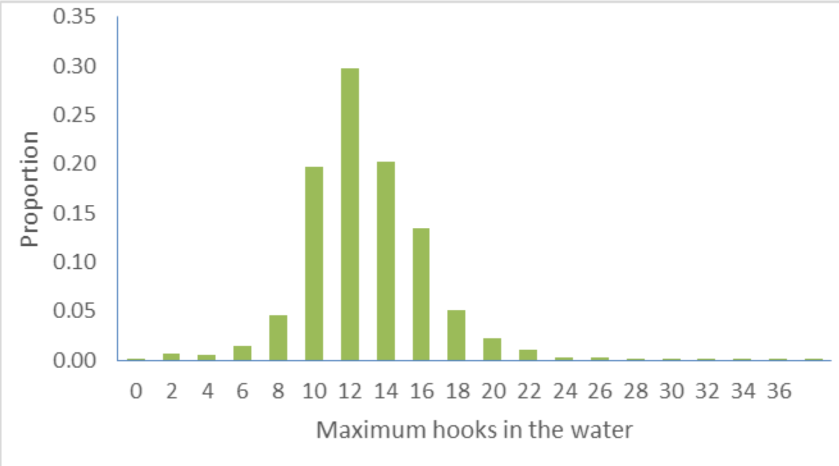

Figure 13: Distribution of the maximum number of hooks in the water at any time for troll effort reported on CELRs.

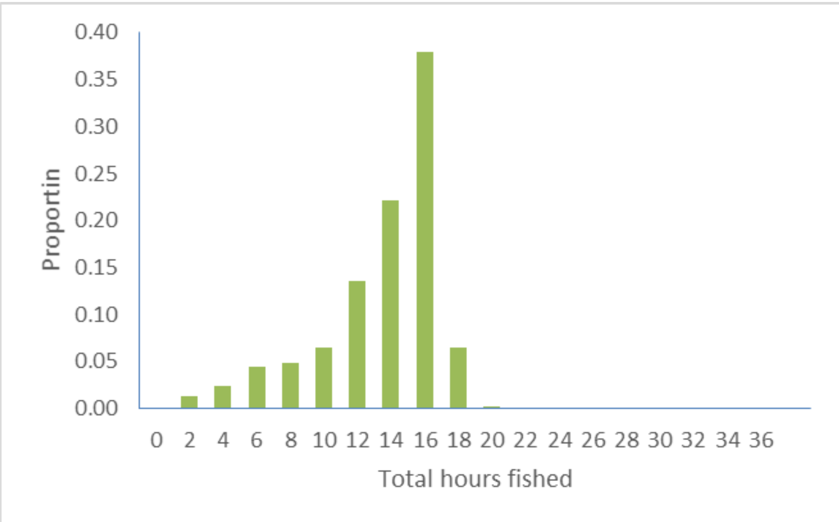

Figure 14: Distribution of duration of fishing for troll effort reported on CELRs.

3.3 Observer and other data

The albacore port sampling programme was established during the 1996–97 albacore fishing season. The first two years of sampling were funded through The Pacific Community (SPC) but the programme has been funded by the Ministry of Fisheries and MPI, and their predecessors, (costs recovered from industry) since 1998–99. Sampling typically occurs at three ports on the west coast of New Zealand, though only two ports were sampled in 2007 and 2008 due to the reduced distribution of fishing effort in those years. Sampling occurs during the austral summer (December-May).

Over the duration of the programme over 93 000 albacore have been sampled for length (Figure 15, Figure 16). The length frequency data are provided to SPC annually and have been incorporated into the regional assessment for South Pacific albacore.

These multi-modal annual length frequency distributions reveal progressions of distinct modes associated with strong year classes. In 1999 a mode is evident in the length intervals 46–55 cm and dominates the catch length distribution in the following year. It remains evident in 2001 and 2002 as a large component of the broad mode in the large length classes, indicating this to be a strong cohort. The modal pattern in 1997 and high mean length may reflect the presence of a large cohort that dominated the fishery in 1995 (Unwin et al. 2005).

In January 2017, when the data for this study were extracted, there were 17 observed fishing trips for troll method in the Centralised Observer Database COD; one each in 1993, 1997, 2007, and 2008, 6 between 2009 and 2019, 4 in 2010–11, and 1 in 2011–12. Deployment of observers on troll vessels was then discontinued because it was not representative of the fishery compared with port sampling. The observed number of lines fished at any one time ranged from 6 to 14 lines (median 11) with presumably a single hook per line. Duration of fishing was not available.

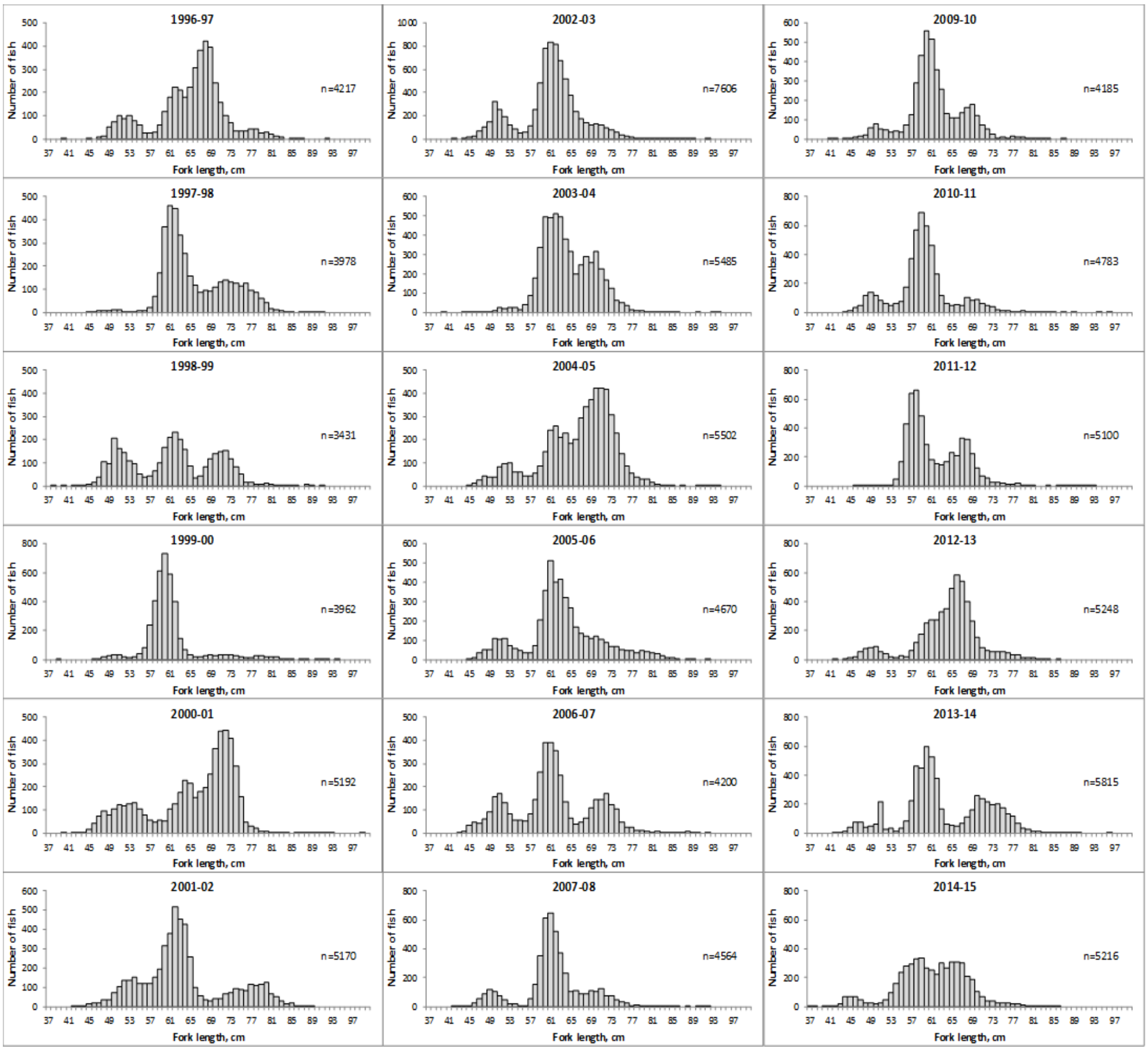

Figure 15: Size composition of albacore from shed sampling of the commercial troll fishery for 1996–97 to 20014–15 (reproduced from Griggs & Large 2016).

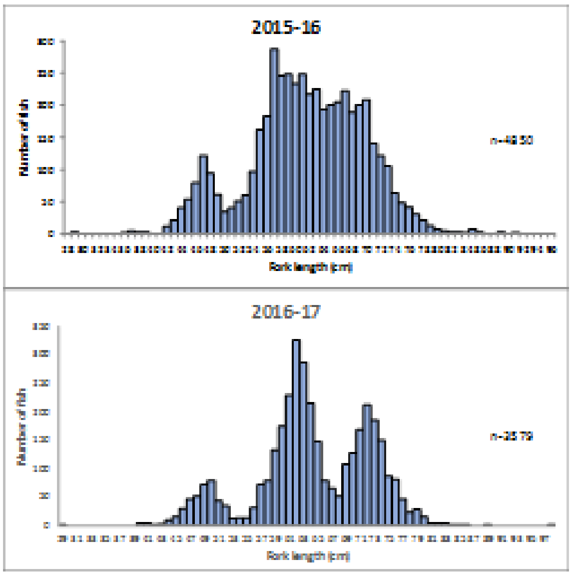

Figure 16: Size composition of albacore from shed sampling of the commercial troll fishery for 2015–16 to 2016–17 (unpublished data from L. Griggs, NIWA).

3.4 Standardised CPUE

3.4.1 Core vessel selection and subsets

The number of vessels that have fished by troll for albacore is large (over 700), and a core fleet selection that required a minimum participation of at least seven qualifying trips a year in at least six years accounted for about 67% of the landed catch, but still resulted in a fleet of over 160 core vessels (Figure 17), which is a large number of levels of an explanatory variable to be included in a standardised CPUE analysis. The observed annual catch rates for those 160 core vessels was very similar to that of the entire fleet (Figure 18).

Raising the criteria to reduce the number of vessels tended to compromise coverage in the most recent years, therefore an alternative approach was taken and the core vessels were analysed in two subsets, with the resulting indices compared for corroboration of the trend. A fleet of 83 core vessels that demonstrated good coverage and overlap in the time series was subsetted and referred to as TROLL 1 (Figure 19). The remaining 77 core vessels are referred to as TROLL 2 and their participation in the troll fishery is shown in Figure 20.

