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School shark fishery characterisation and CPUE

New Zealand Fisheries Assessment Report 2018/35

M.R. Dunn
R. Bian

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EXECUTIVE SUMMARY

Dunn, M.R.; Bian, R. (2018). School shark fishery characterisation and CPUE.

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This report updates descriptive analyses of commercial catch and effort data, and catch-per-unit-effort (CPUE) indices, for the school shark (*Galeorhinus galeus*) fisheries around New Zealand, using data to the end of the 2015–16 fishing year. The previous characterisation and CPUE analysis used data to the end of the 2012–13 fishing year. This report also includes analyses of samples of school shark catch composition provided by the Ministry for Primary Industries Observer Programme, and biomass indices and catch compositions from research trawl surveys around the South Island.

In the period to 2015–16, commercial catches had decreased in Fishstocks SCH 1, 2, 5, and 7, increased in SCH 3, and remained stable in SCH 4 and 8. No substantive changes had taken place in the fishing gears, location, timing, and target species of the fisheries. The fishery continued to be dominated by catches from bottom longline, setnet, and bottom trawl, and taken all around New Zealand, primarily during shark target fishing, or as a bycatch when fishing for mixed inshore species.

The inshore bottom trawl surveys off west and east coasts of the South Island indicated that biomass continued to fluctuate on the west coast, and remained relatively high on the east coast. The catch composition of the surveys consisted predominantly of juveniles and sub-adults. A trawl survey around the southern part of New Zealand (Southland) was conducted during the 1990s, and included offshore areas, and although the series was too short to establish a biomass trend, the data indicated that the trawls caught juvenile, sub-adult, and also large adult fish.

Samples of commercial catch composition from the Observer programme were sparse, but suggested that bottom trawls took a wider range of fish sizes than either bottom longline or setnet fisheries. A comparison of commercial trawl and research trawl survey catch compositions from similar areas suggested that adult fish were caught in greater proportions by the commercial trawls. Catch composition from the Southland trawl survey was similar to that from commercial trawl catches taken from the same area. The Southland surveys were conducted using a larger vessel and trawl net than were used for the east and west coast inshore surveys.

CPUE series were estimated for bottom longline and setnet for nine fishery subunits, which had been defined in the previous characterisation analyses. The series were standardised using generalised linear models, with most models including covariates for vessel, target species, and statistical area. The CPUE series that were accepted by the Ministry for Primary Industries Southern Inshore Fisheries Assessment Working Group (SINSWG) were increasing and then flat in recent years for the far north (Far North/SCH 1E), had a slow overall increase on the west coast (SCH 7, SCH 8, and SCH 1W), had no overall trend on Chatham Rise (SCH 4), and had a slow overall decline around the south of the South Island (lower SCH 3 and SCH 5). In general, it seems that the north, east and west coast regions are doing well, showing flat or increasing trends in CPUE. However, CPUE for the southern region has been gradually declining.

1. INTRODUCTION

The work described in this report was carried out under Ministry for Primary Industries project SCH2016/01 Specific Objective 1, "*To characterise the SCH 1, 2, 3, 4, 5, 7 and 8 fisheries.*", and Specific Objective 2, "*To analyse existing commercial catch and effort data to the end of 2015/16 fishing year and undertake CPUE standardisations for each stock.*".

This report updates the descriptive analysis of the fishery to the end of the 2015–16 fishing year (for school shark fishing years start 1 October) for the seven main fisheries SCH 1, SCH 2, SCH 3, SCH 4, SCH 5, SCH 7, and SCH 8 (Figure 1), and updates standardised catch-per-unit-effort (CPUE) indices for nine agreed stock monitoring units (Table 1), updating similar analyses for the period ending 2012/13 that were described by Starr & Kendrick (2016). In addition, this report provides an analysis of biological samples collected by the Ministry's Observer programme, and biomass indices and biological samples collected during relevant research trawl surveys. The research presented here is background to the Ministry's Working Group report, which summarises the information and presents the final scientific advice on the status of the school shark stocks (Ministry for Primary Industries 2018).

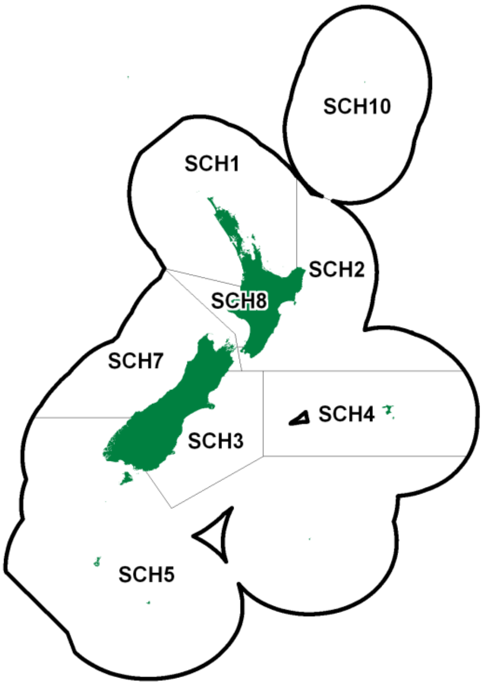

Figure 1: The school shark fishery Quota Management Areas.

Table 1: The nine fishery monitoring units for school shark; permutations of setnet (SN) and bottom longline (BLL) gears for five regions. Core statistical areas are shown, as well as any additional statistical areas needed to complete the fishery definition by capture method. There is no recorded fishing for school shark using setnet on the Chatham Islands (SCH 4). From MPI (2017).

Region	Code	Core Statistical Areas	SN	BLL
Far North & SCH 1E	N/1E	043–010	same as core	same as core
SCH 2 & top of SCH 3	2/3N	011–015	add 018, 020	same as core
Chatham Rise (SCH 4)	SCH4	049–051, 401–412	NA	add 019, 020, 021
lower SCH 3 & SCH 5	3S/5	022–033	same as core	same as core
SCH 7, SCH 8 & lower SCH 1W	7/8/1W	034–042,801	add 016, 017	add 016, 017, 018

Catches for each Quota Management Area (QMA) are given by Ministry for Primary Industries (2017). Over the last three years, annual reported catches decreased in SCH 1, 2, 5, and 7, increased in SCH 3 and 4, and were stable in SCH 8, and the Total Allowable Commercial Catch (TACC) was undercaught in all years and QMAs except SCH 3 in 2016–17 (Figure 2).

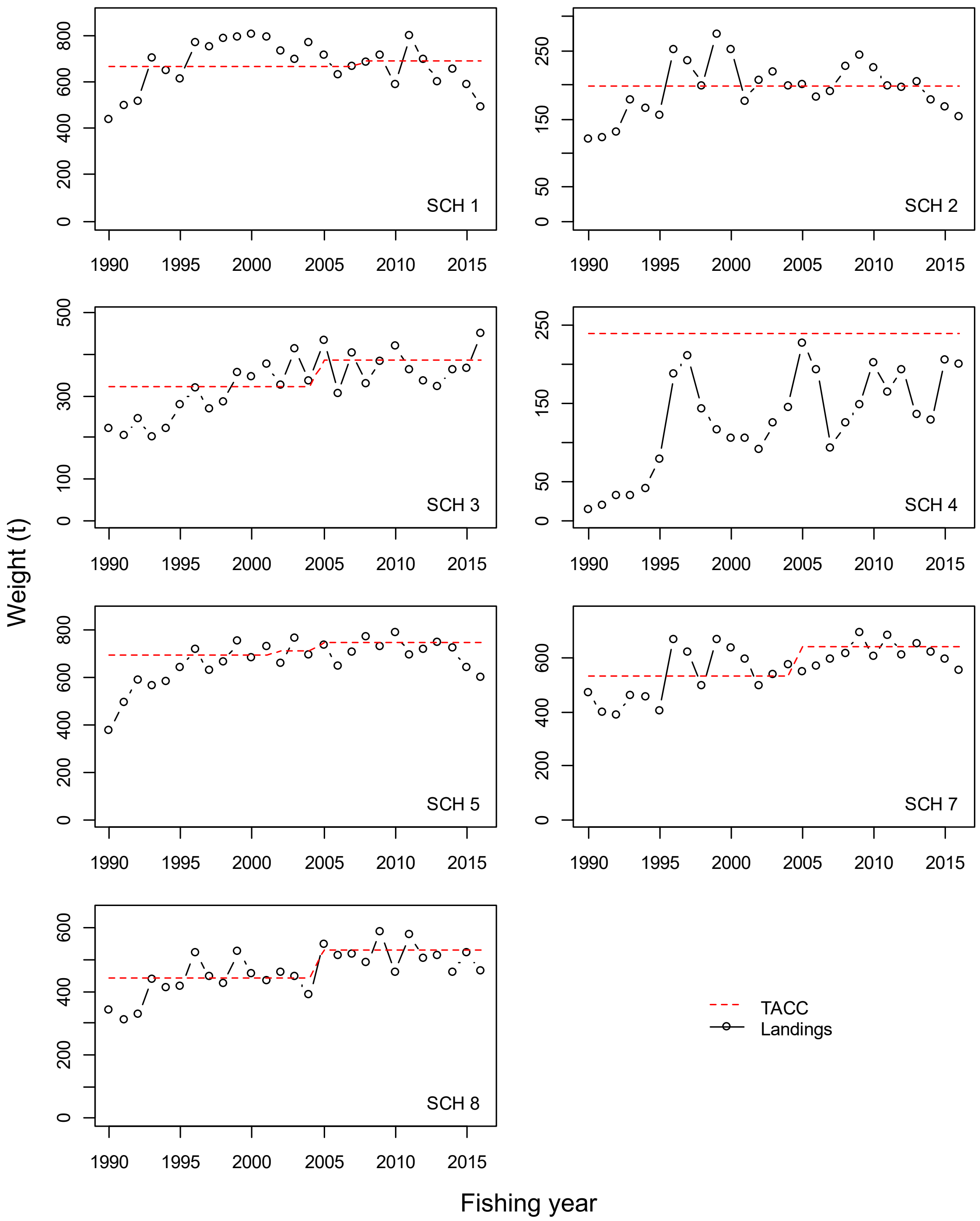

Figure 2: Reported catch weight (t) of school shark, and TACC, by fishstock (QMA) and year.

2. RESEARCH TRAWL DATA

2.1 East Coast South Island

The history of the inshore trawl surveys is described in Ministry for Primary Industries (2018) and references therein. Biomass in the East Coast South Island (ECSI) survey core strata (30–400 m) has been variable, but generally higher in years 2007 onward compared with the 1990s (Figure 3, Table 2). Little biomass was found between 10 and 30 m depth, inshore of the core strata (Table 2). The survey catches have been dominated by juveniles (pre-recruits), with adults absent from the survey in several years (Figure 4). Both males and females have shown broadly similar temporal biomass trends (Figure 4). However, some changes in biomass appear to be caused by changes in the relative abundance of specific components of the stock, for example, a substantial part of the decline in biomass between 2007 and 2008 was caused by a decline in adult males, and the biomass decline between 2008 and 2009 was caused largely by a decline in females.

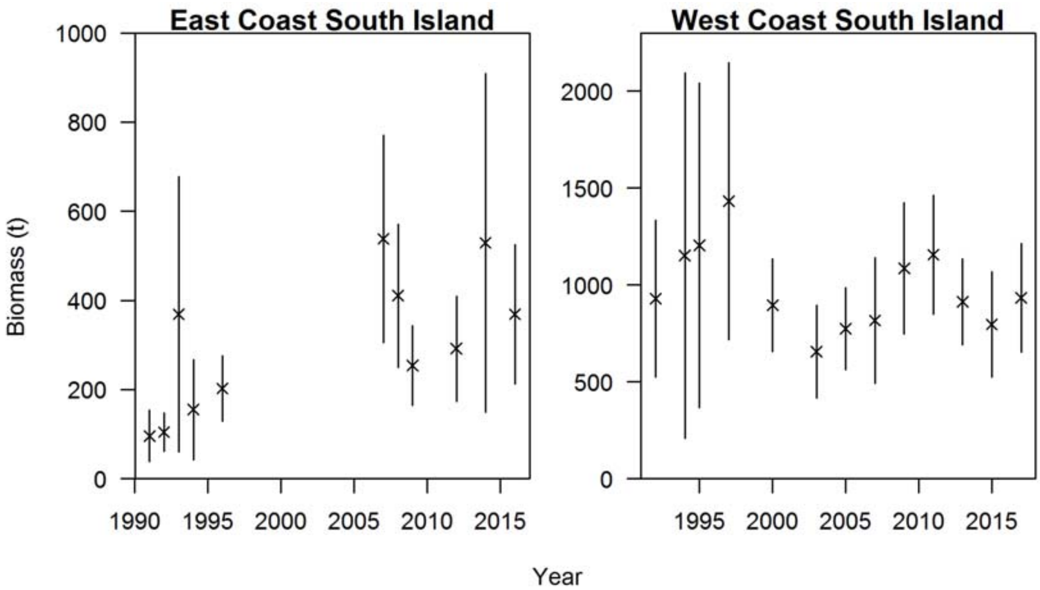

Figure 3: Total school shark biomass and 95% confidence intervals for the ECSI and WCSI inshore trawl surveys.

Table 2: Relative biomass indices (t) and coefficients of variation (CV) for school shark for the East Coast South Island (ECSI) winter surveys. Biomass estimates for ECSI in 1991 have been adjusted to allow for non-sampled strata (7 & 9 equivalent to current strata 13, 16 and 17). – , not measured.

Region	Year	Trip number	Total Biomass estimate	CV (%)	Total Biomass estimate	CV (%)
ECSI (winter)			30–400m		10–400m	
	1991	KAH9105	100	30	-	-
	1992	KAH9205	104	21	-	-
	1993	KAH9306	369	42	-	-
	1994	KAH9406	155	36	-	-
	1996	KAH9608	202	18	-	-
	2007	KAH0705	538	22	552	21
	2008	KAH0806	411	20	-	-
	2009	KAH0905	254	18	-	-
	2012	KAH1207	292	20	310	19
	2014	KAH1402	529	36	547	35
	2016	KAH1605	369	21	379	21

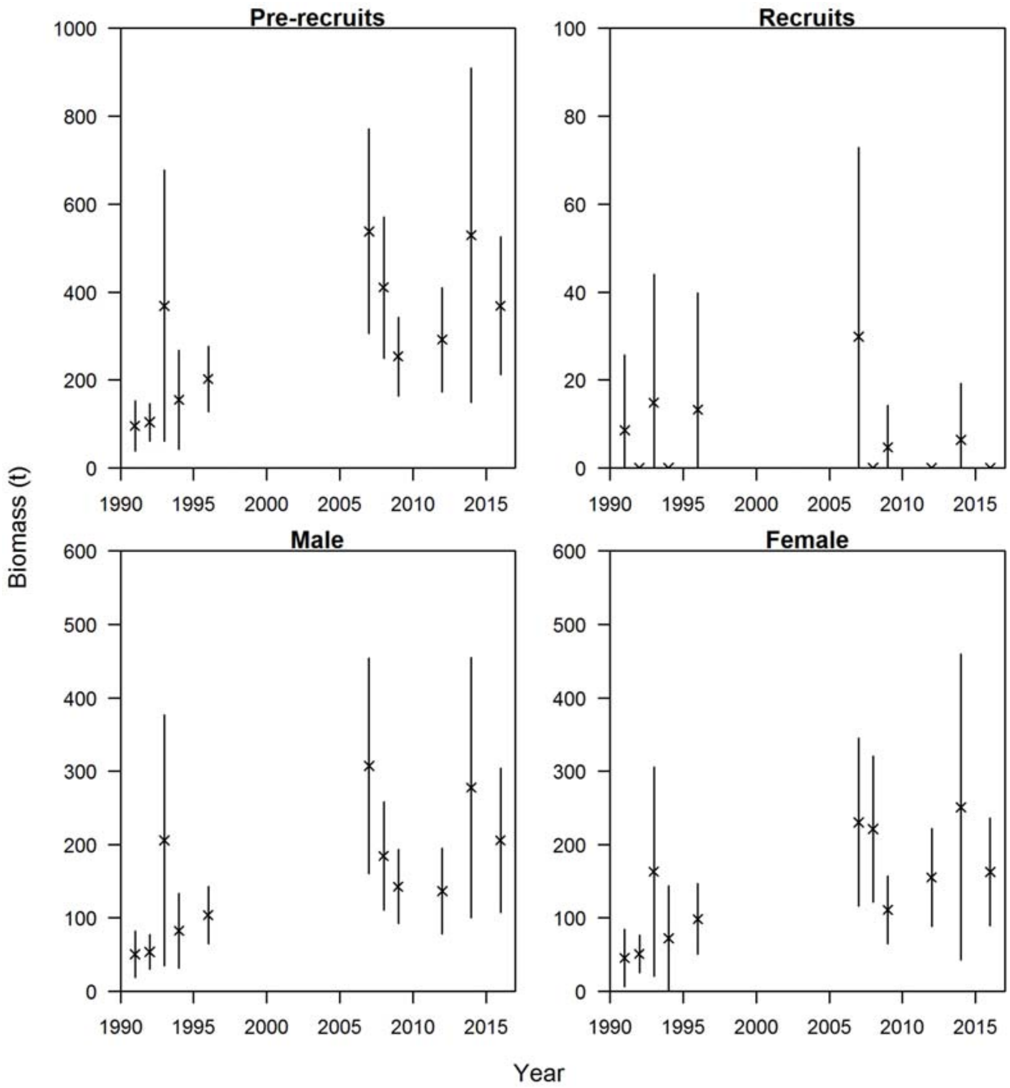

Figure 4: School shark biomass and 95% confidence intervals for pre-recruits (<134 cm TL) and recruits, and all lengths of males and females, from ECSI winter surveys in core strata (30–400 m).

The ECSI survey appears to be monitoring pre-recruited cohorts reasonably well, but not the recruited school shark size distribution. The size range caught is reasonably consistent between surveys, with no obvious changes in catch composition (Figure 5). The sex ratio in the mode of the length composition was close to 50:50. In some years (e.g., 1991, 2007) the larger fish were predominantly female, whereas other years (e.g., 2008, 2016) they were predominantly male.

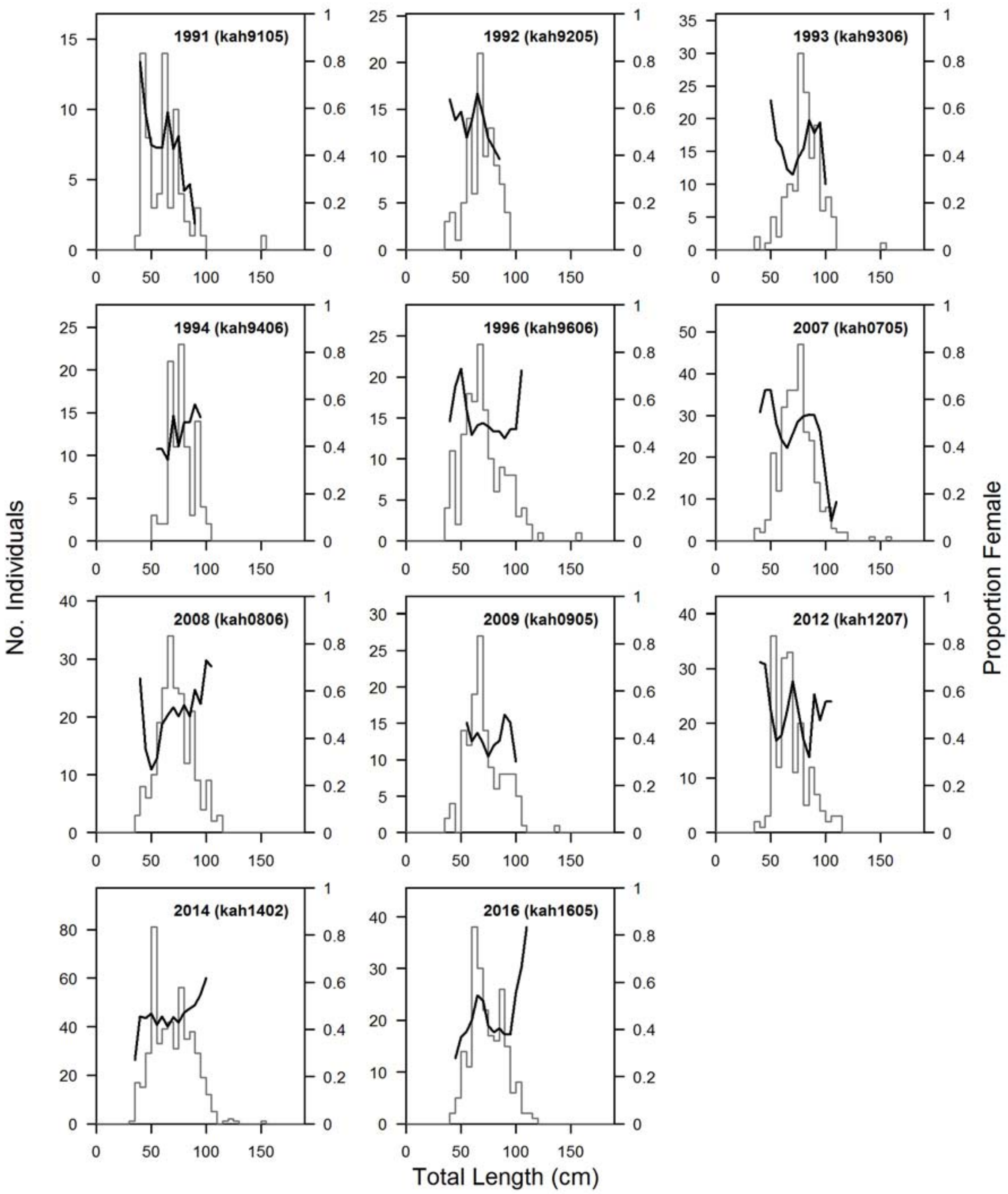

Figure 5: Scaled length frequency distributions (grey line histograms) and sex ratio (black lines) for school shark in core strata (30–400 m) for ECSI winter surveys. The overall ratio of sample size to catch size was 1.0, therefore the scaled number of individuals approximates closely the number of fish measured. The length distributions are shown for 5 cm length bins. The sex ratio is a moving average of sex ratio by length bin.

2.2 West Coast South Island

Biomass has been variable in the West Coast South Island (WCSI) trawl survey, with high CVs in the years before 2000 (Figure 6, Table 43). The survey catches have been dominated by juveniles (pre-recruits) (Figure 6). Both males and females have shown broadly similar temporal biomass trends, with males slightly more common in the catch.

Table 3: Relative biomass indices (t) and coefficients of variation (CV) for school shark for the West Coast South Island (WCSI) surveys (including both the West Coast South Island, and Tasman and Golden Bays).

Region	Year	Trip number	Total Biomass estimate	CV (%)
WCSI			20–400 m	
	1992	KAH9204	933	22
	1994	KAH9404	1 151	41
	1995	KAH9504	1 204	65
	1997	KAH9701	1 432	25
	2000	KAH0004	896	13
	2003	KAH0304	655	18
	2005	KAH0503	774	14
	2007	KAH0704	816	20
	2009	KAH0904	1 085	16
	2011	KAH1104	1 155	13
	2013	KAH1305	913	12
	2015	KAH1503	795	17
	2017	KAH1703	933	15

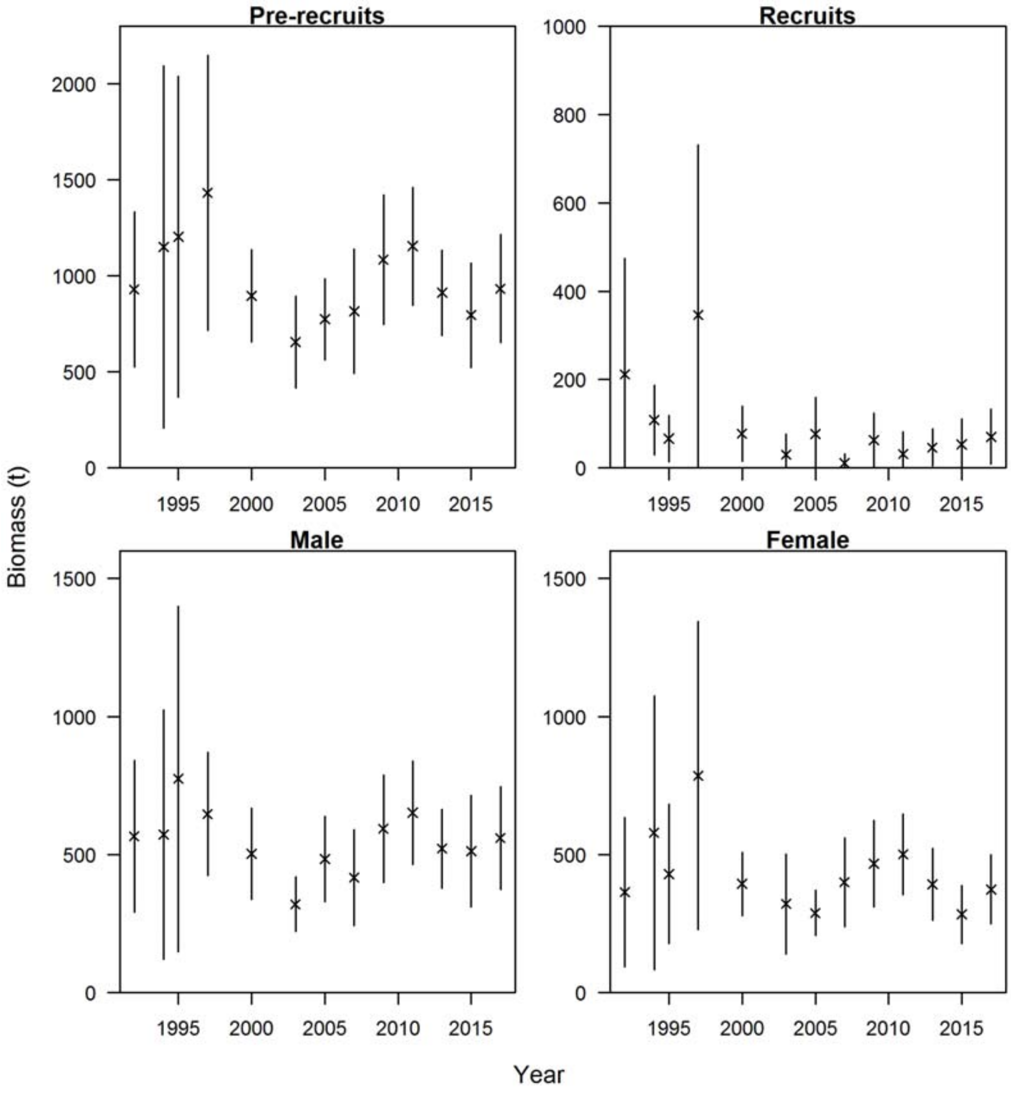

Figure 6: School shark biomass and 95% confidence intervals for pre-recruits (<134 cm TL) and recruits, and all lengths of males and females, from WCSI surveys.

The WCSI survey appears to be monitoring pre-recruited cohorts reasonably well from 2000 onwards, but not the recruited school shark size distribution. The size range caught is reasonably consistent between surveys, and relatively broad compared to the ECSI surveys (see Figure 45), with no obvious changes in catch composition (Figure 7). The mode at <50 cm (0+ cohort) appears generally more pronounced in the WCSI surveys (e.g., in 2009) compared to the ECSI surveys. The sex ratio in the mode of the length composition was close to 50:50, with an increase in males at around 100–120 cm, and an increase in females at lengths around 120 and larger; these are consistent with the accumulation of males and females at their respective maximum lengths (where females grow larger than males).