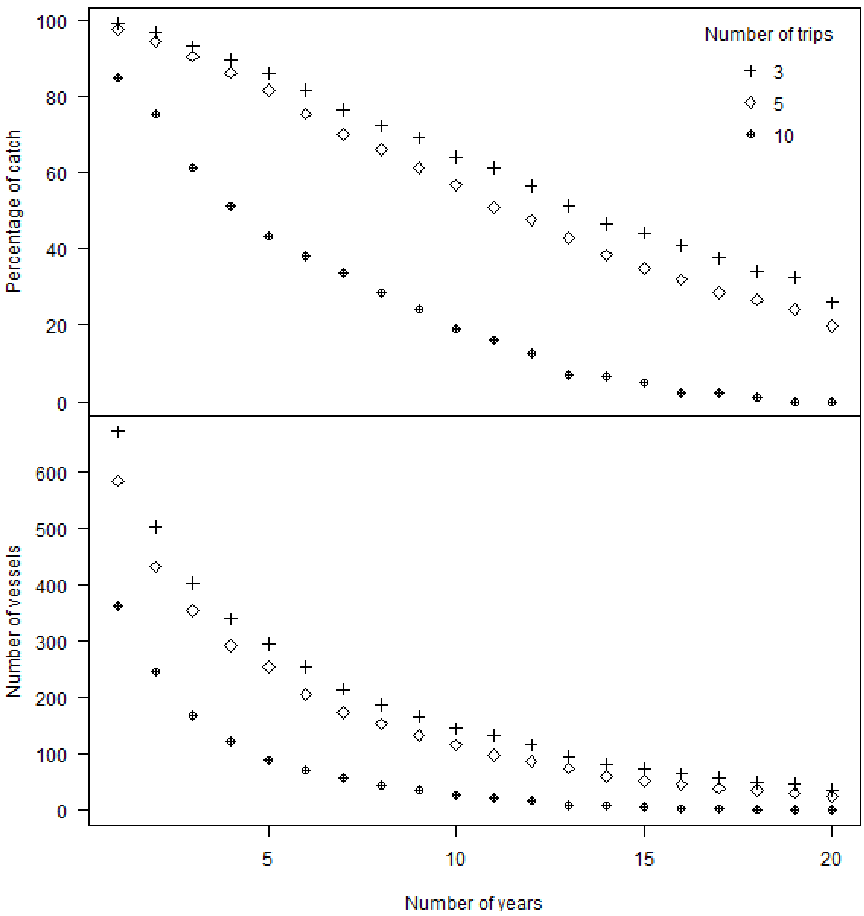

Figure 17: The number of vessels [lower] and the proportion of estimated ALB 1 catch [upper] retained in the CPUE dataset depending on the minimum number of qualifying years used to define core vessels. The three series illustrate alternative definitions of a qualifying year, with the minimum number of trips per year indicated in the legend.

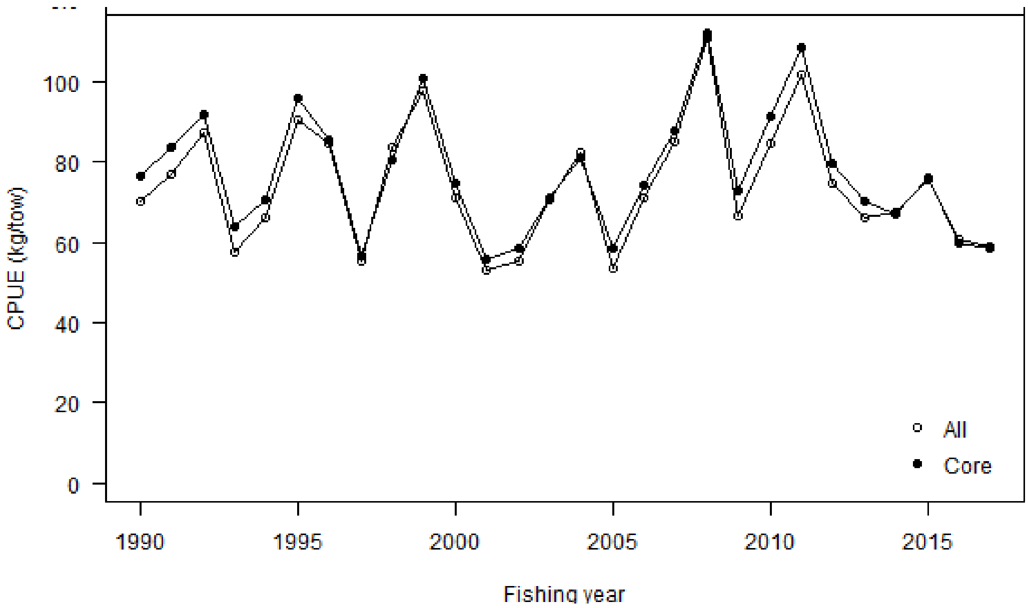

Figure 18: Unstandardised CPUE (geometric mean of positive catches) for the entire dataset (All) and core vessels (Core), by fishing year for 1989–90 (1990) to 2016–17 (2017).

Figure 19: The participation of the TROLL 1 subset of core vessels (based on at least seven qualifying trips per year in at least six years). Plot shows the number of trips for each vessel in each fishing year, where 1990 is the 1989–90 fishing year.

Figure 20: The participation of the TROLL 2 subset of core vessels (based on at least seven qualifying trips per year in at least six years). Plot shows the number of trips for each vessel in each fishing year, where 1990 is the 1989–90 fishing year.

3.4.2 Model selection

The parameterisation of the negative binomial models for alternative vessel subsets was similar in that *duration* of fishing was the variable with the most explanatory power followed by *vessel ID*. The *Area*Month* interaction effect was the third most important variable in both cases. The two models explained about 21% and 24%, respectively, of the variance in catch rates, as indicated by the R^2 for the final model in bold (Table 5, Table 6). *Sea Surface Temperature* (SST) and its derivatives were not accepted into either model.

The final model formula, for each model, was

$$\sim fyear + poly(\log(duration), 3) + vessel + area{:}month.$$

Table 5: Summary of the final negative binomial model of the TROLL 1 core vessel subset. Independent variables are listed in the order of acceptance to the model. DF, degrees of freedom; AIC, Akaike Information Criterion; R^2, proportion of deviance explained at each step and for the final model in bold; Final, whether or not the variable was included in the final model. Fishing year was forced as the first variable.

Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2 (%)	Final
fyear	28	-228 907	457 870	4.56	*
poly(log(duration), 3)	31	-226 576	453 214	14.83	*
vessel	113	-225 529	451 285	19.08	*
Area:Month	187	-224 964	450 303	**21.28**	*
poly(MonthlyAnomaly, 3)	190	-224 907	450 194	21.51	
poly(log(days), 3)	193	-224 893	450 171	21.56	
poly(AnnualAnomaly, 3)	196	-224 886	450 164	21.58	
poly(SST, 3)	199	-224 882	450 163	21.60	

Table 6: Summary of the final lognormal model of the TROLL 2 core vessel subset. Independent variables are listed in the order of acceptance to the model. DF, degrees of freedom; AIC, Akaike Information Criterion; R^2, proportion of deviance explained at each step and for the final model in bold; Final, whether or not the variable was included in the final model. Fishing year was forced as the first variable.

Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R2 (%)	Final
fyear	28	-243 271	486 599	5.17	*
poly(log(duration), 3)	31	-240 547	481 156	16.49	*
vessel	107	-239 252	478 719	21.39	*
Area:Month	182	-238 666	477 697	**23.51**	*
poly(MonthlyAnomaly, 3)	185	-238 584	477 538	23.80	
poly(log(days), 3)	188	-238 574	477 524	23.84	
poly(AnnualAnomaly, 3)	191	-238 565	477 512	23.87	
poly(SST, 3)	194	-238 557	477 502	23.90	

3.4.3 Model fits

Diagnostic residual plots are presented for each model in Appendix A. For both models the fit of the data appears to be adequate with some departure from the negative binomial assumption in the extreme tails of the distribution and some patterns in the residuals that are not adequately modelled.

Forward stepwise selection, and its influence on the standardised series, of each variable as it was accepted into the models are summarised in Figures 21 and 22. Influence plots (Bentley et al. 2012) for each significant predictor variable in each model are presented in Appendix B. They describe the combined effect of the expected log catch rate at each level of the variable (model coefficients), and the distribution of the underlying data.

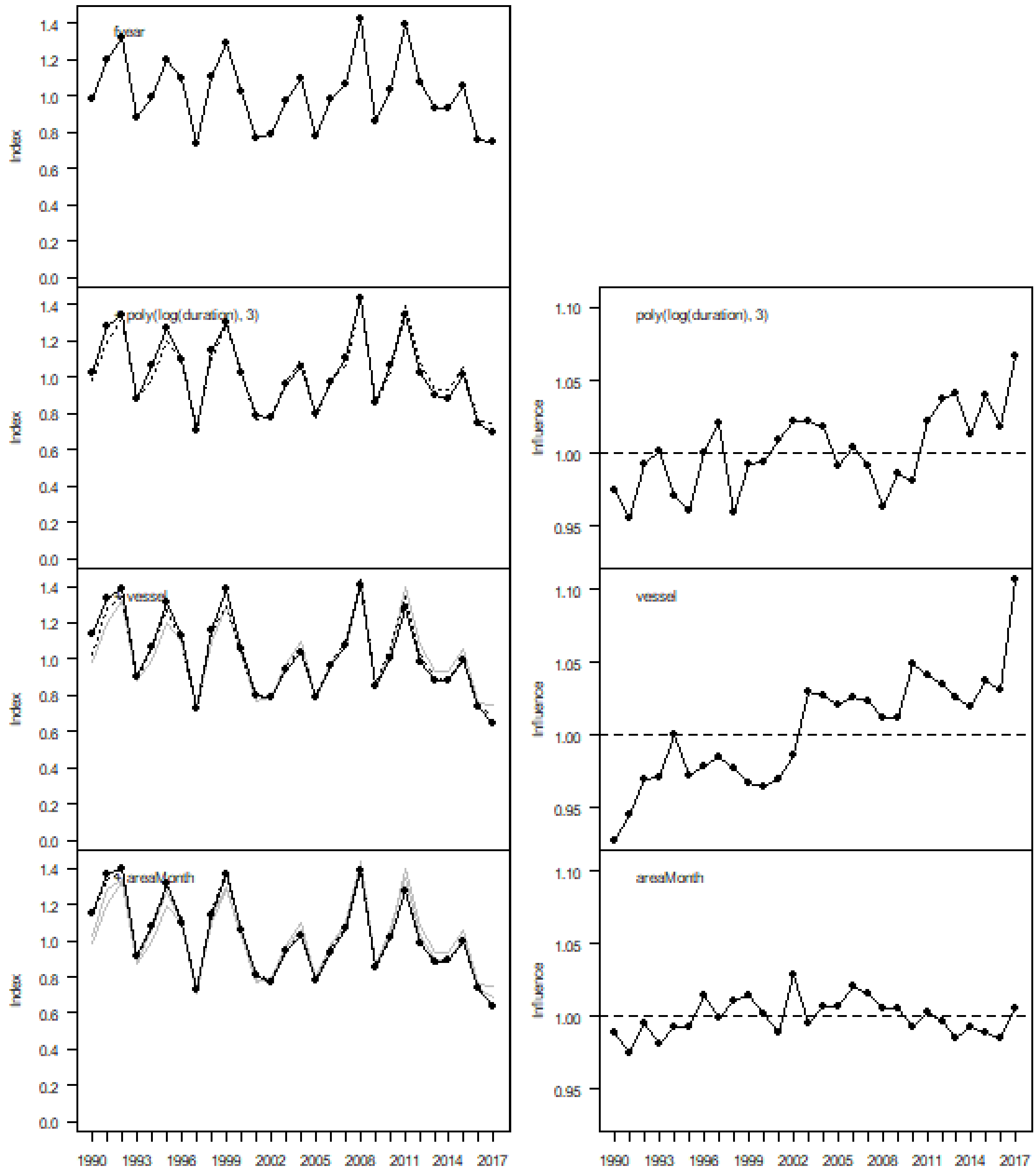

Figure 21: Step and annual influence plot for TROLL 1. [left column] CPUE index at each step in the selection of variables. The index obtained in the previous step (if any) is shown by a dotted line and for steps before that by grey lines. [right column] Annual influence on observed catches arising from a combination of its model coefficients and its distributional changes over years, for each explanatory variable in the final model.

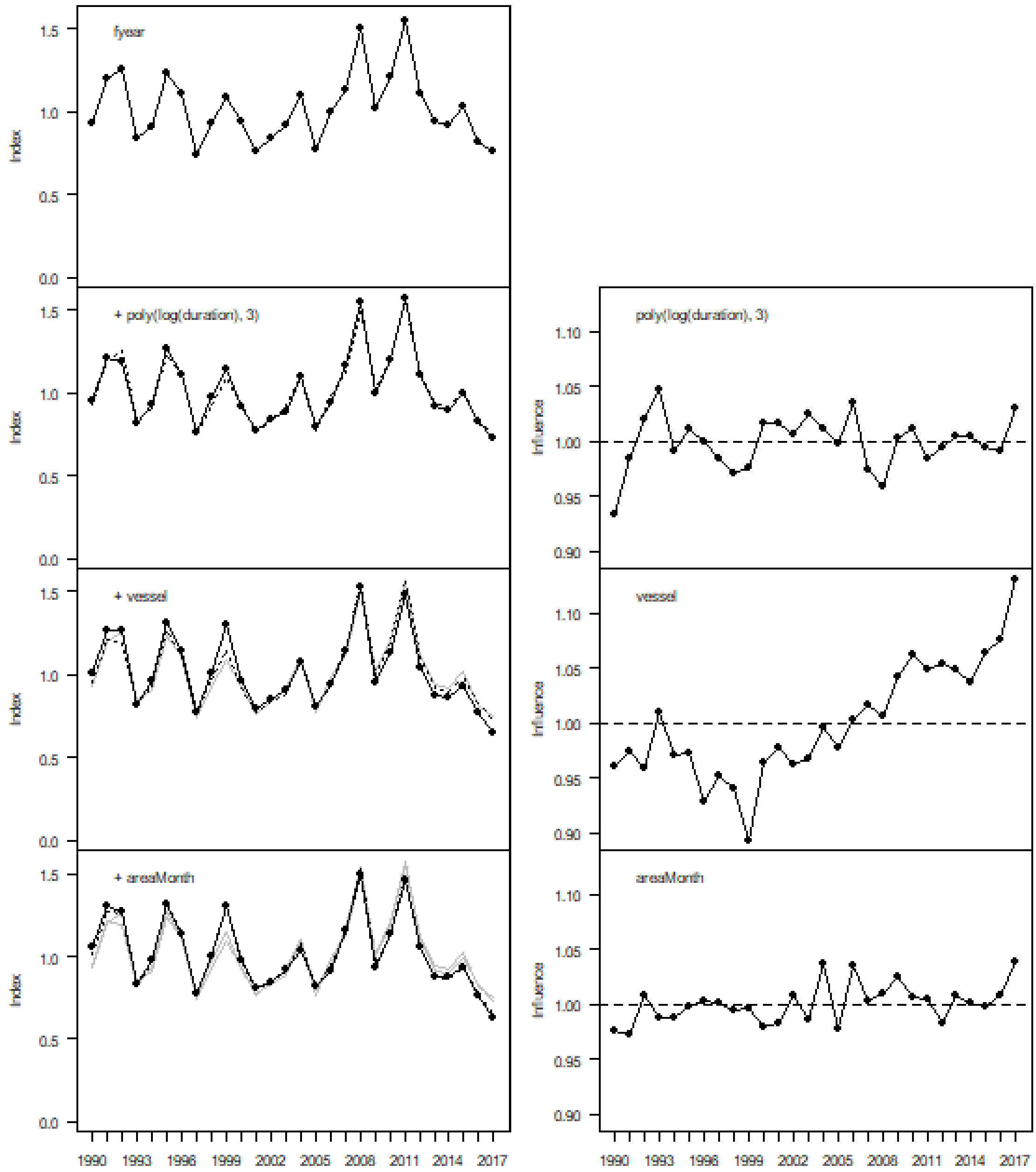

Figure 22: Step and annual influence plot for TROLL 2. [left column] CPUE index at each step in the selection of variables. The index obtained in the previous step (if any) is shown by a dotted line and for steps before that by grey lines. [right column] Annual influence on observed catches arising from a combination of its model coefficients and its distributional changes over years, for each explanatory variable in the final model.

For both TROLL 1 (Figure B1) and TROLL 2 (Figure B4) there is a near linear relationship between *duration* of fishing and predicted catch over the range in which most of the data occur, with some complexity at the extremes where there are few observations. There has been a trend, particularly in the most recent decade, towards longer fishing duration and that has translated into increased observed CPUE.

For both TROLL 1 (Figure B2) and TROLL 2 (Figure B5) there is some contrast in performance between vessels and a tendency over time for the better performing vessels to be retained in the fishery so that the overall influence of *vessel* on observed CPUE has been to increase observed catch rates by

15 to 20%. The model adjusts for this trend by lifting points at the beginning of the series and lowering those in more recent years.

Offering the models an area*month interaction is analytically defensible for any highly migratory fishery where the relative importance of an area changes with season. It has been noted in previous analyses that there is little contrast in catches between areas or months in the dataset, presumably because fishers are able to track the abundance of albacore closely. The effect of changes to the area*month of fishing is slight (Figure B3, Figure B6) and mostly seen in the lifting of some earlier points in the series.

3.4.4 Trends in model year effects

The effect of standardisation on both series is slight, changing each series to one which declines slightly over the time period.

The year effects from both models resemble each other closely despite the two analyses being based on independent subsets of core vessels. Each series varies around unity in a 3–4 year cycle characterised by considerable magnitude and changes in direction that are not likely to signal biological processes and by a slight (by comparison) declining trend overall. The error bars around each point are small relative to the interannual variance and suggest that the overarching pattern is not one of noise, but reflects real interannual availability experienced across the fleet with only small differences able to be affected by the fishing behaviour of individual vessels (Figure 23, Figure 24).

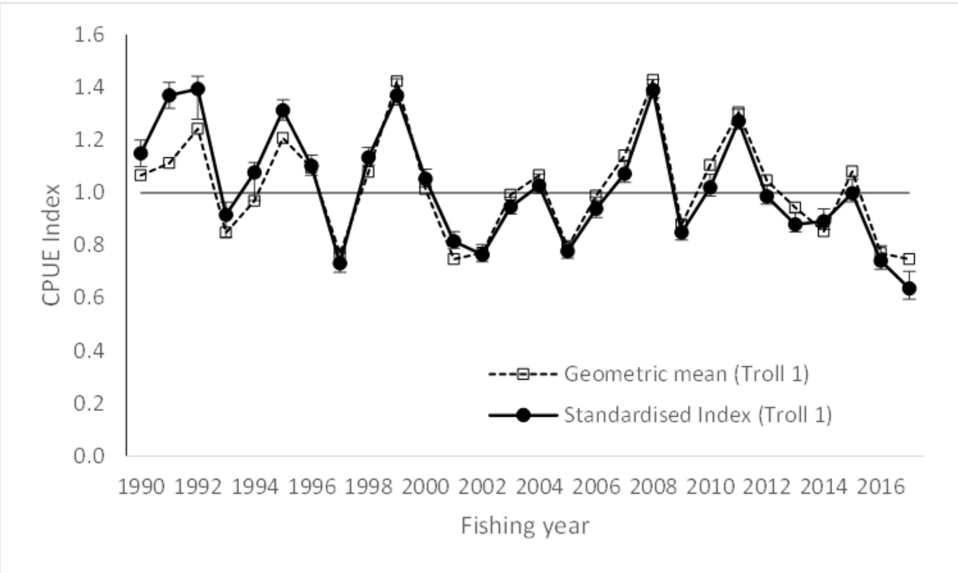

Figure 23: Effect of standardisation on observed CPUE of troll-caught albacore in New Zealand waters (vessel subset = TROLL 1). The core vessels comprise 160 vessels that completed a minimum of seven troll trips per year in at least six years. TROLL 1 is a subset of 83 of those vessels.