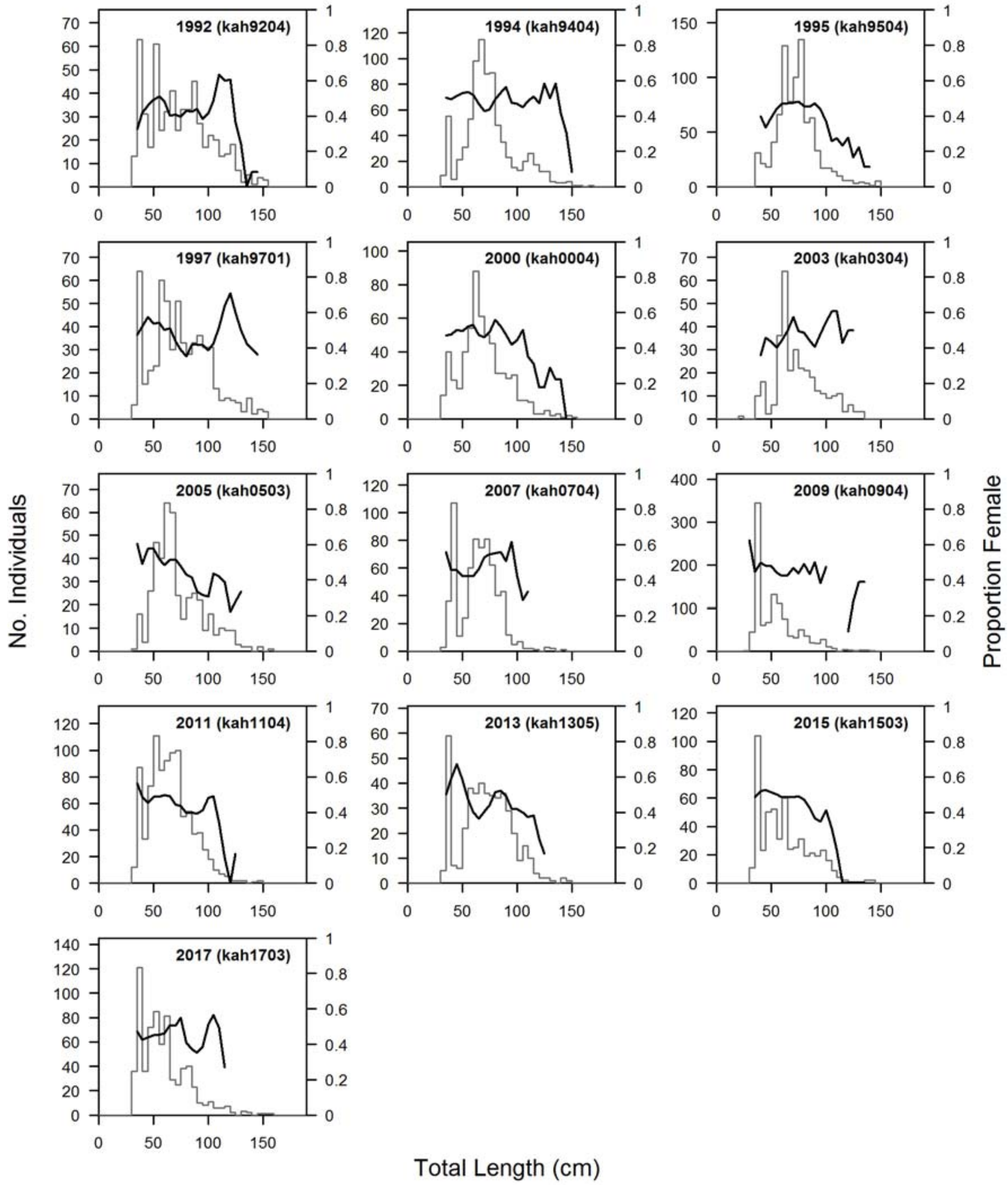

Figure 7: Scaled length frequency distributions (grey line histograms) and sex ratio (black lines) for school shark for WCSI surveys. The overall ratio of sample size to catch size was 1.0, therefore the scaled number of individuals approximates closely the number of fish measured. The length distributions are shown for 5 cm length bins. The sex ratio is a moving average of sex ratio by length bin.

2.3 Southland

Surveys of the Southland region were conducted for a number of years in the late 1980s to mid-1990s. Initial surveys were conducted by the *Shinkai Maru* in June 1986, and *Akebono Maru No. 3* in November 1986, then a time series of annual two-phase stratified random surveys by *Tangaroa* were conducted in February-May between 1993 and 1996 (Hurst & Bagley 1994). Only the *Tangaroa* surveys formed a comparable time series (Table 4).

Biomass of pre-recruits, recruits, and males and females, showed similar trends (Figure 8). Pre-recruits were more abundant than recruits, but recruits formed a greater proportion of the biomass than seen in the West Coast and East Coast South Island inshore trawl surveys. An increase in biomass between 1994 and 1996 was also seen in the east coast South Island survey.

The length composition of the Southland survey catches was fairly similar over time (Figure 9). Whereas the inshore surveys of the east and west coasts of the South Island mostly caught fish smaller than 100 cm, the Southland survey mostly caught fish larger than 100 cm, including a notable proportion of fish greater than 150 cm.

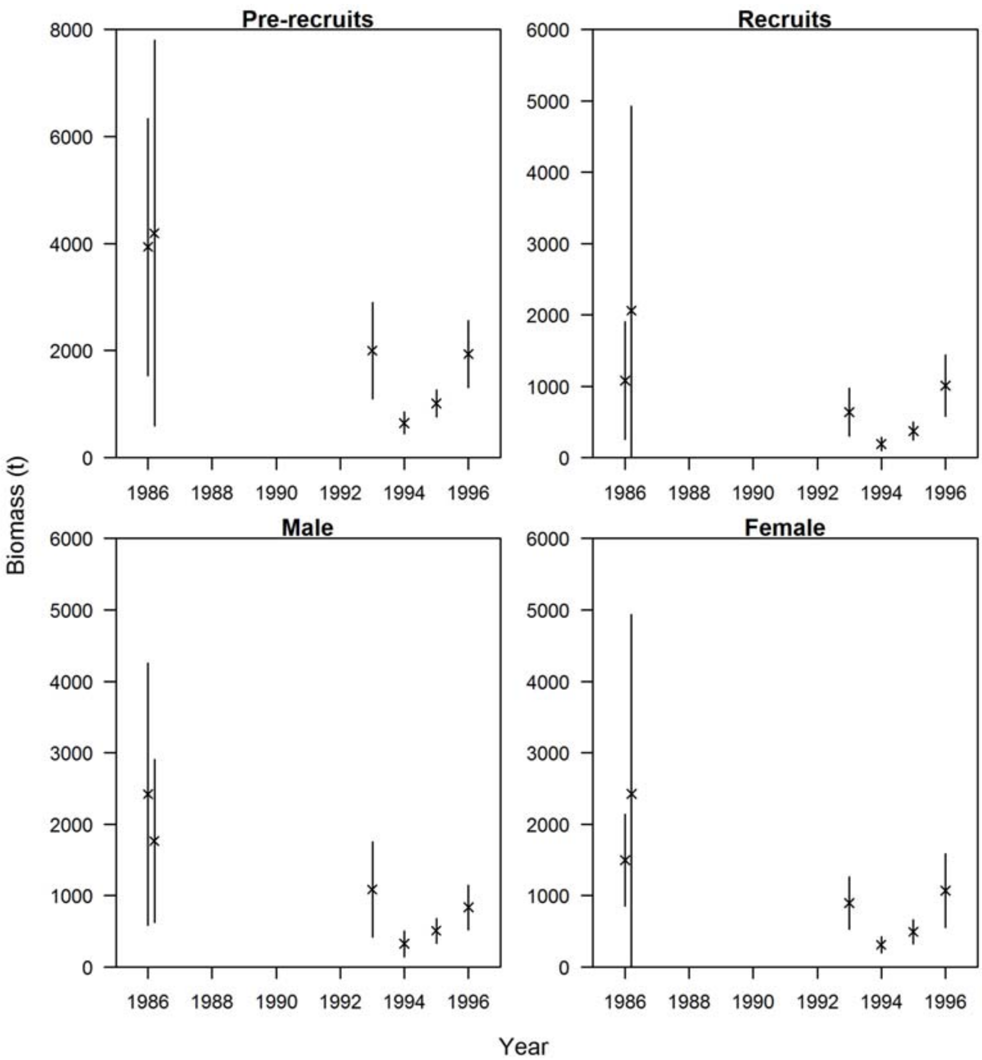

Figure 8: School shark biomass and 95% confidence intervals for pre-recruits (<134 cm TL) and recruits, and all lengths of males and females, from Southland surveys.

Table 4: Relative biomass indices (t) and coefficients of variation (CV) for school shark for the Southland surveys.

Region	Year	Trip number	Depth (m)	Total Biomass estimate	CV (%)
Southland					
	1986	SHI8601	50–600	4 194	43
	1986	AKS8601	50–600	3 939	31
	1993	TAN9301	30–600	2 002	23
	1994	TAN9402	30–600	660	16
	1995	TAN9502	30–600	1 012	13
	1996	TAN9604	30–600	1 936	16

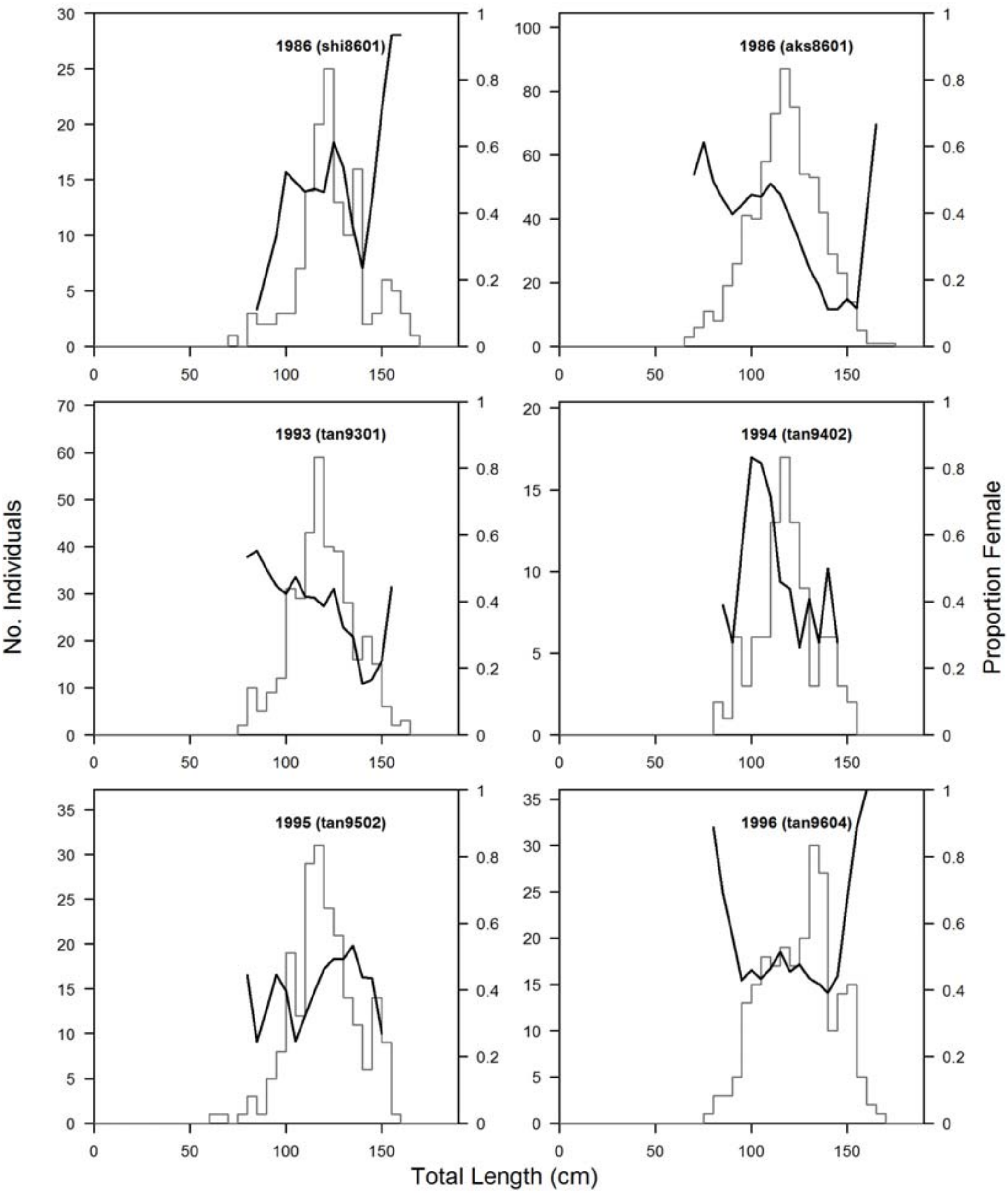

Figure 9: Scaled length frequency distributions (grey line histograms) and sex ratio (black lines) for school shark for Southland surveys. The overall ratio of sample size to catch size was about 1.1, therefore the scaled number of individuals is slightly higher than the number of fish measured. The length distributions are shown for 5 cm length bins. The sex ratio is a moving average of sex ratio by length bin.

3. OBSERVER CATCH COMPOSITION DATA

The Ministry's Observer Programme has collected school shark sex and length data in every year since 1992–93 (Table 5) and from most fished regions around New Zealand (Figure 10). A total of 8808 fish and 60.9 t were measured. The weight sampled, and number of fish measured, was relatively low; the percentage of the annual catches that were sampled by observers was usually less than 0.1%, and at most 0.8% (2007–08). Because of the low proportion of catches sampled, the potential that the samples were not representative of the overall catch is high.

Table 5: Summary of Observer Programme samples taken of school shark by fishing year, showing the number of tows, trips, and vessels sampled, the weight of fish sampled, and the number of fish measured for length (*n* measured).

Fishing year	Tows	Trips	Vessels	Weight sampled (t)	*n* measured
1992–93	8	3	3	0.1	10
1993–94	4	2	2	0.1	21
1994–95	36	5	5	1.3	95
1995–96	21	6	6	0.3	23
1996–97	21	4	4	1.2	96
1997–98	37	4	4	2.1	162
1998–99	28	9	9	1.2	122
1999–00	36	11	11	1.6	134
2000–01	77	12	11	2.7	205
2001–02	81	16	15	2.6	222
2002–03	125	14	13	4.1	409
2003–04	23	8	6	0.5	38
2004–05	58	16	14	2.6	260
2005–06	45	11	9	1.4	152
2006–07	48	17	16	2.0	280
2007–08	195	31	30	25.3	2 509
2008–09	47	8	7	1.9	162
2009–10	40	8	7	1.2	119
2010–11	28	7	6	1.6	199
2011–12	19	5	5	1.1	121
2012–13	12	8	7	1.8	230
2013–14	44	8	8	0.3	193
2014–15	90	11	10	0.9	1 223
2015–16	116	20	14	3.0	1 823

Catch-weighted length-frequency distributions were only calculated for year and area subsets where the data came from three or more vessels, and at least 50 fish were measured. For the fishery monitoring units, length compositions were calculated only for four year-area combinations (Figure 11). The catches sampled in the far north (N/1E) were from bottom longlines, and almost entirely relatively small fish consistent with 0+ group; these samples may indicate a nursery area. The catches sampled from the lower South Island and Sub-Antarctic (3S/5 SN) were similar in both years sampled, and included mostly larger and adult fish (over 100 cm TL); a predominance of larger fish in this area would be consistent with research trawl surveys catches (see Figure 9). The sampled catch from setnets off the west coast North and South Islands (7/8/1 W) were largely of intermediate sizes, and accordingly the largest fish were predominantly adult males, not females.

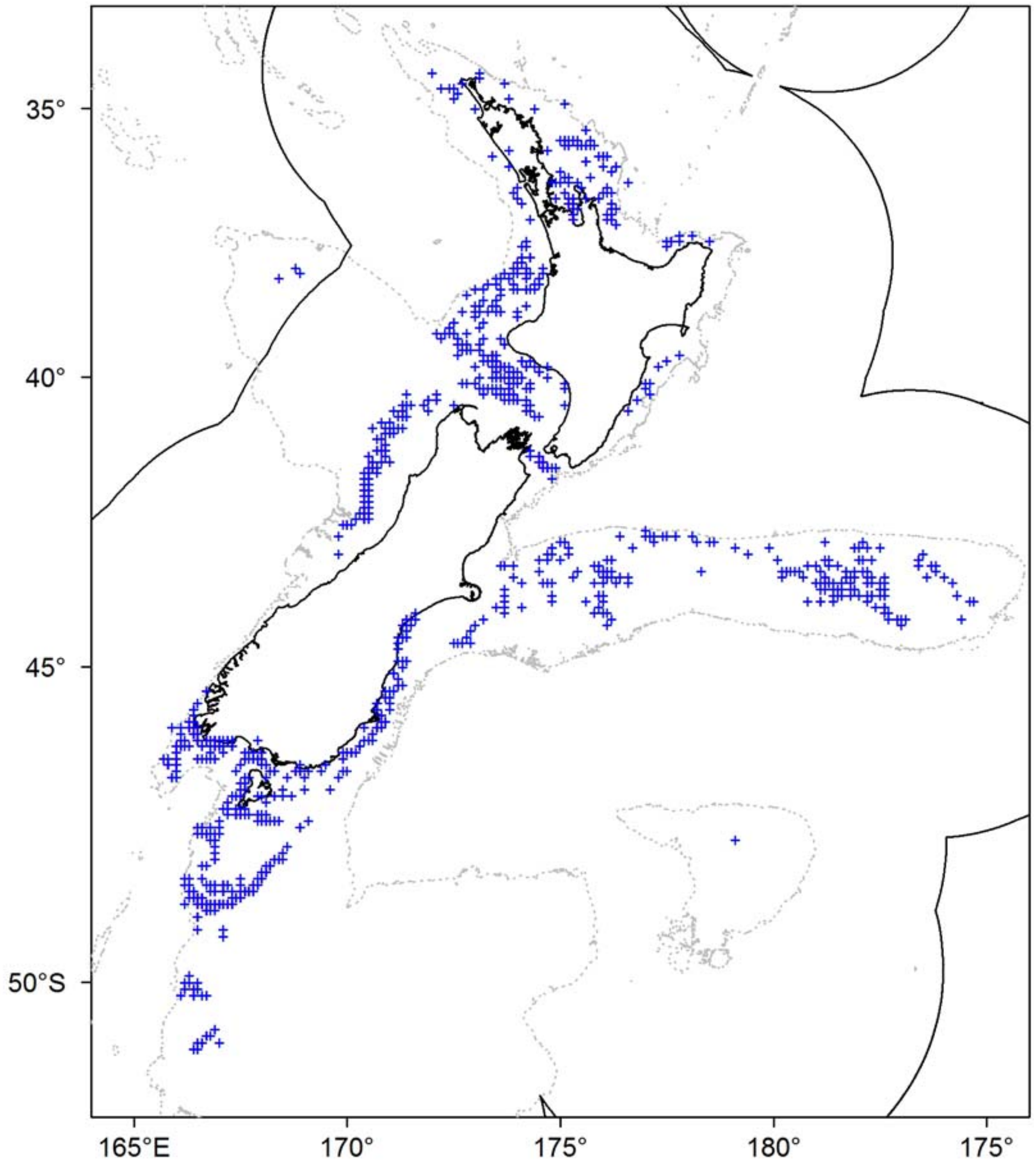

Figure 10: Location of all Observer samples of commercial fishery catch length composition (+). Solid line, EEZ; dotted grey line, 1000 m isobath.

No bottom trawl fishery CPUE are currently accepted for use as indices of stock biomass (Ministry for Primary Industries, 2017).

Samples of bottom trawl catches from the lower South Island and Sub-Antarctic (3S/5) were comprised largely of fish greater than 100 cm, including in some years a notable proportion greater than 150 cm (2000–01 and 2009–10), which were largely adult females (Figure 12). The length composition was fairly similar in sampled years between 2001–02 and 2010–11, with larger (female) fish relatively scarce in 2012–13.

Length distributions from samples of bottom trawl catches from the west coast of the North and South Islands (7/8/1W) were relatively broad, and variable, although the largest sizes of fish (adult females) were relatively infrequent in most years (Figure 13). The unusually small fish sampled in 2009–10 were mostly less than 35 cm (the lower bound of 0+ group; Francis & Mulligan, 1998), and as small as 29 cm, and therefore may not have been school shark, or may have been pre-term neonates expelled from the female during capture.

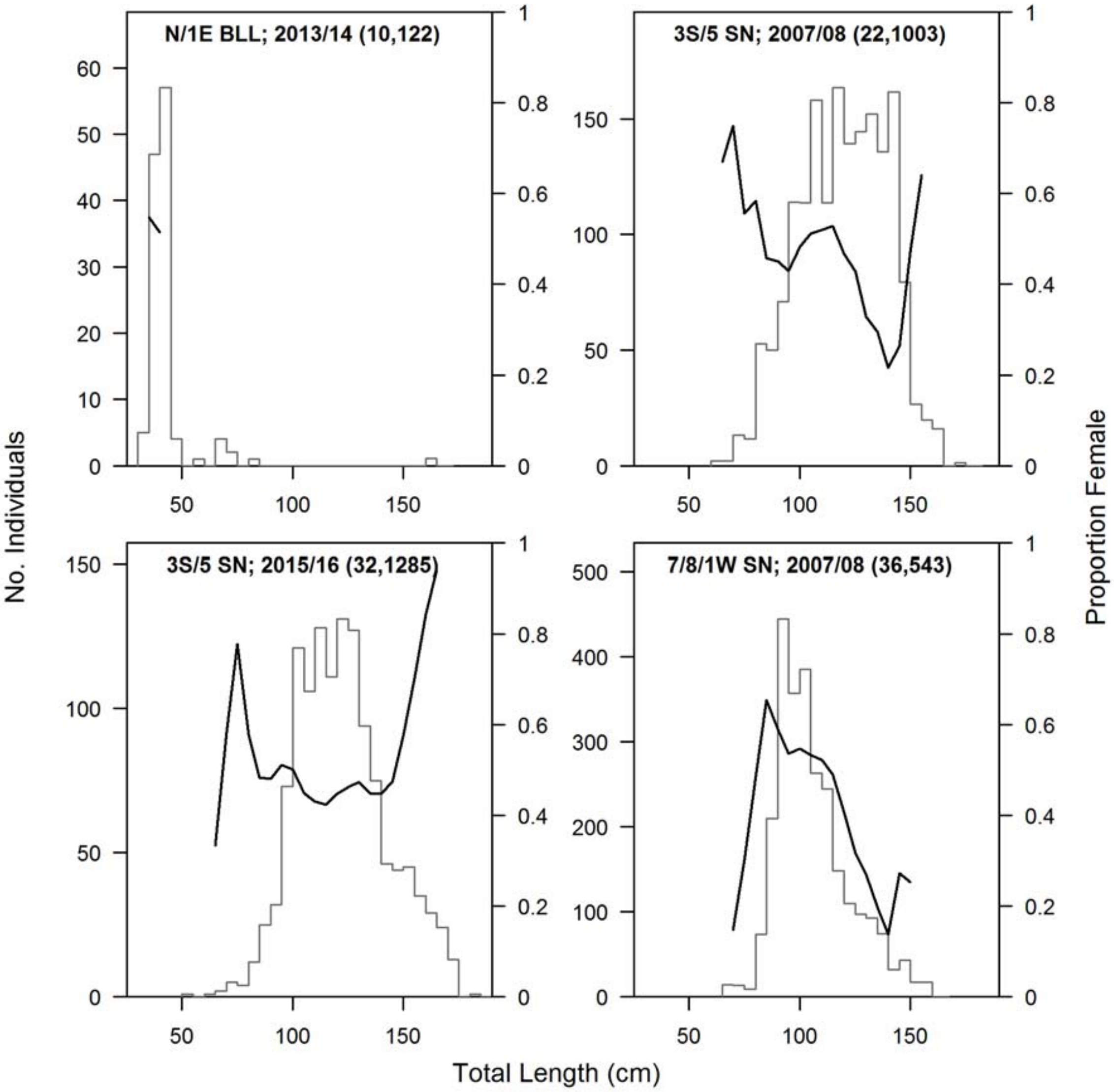

Figure 11: Scaled length frequency distributions (grey line histograms) and sex ratio (black lines) for school shark in monitoring fisheries (see Table 1) sampled by Observers. The length distributions are shown for 5 cm length bins. The sex ratio is a moving average of sex ratio by length bin. SN, setnet. Numbers in parentheses are the number of events where school shark were sampled, and the number of fish measured (before catch weight scaling).

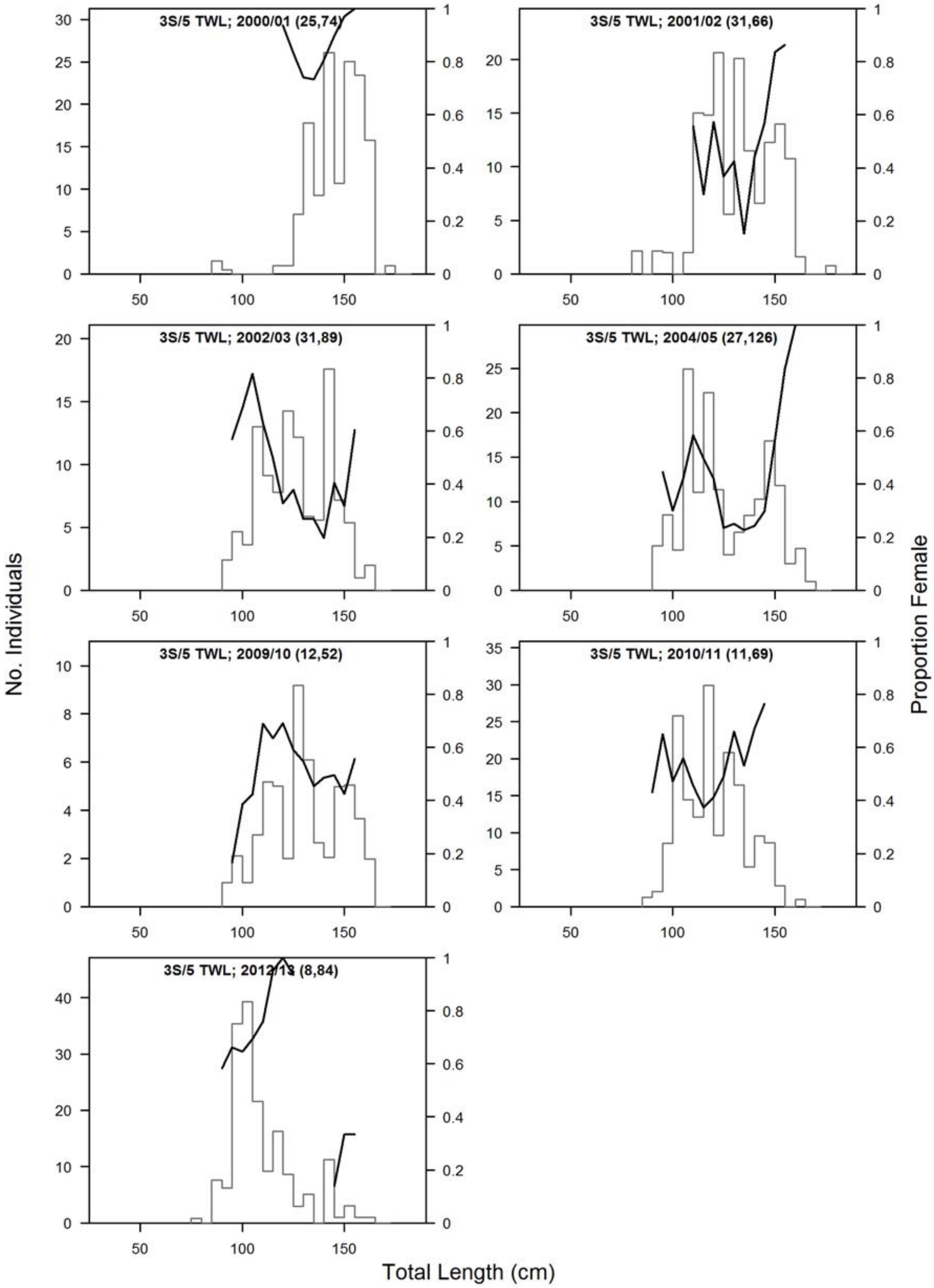

Figure 12: Scaled length frequency distributions (grey line histograms) and sex ratio (black lines) for school shark in 3S/5 trawl fisheries sampled by Observers. The length distributions are shown for 5 cm length bins. The sex ratio is a moving average of sex ratio by length bin. Numbers in parentheses are the number of events where school shark were sampled, and the number of fish measured (before catch weight scaling).

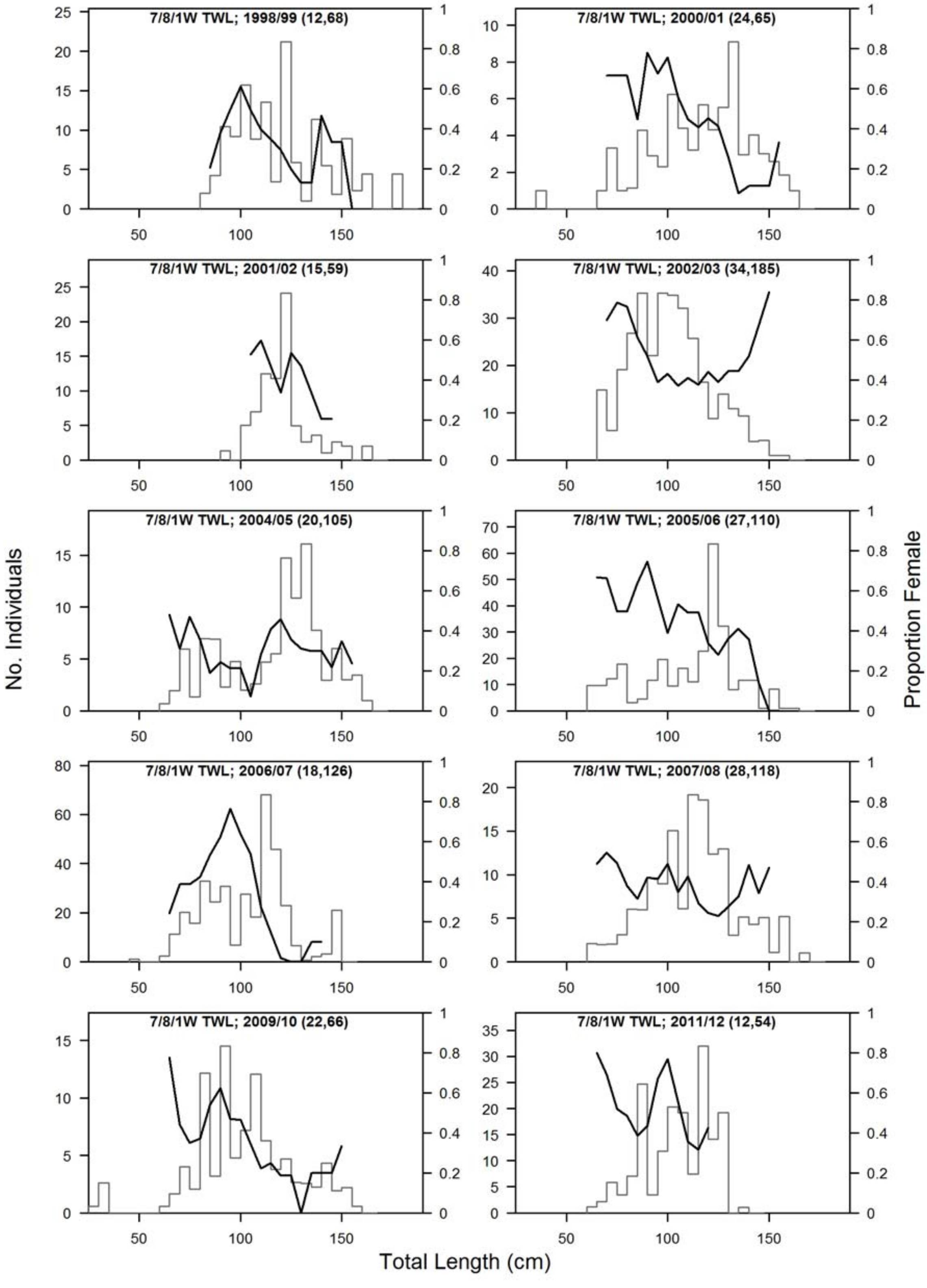

Figure 13: Scaled length frequency distributions (grey line histograms) and sex ratio (black lines) for school shark in 7/8/1W trawl fisheries sampled by Observers. The length distributions are shown for 5 cm length bins. The sex ratio is a moving average of sex ratio by length bin. Numbers in parentheses are the number of events where school shark were sampled, and the number of fish measured (before catch weight scaling).

To evaluate the potential length compositions of more of the fishery subunits, the criteria for calculating length compositions was removed (i.e., all data were used). As a result, length compositions could be calculated for seven of the ten stock monitoring units (being the bottom longline and setnet fisheries), plus four of the five areas for bottom trawl (Figure 14). Both juveniles (under 100 cm TL) and large adults (over 150 cm TL) were sampled in all areas. Bottom trawls captured fish as large as those caught by bottom longline or setnet, and in general captured the widest length range. In 3S/5, and 7/8/1W, bottom trawls sampled by observers captured very few fish under 50 TL, although these were commonly caught in the inshore trawl surveys (see Figure 5 and Figure 7). The samples meeting selection criteria for N/1E bottom longline indicated that only small fish were caught (see Figure 11), but the inclusion of all samples revealed that the catch was dominated by larger (over 100 cm TL) fish (presumably a relatively large number of small catches and samples were taken in this fishery). The catches of predominantly adults in SCH 4 seemed to be dominated be females. Elsewhere the sex ratio generally fluctuated around 50:50, increasing towards females as the length exceeded the male maximum size (L_∞).

3.1 Comparison of research and commercial samples

A comparison of the sampled length compositions of inshore research and commercial trawls suggests that research trawls catch a greater proportion of smaller fish (under 50 cm) and, perhaps more pronounced, they catch a smaller proportion of larger (over 100 cm) fish (Figure 15). This is in accordance with the conclusion of Ministry for Primary Industries (2017) that inshore trawl surveys should be viewed predominantly as juvenile school shark surveys. Length compositions from samples of commercial catches confirm that some adults are present (somewhere) within the same area as the inshore trawl surveys, and could comprise a substantial proportion of the catch by bottom trawls, although the observer samples were most likely to have come from larger vessels fishing persistently offshore, whereas the research survey was spatially stratified. In the Southland area, the length compositions of fish caught by research trawls and commercial trawls was similar.

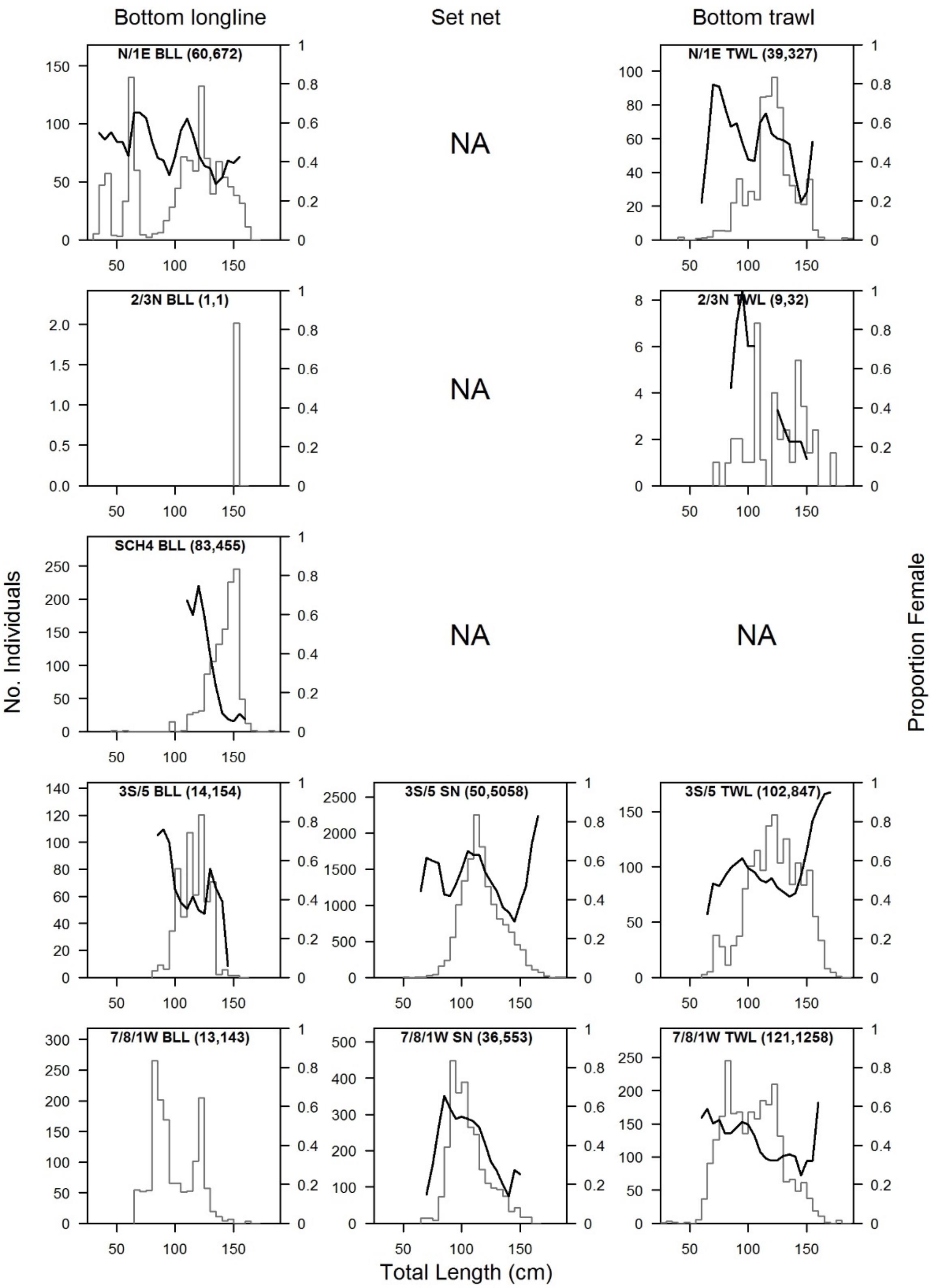

Figure 14: Scaled length frequency distributions (grey line histograms) and sex ratio (black lines) for school shark in bottom longline, setnet, and bottom trawl fisheries sampled by Observers. All data used (no number of vessels or trips criteria applied). The length distributions are shown for 5 cm length bins. The sex ratio is a moving average of sex ratio by length bin (samples from 7/8/1W SN were almost all unsexed). Numbers in parentheses are the number of events where school shark were sampled, and the number of fish measured (before catch weight scaling).

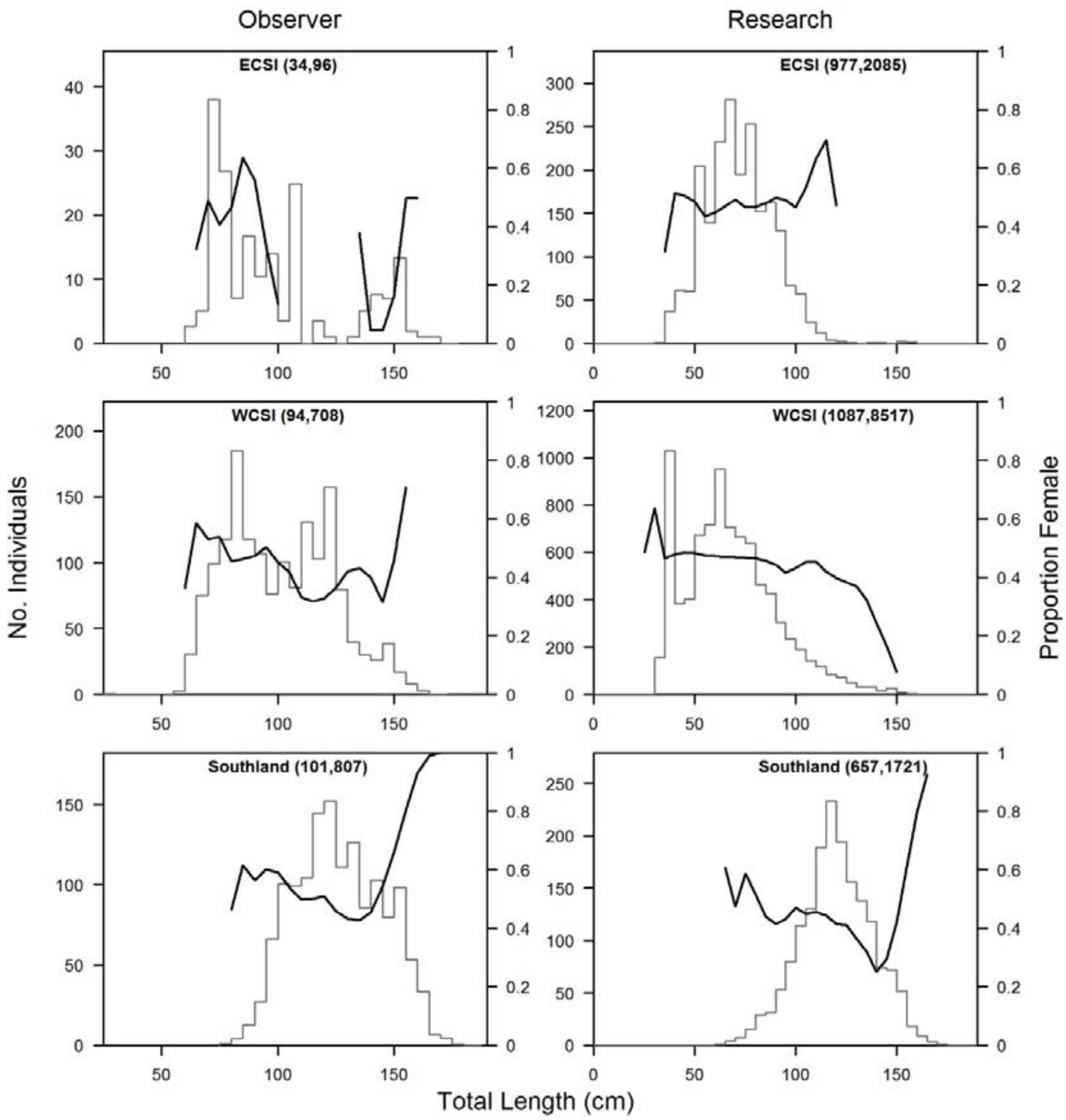

Figure 15: Scaled length frequency distributions (grey line histograms) and sex ratio (black lines) for school shark in bottom trawl fisheries sampled by Observers, and research trawl surveys, for overlapping statistical areas. All data combined. The length distributions are shown for 5 cm length bins. The sex ratio is a moving average of sex ratio by length bin. Numbers in parentheses are the number of events where school shark were sampled, and the number of fish measured (before catch weight scaling).

4. DESCRIPTION OF THE FISHERY

4.1 Catch and Effort data

Following Starr & Kendrick (2016), three data extracts were obtained from the Ministry's database Warehou: (1) all fishing event information along with all school shark landing information from every trip which recorded landing school shark in any New Zealand school shark QMA (SCH 1, SCH 2, SCH 3, SCH 4, SCH 5, SCH 7 or SCH 8, from 1 October 1989 to 30 September 2016); (2) all New Zealand trips using the methods BLL (bottom longline) and which targeted BNS, HPB, HAP, BAS, LIN, SCH, SNA, BCO or TRU; (3) all New Zealand trips which used the setnet method, without regard to target species. The data extracts were provided in MPI rep logs 11067 and 11197. The first data extract was used to characterise the fisheries, and all the three were used for CPUE standardisations.

Three datasets: rolled-up characterisation data; unrolled event level characterisation data; and rolled-up CPUE data, were generated. The level of roll-up for the characterisation data was a trip-target-stat-area record, and for the CPUE data was a trip-date record.

Data were prepared by linking the fishing event of each trip to the landing section, based on supplied trip identification numbers. Catch and effort data were then processed and groomed to provide the analysis data sets. Unless specified, the following steps in data grooming and preparation followed Starr & Kendrick (2016): further details of the data grooming and processing are provided in Appendix A.

The rationale for excluding landings having certain destination codes was described in detail by Starr & Kendrick (2016). The landings excluded accounted for only a small proportion of the landings; just 3.2% overall (Table 6), although was relatively high for several years in SCH 3, and increasing since 2008–09 in SCH 4 (Figure 16); if this trend were to continue further examination of the fishery in SCH 4 would be useful to determine why this code was being used relatively frequently.

Table 6: Total landings over 1989–90 to 2015–06 by destination codes, showing the codes included and excluded from use in subsequent data analyses.

Destination code	Description	How used	Green weight (t)
A	Accidental loss	Keep	36.7
C	Disposed to Crown	Keep	0.9
E	Eaten	Keep	27.4
F	Section 111 Recreational catch	Keep	7.6
H	Loss from holding pot	Keep	0.0
L	Landed to NZ	Keep	81 593.6
O	Conveyed outside NZ	Keep	63.5
S	Seized by Crown	Keep	0.3
U	Bait used on board	Keep	16.8
W	Sold at wharf	Keep	5.1
X	QMS returned to sea, except 6A	Keep	29.5
B	Bait stored for later use	Drop	2.2
D	Discarded	Drop	21.8
J	Observer Authorised Discard	Drop	36.2
NP	Not provided	Drop	39.2
P	Holding receptacle in water	Drop	0.0
Q	Holding receptacle on land	Drop	634.2
R	Retained on board	Drop	1 137.9
T	Transferred to another vessel	Drop	849.4

The fishing methods RLP, CP, FN (rock lobster potting, cod potting, and fyke nets respectively) were considered highly unlikely to capture school shark, and were excluded.

For CPUE analyses, the “daily-effort-stratum” method was used. The following steps were used to “rollup” the event-based data to a “daily-stratum”: sum effort for each day of fishing in the trip; sum estimated catch of the top-five species for each day of fishing in the trip; calculate the modal statistical area and target species for each day of fishing, weighted by the number of fishing events (these are the values assigned to the effort and catch for that day of fishing); distribute landings proportionately to each day of the trip based on the species estimated catch or to the daily effort when there is no species estimated catch, without maintaining QMA integrity.

The conversion factors for state codes to greenweight were the same as the previous analysis, i.e., the conversion factors for dressed and head-and-gutted (the two primary codes used) were 1.95 and 1.85, where greenweight was the product of conversion factor, number of units of product, and unit weight. The grooming method of Starr (2007) to replace missing greenweight with the median of the same year and state code, or a value of one, was not used here. This was because the median was found to be either zero or NA, and assuming an assumed state code of one could introduce a bias. Therefore these records were excluded from analysis data sets.

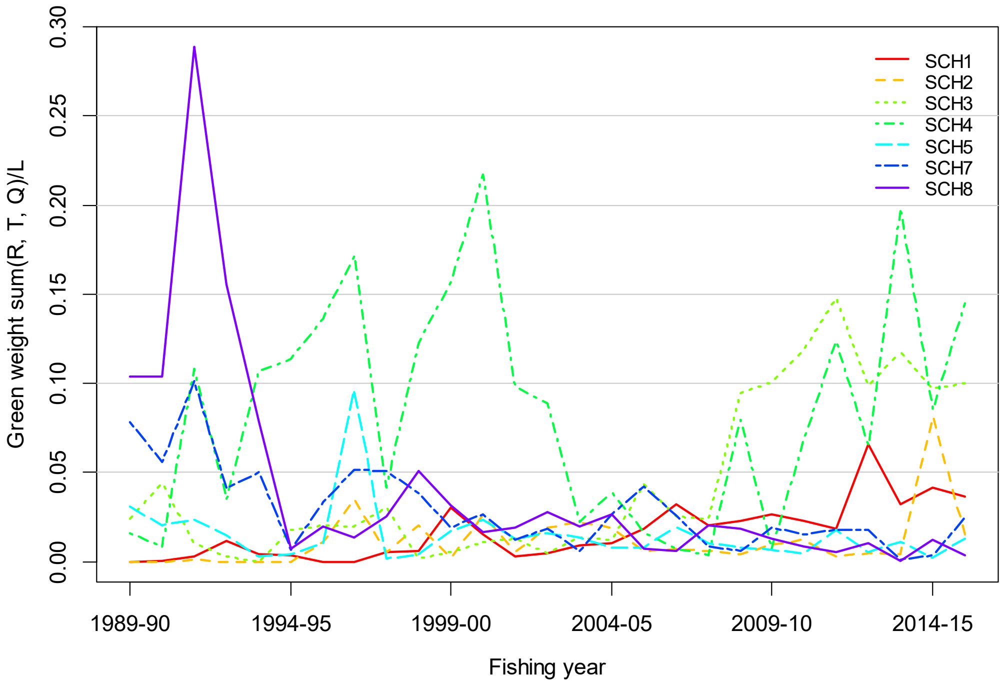

Figure 16: The extent of school shark catches reported in intermediate holding states (potential double-counting of catches), calculated as the sum of weight for destination codes R, T, and Q divided by weight for destination code L (see Table 6) by school shark FMA and year.

The "out of range" method described by Starr & Kendrick (2016) was also applied, and this resulted in no data being excluded. Data were checked for implausible values and corrected or excluded using a method based on the median and standard deviation of logged catches (logged as appropriate) and expert opinion (see Appendix A).

Effort data were checked and imputed for the CPUE data set. Outliers were identified by considering plausible effort range(s) on the basis of expert knowledge, and examination of the frequency distribution of effort. Vessel effort number, total hook number, total length of net, and fishing duration were calculated, and the outlying values were replaced with the calculated vessel medians. Where the imputed median was also out of range, the field was replaced with an NA (thereby being excluded from CPUE analyses).

Selection criteria were applied to the CPUE analysis data sets, to restrict them to fishing gears and areas identified as appropriate fishery monitoring units (MPI 2017). The vessel selection criteria used were the same as those applied by Starr & Kendrick (2016).

The overall proportion of landings reported on the CELR form dropped to below 20% in every year from 2007–08 except 2008–09 (Figure 17). The usage of the CELR form in some QMAs (notably SCH 1, SCH 4 and SCH 5) has remained below 10% since 2007–08.

Landings were matched with effort for every trip while maintaining the integrity of the QMA-specific information; this worked well for all QMAs except SCH 8, where about one third of the records were lost (Table 7) as a result of trips being in statistical areas that were in more than one QMA, and reporting landings from more than one QMA. This amount of lost landings was previously considered acceptable for the purposes of characterising the fishery, but not for CPUE analyses (Starr & Kendrick 2016). The percentage of the official reported landings accounted for by the groomed data set has remained fairly constant over time (Figure 18).

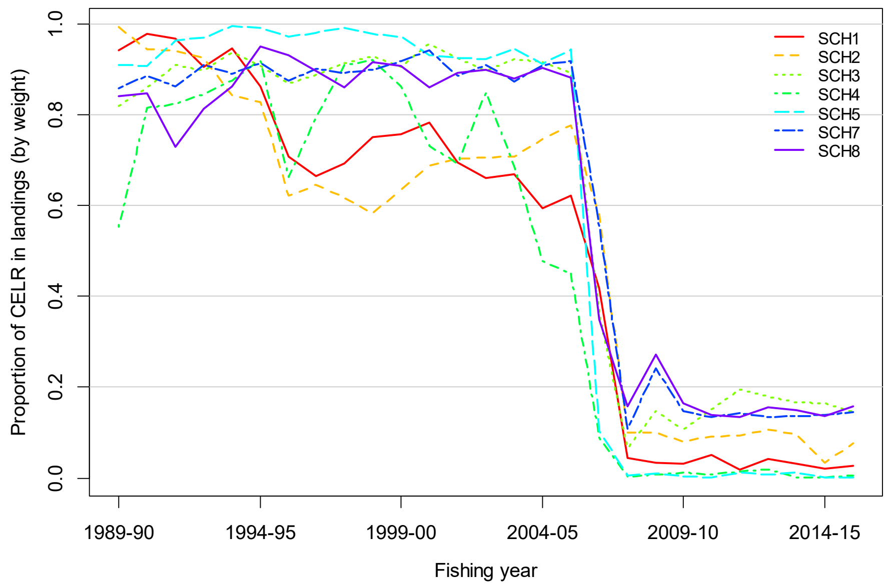

Figure 17: Proportion of landings recorded on CELR forms by fishing year and QMA.

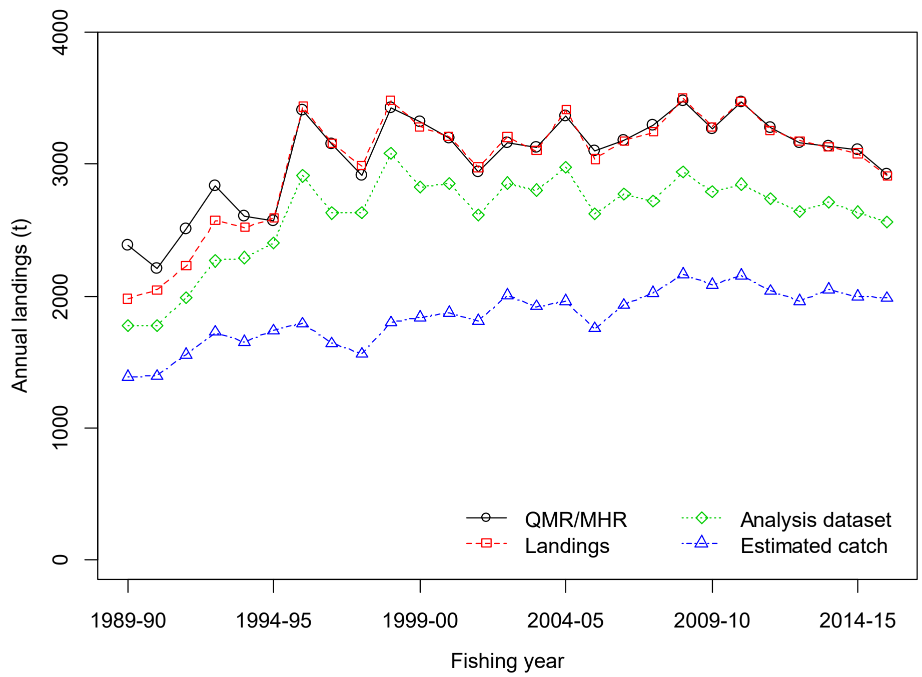

Figure 18: The total landings of school shark by fishing year official landings statistics (Landings), fisheries management forms (MHR, Monthly Harvest Returns; QMR, Quota Management Reports), estimated catch event-by-event forms (CLR and equivalents), and in the fisheries characterisation data set (Analysis dataset).

Table 7: Percentage of the effort data retained after data grooming by fishing year and QMA.