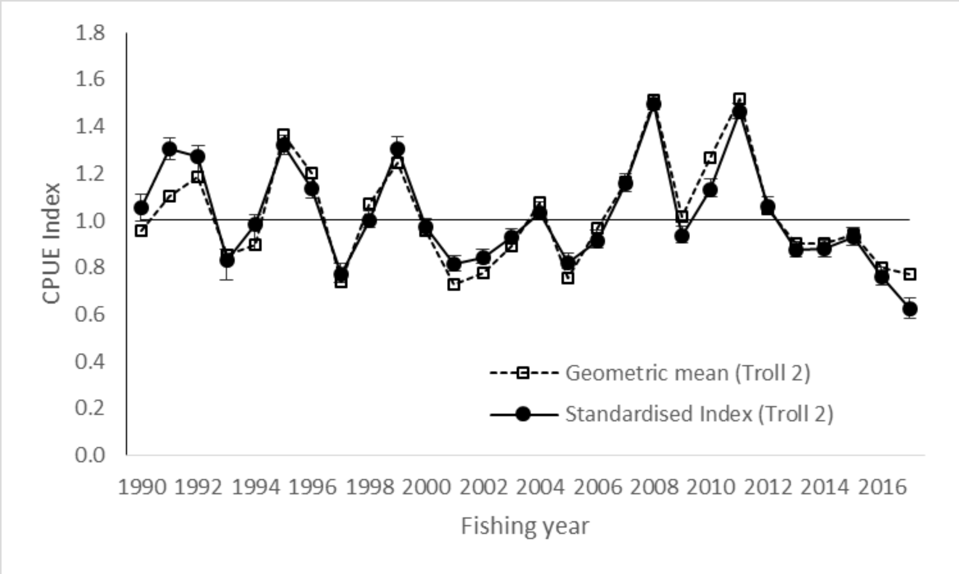

Figure 24: Effect standardisation on observed CPUE of troll-caught albacore in New Zealand waters (vessel subset = TROLL 2). The core vessels comprise 160 vessels that completed a minimum of seven troll trips per year in at least six years. TROLL 2 is a subset of 77 of those vessels.

3.4.5 Multivariate ENSO Index (MEI)

There is wide scale acceptance that large-scale climatic effects have an effect on the distribution and migration of albacore, and the El Niño/Southern Oscillation (ENSO) is the most important coupled ocean-atmosphere phenomenon to cause global climate variability on interannual time scales. The mechanisms are many and various and can sometimes be conflicting. In the North Pacific, El Niño events can create a northward and onshore extension of the range of albacore leading to them concentrating on the Californian coast. In the southeast Atlantic, the availability of juvenile albacore to the nearshore fisheries of South Africa is reduced in El Niño years due to contraction of their range. Mechanisms associated with El Niño events that can retain or contract the range of highly migratory fish include deeper thermoclines that reduce their availability to surface methods and upwelling fronts that provide good foraging or through which they are reluctant to penetrate.

It is interesting to note that although El Niño events can generate an extreme water temperature response, the sign of that response relative to normal temperatures is not always predictable (Uddstrom & Oien 1999). For example, high SST anomalies in New Zealand waters coincided with La Niña in 1999 and with El Niño in 2015. Other mechanisms that are not captured by the ENSO index include marine heatwaves, with recent increases in their frequency, duration, and intensity discussed by Oliver et al. (2018).

The Multivariate ENSO Index (MEI) attempts to monitor ENSO based on the six main observed variables over the tropical Pacific. These six variables are: sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky (http://www.cdc.noaa.gov/enso/index.html).

The MEI (sign reversed so that negative values correspond to El Niño events) is plotted for comparison with the standardised CPUE series for TROLL 1 and TROLL 2 in Figure 25.

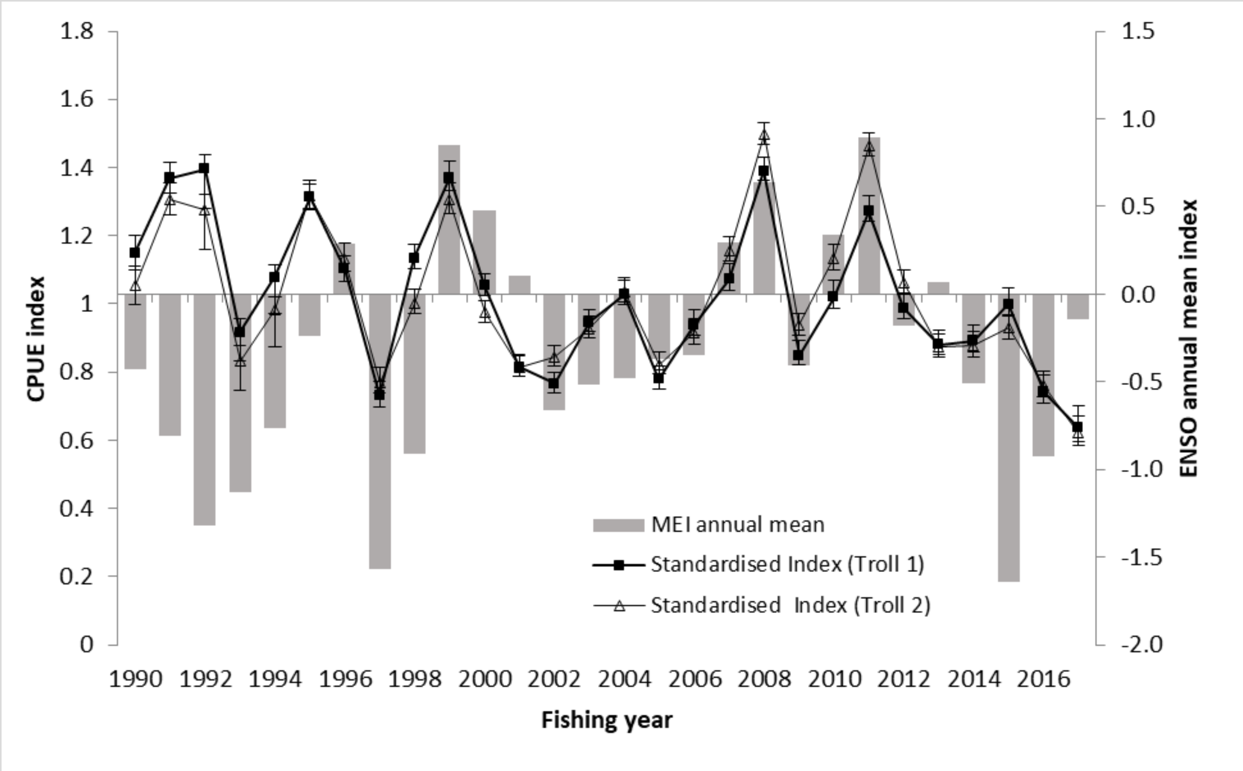

Figure 25: Comparison of annual indices of availability of troll-caught albacore in New Zealand waters (TROLL 1 and TROLL 2) with annual means of the Multivariate ENSO Index (MEI) an indicator of large climatic shifts affecting the South Pacific. The sign of ENSO index is reversed so that negative values indicate El Niño events.

Although not correlated with the MEI overall, peaks in standardised CPUE do correspond to significant La Niña events, occurring in 1998–99, 2007–08, and in 2010–11 fishing years. The CPUE of juvenile albacore in the troll fishery also appears to respond negatively (but not perfectly) to El Niño events, particularly in the most recent two decades.

Estimated catches recorded in the early to mid 1990s are contaminated by reporting of greenweight, even after grooming, and may account for the divergence of the two signals in the early part of the series.

It is beyond the scope of this project to conjecture the mechanism for the effect that ENSO events may have on the availability of albacore to the nearshore troll fishery in New Zealand, but the difference in the scale of variance within and between years suggests that if it is related to the formation or depth of thermoclines, as suggested by Unwin et al. (2005); they may not necessarily be within New Zealand waters but at a larger geographical and temporal scale than the New Zealand catch effort data.

3.4.6 Interpretation of shed sampled length frequencies

If CPUE of troll-caught albacore does not index abundance, then it is unlikely to help interpret the shed sampled length frequencies.

If the oceanographic structures indicated by the MEI were responsible for contraction of the range of primarily or exclusively one or more age classes, then it might indeed invalidate the existing value of that series in describing year strength. There is no indication of that. By comparing the modal pattern in the catch in 1996–97, which was a strong El Niño year and one of unusually low CPUE, with the catch compositions in 1998–99 and 2007–08 which were strong La Niña years that corresponded with peaks in CPUE, no strong dissimilarities are evident. All three cohorts are present in each of those years.

4. CONCLUSIONS

a) The standardised annual CPUE indices fluctuate around unity in a 3–4 year cycle with small error bars around each point. This is not a noisy signal, because the within year variance is small relative to the interannual fluctuations.
b) The trend and precision of the annual indices is very similar when the analysis is repeated using a completely different subset of core vessels.
c) The core vessels appear representative of the entire troll fleet regardless of experience (participation); the unstandardised CPUE for all troll vessels is little different from that for core vessels.
d) Standardisation has very little effect on the unstandardised series. There is very little contrast in predicted CPUE among months and among statistical areas, indicating that either abundance is homogeneous when the fish are available or that fishers can track abundance almost perfectly.
e) Local scale environmental effects were not accepted into the model, indicating that there is little contrast in catches for the months and areas in which the fishery operates.

5. MANAGEMENT IMPLICATIONS

CPUE of troll caught albacore within New Zealand waters is unlikely to be an index of abundance of the stock. If it does contain a signal of recruitment strength, then it is likely overwhelmed by effects that are not captured by catch effort data within New Zealand waters. While not correlated with the MEI overall, peaks in standardised CPUE do correspond to significant La Nina events.

In hindsight, the catch effort data for the first half of the 1990s should have been discarded. Dividing catch (t) by catch (thousands of fish) summarised in Table 1 yields unrealistically small average fish weights prior to 1995–96).