Fishing year	SCH 1	SCH 2	SCH 3	SCH 4	SCH 5	SCH 7	SCH 8
1989–90	88	66	74	69	92	79	75
1990–91	71	79	75	50	91	79	64
1991–92	82	74	73	90	91	76	71
1992–93	88	79	75	71	94	62	69
1993–94	90	77	72	88	96	75	74
1994–95	91	71	73	44	95	76	83
1995–96	88	70	72	85	68	67	67
1996–97	81	69	73	88	68	58	73
1997–98	84	76	67	87	71	70	66
1998–99	83	80	73	94	73	72	71
1999–00	86	77	73	90	90	68	56
2000–01	90	80	74	88	91	69	74
2001–02	87	79	75	86	93	72	64
2002–03	90	83	77	90	94	74	61
2003–04	90	74	73	85	96	76	70
2004–05	85	77	78	90	89	71	67
2005–06	88	81	70	87	94	69	62
2006–07	84	83	79	89	93	74	72
2007–08	90	89	88	96	94	64	65
2008–09	91	95	80	95	93	74	60
2009–10	90	91	84	96	95	69	60
2010–11	88	86	85	96	92	65	61
2011–12	87	85	88	97	93	75	56
2012–13	87	90	84	90	90	75	58
2013–14	88	88	82	95	93	83	63
2014–15	88	84	88	95	93	73	67
2015–16	90	91	87	89	93	85	64

4.2 Description of the fishery

The school shark fishery varies by QMA. In summary (statistics reported here refer to the 2013–14 to 2015–16 fishing years):

SCH 1
About 31% of the SCH 1 landings were taken by bottom trawl while targeting tarakihi and snapper, with smaller catches when targeting trevally and red gurnard. The bottom longline SCH 1 fishery, taking about 24% of the total landings, was primarily directed at school shark, with hapuku and snapper being other important targets. The setnet fishery, which took about 22% of the landings, was mainly targeted at school shark, with some additional targeting of rig, trevally, gurnard and snapper.

SCH 2
SCH 2 were caught primarily in the bottom trawl fishery (37%) targeting tarakihi, hoki, gemfish and gurnard; and the bottom longline fishery (36%) targeting school shark, ling, hapuku/bass and bluenose. About 18% of the catch was taken in setnet targeting school shark, blue warehou and blue moki.

SCH 3
SCH 3 was predominantly caught in the setnet fishery (59%) targeting school shark and rig, with some targeting of spiny dogfish and tarakihi; and in the bottom trawl fishery (26%) targeting red cod, with some targeting of flatfish, barracouta and tarakihi. Mixed targeted bottom longline took about 9% of the catch.

SCH 4
SCH 4 was primarily (92%) a bottom longline fishery targeted at bluenose, hapuku/bass, ling and a few school shark. There was also a small bottom trawl fishery (7% of catches) which targeted a range of species including tarakihi, barracouta, stargazer, hoki and scampi. The setnet fishery has been small (less than 5%) and cannot be used to monitor the Fishstock.

SCH 5
SCH 5 was almost entirely caught in the school shark targeted setnet fishery (87%), with some minor targeting of rig. About 8% was taken by bottom trawl primarily targeting stargazer and squid, and 4% by bottom longline primarily targeting hapuku/bass and ling.

SCH 7
SCH 7 were caught by the setnet fishery (14%) targeting school shark, rig and spiny dogfish; bottom longline (41%) targeting school shark, hapuku/bass and ling; and bottom trawl (42%) targeting barracouta, tarakihi, flatfish, hoki, red cod and others.

SCH 8
SCH 8 were caught mainly (59%) by setnet targeting school shark and rig; and by bottom longline (30%) targeting school shark and hapuku/bass. About 10% was caught by bottom trawl targeting gurnard, tarakihi and trevally.

The spatial distribution of the school shark fishery using event-by-event data up until the previous characterisation (2007–08 to 2012–13), and in the three years since then (2013–14 to 2015–16) are shown in Figure 19 to Figure 24.

The fisheries for school shark are complex, with the relative importance of the major capture methods differing among the eight QMAs. For setnet, the historical school shark catches off the west coast of the South Island did not exist in 2013–14 to 2015–16, but the catch pattern was otherwise similar (Figure 19 and Figure 20). For bottom longline, the distribution of catches was very similar between the two time periods, but with less catch around the southern tip of the South Island during 2013–14 to 2015–16 (Figure 21 and Figure 22). For bottom trawl, there was some contraction of the fished area off the west coast, but in general no material difference between the spatial distribution during the two time periods (Figure 23 and Figure 24).

The relative importance of the three main capture methods varies by QMA, with setnet predominating in SCH 3, SCH 5, and SCH 8; bottom trawl catches were similar to setnet in SCH 2, SCH 7, and SCH 1W, and bottom longline predominated in SCH 1E (by a small margin) and SCH 4 (Figure 25 and Figure 26). In recent years there was no material change in this distribution.

For setnet, target species was largely school shark (SCH) in SCH 1W, SCH 2 (albeit variable), SCH 5, SCH 7, and SCH 8. SCH is also often taken whilst targeting rig (SPO), and sometimes trevally (TRE), warehou (WAR), and moki (MOK) (Figure 27 and Figure 28). In recent years, targeting of SCH in SCH 1E has declined, and catches of SCH whilst targeting SPO have declined in SCH 8.

For bottom longline, target species was largely SCH in SCH 7, SCH 8, and SCH 1W (although this has declined) (Figure 29 and Figure 30). To the south, SCH was usually taken with hapuka/bass (HPB) and ling (LIN); to the north with snapper (SNA), HPB, LIN, bluenose (BNS), and terakihi (TAR). In recent years, targeting SCH in SCH 1E declined and almost disappeared, and SCH has started to appear in events targeting TAR. Catches in SCH target events increased in SCH 4. Catches of SCH in HPB target events increased in SCH 7, and decreased in SCH 5.

For bottom trawl, the target species reported when catching SCH has been most complex, with SCH more rarely described as the target species (Figure 31 and Figure 32). Catches of SCH were largely taken whilst targeting TAR around the North Island, and red cod (RCO), TAR, stargazer (STA), and barracouta (BAR) around the South Island. In recent years, SCH catches in TRE target fisheries have almost disappeared in SCH 8, and been replaced by SCH target; and SCH catches in GUR target have increased in SCH 4 and SCH 7.

For setnet, there have been different seasonal patterns of catches around the North and South Islands (Figure 33 and Figure 34). Around the South Island, most SCH catches have been in spring and early summer, with most pronounced seasonality in SCH 7. Around the North Island, there is less seasonality, with some decline in catches in winter. In recent years, there has been no material change in seasonality.

For bottom longline, there have again been different seasonal patterns around the North and South Islands (Figure 35 and Figure 36). Around the South Island, catches tend to be sporadic. In recent years, there have been proportionally greater catches during winter around the North Island (in SCH 8 especially).

For bottom trawl, there has been a more uniform seasonal catch distribution (Figure 37 and Figure 38). There have been smaller catches in winter in SCH 3, and catches during winter around the North Island. In recent years, SCH 8 catches used to be relatively small in winter-spring, but recently the smaller catches have been in summer.

The seasonal patterns in setnet, but not bottom longline or bottom trawl, suggest that the setnet patterns are more likely operational, rather than a consequence of fish movement.

For setnet fishing reported on an NCELR, there is no direct information on bottom depth (setnet NCELR forms do not require it; it might be inferred from the latitude and longitude however). School shark occur over a wide depth range, with most catches in target fisheries at depths less than 200 m (Figure 39 to Figure 41).

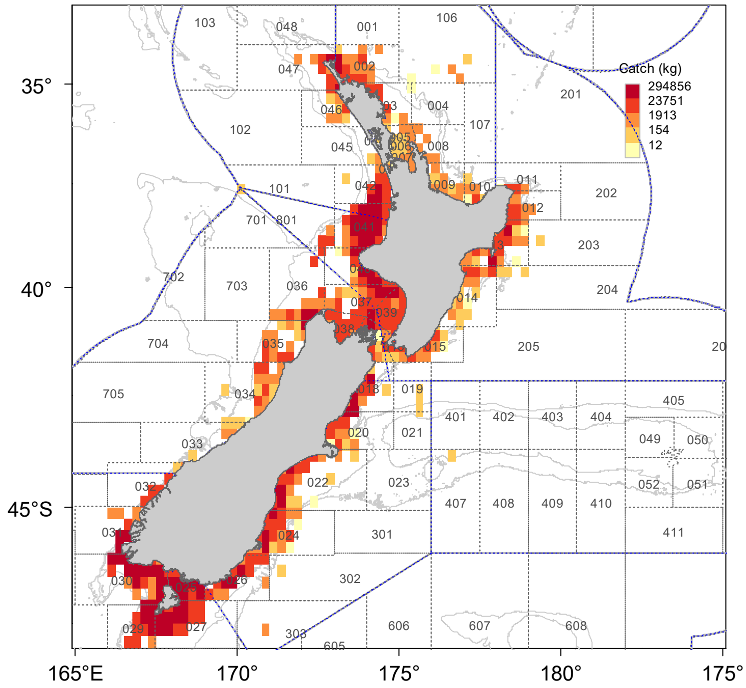

Figure 19: Distribution of school shark catch by 0.25 degree latitude and longitude cells for setnet and fishing years 2007–08 to 2012–13.

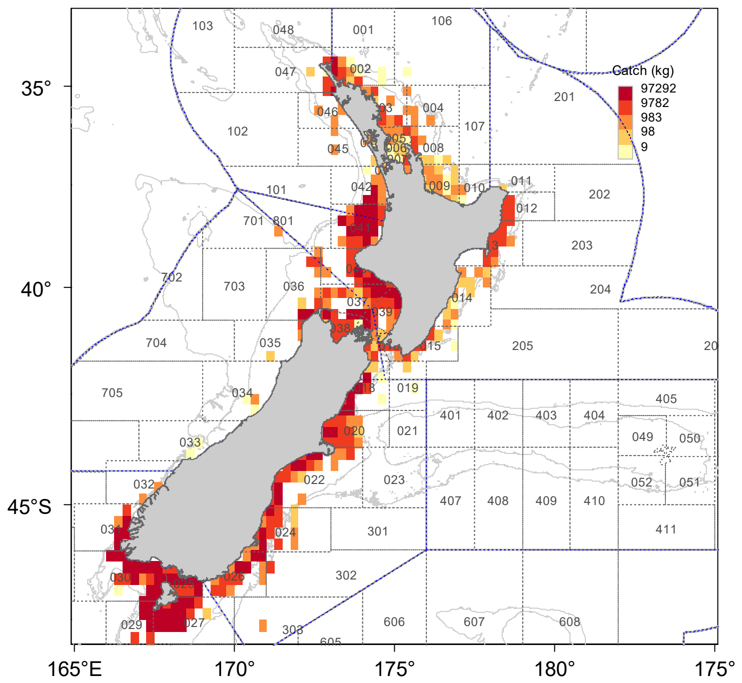

Figure 20: Distribution of school shark catch by 0.25 degree latitude and longitude cells for setnet and fishing years 2013–14 to 2015–16.

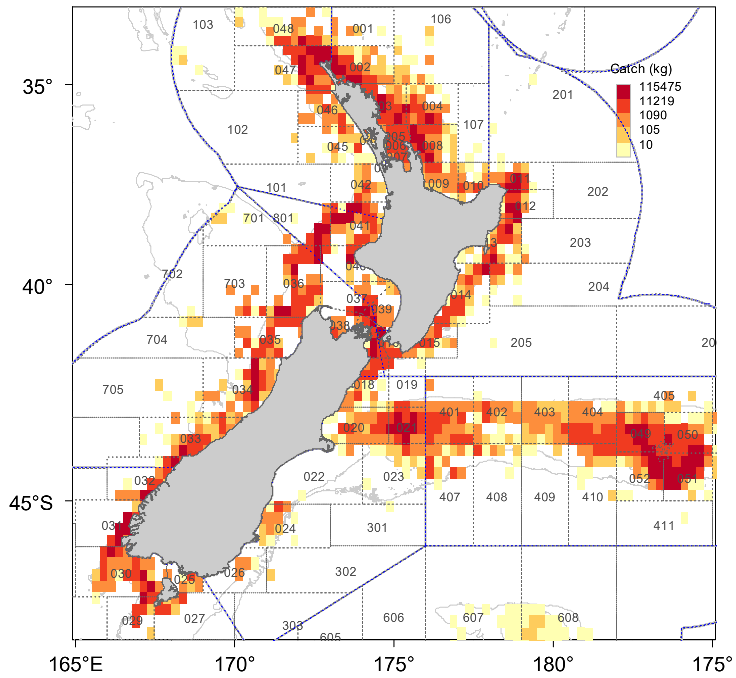

Figure 21: Distribution of school shark catch by 0.25 degree latitude and longitude cells for bottom longline and fishing years 2007–08 to 2012–13.

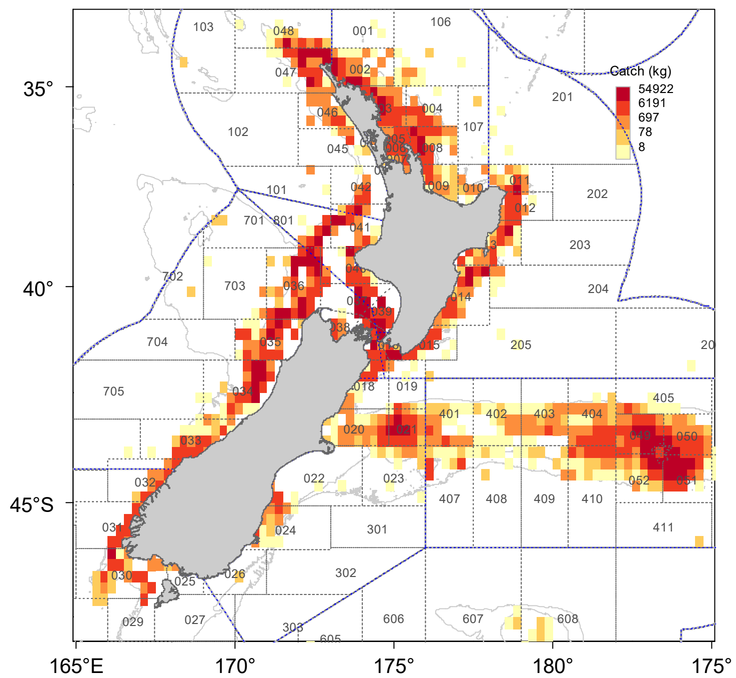

Figure 22: Distribution of school shark catch by 0.25 degree latitude and longitude cells for bottom longline and fishing years 2013–14 to 2015–16.

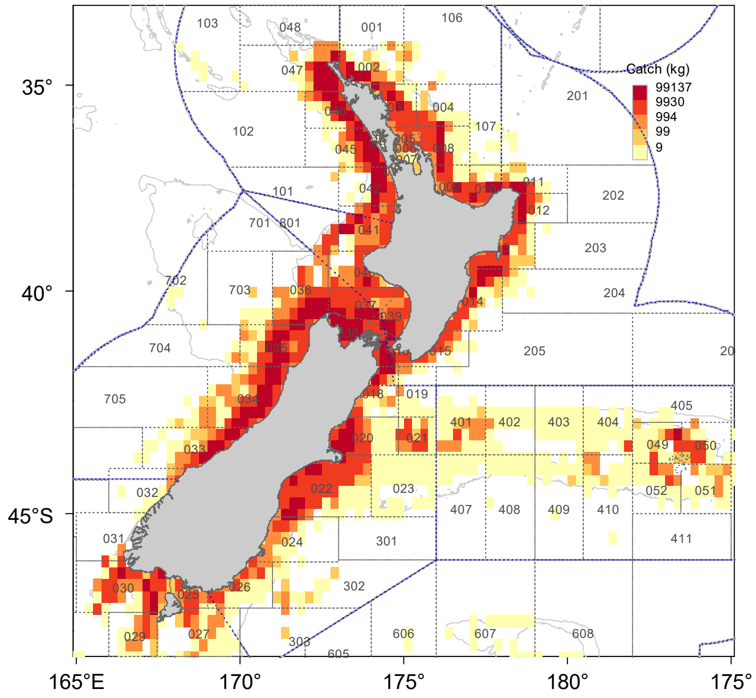

Figure 23: Distribution of school shark catch by 0.25 degree latitude and longitude cells for bottom trawl and fishing years 2007–08 to 2012–13.

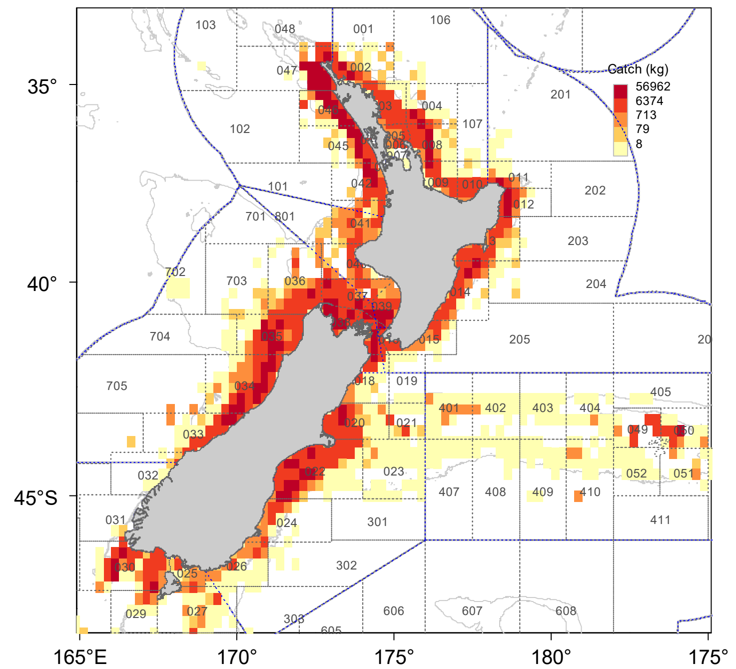

Figure 24: Distribution of school shark catch by 0.25 degree latitude and longitude cells for bottom trawl and fishing years 2013–14 to 2015–16.

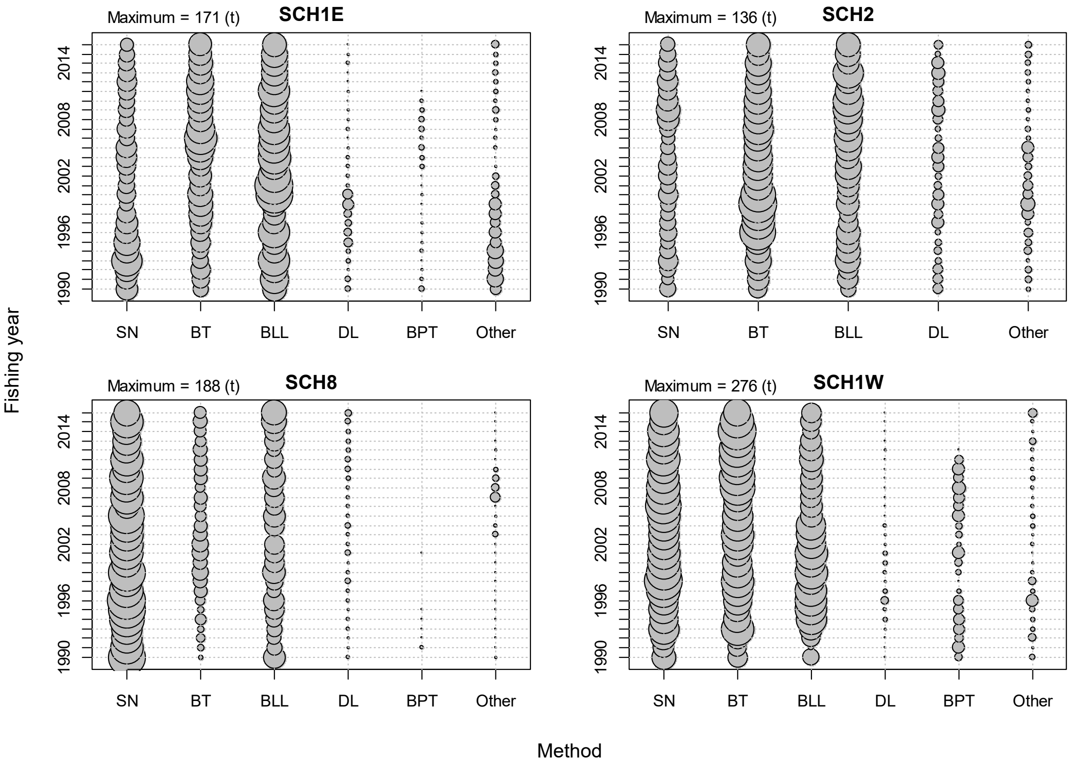

Figure 25: Distribution of school shark landings around the North Island by fishing year and major fishing methods. Circles are proportional to landing size within each panel, with the largest landing size indicated above each panel.

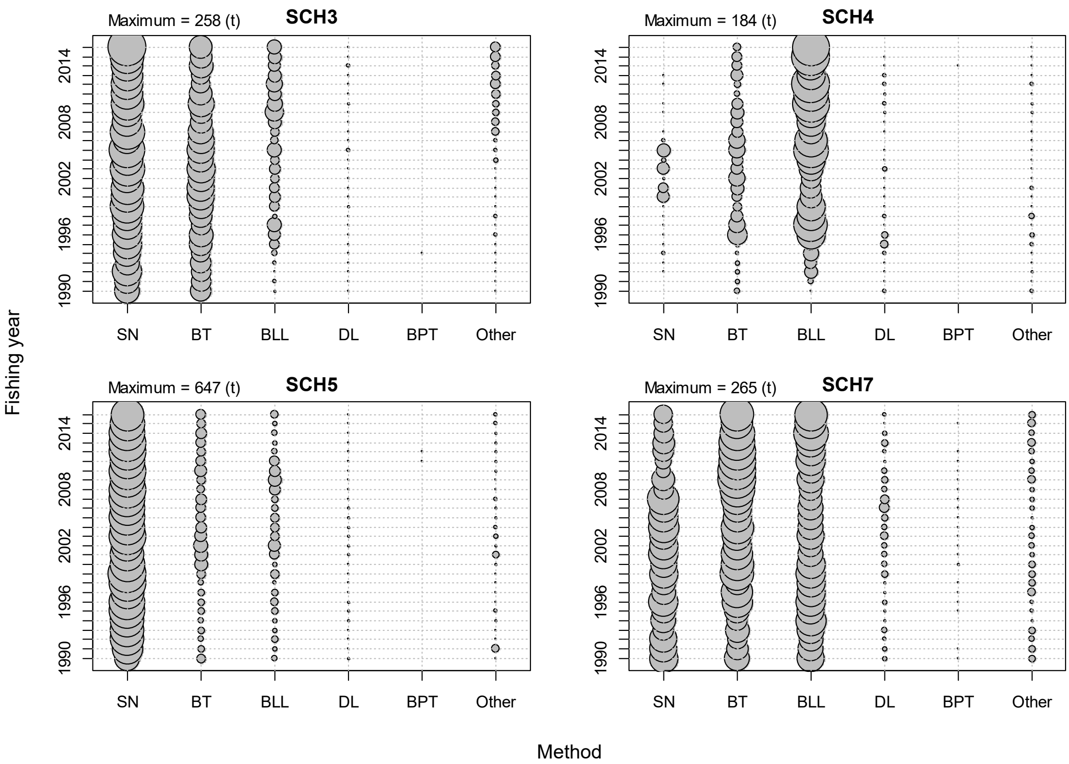

Figure 26: Distribution of school shark landings around the South Island by fishing year and major fishing methods. Circles are proportional to landing size within each panel, with the largest landing size indicated above each panel.

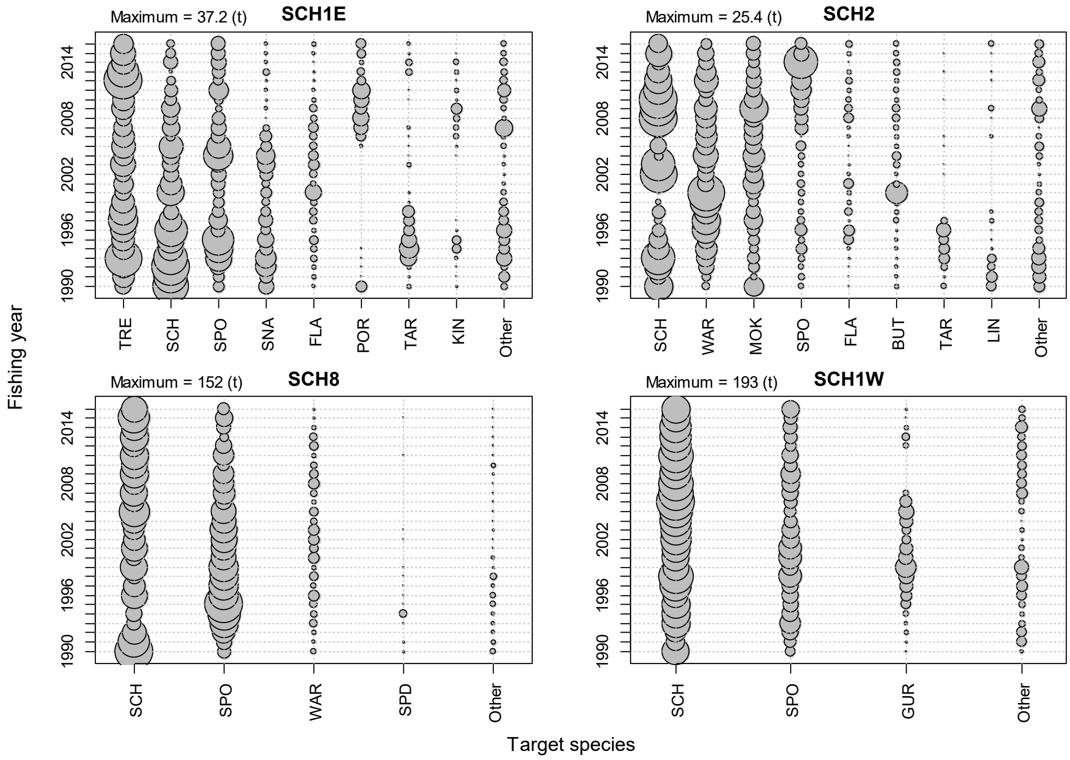

Figure 27: Distribution of school shark landings by setnet around the North Island by fishing year and target species. Circles are proportional to landing size within each panel, with the largest landing size indicated above each panel.

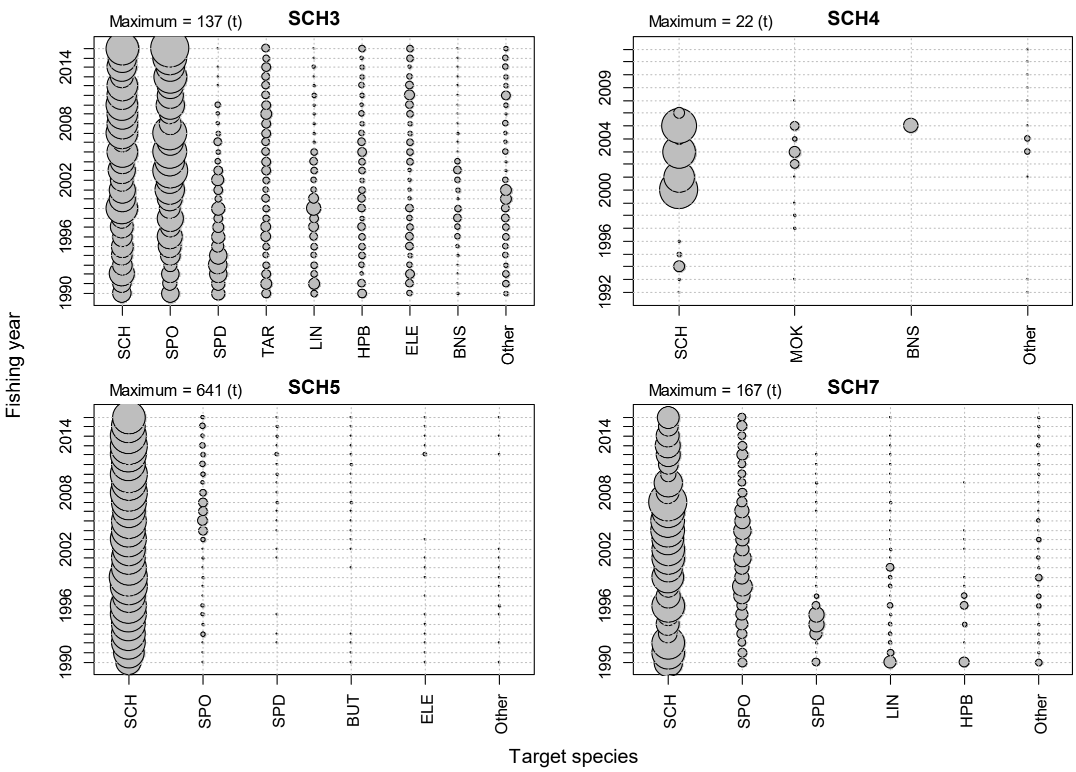

Figure 28: Distribution of school shark landings by setnet around the South Island by fishing year and target species. Circles are proportional to landing size within each panel, with the largest landing size indicated above each panel.