6. ACKNOWLEDGMENTS

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APPENDIX A: Model fits

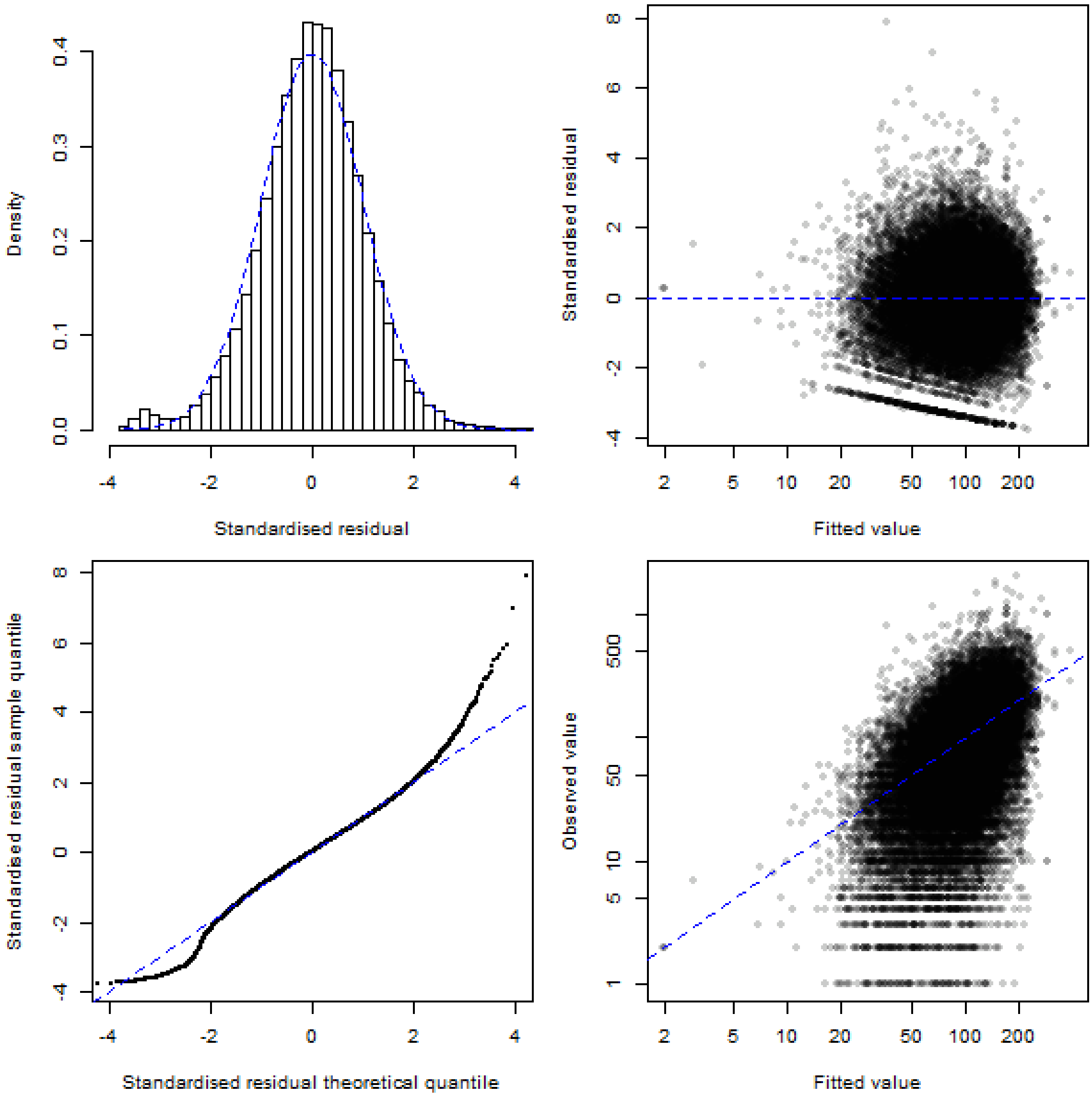

Figure A1: Plots of the fit of the standardised CPUE model to successful catches of albacore in the TROLL 1 vessel subset of the troll fishery. [Upper left] histogram of the standardised residuals compared with a lognormal distribution (SDSR: standard deviation of standardised residuals. MASR: median of absolute standardised residuals); [Upper right] Q-Q plot of the standardised residuals; [Lower left] Standardised residuals plotted against the predicted model catch per trip; [Lower right] Observed catch per record plotted against the predicted catch per record.

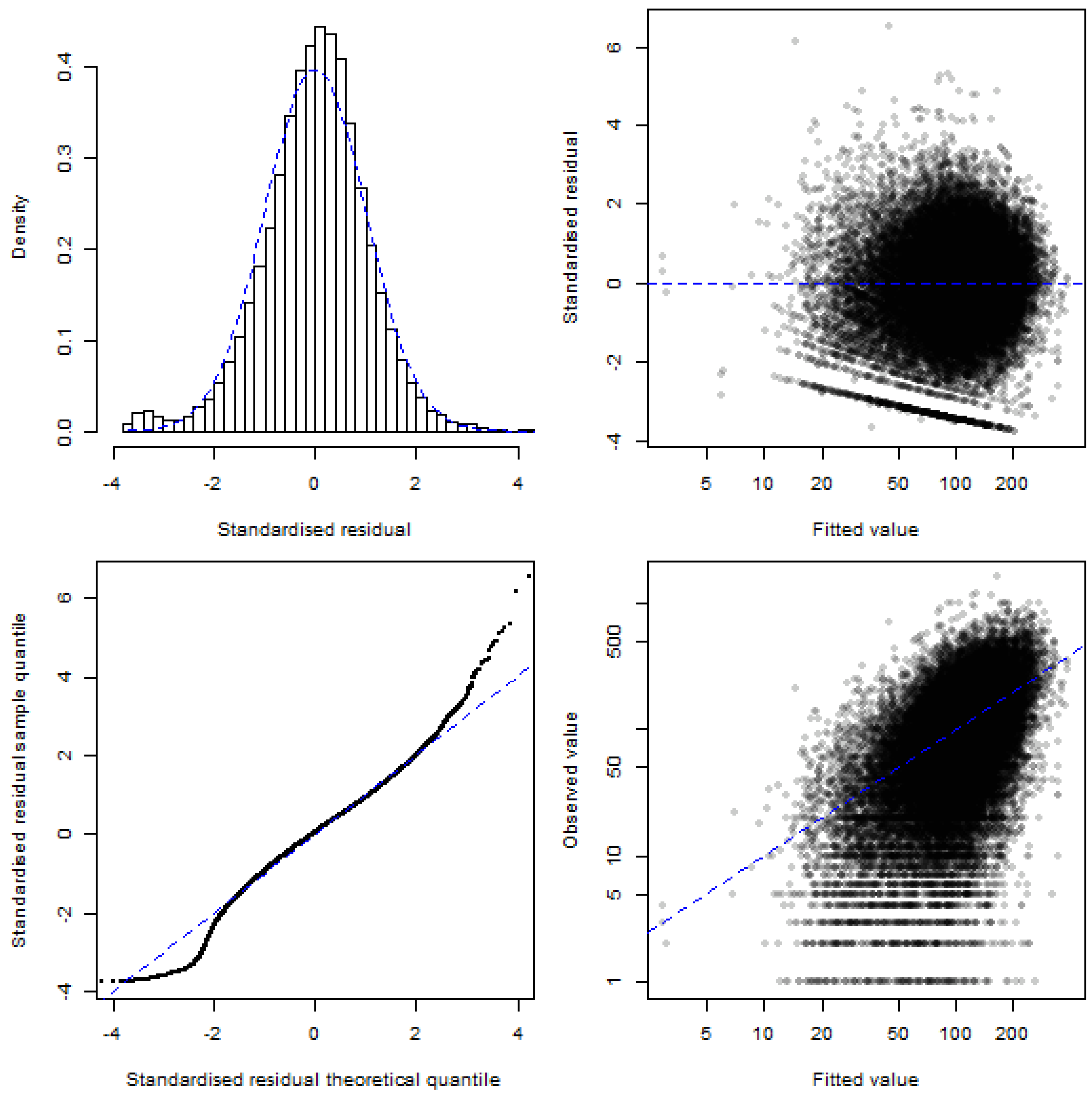

Figure A2: Plots of the fit of the standardised CPUE model to successful catches of albacore in the TROLL 2 vessel subset of the troll fishery. See caption to Figure A1 for details.

APPENDIX B: Model term influence plots

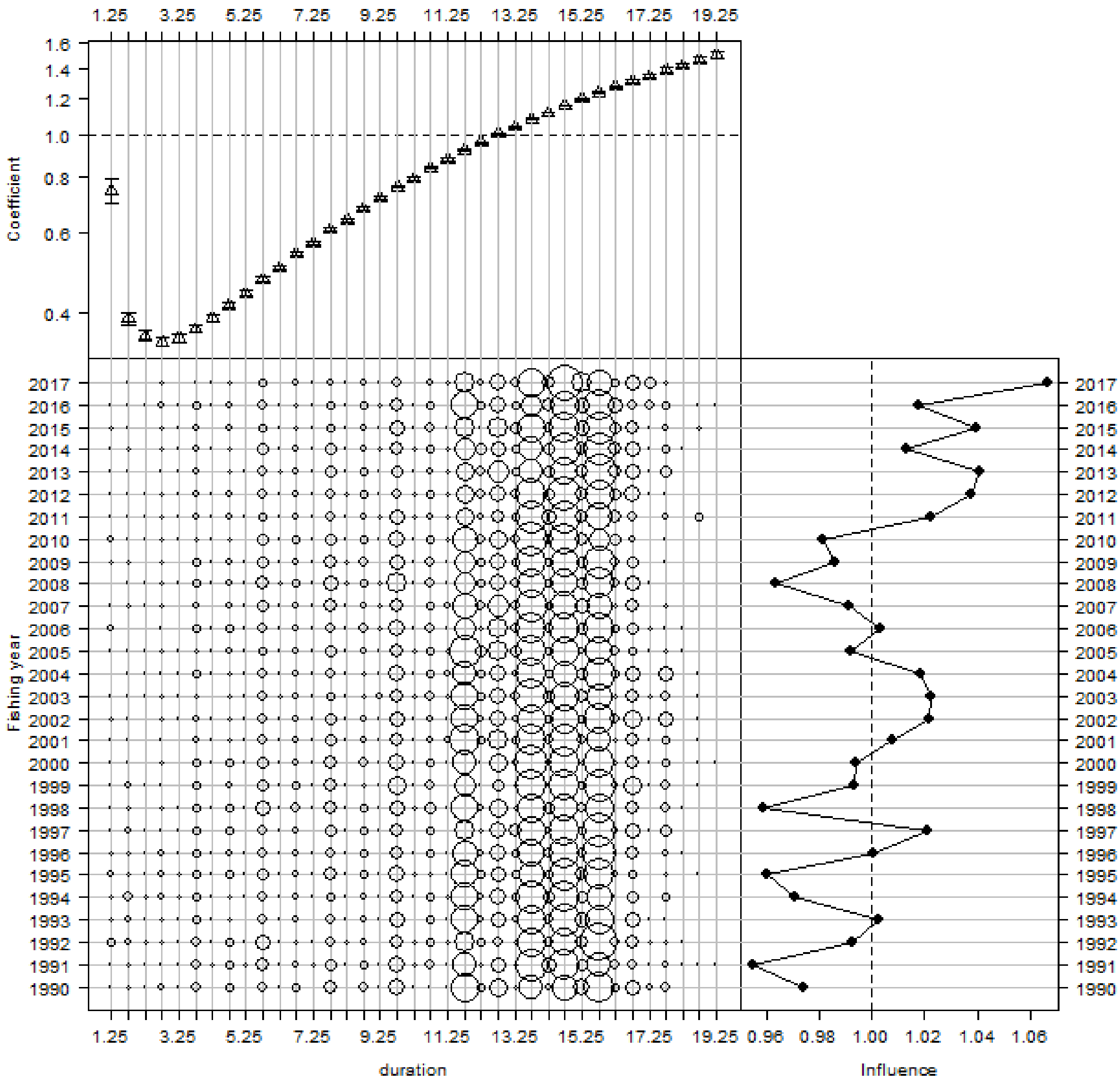

Figure B1: Effect and influence of log(*duration*) in TROLL 1. Top: relative effect by level of variable. Bottom-left: relative distribution of variable by fishing year. Bottom-right: influence of variable on unstandardised CPUE by fishing year.