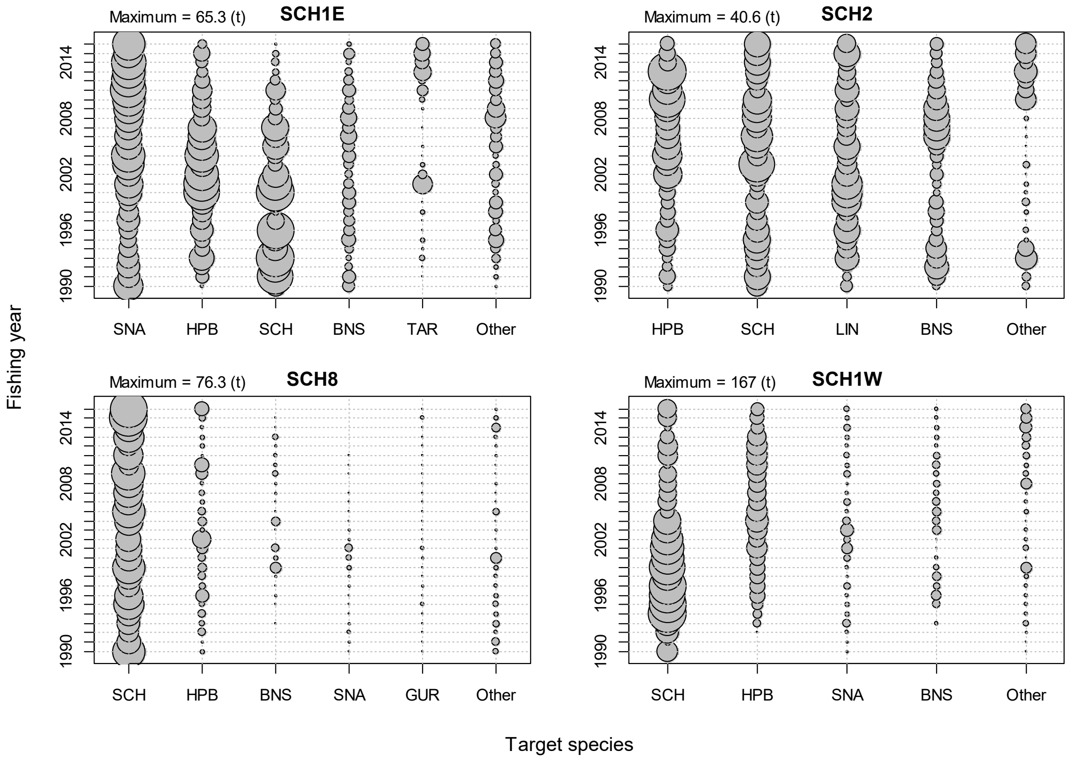

Figure 29: Distribution of school shark landings by bottom longline around the North Island by fishing year and target species. Circles are proportional to landing size within each panel, with the largest landing size indicated above each panel.

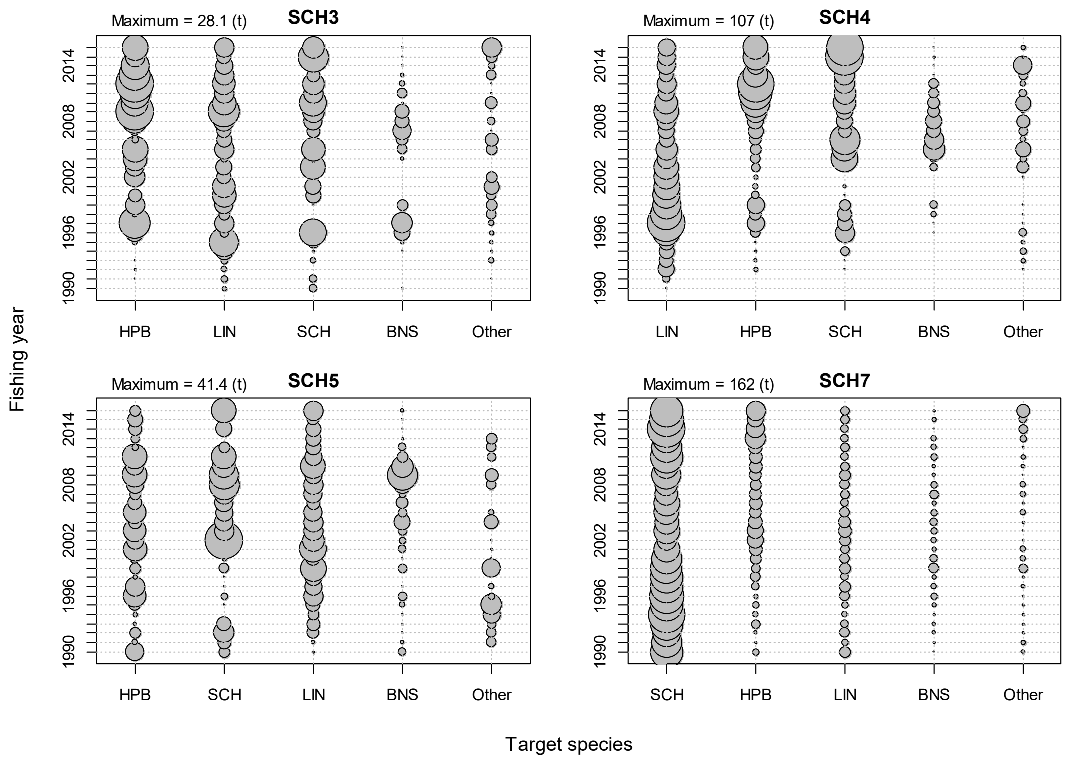

Figure 30: Distribution of school shark landings by bottom longline around the South Island by fishing year and target species. Circles are proportional to landing size within each panel, with the largest landing size indicated above each panel.

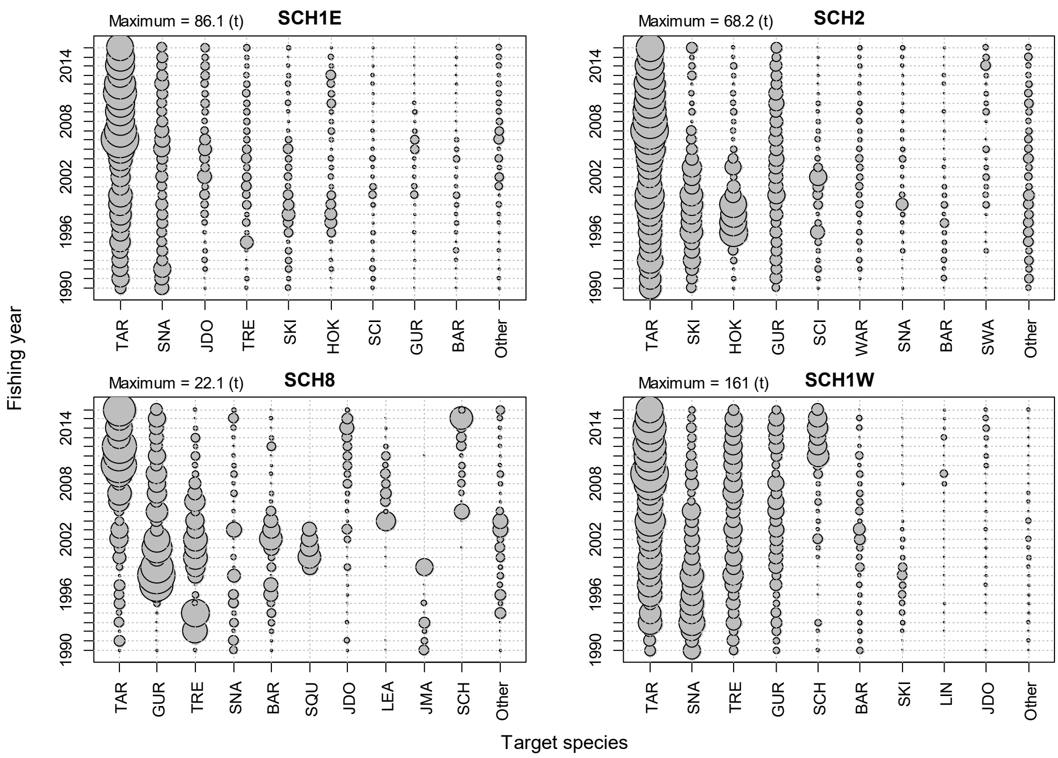

Figure 31: Distribution of school shark landings by bottom trawl around the North Island by fishing year and target species. Circles are proportional to landing size within each panel, with the largest landing size indicated above each panel.

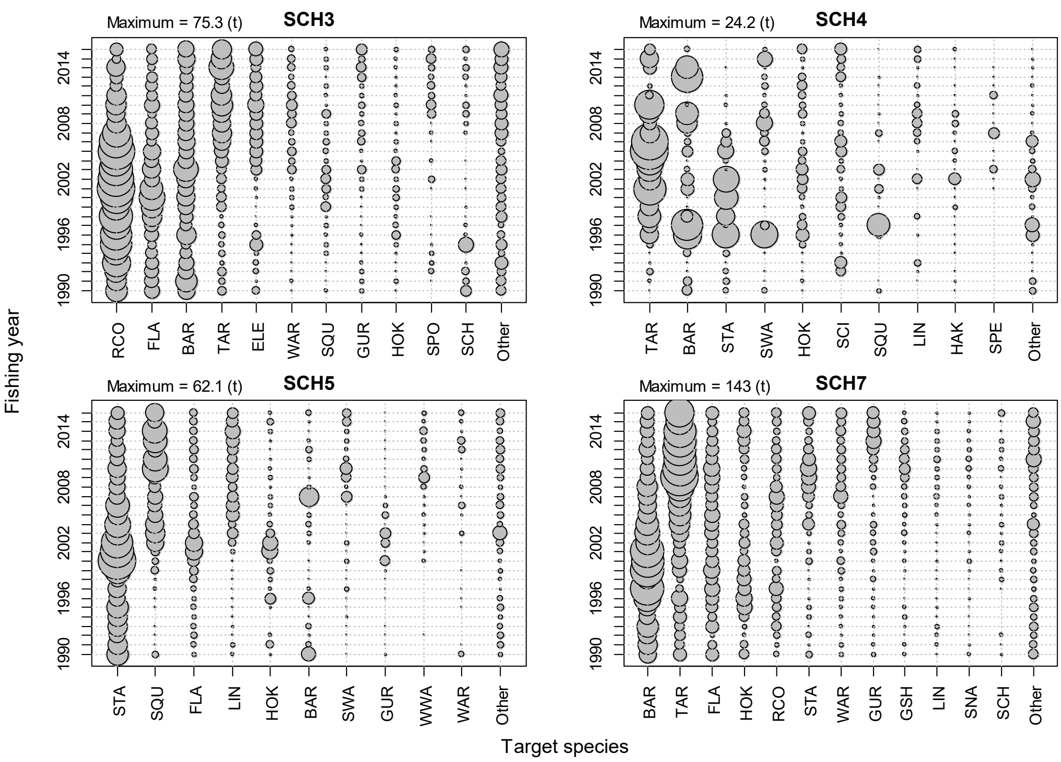

Figure 32: Distribution of school shark landings by bottom trawl around the South Island by fishing year and target species. Circles are proportional to landing size within each panel, with the largest landing size indicated above each panel.

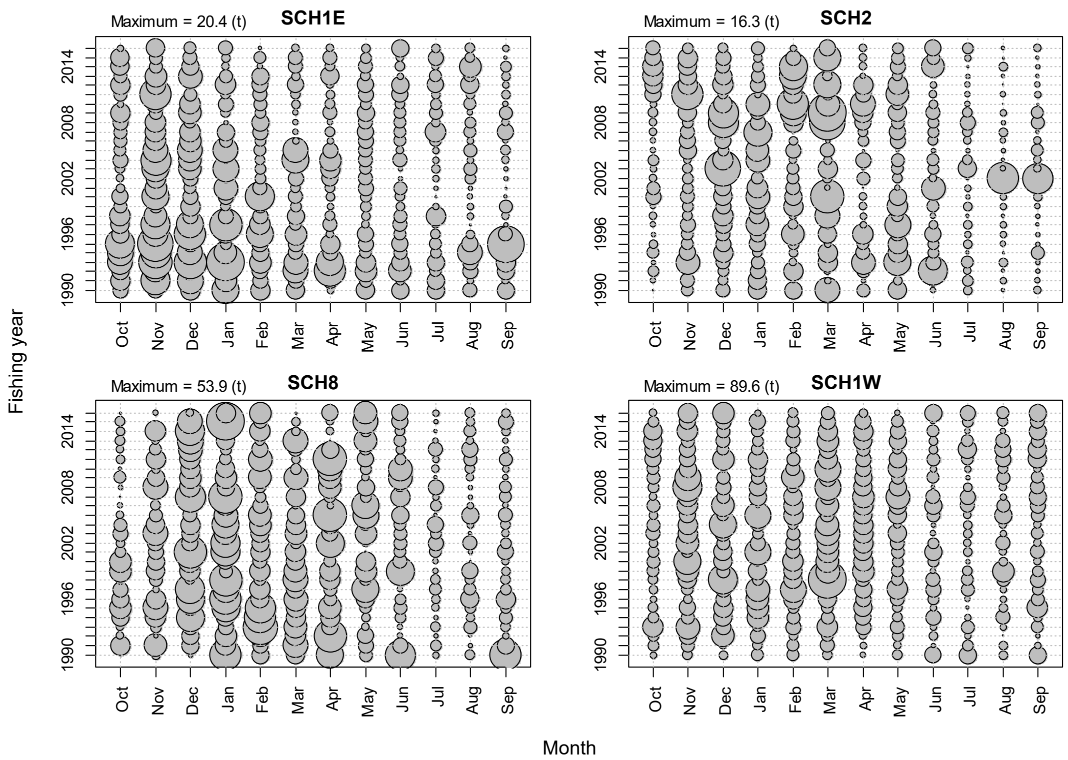

Figure 33: Distribution of school shark landings by setnet around the North Island by fishing year and month. Circles are proportional to landing size within each panel, with the largest landing size indicated above each panel.

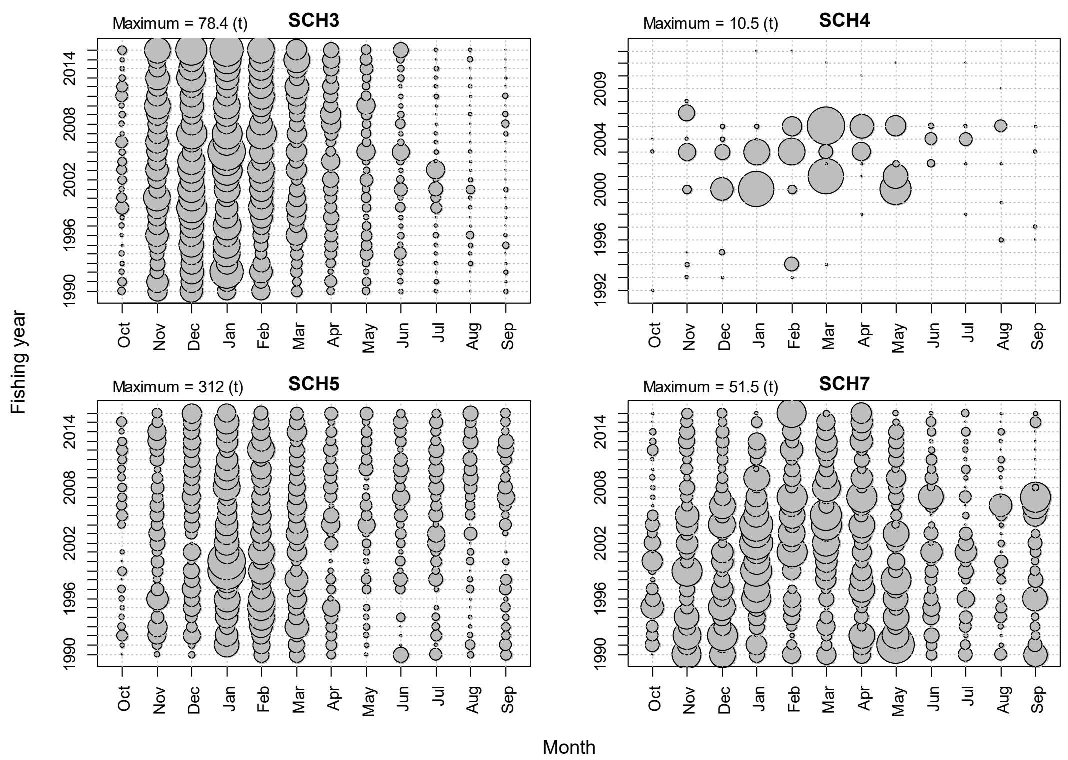

Figure 34: Distribution of school shark landings by setnet around the South Island by fishing year and month. Circles are proportional to landing size within each panel, with the largest landing size indicated above each panel.

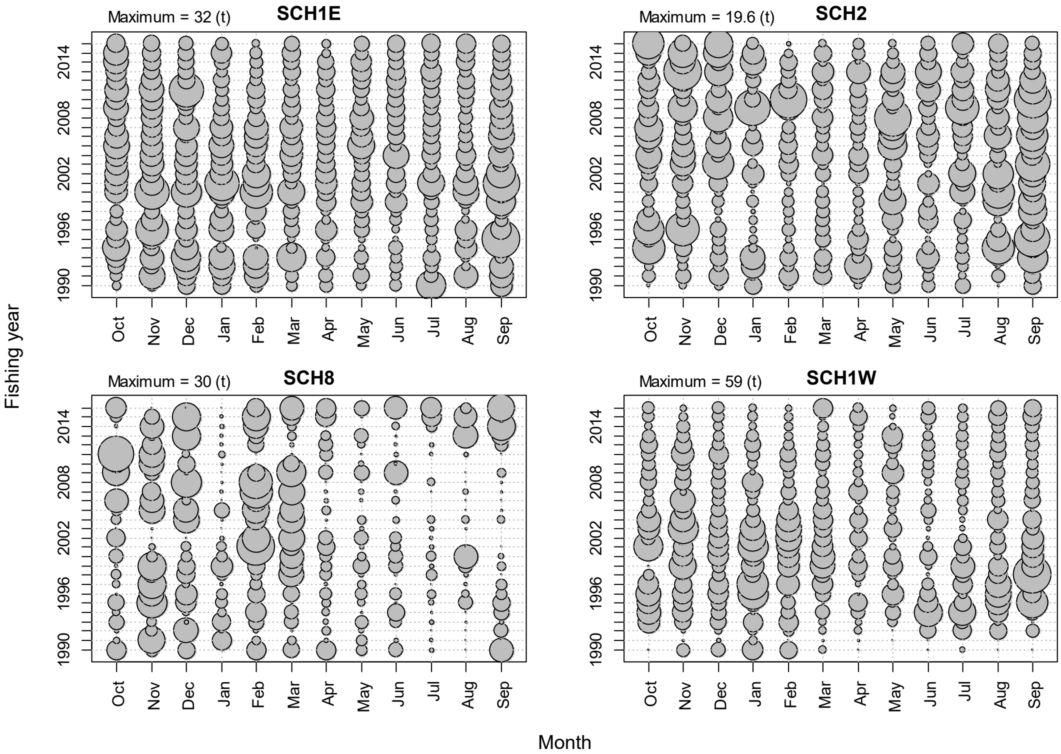

Figure 35: Distribution of school shark landings by bottom longline around the North Island by fishing year and month. Circles are proportional to landing size within each panel, with the largest landing size indicated above each panel.

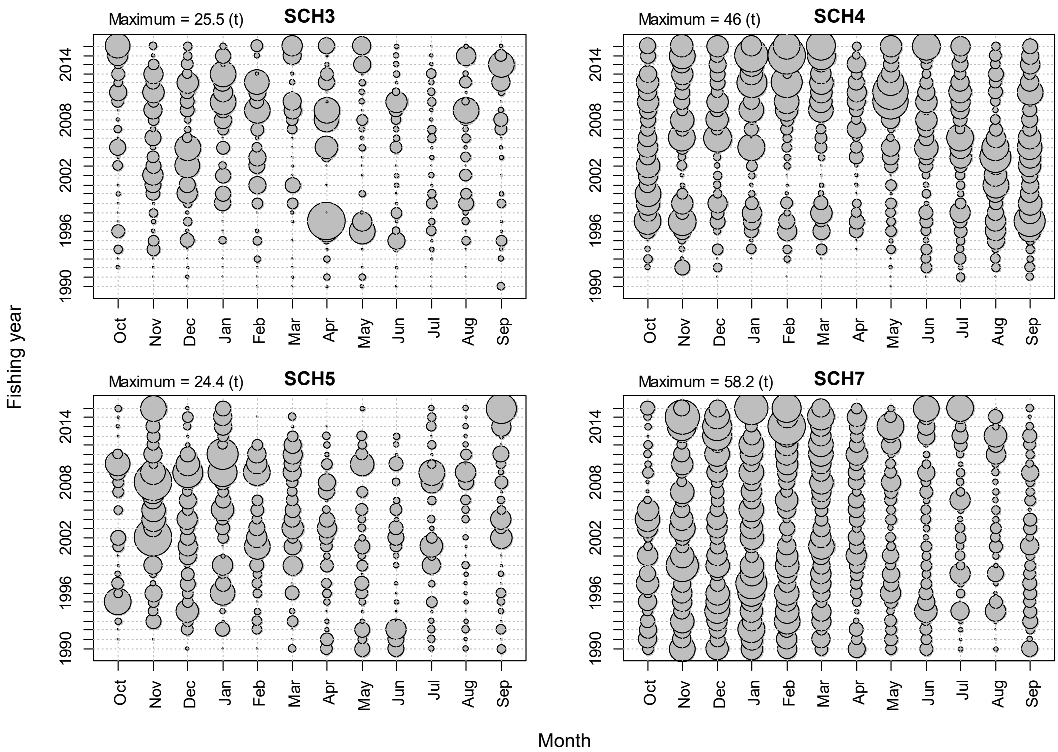

Figure 36: Distribution of school shark landings by bottom longline around the South Island by fishing year and month. Circles are proportional to landing size within each panel, with the largest landing size indicated above each panel.

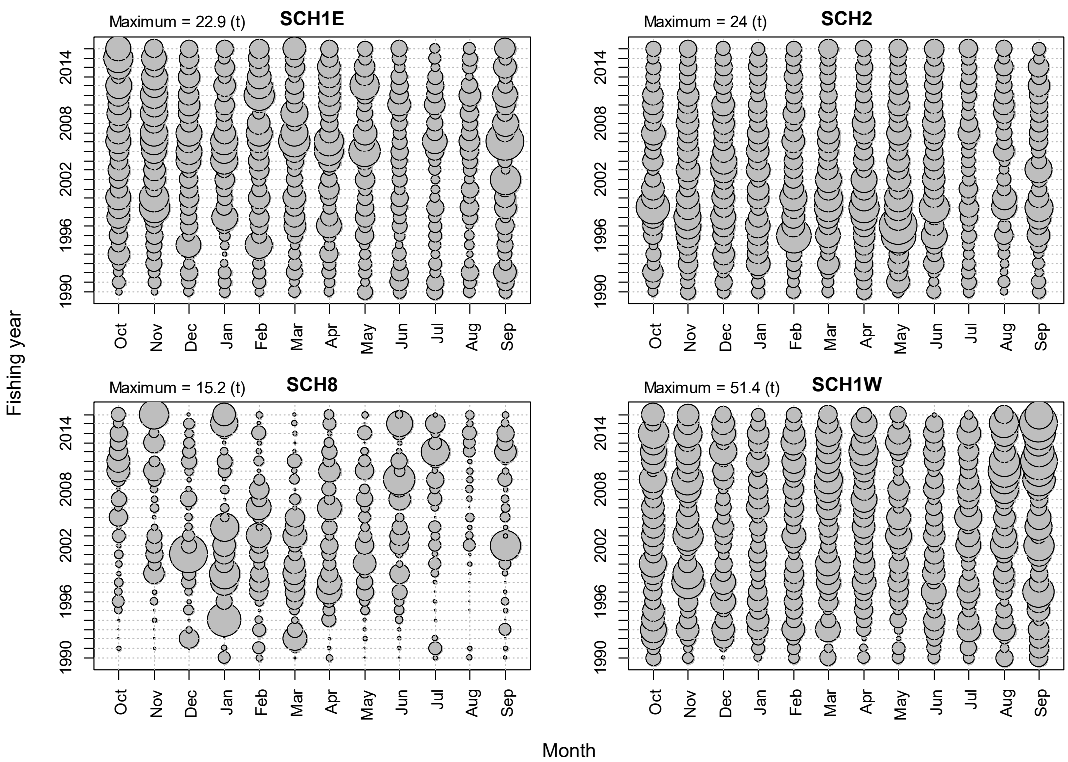

Figure 37: Distribution of school shark landings by bottom trawl around the North Island by fishing year and month. Circles are proportional to landing size within each panel, with the largest landing size indicated above each panel.

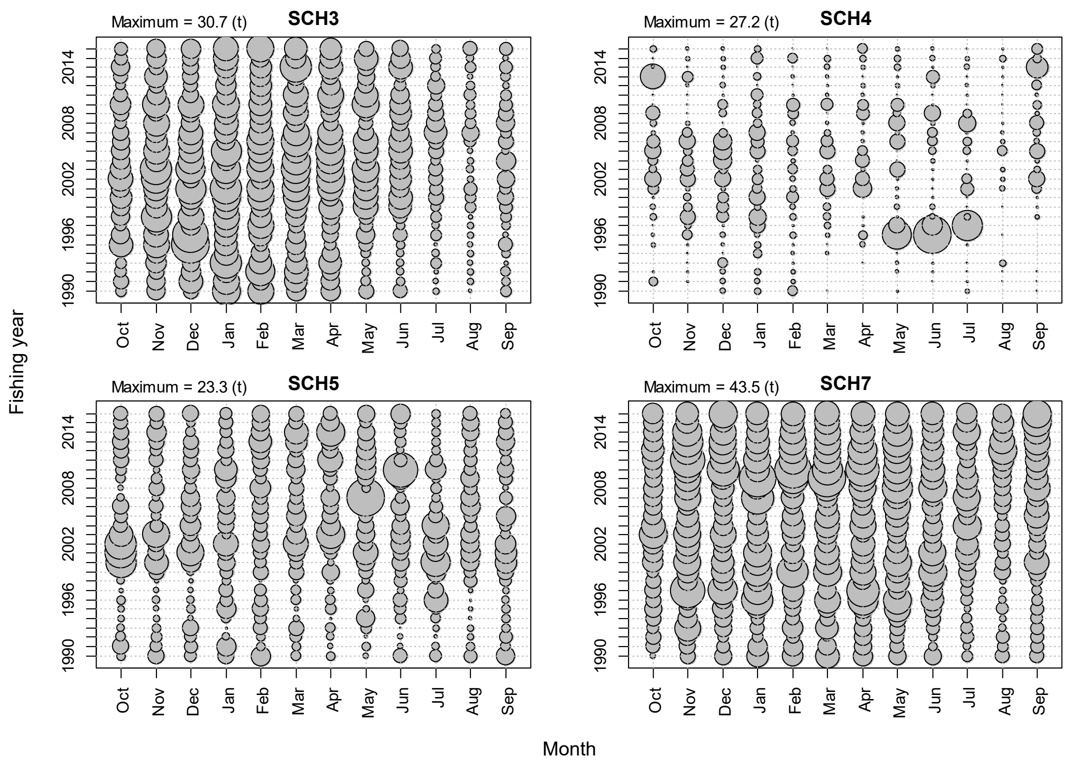

Figure 38: Distribution of school shark landings by bottom trawl around the South Island by fishing year and month. Circles are proportional to landing size within each panel, with the largest landing size indicated above each panel.

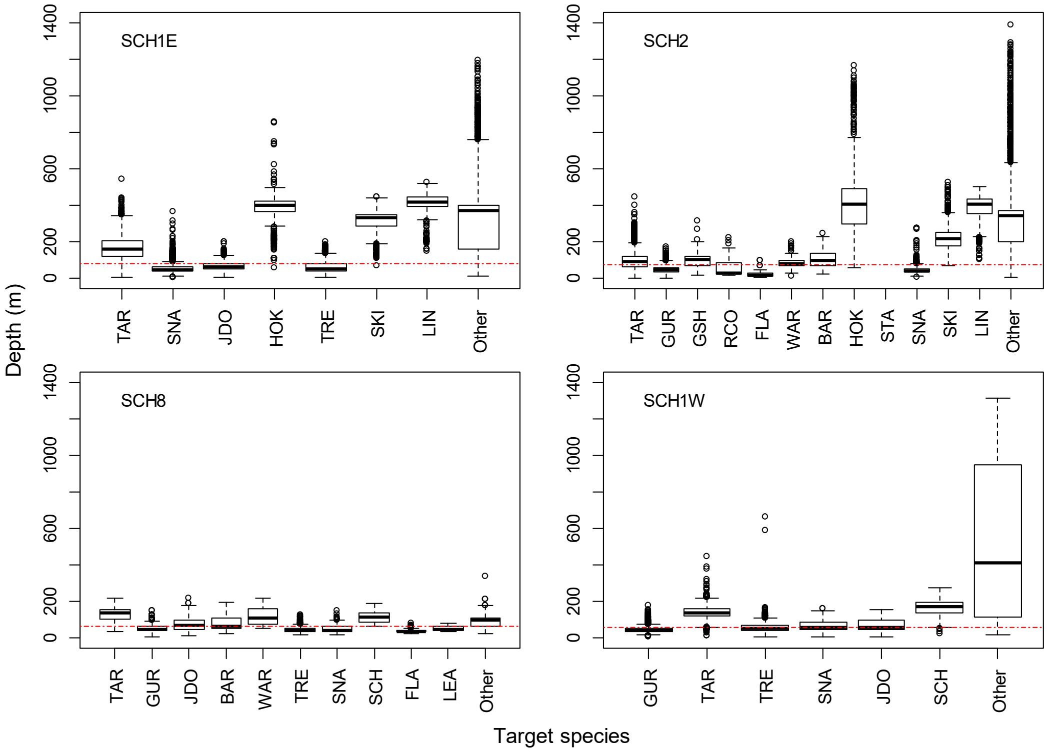

Figure 39: Box plots of bottom depth for bottom trawl catches of school shark for fishery monitoring units around the North Island, using data from 2007–08 to 2015–16. Solid lines represent the median, and the boxes the inter-quartile range, whiskers extend to around the 95% intervals (see R help files for details on default settings), and points indicate outliers beyond this range. The horizontal broken line indexes the median depth across all records.

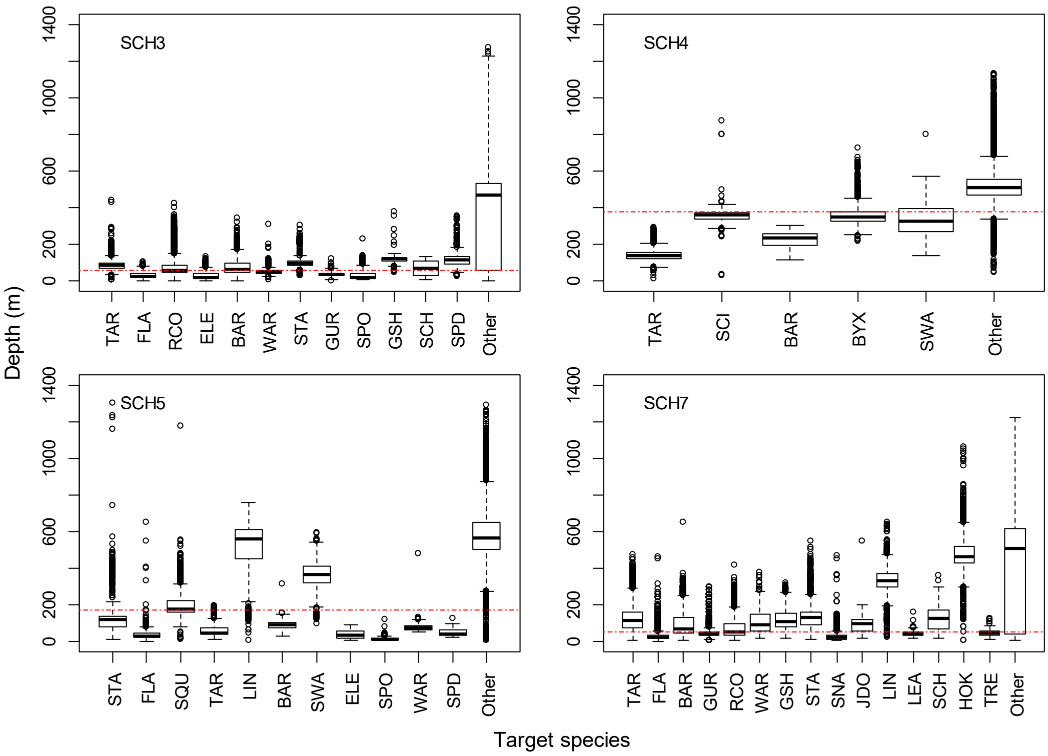

Figure 40: Box plots of bottom depth for bottom trawl catches of school shark for fishery monitoring units around the South Island, using data from 2007–08 to 2015–16. For box plot explanation see Figure 39. The horizontal broken line indices the median depth across all records.

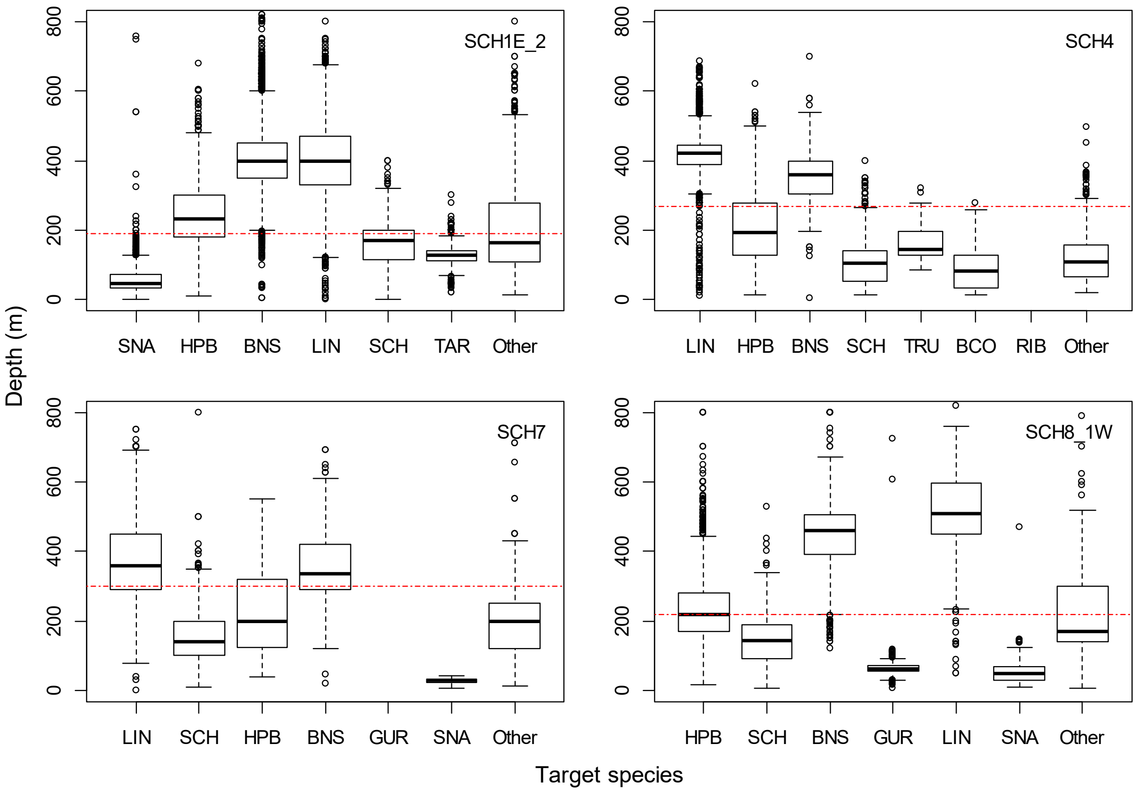

Figure 41: Box plots of bottom depth for bottom longline catches of school shark for fishery monitoring units around the South Island, using data from 2007–08 to 2015–16. For box plot explanation see Figure 39. The horizontal broken line indices the median depth across all records.

5. HISTORICAL AND OTHER CATCHES

No research has been done on the recreational catch since 2012, and this research suggested that annual recreational catches were less than 100 t (Ministry for Primary Industries 2017). Illegal catch has not been quantified. Some discarding is known, but has not been quantified. No quantitative data are available on customary catches, although some pre-European catches are known.

The derivation of the original TACCs for school shark are documented in Ministry of Agriculture and Fisheries (1984). In 1984, there was a perception that school shark was the most important elasmobranch fishery in both tonnage and value but was overfished, and a recommendation was made to reduce catches by 75%, although this was revised in a subsequent review to 50% (MAF unpublished report). Ministry of Agriculture and Fisheries (1985) reports that school shark catch rates had declined in the established fisheries, with the largest declines off New Plymouth and Wanganui Further details are provided in Ministry of Agriculture and Fisheries (1985, 1986). The Southland and Chatham Islands TACs were set based on absolute abundance estimates from trawl surveys (a method later considered to be invalid), with the highest of four survey estimates used. Southland was thought to be a separate stock at the time, and considered less depleted. These perceptions of stock structure and status were reflected in scientific advice at the time of the introduction of the QMS, for example Paul (1988), states that trawl surveys off southern NZ indicated a “reasonably large dispersed stock offshore, which meant that catches here were more likely to be sustainable at recent levels”. The assumption of a separate southern stock in the mid- and late-1980s pre-dated the school shark tagging exercises that showed wide ranging movements around New Zealand and to Australia (Hurst et al. 1999; Francis 2010).

Shark fisheries in the early 1900s are occasionally mentioned in some documents. Mabbett (1977) describes sharks as a staple food, and that it had been for centuries, with "tens of thousands" landed annually. Historical photographs of shark catches around this time suggest that school shark would have been a component of these catches (M. Francis, NIWA, pers. comm.). Matthews (1910) also describes shark catches in the early 1990s of up to 7000 sharks a fortnight (65 per canoe).

The historical school shark fishery is most completely described by Francis (1998). Fishing for school shark was known since the early 1900s (as above), but catches probably remained low until the early 1940s, with liver processing factories established in Auckland in 1942 and Wellington in 1943. Crude estimates of annual catches at this time peaked at around 2500 t, but catches subsequently decreased. In the 1950s, an export market for school shark flesh developed, with catches of around 300–600 t a year between 1957 and 1971, but this market ceased in 1972 because school shark flesh had mercury levels above Australian legal limits. From the late 1970s, annual school shark catches increased dramatically, from around 500 t to 5600 t, as Australian markets reopened, improved fishing technology was available, and fishers tried to establish 'catch histories' for school shark in advance of the introduction of the QMS. The conservative total TACC that was introduced reflected concerns that the recent rapid expansion of the fishery was not sustainable, and that school shark populations were unproductive and therefore at risk (see Blackwell & Francis 2010). Appeals by fishers to the Quota Appeal Authority resulted in the allocation of additional quota to some fishers, leading to an increase in the total TACC to 3106 t by 1995–96. Landings generally followed the TACC upwards, and exceeded the total TACC for the first time in 1995–96. The quantitative historical (pre-QMS) catch history presented in Ministry for Primary Industries (2017) has its origins in Francis & Paul (2013).

6. CPUE ANALYSES

The following sections summarise the results and show the final indices. The extensive figures and tables giving further results and diagnostics for the CPUE models are presented in Appendix B (these Table 8 – Table 23, and Figure 58 – Figure 145).

6.1 Bottom longline – Far North & SCH 1E (N/1E)

This CPUE analysis was accepted in 2018 by the Southern Inshore Stock Assessment Working Group (SINSWG) and the Plenary (Ministry for Primary Industries 2018) with a research rating of '1' (High Quality).

There was good temporal overlap of vessels in the fishery, with about 60–80% of the annual catches retained in the CPUE analysis data set, a trend for events to record fewer sets but more hooks, and a decrease over time in the proportion of trips with zero school shark landings (Figure 58 - Figure 60).

The lognormal model explained 40.3% of the deviance with the predictors fishing year, vessel, target species, and statistical area, and the binomial model 16.0% of the deviance with the predictors fishing year, vessel, and target species (Table 8 and Table 9).

The model diagnostics showed no influential outliers and very good residual patterns; there was, however, some funnelling in the predicted versus fitted values indicating decreasing variance (reducing the veracity of estimated confidence intervals), and the extreme lower tail of the distribution had larger values than expected (Figure 61 and Figure 62). Such diagnostics were considered "good".

The standardisation effect was moderate, and reduced CPUE in the early to mid-2000s (Figure 42), with this effect persistent across all predictors (Figure 63 - Figure 65). The increase in the index was driven by snapper (the majority of the data), and the decline since 2000 was strongest in hapuka/bass;

trends in statistical areas were generally similar, except for those with sparse data (Figure 66 and Figure 67).

The updated lognormal series declines from the early 2000s, where the lognormal index estimated by Starr & Kendrick (2016) was increasing (Figure 43). The effect of combining the lognormal model with the binomial model is to change the declining lognormal series into an overall increasing series (Figure 42).

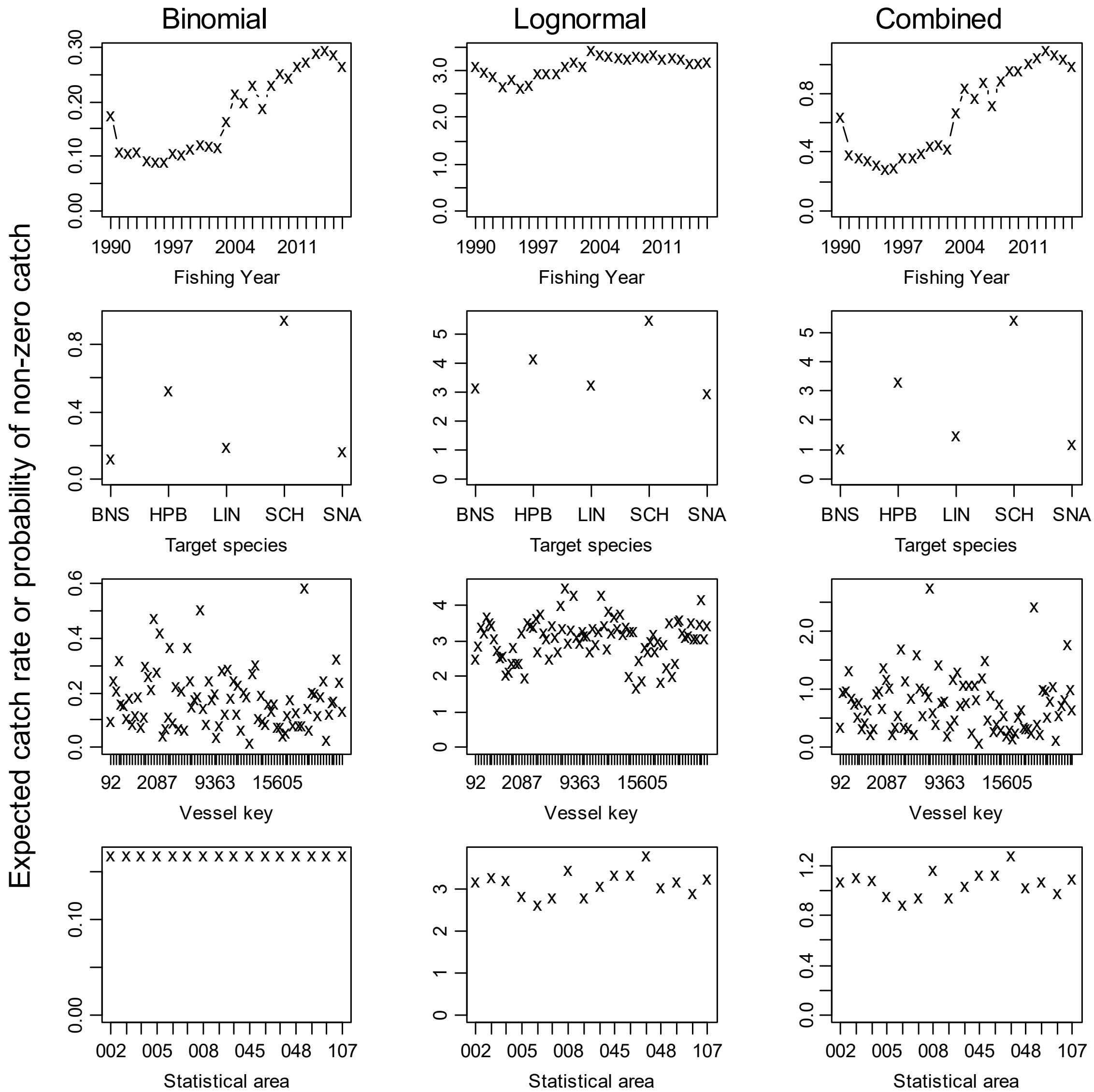

Figure 42: Bottom longline Far North & SCH 1E (N/1E), predicted effects from the binomial, lognormal, and combined models. All predictions made with other predictors set to their median values; a horizontal straight line indicates that the predictor was not selected by the model.

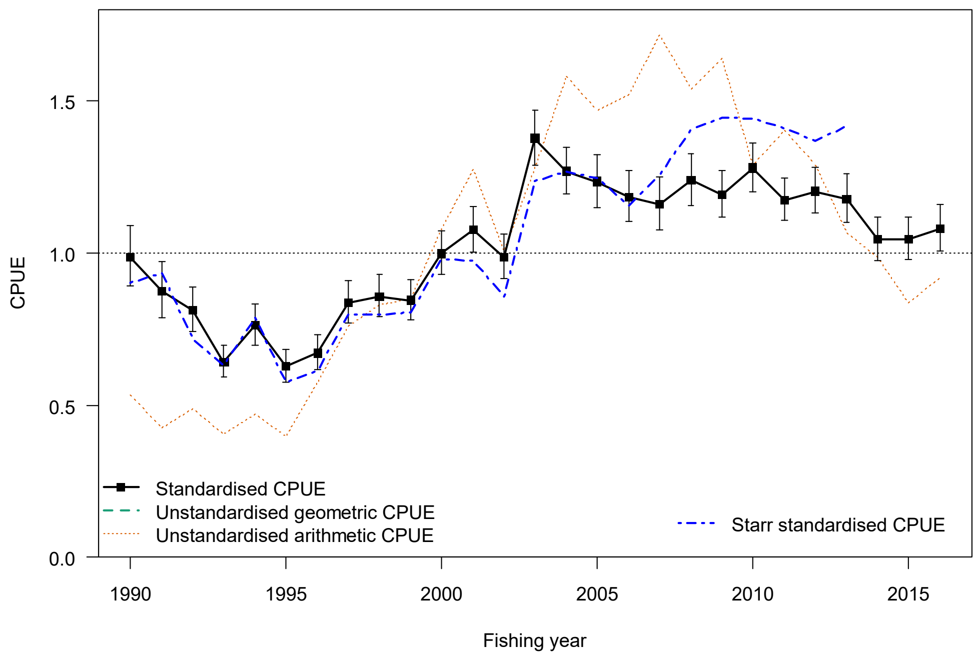

Figure 43: Bottom longline Far North & SCH 1E (N/1E), relative lognormal and unstandardized CPUE indices for school shark.

6.2 Setnet - Far North & SCH 1E (N/1E)

This CPUE analysis was accepted in 2018 by the SINSWG and the Plenary (Ministry for Primary Industries 2018) with a research rating of '1' (High Quality).

There was good temporal overlap of vessels in the fishery, with about 70–95% of the annual catches retained in the CPUE analysis data set, with stable fishery characteristics (Figure 68 – Figure 70).

Only the lognormal model was used to derive the CPUE index (following Starr & Kendrick 2016). The lognormal model explained 59.6% of the deviance with the predictors fishing year, vessel, and target species (Table 10).

The model diagnostics were good (Figure 71). The predicted effects were reasonable (Figure 72). The standardisation effect was moderate, with a reduction in the series in the early to mid-2000s from the vessel effect, and a reduction in CPUE at the start of the index from the target species effect (Figure 73 and Figure 74). The increase in CPUE in the second half of the index was seen, to some extent, in all target species (Figure 75).

The updated lognormal series is relatively high from about 2007, and similar to that estimated by Starr & Kendrick (2016) (Figure 44). For N/1E, the bottom longline index, and lognormal setnet index, were therefore broadly similar, and increased from the early 2000s.

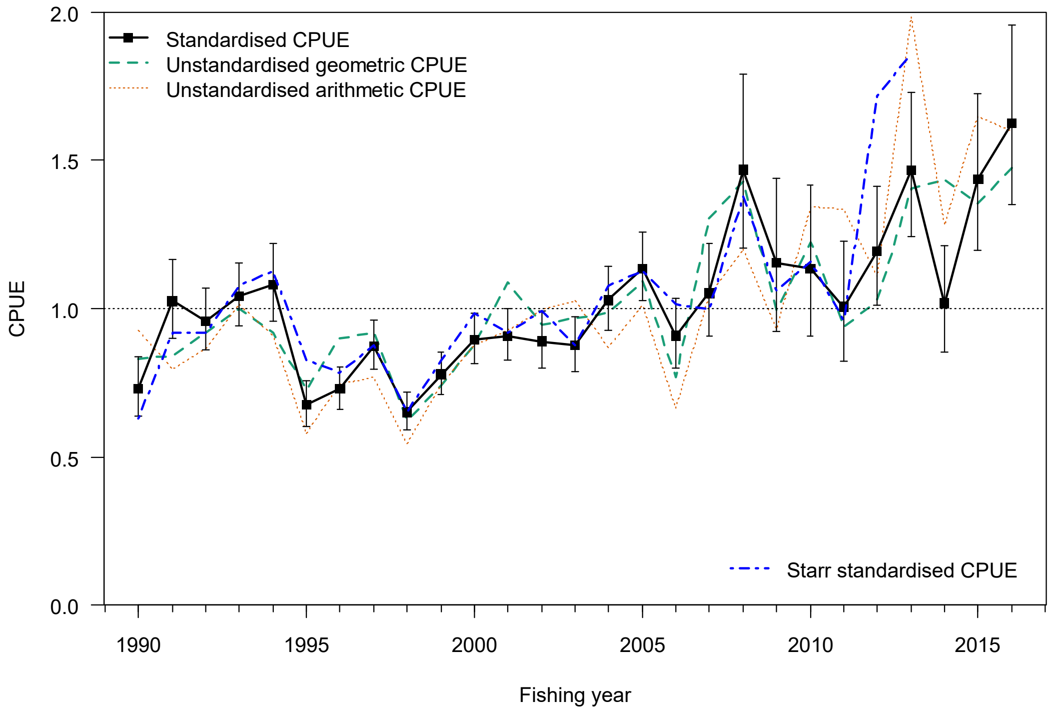

Figure 44: Relative lognormal and unstandardized CPUE indices for school shark N/1E setnet.

6.3 Bottom longline – SCH 2 and top of SCH 3 (2/3N)

This CPUE analysis was rejected in 2018 by the SINSWG and the Plenary (Ministry for Primary Industries 2018), although given a research rating of '1' (High Quality). The rationale for rejecting the index was the conflict with the setnet index for the same area (see Section 6.4).

There was acceptable overlap of vessels in the fishery, with about 80% of the annual catches retained in the CPUE analysis data set, a trend for the number of sets and hooks to increase over time, and a decrease and then increase over time in the proportion of trips with zero school shark landings with the inflection point being in about 2011 (Figure 76 – Figure 78).

The lognormal model explained 29.0% of the deviance with the predictors fishing year, target species, vessel, statistical area, and number of hooks, and the binomial model 10.0% of the deviance with the predictors fishing year, target species, vessel, and target species (Table 11 and Table 12).

The model diagnostics were good (Figure 79 and Figure 80). The standardisation effect was relatively small, with target species and vessel having opposing effects (Figure 81 – Figure 83). The increase in CPUE at the end of the time series was seen in hapuka/bass, but not other species, and similarly the increase in Statistical Area 011 was not seen elsewhere (Figure 84 and Figure 85).

The lognormal index shows a steady decline over time, and the effect of combining the binomial and lognormal models is to introduce a larger decline in the 1990s (Figure 45). The updated lognormal index was, similar to that estimated by Starr & Kendrick (2016), increasing (Figure 46).

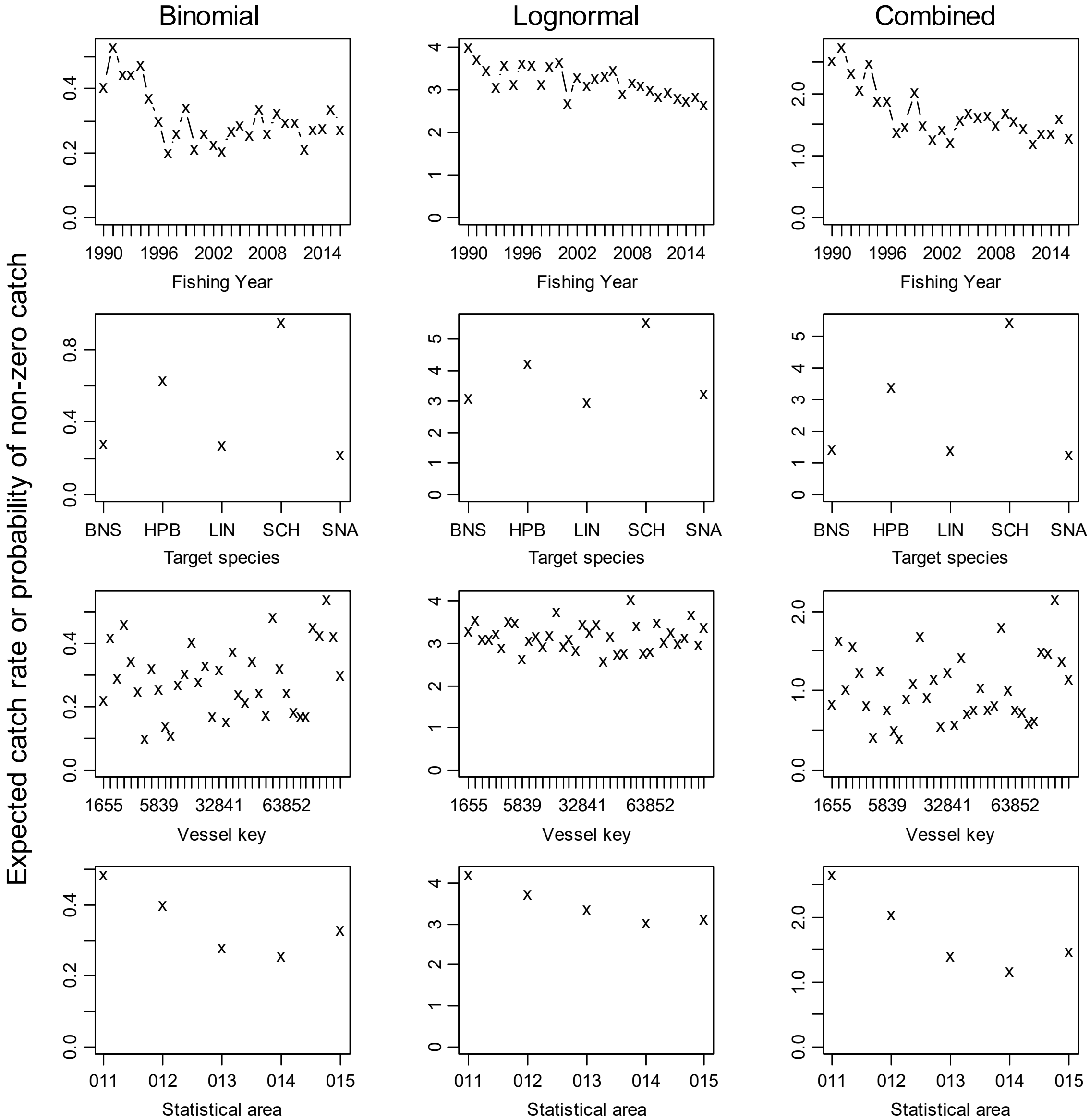

Figure 45: Bottom longline SCH 2 and top of SCH 3 (2/3N), predicted effects from the binomial, lognormal, and combined models. All predictions made with other predictors set to their median values; a horizontal straight line indicates that the predictor was not selected by the model.