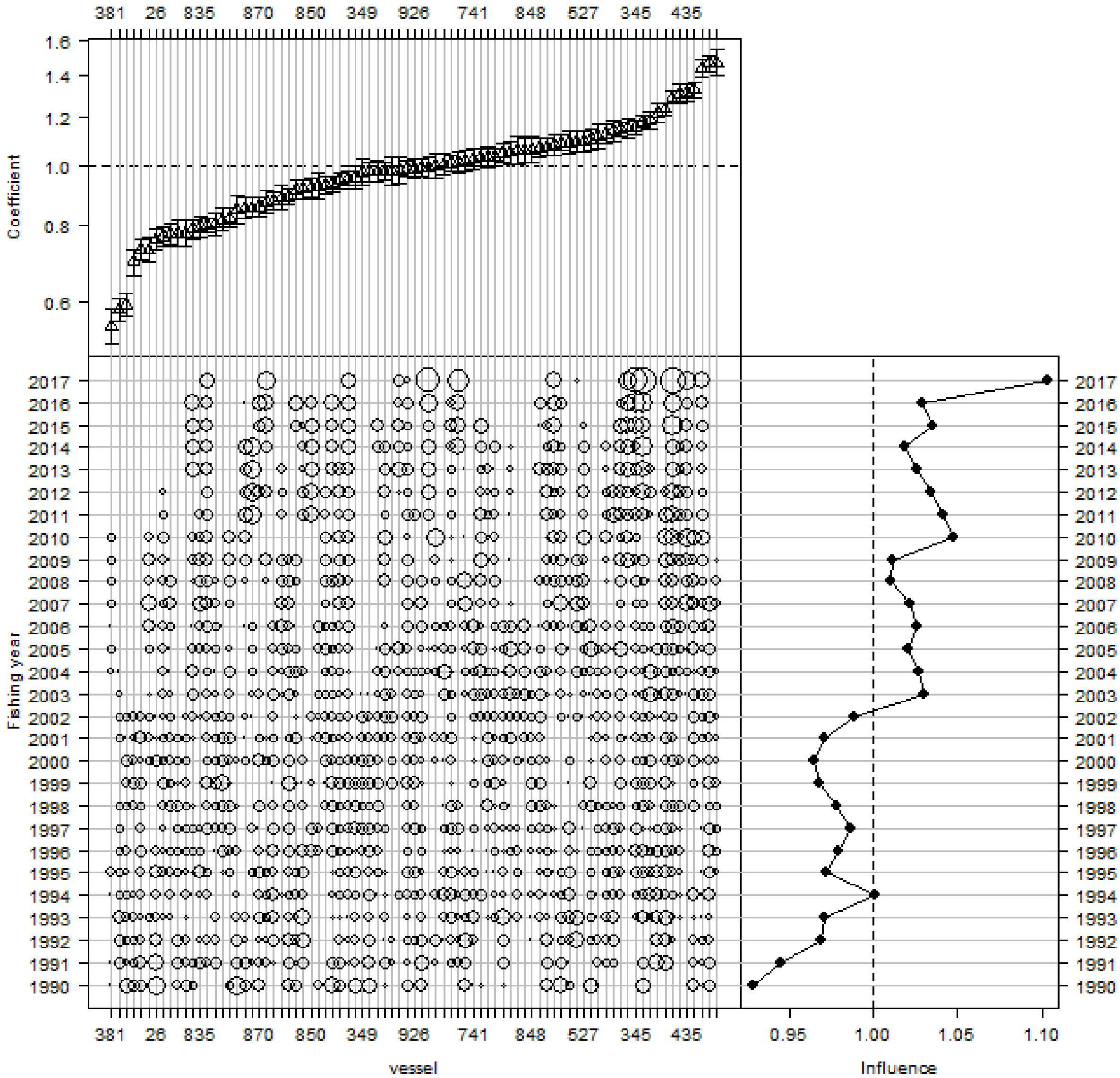

Figure B2: Effect and influence of *vessel* in TROLL 1. Top: relative effect by level of variable. Bottom-left: relative distribution of variable by fishing year. Bottom-right: influence of variable on unstandardised CPUE by fishing year.

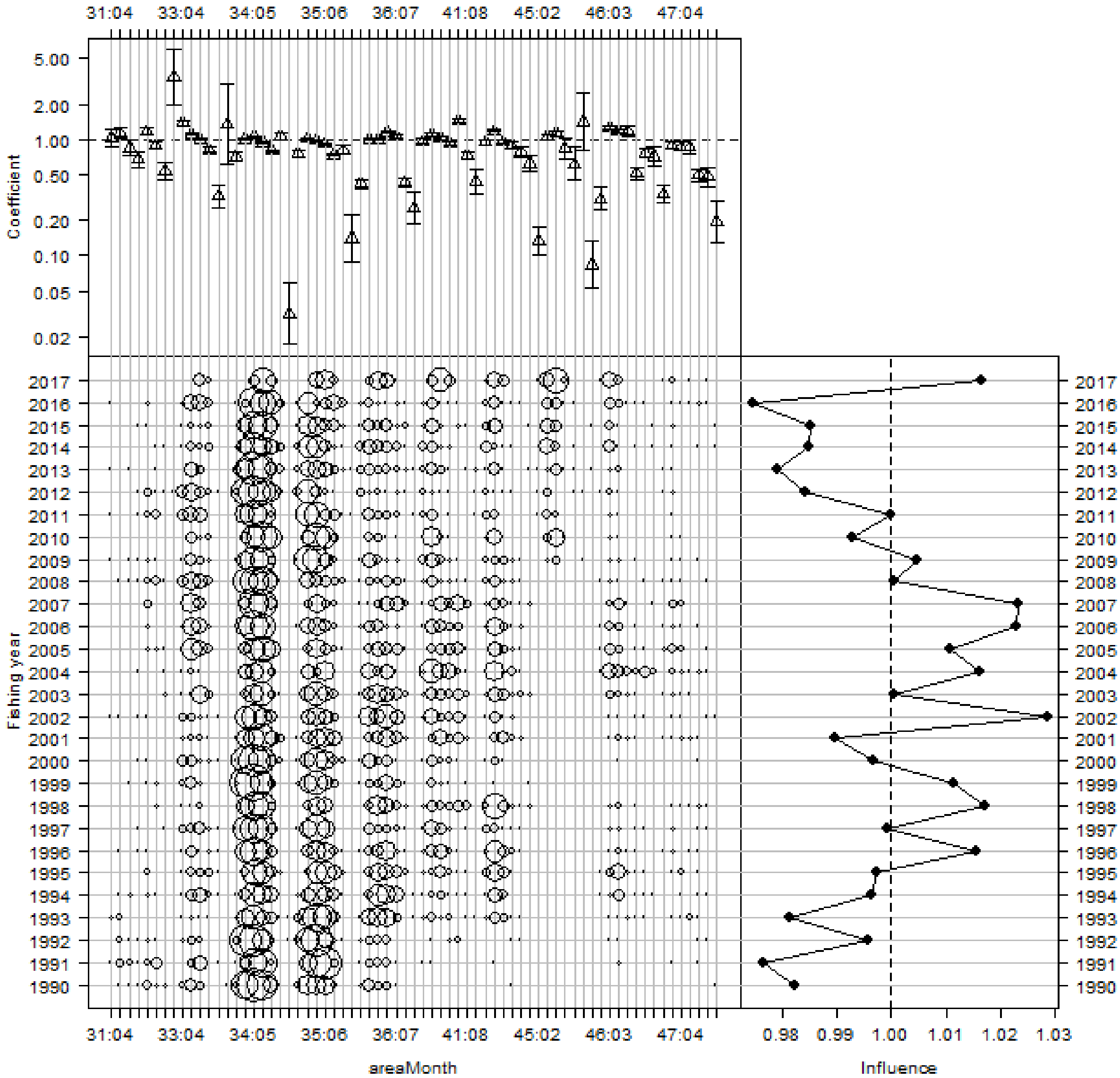

Figure B3: Effect and influence of *area*month* in TROLL 1. Top: relative effect by level of variable. Bottom-left: relative distribution of variable by fishing year. Bottom-right: influence of variable on unstandardised CPUE by fishing year.