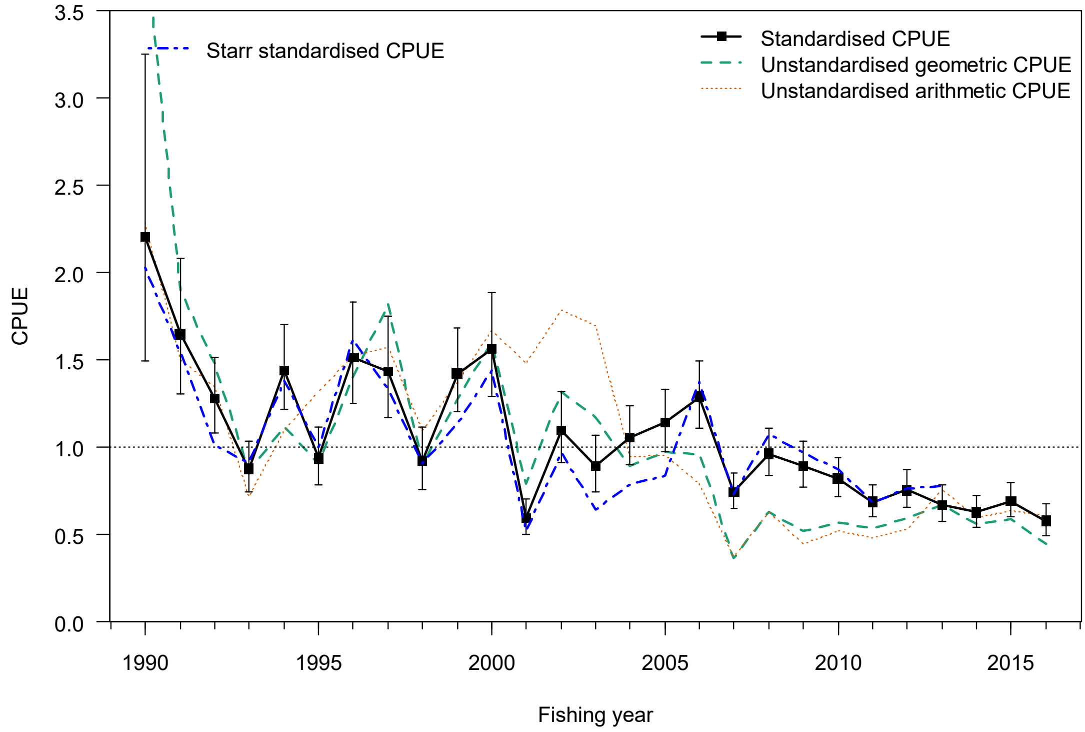

Figure 46: Relative lognormal and unstandardized CPUE indices for school shark 2/3N bottom longline.

6.4 Setnet – SCH 2 and top of SCH 3 (2/3N)

This CPUE analysis was rejected in 2018 by the SINSWG and the Plenary (Ministry for Primary Industries 2018), although given a research rating of '1' (High Quality). The rationale for rejecting the index was that it conflicts with the bottom longline index for the same area (see Section 6.3).

There was acceptable overlap of vessels in the fishery, with about 85% of the annual catches retained in the CPUE analysis data set, and a steady decrease in the proportion of trips with zero school shark landings (Figure 86– Figure 88).

The lognormal model explained 33.1% of the deviance with the predictors fishing year, vessel, target species, and statistical area (Table 13).

The model diagnostics were good (Figure 89). The predicted effects were reasonable, with CPUE decreasing to the south of the region (Figure 90). The standardisation effect was strongest at the start of the series (statistical area), and around 2005 (vessel and target species), but was only moderate overall (Figure 91 – Figure 93). The increasing trend in CPUE was seen, to some extent, in all statistical areas, in rig target fishing, to a lesser extent in warehou and school shark target, but not in moki target fishing (Figure 94 and Figure 95).

The lognormal, index shows a steady increase over time, and was similar to that estimated by Starr & Kendrick (2016) (Figure 47). A combined model was not estimated for 2/3N setnet; although this might be preferable, it would not have mitigated the conflict between this series and the 2/3N bottom longline series (it would have made the conflict worse).

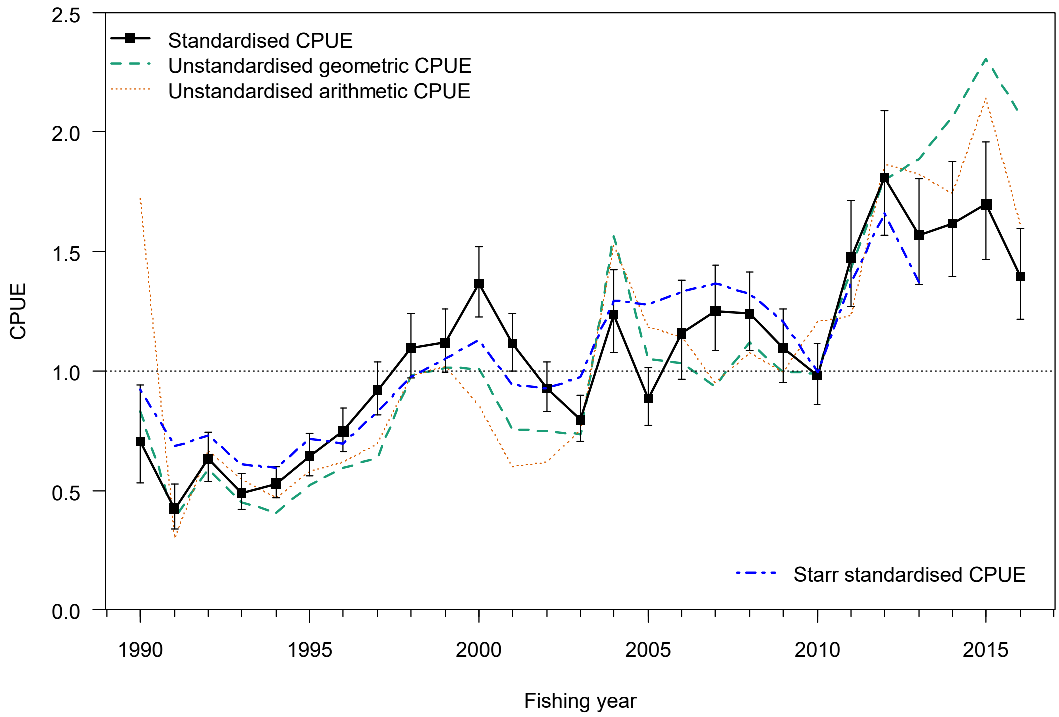

Figure 47: Relative lognormal and unstandardized CPUE indices for school shark 2/3N setnet.

6.5 Bottom longline – SCH4 (SCH 4)

This CPUE analysis was accepted in 2018 by the SINSWG and the Plenary (Ministry for Primary Industries 2018), and given a research rating of '1' (High Quality). Although the index was accepted, it was not considered long enough, nor did it show sufficient trend, for management reference points to be adopted (Ministry for Primary Industries 2018). A longer time series was rejected because it was considered to be compromised by changes to catch and effort reporting (Ministry for Primary Industries 2018).

There was acceptable overlap of vessels in the fishery, with about 80% or more of the annual catches retained in the CPUE analysis data set, a slow decline in the number of hooks used by set, and a steady decrease in the proportion of trips with zero school shark landings that has stabilized since about 2011 (Figure 96 – Figure 98).

The lognormal model explained 36.0% of the deviance with the predictors fishing year, vessel, target species, statistical area, and number of hooks, and the binomial model explained 14.0% with the predictors fishing year, target species, vessel, and statistical area (Table 14 and Table 15).

The model diagnostics were good (Figure 99 and Figure 100). The predicted effects were reasonable, with the combined index influenced strongly by the binomial model (Figure 48). The standardisation had a relatively small effect, with a steady trend from vessel countered by an inverse trend for statistical area (Figure 101 – Figure 103). The temporal trend was generally similar across target species and statistical areas (at least the years of particularly high and low CPUE), except where data were sparse (Figure 104 and Figure 105).

The lognormal index was variable over time with no clear trend, and was similar to that estimated by Starr & Kendrick (2016) (Figure 49).

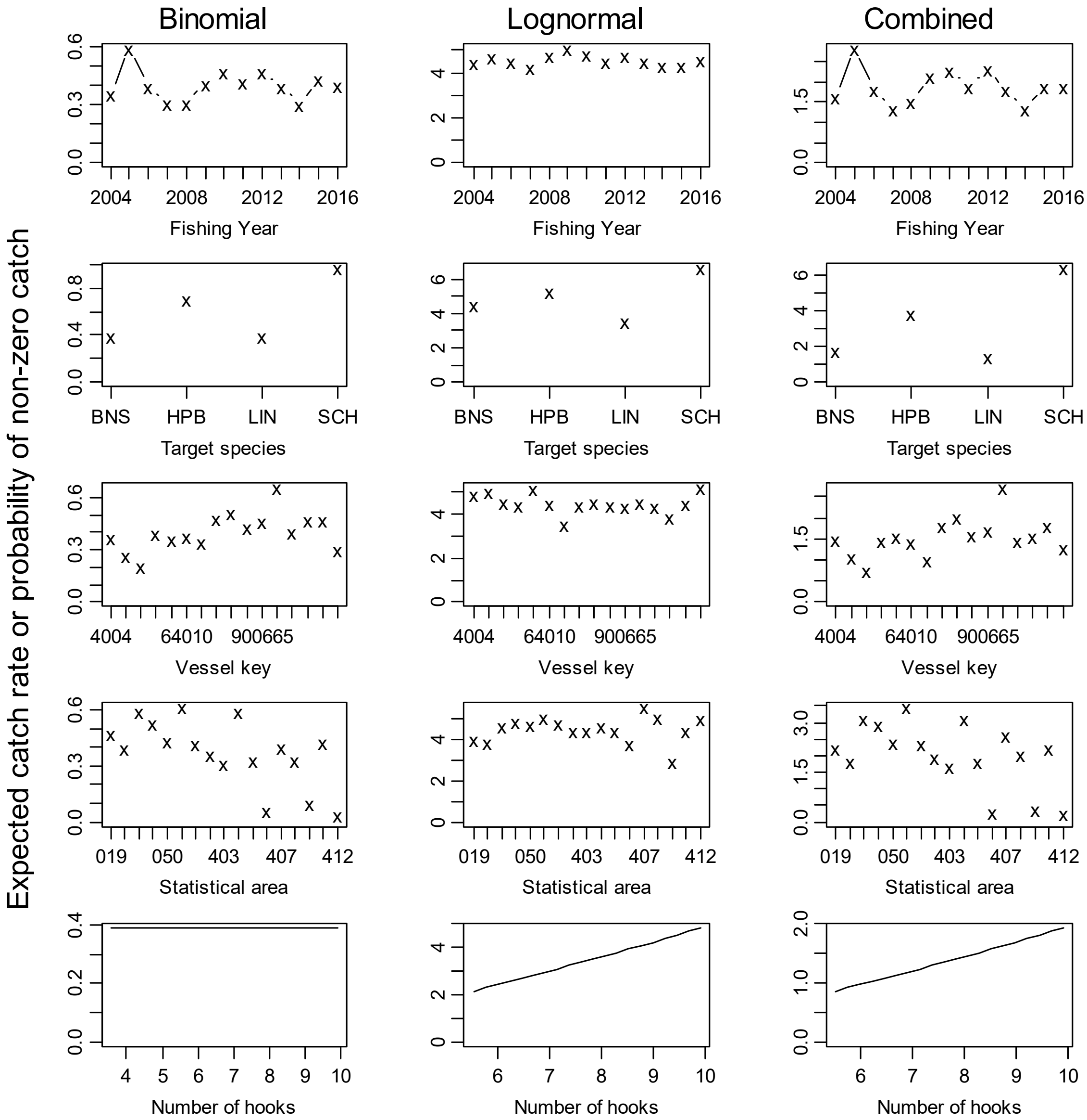

Figure 48: Bottom longline SCH 4, predicted effects from the binomial, lognormal, and combined models. All predictions made with other predictors set to their median values; a horizontal straight line indicates that the predictor was not selected by the model.

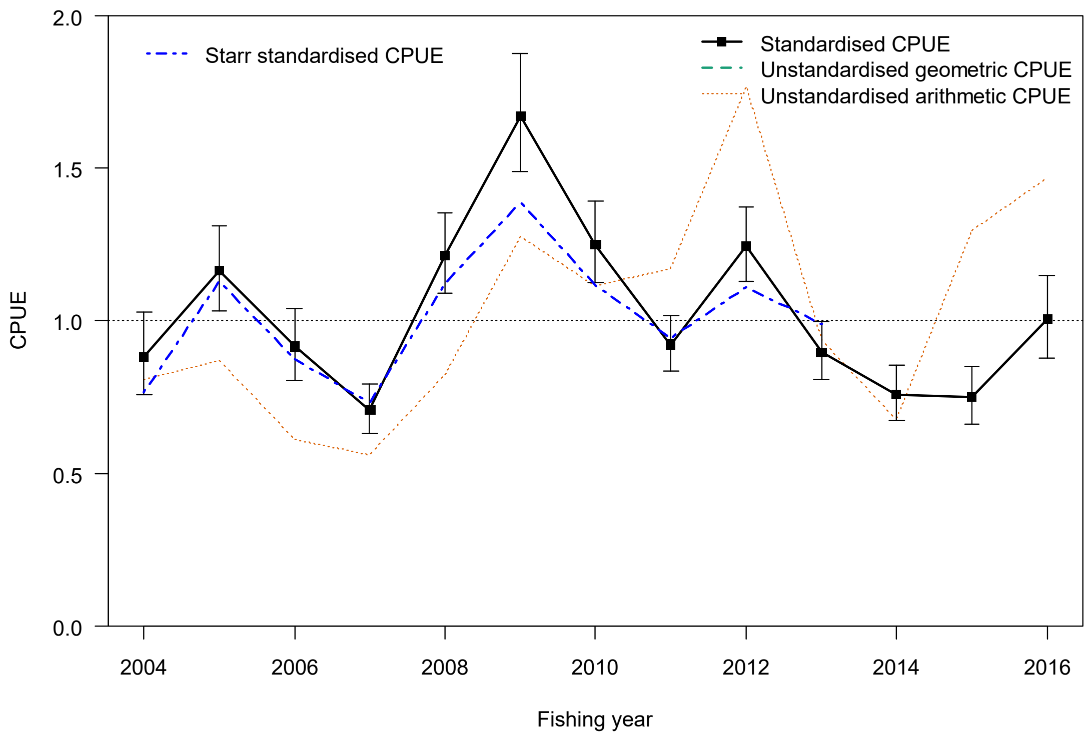

Figure 49: Relative lognormal and unstandardized CPUE indices for school shark SCH 4 bottom longline.

6.6 Bottom longline – Lower SCH 3 & SCH 5 (3S/5)

This CPUE analysis was rejected in 2018 by the SINSWG and the Plenary (Ministry for Primary Industries 2018), and given a research rating of '3' (Low Quality). It was rejected because the series exhibited high variability and therefore no clear trends, and was also informed by a relatively small amount of data (Ministry for Primary Industries 2018).

There was acceptable overlap of vessels in the fishery, the proportion of the annual catches retained in the CPUE analysis data set was variable but tended to increase over time, and there was a steady increase in the number of hooks per set (Figure 106 – Figure 108).

The lognormal model explained 37.0% of the deviance with the predictors fishing year, target species, vessel, statistical area, and number of hooks, and the binomial model explained 11.0% with the predictors fishing year, target species, and vessel (Table 186 and Table 19).

The model diagnostics were good (Figure 109 and Figure 110). The predicted effects were reasonable, with the combined index influenced strongly by the binomial model, and the recent (since about 2000) increasing binomial and decreasing lognormal trends resulting in a stable combined series (Figure 50). The standardisation had a relatively strong effect, in particular hapuka/bass target in 2001, and vessel in 2006, with the standardisation generally increasing the index from the mid-2000s (Figure 111 – Figure 113). Fishing was not continuous for any target species or statistical area, with individual target species and statistical area trends variable and sometimes conflicting (Figure 114 and Figure 115).

The lognormal index was variable over time, and similar to that estimated by Starr & Kendrick (2016) (Figure 51).

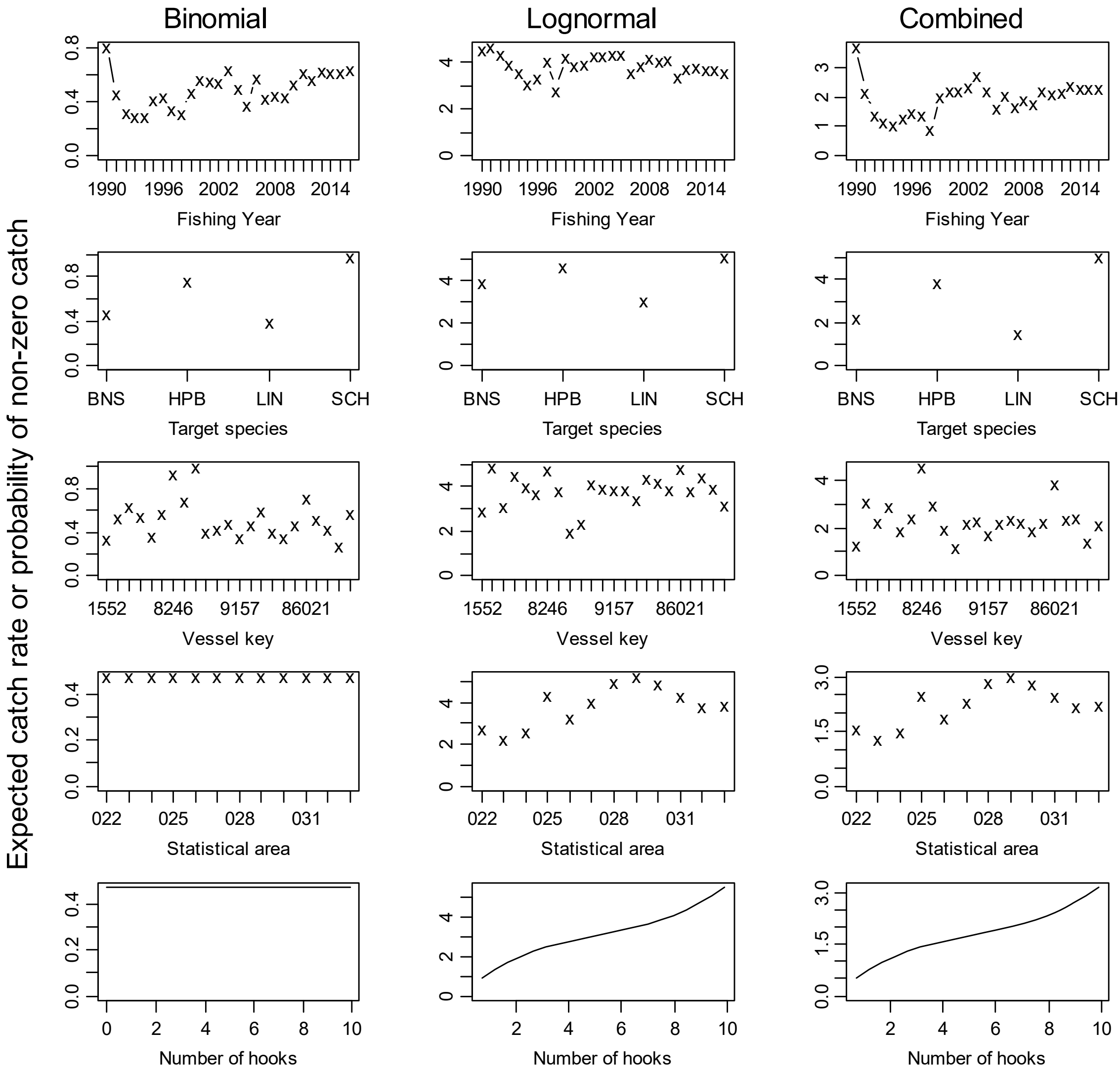

Figure 50: Bottom longline Lower SCH 3 & SCH 5 (3S/5), predicted effects from the binomial, lognormal, and combined models. All predictions made with other predictors set to their median values; a horizontal straight line indicates that the predictor was not selected by the model.

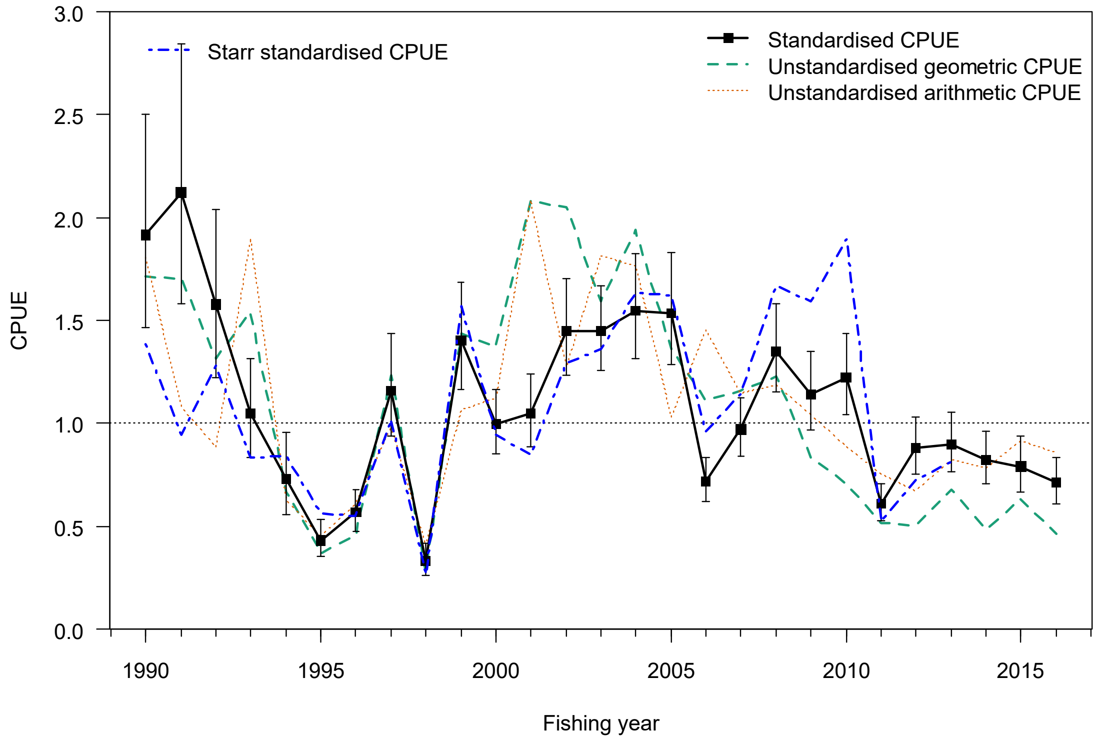

Figure 51: Relative lognormal and unstandardized CPUE indices for school shark 3S/5 bottom longline.

6.7 Setnet – Lower SCH 3 & SCH 5 (3S/5)

This CPUE analysis was accepted in 2018 by the SINSWG and the Plenary (Ministry for Primary Industries 2018), and given a research rating of '1' (High Quality). The series accepted in 2018 was from the combined model; the index was previously accepted as a lognormal-only series (Starr & Kendrick 2016).

There was good overlap of vessels in the fishery, the proportion of the annual catches retained in the CPUE analysis data set was high and generally over 80%, there was a slow decline in the proportion of sets with zero school shark catch, and an otherwise stable fishery (Figure 116 – Figure 118).

The lognormal model explained 59.8% of the deviance with the predictors fishing year, target species, vessel, and statistical area, and the binomial model explained 17.0% with the predictors fishing year, vessel, and target species (Table 18 and Table 19).

The model diagnostics were good, although the lognormal model was not predicting the extreme small catches well (Figure 119 and Figure 120). The predicted effects were reasonable, with both the binomial and lognormal series indicating relatively low CPUE since about 2000 (Figure 52). The standardisation had a fairly strong effect, with a vessel effect that changed a flat or increasing trend into a decreasing trend, a statistical area effect that caused the series to decrease from the mid-2000s, and a relatively strong influence from spiny dogfish target fishing (Figure 121 – Figure 123).

The decreasing trend in the lognormal series was seen across all target species, and all statistical areas (Figure 124 and Figure 125). The lognormal index was similar to that estimated by Starr & Kendrick (2016) (Figure 53).