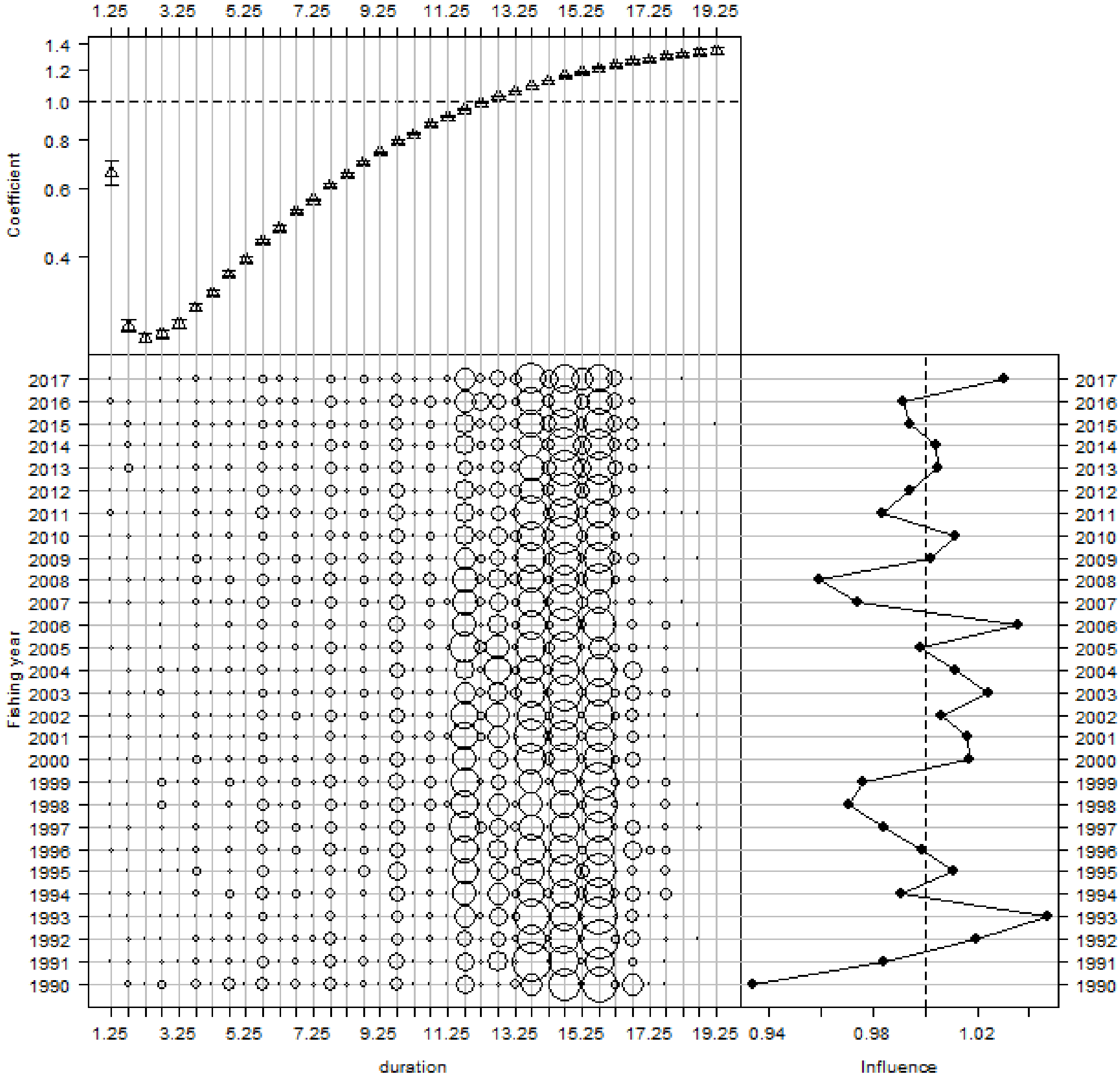

Figure B4: Effect and influence of log(*duration*) in TROLL 2. Top: relative effect by level of variable. Bottom-left: relative distribution of variable by fishing year. Bottom-right: influence of variable on unstandardised CPUE by fishing year.

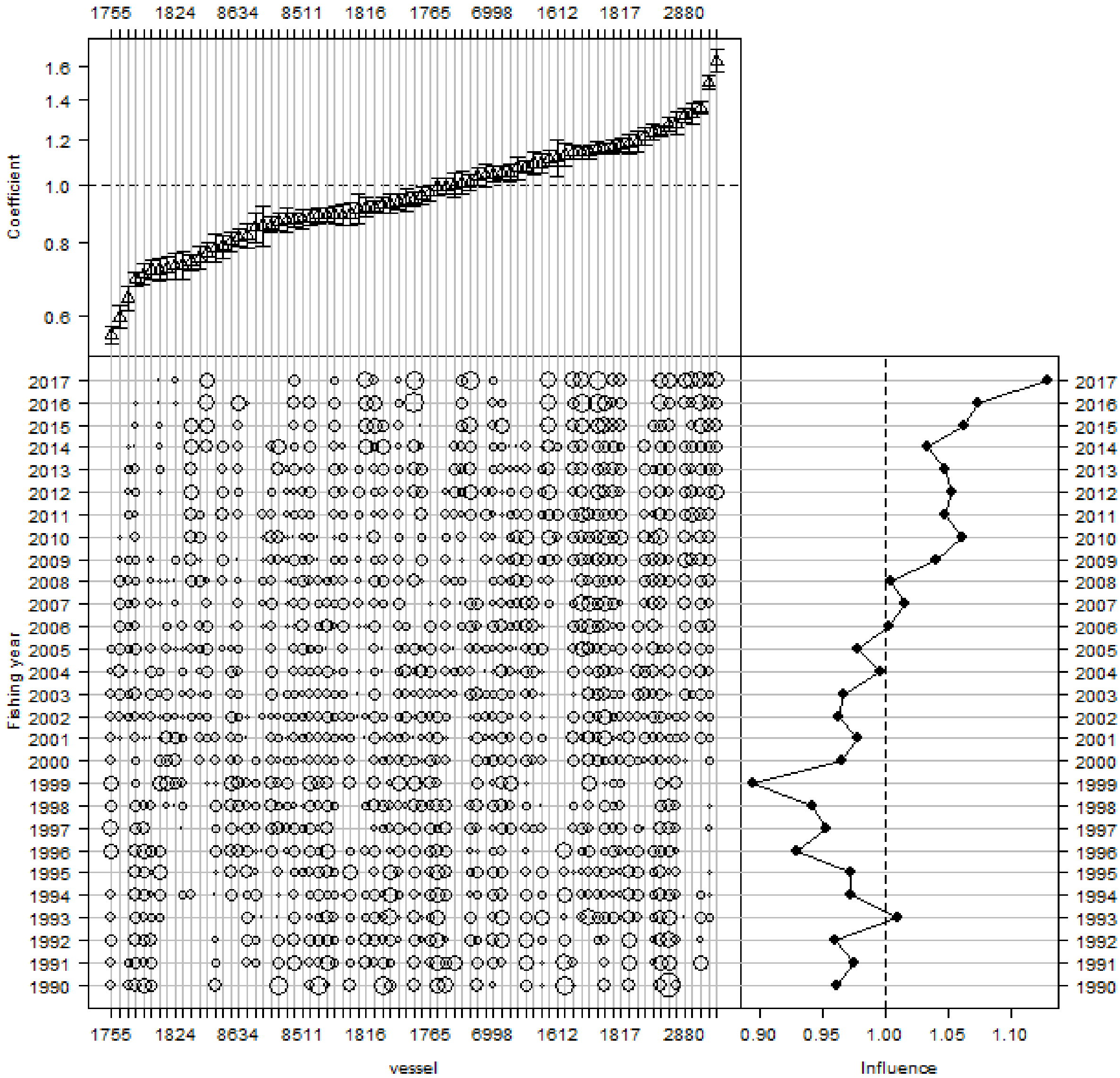

Figure B5: Effect and influence of vessel in TROLL 2. Top: relative effect by level of variable. Bottom-left: relative distribution of variable by fishing year. Bottom-right: influence of variable on unstandardised CPUE by fishing year.

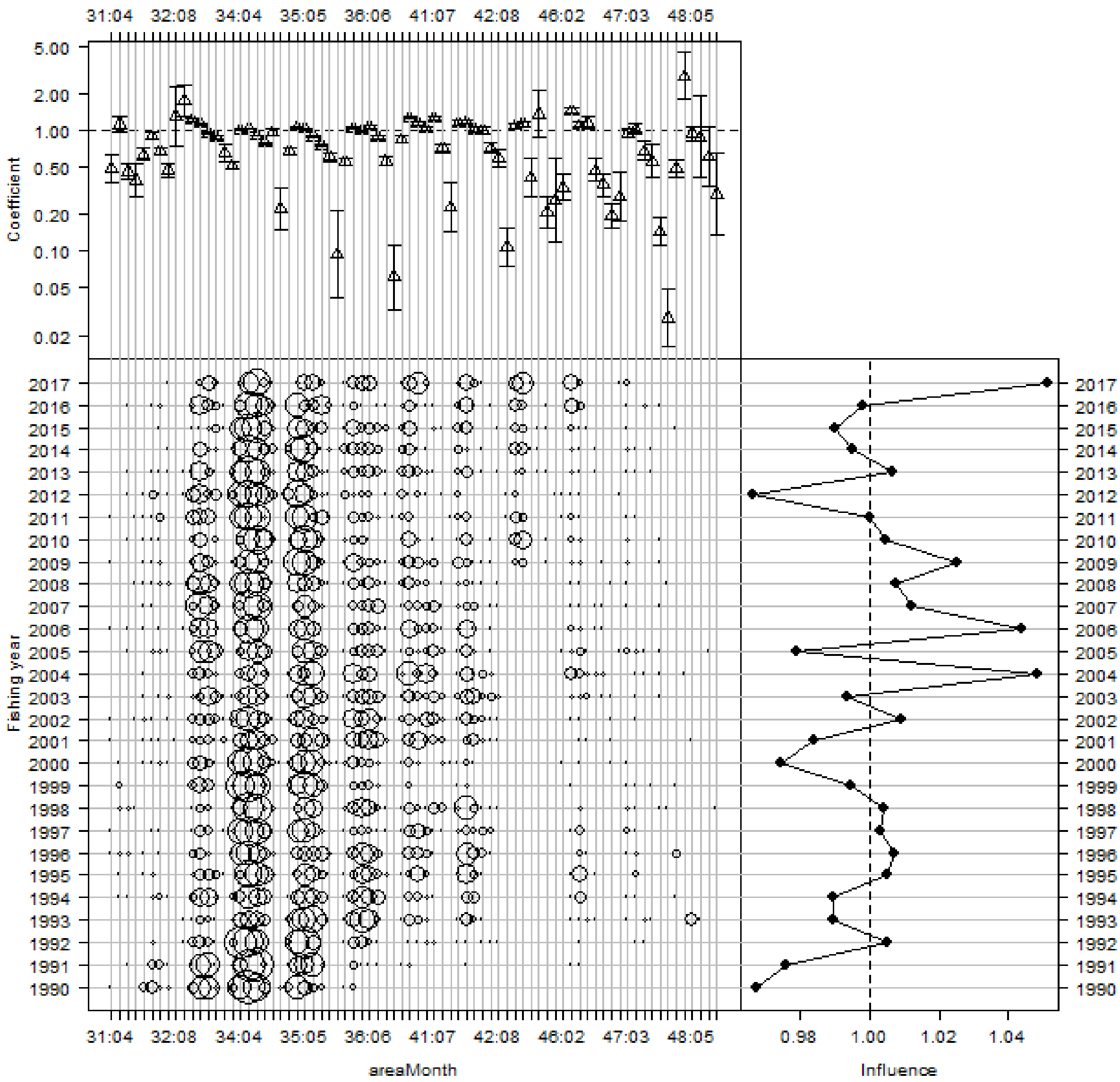

Figure B6: Effect and influence of *area*month* in TROLL 2. Top: relative effect by level of variable. Bottom-left: relative distribution of variable by fishing year. Bottom-right: influence of variable on unstandardised CPUE by fishing year.

APPENDIX C: Data summaries

Table C1: Data summary for the fisheries defined for standardised CPUE analysis for core vessels (two independent subsets of qualifying core vessels based on a minimum of 7 sets per year for at least 6 years); TROLL 1 [upper] TROLL 2 [lower]. Vessels, number of core vessels; Trips, number of trips; Events, total number of vessel-days; Effort, total duration; Catch, total estimated catch from ALB 1 (in thousands of fish); percentage of trips and of records that reported a catch of albacore.

TROLL 1

Fishing year	Vessels	Trips	Events	Effort(hrs)	Catch ('000s fish)	Trips with catch (%)	Events with catch (%)
1990	35	265	1 004	13 148	100.3	100.00	99.90
1991	47	341	1 204	15 495	147.0	99.71	99.34
1992	50	379	1 420	18 899	190.3	99.47	99.30
1993	57	373	1 463	19 505	130.1	99.20	98.15
1994	62	443	1 908	24 661	193.0	99.77	99.63
1995	59	489	1 760	22 629	213.5	100.00	99.49
1996	58	465	1 603	21 890	178.1	97.20	94.64
1997	57	449	1 640	22 319	122.8	95.99	93.41
1998	54	521	1 824	24 219	204.1	97.89	97.53
1999	46	335	1 113	14 840	145.5	98.51	98.20
2000	60	566	1 949	26 014	203.3	99.82	98.77
2001	60	520	2 016	26 967	157.7	99.04	98.31
2002	62	566	2 130	28 957	170.1	99.65	99.20
2003	61	490	2 029	27 467	200.4	99.80	99.51
2004	57	411	1 544	20 970	171.8	99.76	99.55
2005	56	432	1 677	22 058	132.2	100.00	99.40
2006	53	332	1 245	16 538	124.4	100.00	99.92
2007	36	254	1 135	15 026	123.1	99.21	99.47
2008	44	414	1 597	20 689	231.4	100.00	99.56
2009	42	337	1 371	17 974	118.5	99.70	98.91
2010	33	278	1 059	13 661	111.2	99.64	99.43
2011	36	311	1 315	17 633	185.3	100.00	99.62
2012	39	368	1 537	20 006	168.2	99.73	99.54
2013	35	324	1 446	19 864	136.4	100.00	99.65
2014	34	301	1 238	16 316	115.9	99.67	99.27
2015	27	254	1 186	16 675	127.8	100.00	99.33
2016	25	237	1 157	15 654	89.3	100.00	98.79
2017	15	130	654	9 108	49.1	100.00	98.17

TROLL 2

Fishing year	Vessels	Trips	Events	Effort(hrs)	Catch (000's fish)	Trips with catch (%)	Events with catch (%)
1990	27	185	818	10 700	83.8	99.46	99.39
1991	37	287	1 150	15 174	152.3	99.65	99.48
1992	39	287	1 158	15 991	160.0	100.00	99.65
1993	44	302	1 218	16 962	112.1	100.00	99.34
1994	50	353	1 579	21 170	158.1	100.00	99.56
1995	45	328	1 396	18 969	190.0	100.00	99.36
1996	45	332	1 255	16 905	152.8	90.36	90.52
1997	46	338	1 224	16 255	100.7	94.38	93.87
1998	48	399	1 443	19 302	147.9	88.47	87.94
1999	38	281	981	12 960	117.1	94.31	93.78
2000	54	533	2 054	27 883	211.1	99.62	98.00
2001	61	568	2 099	28 290	176.1	99.82	98.76
2002	63	620	2 197	29 461	203.4	99.19	99.41
2003	56	536	2 041	27 886	206.5	99.25	99.41
2004	53	407	1 361	18 520	164.2	99.51	99.56
2005	54	525	1 952	25 695	164.9	99.43	99.54
2006	48	372	1 350	18 539	147.0	99.73	99.63
2007	47	391	1 365	17 756	168.9	99.23	99.56
2008	52	569	1 881	24 283	311.6	99.47	99.79
2009	50	468	1 884	25 105	210.9	99.36	99.63
2010	43	364	1 452	19 303	192.5	99.73	99.59
2011	49	531	1 866	23 884	313.1	100.00	99.68
2012	48	567	1 960	24 545	234.3	100.00	99.59
2013	48	504	1 913	24 847	195.5	99.60	99.79
2014	45	395	1 647	21 462	163.9	99.75	99.45
2015	33	330	1 547	20 130	171.7	100.00	99.68
2016	31	303	1 415	18 195	125.5	100.00	99.51
2017	28	234	1 161	15 399	95.5	100.00	99.40

APPENDIX D: CPUE indices

Table D1: Unstandardised and standardised CPUE for the subsets of core vessels. TROLL 1 [upper] and TROLL 2 [lower] for ALB 1.

TROLL 1

Fishing year	All Arith.	Core Arith.	All Geom.	Geometric mean (Troll 1)	Standardised index (Troll 1)	SE
1990	1.0157	0.9968	0.9634	1.0668	1.1497	0.02542
1991	1.1374	1.2018	1.0535	1.1120	1.3696	0.02321
1992	1.2662	1.3360	1.1985	1.2429	1.3946	0.02154
1993	0.8323	0.8834	0.7885	0.8491	0.9159	0.02120
1994	0.9164	0.9997	0.9101	0.9694	1.0773	0.01852
1995	1.2554	1.2259	1.2447	1.2075	1.3131	0.01922
1996	1.1155	1.0924	1.1618	1.0950	1.1021	0.02004
1997	0.8309	0.7459	0.7589	0.7690	0.7318	0.01970
1998	1.0561	1.0956	1.1485	1.0786	1.1345	0.01906
1999	1.1800	1.3187	1.3410	1.4226	1.3704	0.02378
2000	0.9472	1.0286	0.9782	1.0141	1.0526	0.01822
2001	0.7561	0.7841	0.7299	0.7480	0.8157	0.01818
2002	0.7909	0.7936	0.7618	0.7724	0.7652	0.01767
2003	0.9498	0.9919	0.9681	0.9926	0.9460	0.01798
2004	1.1513	1.0875	1.1327	1.0659	1.0279	0.02093
2005	0.7274	0.7798	0.7330	0.7931	0.7782	0.01971
2006	0.9702	0.9791	0.9742	0.9890	0.9388	0.02239
2007	1.0875	1.0615	1.1681	1.1415	1.0718	0.02378
2008	1.5032	1.4335	1.5227	1.4282	1.3890	0.02004
2009	0.8932	0.8398	0.9148	0.8800	0.8494	0.02157
2010	1.1040	1.0259	1.1597	1.1048	1.0202	0.02469
2011	1.4267	1.3779	1.3934	1.3041	1.2718	0.02213
2012	1.0466	1.0664	1.0269	1.0469	0.9868	0.02136
2013	0.8956	0.9159	0.9056	0.9443	0.8802	0.02132
2014	0.9513	0.9093	0.9253	0.8534	0.8925	0.02322
2015	1.0583	1.0522	1.0393	1.0803	0.9982	0.02406
2016	0.8358	0.7545	0.8338	0.7705	0.7424	0.02404
2017	0.7795	0.7300	0.8115	0.7482	0.6372	0.03234

TROLL 2

Fishing year	All Arith.	Core Arith.	All Geom.	Geometric mean (Troll 2)	Standardised index (Troll 2)	SE
1990	1.0157	0.9877	0.9634	0.9588	1.0554	0.02792
1991	1.1374	1.2310	1.0535	1.1032	1.3064	0.02334
1992	1.2662	1.2727	1.1985	1.1839	1.2746	0.02315
1993	0.8323	0.8452	0.7885	0.8507	0.8319	0.02297
1994	0.9164	0.9105	0.9101	0.8945	0.9821	0.02004
1995	1.2554	1.3503	1.2447	1.3632	1.3183	0.02139
1996	1.1155	1.1124	1.1618	1.2002	1.1334	0.02247
1997	0.8309	0.7575	0.7589	0.7399	0.7701	0.02243
1998	1.0561	0.9509	1.1485	1.0693	1.0014	0.02094
1999	1.1800	1.0955	1.3410	1.2457	1.3049	0.02510
2000	0.9472	0.9305	0.9782	0.9557	0.9752	0.01764
2001	0.7561	0.7598	0.7299	0.7303	0.8138	0.01770
2002	0.7909	0.8392	0.7618	0.7769	0.8441	0.01708
2003	0.9498	0.9130	0.9681	0.8890	0.9265	0.01787
2004	1.1513	1.1001	1.1327	1.0780	1.0341	0.02171
2005	0.7274	0.7626	0.7330	0.7567	0.8228	0.01811
2006	0.9702	0.9754	0.9742	0.9674	0.9141	0.02135
2007	1.0875	1.1171	1.1681	1.1645	1.1564	0.02124
2008	1.5032	1.5108	1.5227	1.5120	1.4963	0.01825
2009	0.8932	1.0058	0.9148	1.0187	0.9364	0.01845
2010	1.1040	1.1897	1.1597	1.2681	1.1322	0.02108
2011	1.4267	1.5099	1.3934	1.5167	1.4621	0.01884
2012	1.0466	1.0674	1.0269	1.0496	1.0616	0.01901
2013	0.8956	0.9127	0.9056	0.9040	0.8726	0.01859
2014	0.9513	0.9112	0.9253	0.9016	0.8774	0.02012
2015	1.0583	1.0042	1.0393	0.9424	0.9286	0.02056
2016	0.8358	0.8011	0.8338	0.7995	0.7596	0.02166
2017	0.7795	0.7341	0.8115	0.7693	0.6239	0.02427