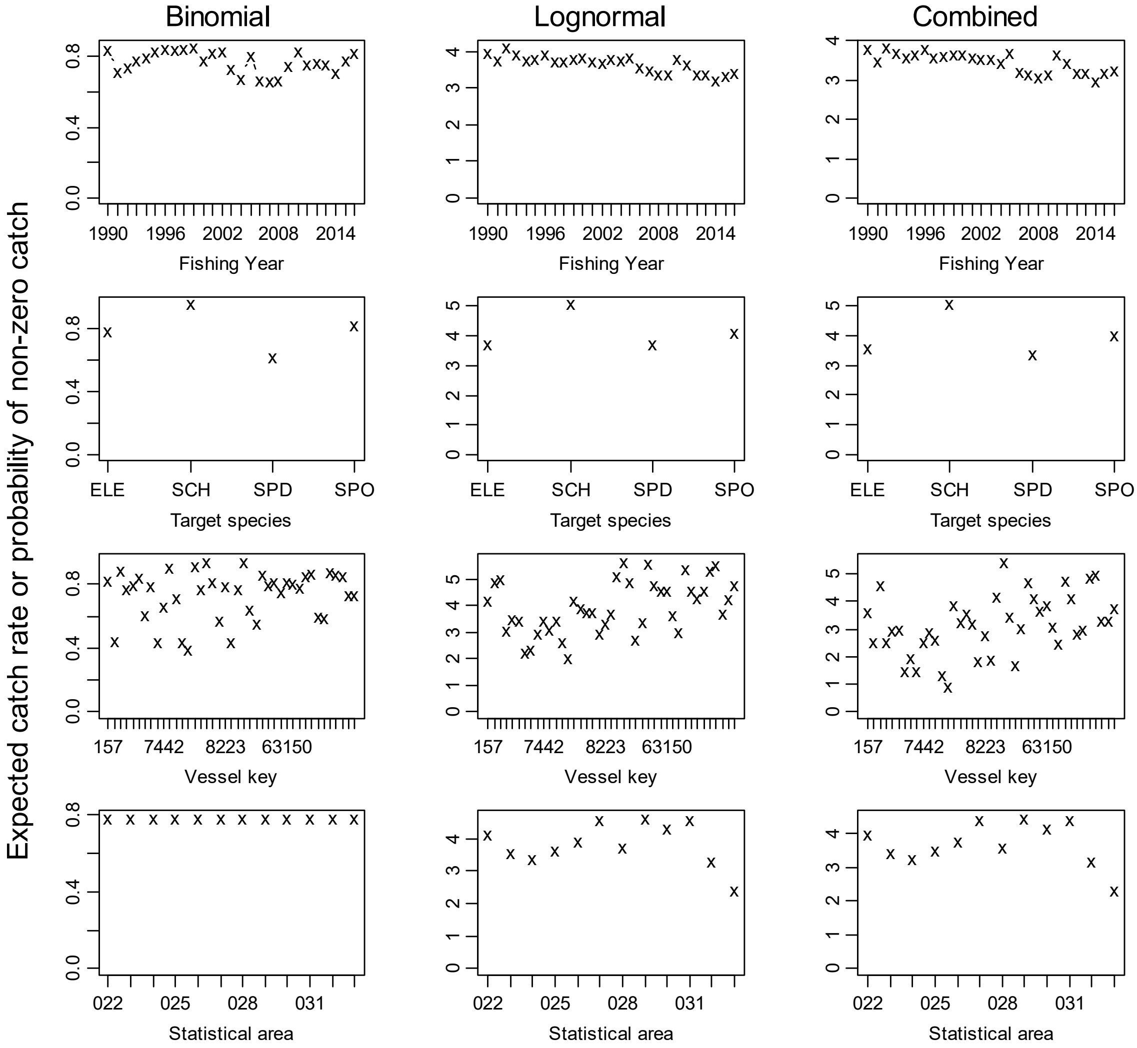

Figure 52: Setnet Lower SCH 3 & SCH 5 (3S/5), predicted effects from the binomial, lognormal, and combined models. All predictions made with other predictors set to their median values; a horizontal straight line indicates that the predictor was not selected by the model.

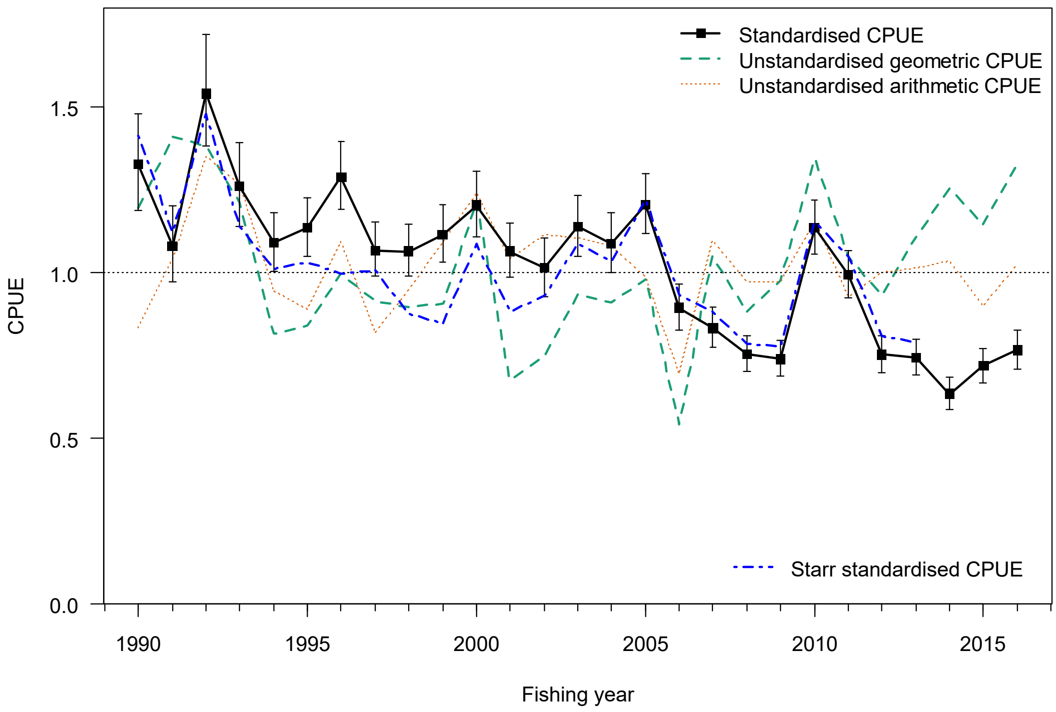

Figure 53: Relative lognormal and unstandardized CPUE indices for school shark 3S/5 setnet.

6.8 Bottom longline – SCH 7, SCH 8 & Lower SCH 1W (7/8/1W)

This CPUE analysis was accepted in 2018 by the SINSWG and the Plenary (Ministry for Primary Industries 2018), and given a research rating of ‘1’ (High Quality).

There was good overlap of vessels in the fishery, the proportion of the annual catches retained in the CPUE analysis data set was about 70%, there was a slow decline in the proportion of sets with zero school shark catch until about 2011, after which it slowly increased, and there was a temporal trend towards fewer sets with more hooks (Figure 126 – Figure 128).

The lognormal model explained 52.6% of the deviance with the predictors fishing year, target species, vessel, number of hooks, and statistical area, and the binomial model explained 24.0% with the predictors fishing year, target species, and vessel (Table 20 and Table 21).

The model diagnostics were good (Figure 129 and Figure 130). The predicted effects were reasonable, with the lognormal series showing a steady temporal trend, but the binomial increasing, such that the combined series increased (Figure 54). The standardisation had a moderate effect, with the greatest influence at the start of the time series, where the standardisation reduced the relatively high CPUE (Figure 131 – Figure 133).

The peak in CPUE in the middle of the time series was seen in all target species and statistical areas, and a recent increase in CPUE was seen only in hapuka/bass and Statistical Areas 037 and 039, with recent CPUE decreasing in 018, 035, and 038 (Figure 134 and Figure 135). The lognormal index was similar to that estimated by Starr & Kendrick (2016), except that an increase in CPUE from about 2010 estimated by Starr & Kenrick (2016) was not seen in the updated series (Figure 55).

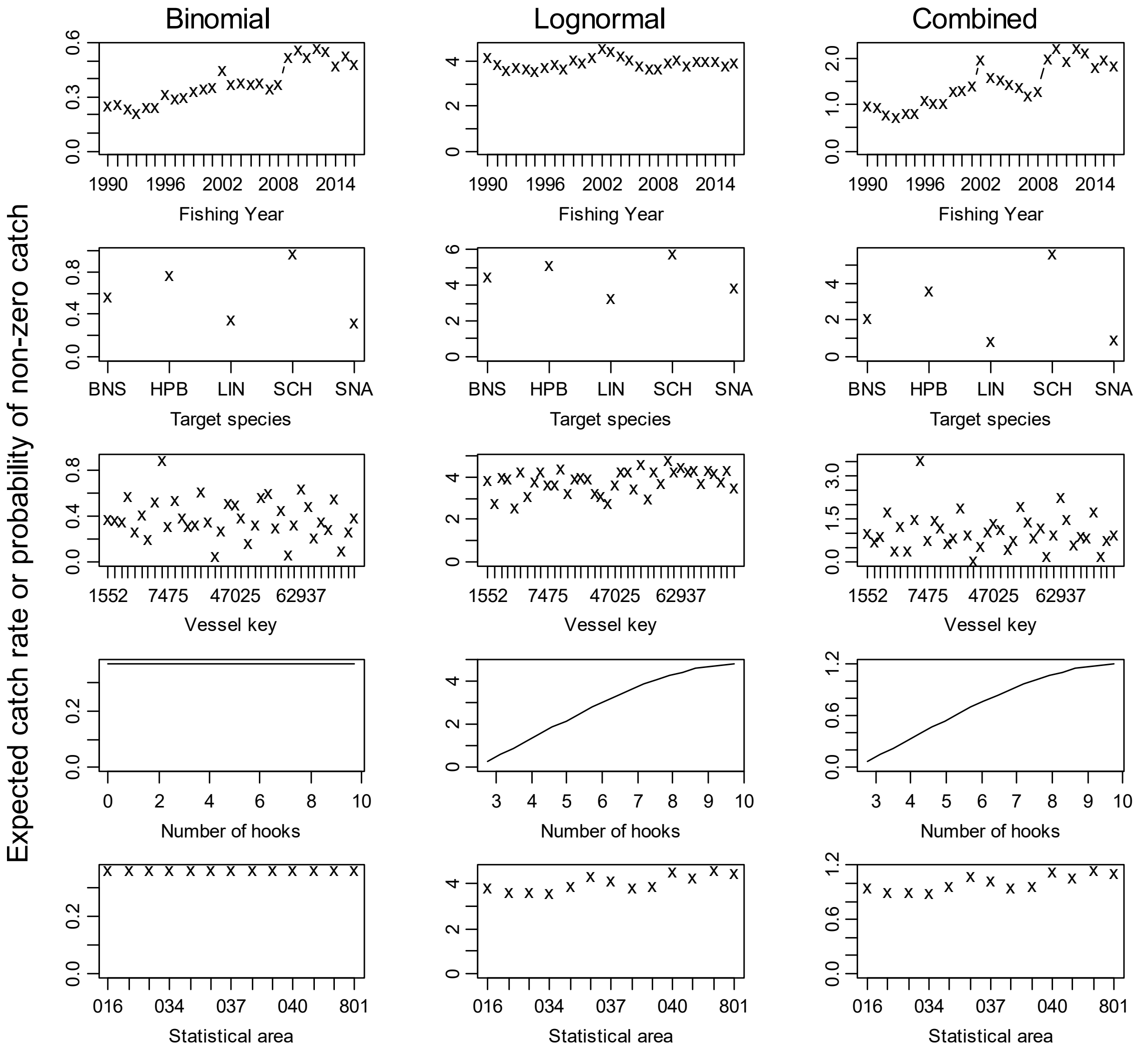

Figure 54: Bottom longline, SCH 7, SCH 8 & Lower SCH 1W (7/8/1W) and predicted effects from the binomial, lognormal, and combined models. All predictions made with other predictors set to their median values; a horizontal straight line indicates that the predictor was not selected by the model.

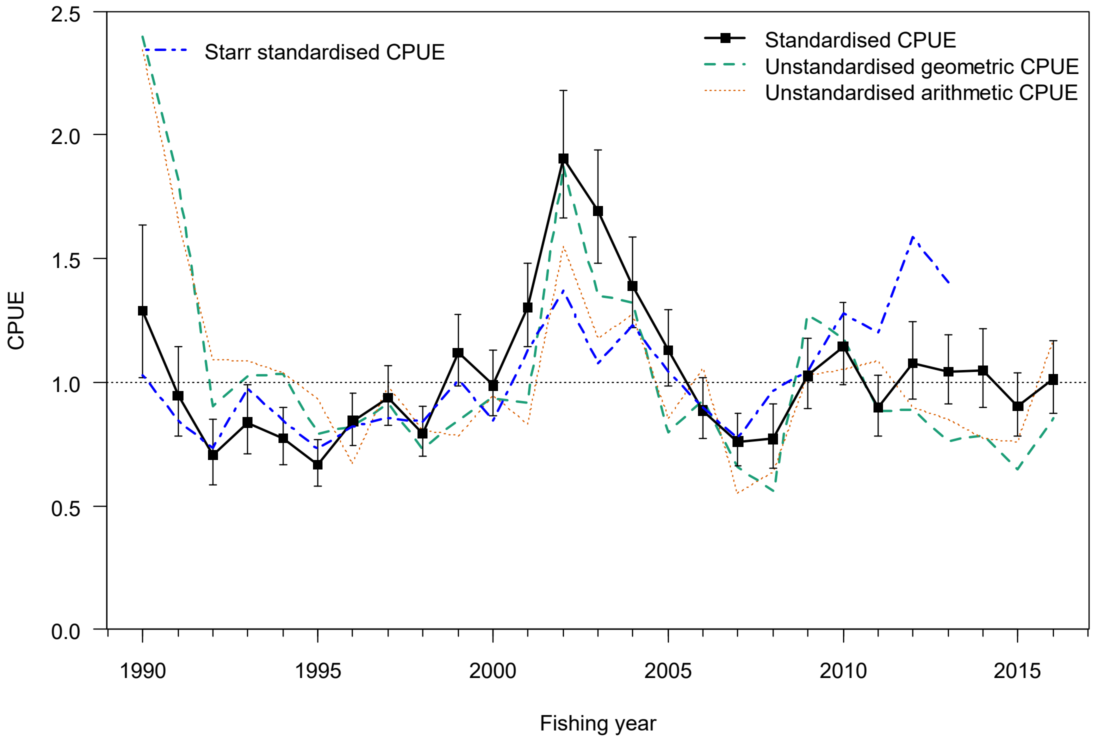

Figure 55: Relative lognormal and unstandardized CPUE indices for school shark 7/8/1W bottom longline.

6.9 Setnet – SCH 7, SCH 8 & Lower SCH 1W (7/8/1W)

This CPUE analysis was accepted in 2018 by the SINSWG and the Plenary (Ministry for Primary Industries 2018), and given a research rating of '1' (High Quality).

There was good overlap of vessels in the fishery, the proportion of the annual catches retained in the CPUE analysis data set was 80% or more, there was a drop in the proportion of sets with zero school shark catch early 2000s, and the fishery was otherwise stable (Figure 136 – Figure 138).

The lognormal model explained 44.3% of the deviance with the predictors fishing year, target species, vessel, and statistical area, and the binomial model explained 24.0% with the predictors fishing year, target species, and statistical area (Table 22 and Table 23).

The model diagnostics were acceptable (Figure 139 and Figure 140). The predicted effects were reasonable, with the lognormal series showing a steady temporal trend, but the binomial increasing, such that the combined series increased (Figure 56). The standardisation had a large influence, turning a largely flat early series into a decreasing trend, and a recent increasing trend into a flat series. The target species was most influential in creating this effect, with the recent reduction in CPUE also brought about by a vessel effect; there was good overlap between vessels, but nevertheless a change in the predominant vessels in the fishery in the early 2000s (Figure 141 – Figure 143).

The CPUE trends for specific target species and statistical areas were mixed, with some statistical areas having a recent decreasing trend (e.g., 034), whereas others were essentially flat (e.g., 039), and others increasing (e.g., 036) (Figure 144). There were temporal gaps in the time series for specific target species, and whilst all showed the initial decline in CPUE (to varying extents), there was substantial inter-annual variability in the indices (Figure 145).

The lognormal index was similar to that estimated by Starr & Kendrick (2016) (Figure 57).

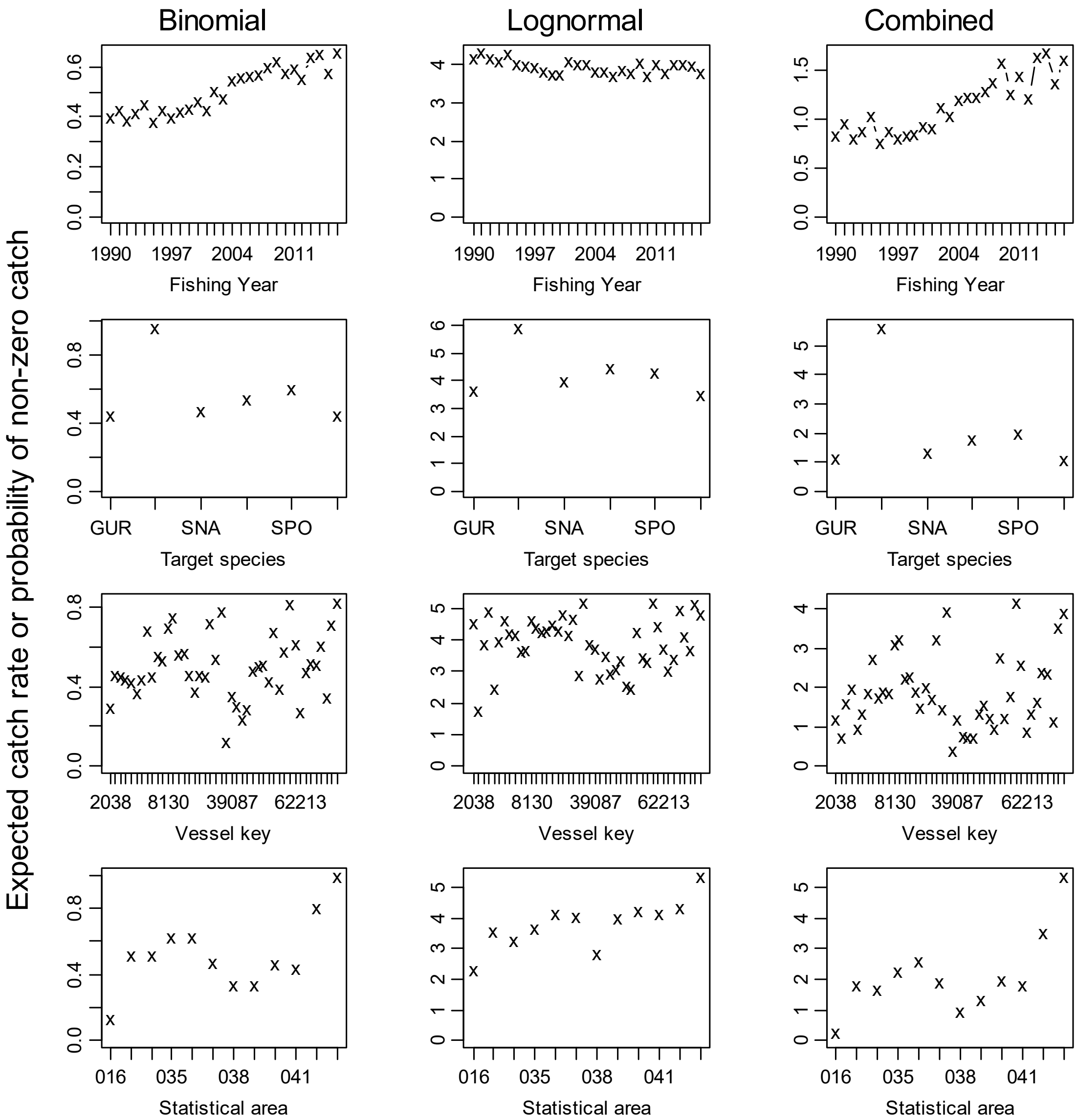

Figure 56: Setnet, SCH 7, SCH 8 & Lower SCH 1W (7/8/1W). predicted effects from the binomial, lognormal, and combined models. All predictions made with other predictors set to their median values; a horizontal straight line indicates that predictor was not selected by the model.

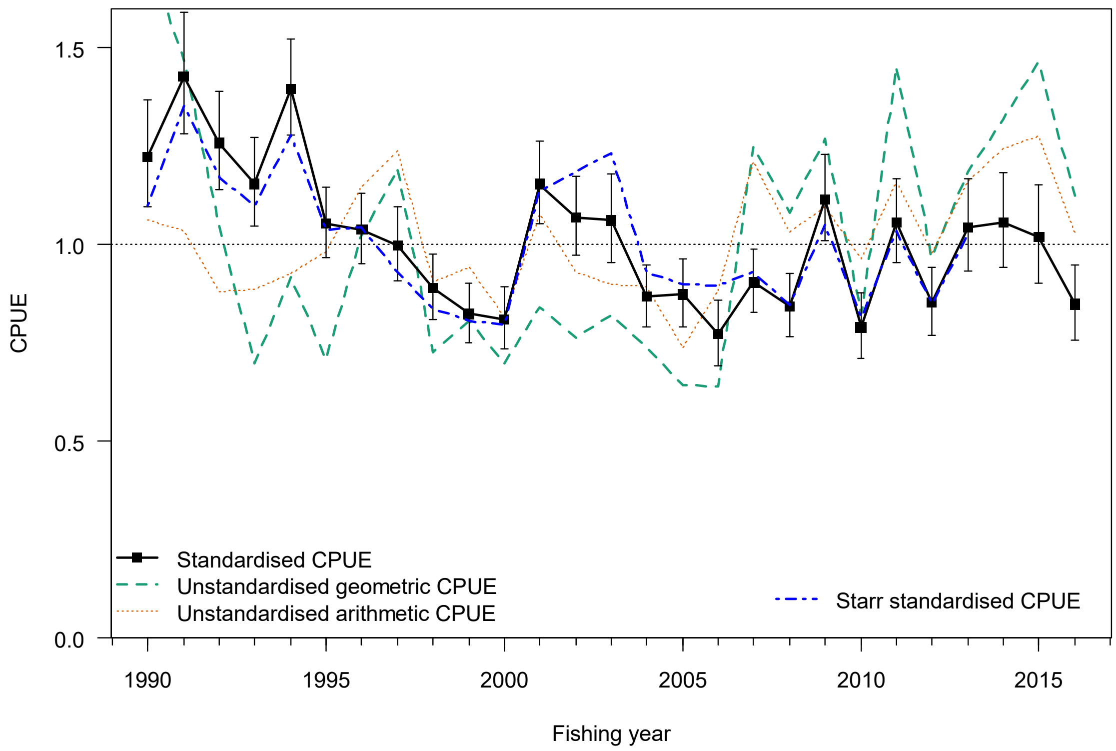

Figure 57: Relative lognormal and unstandardized CPUE indices for school shark 7/8/1W setnet.

7. DISCUSSION

The school shark characterisation was relatively complex, having numerous monitoring units, because of the broad distribution of the species around New Zealand, and the multiple gears used to target and catch school shark. Bottom trawl CPUE was previously rejected because it was not a large fishery (overall, in terms of school shark catch), and because of a perception that trawls did not catch larger school shark (Ministry for Primary Industries 2017). The 2018 analyses suggested that trawls did catch larger fish, and trawl CPUE indices may therefore be worthy of future investigation, especially for areas such as 2/3N where the bottom longline and setnet CPUE series conflicted.

Additional length samples from commercial catches were collected under the school shark Adaptive Management Programme; it would be prudent to locate and add these samples to future analyses.

A previous conflict between CPUE series for bottom longline and setnet occurred for 7/8/1W, but in the 2018 analyses this was mitigated by using the delta-lognormal approach, with which both series showed similar combined-series trends. The delta-lognormal approach is currently preferred for inshore fisheries CPUE analyses (Ministry for Primary Industries 2018), but is different from the lognormal-only models used in the previous school shark setnet CPUE analyses (Starr & Kendrick 2016). In many CPUE series, the dominant influence on the combined index was from the binomial model (catch or not). This component of the data therefore warrants careful consideration. Analyses of the event-based data available from about 2008 could be helpful in this regard.

Some differences between the 2018 CPUE series and those previously estimated were found (Starr & Kendrick 2016). The differences were unexpected, and detailed analyses of data and methodology were conducted to try and establish the cause. This curtailed the research time and intended scope of this project. The analyses were presented to the SINSWG on 21 December 2017 and 24 April 2018. A number of potential issues were examined, particularly concerning allocation of target species to trips, where changes in assumptions would result in the inclusion or exclusion of the record from the CPUE data set (because target species was a selection criterion). The approach taken to data grooming for the analyses described in this report was accepted by the SINSWG, and is detailed here in Appendix A.

Future analyses might (a) attempt to resolve the conflict between indices for 2/3N, which might include more detailed spatial and temporal analyses of these data, estimating compositions (length, sex) of the catches, and additional CPUE analyses (trawl); (b) if that is successful, then it may be possible to move towards a whole-of-New-Zealand CPUE index, which will require consideration of appropriate weighting of subareas, and an assumption of stock structure (whilst a whole-of-New Zealand index would be consistent with the single stock currently assumed, it might reduce or remove the ability to examine and respond to regional trends, and could therefore be considered to be less precautionary).

For both bottom trawl surveys and observer samples, the variability in catch composition by length and sex, for the same area and adjacent years, suggested that the population was stratified by size and sex, and that spatial availability of these population components might be dynamic. As a result, the available catch samples, although potentially representative of the catch and indicating some large-scale distributional patterns, seem unlikely to be representative of the overall population structure. Nevertheless, the samples suggested that smaller fish (including neonates) may be found most frequently around the north of New Zealand, larger fish including the greatest proportion of mature females may be found to the south, and intermediate sized fish were found in between.

This document provides background information to the assessment of school shark for 2018. The use of the CPUE indices, including the derivation of Bmsy- and Fmsy-proxy reference points, and subsequent conclusions on the status of the stocks, are described in Ministry for Primary Industries (2018).

8. ACKNOWLEDGMENTS

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APPENDIX A

The CPUE data processing and grooming are summarised below:

1. The data request was specified to be the same as the previous analysis (Starr & Kendrick 2016; possible because the MPI extract number was reported in that FAR).

2. Landings data were groomed:

- Best dates were determined (form dependent)

If landing date was missing or logically flawed (e.g., before start date) use the end date.
If end date missing can replace with landings date.
If trip length too long (>95% quantile) and not apparently a reversal of fields, then set to NA.

- Landings data were imputed for missing records as follows:

If the green_weight was missing then green_weight = conv_factor*unit_num*unit_weight.
If the conv_factor was missing it was imputed with the median of all other conv_factors reported within the same year and for the same state_code, (with a switch added so the user can choose to replace it with a value of 1)
Green_weights were adjusted for state_codes DRE and HGU, i.e., green_weight = green_weight *1.95/conv_factor for DRE and green_weight = green_weight *1.85/conv_factor for HGU.
Landings were excluded if their destination_codes were 'B', 'D', 'P', 'Q', 'R', 'T', 'J' and 'NP'.

3. Estimated catch treatment

- Estimated catch records for each event for the top 5 or top 8 species were ranked in terms of estimated weight, in descending order.
- The estimated catches for top 6 to 8 species were excluded to make the estimated catch records consistent for all fishing years 1989–90 to 2015–16 (for the CPUE analyses).

4. Effort data grooming

- Exclude all trips that reported multiple primary_methods (user can choose not to exclude).
- Exclude all trips reporting on multiple form_types (user can choose not to exclude).
- Allocate start_stats_area_codes to records that have missing start_stats_area_codes given reported start_latitude and start_longitude positions and statistical area boundary polygon data.
- Link estimated catches of school shark and their species rank to the effort data by event_key.
- Roll up event level records to a trip-day level (combinations of trip_id and start_date [event start_date not trip_start_date]), as follows:

Sum up numeric variables reported for all events occurring by trip/start_date combination, i.e., estimated school shark catch, effort_num, total_net_length, total_hook_num, fishing_duration, etc.
Allocate the categorical codes reported most frequently for a trip/start_day combination, i.e., target_species and start_stats_area_code. When a draw occurs (equal count for two or more categorical code), the categorical variable can be chosen as that with the greatest catch, or where no estimated catch occurred, by effort. The user can also choose on the basis of alphabetic order; this was actually used in this CPUE analysis, for the purpose of being consistent with what was reported by Starr & Kendrick (2016).

5. Linking landed green weight to effort

Determine and exclude effort from ambiguous stocks (e.g., effort in stat-area 018 and landing in stocks SCH 2 and 3).

- Exclude effort records with no matching landings at the stock-trip level.
- Aggregate estimated school shark catches at the stock-trip level (est_sch_total).
- Green_weight proration proportions calculated for each trip-day.

If est_sch_total > 0, prorate = est_sch/est_sch_total.

If est_sch_total = 0, prorate = effort/effort_total. When primary_method = SN, effort = total_net_length and when primary_method is among BLL, BPT, BT or others, effort = effort_num.

- Aggregate landing green_weights to stock-trip to make sure each stock-trip has only one green_weight.
- Link landing green_weights to effort data by stock-trip.
- Calculate prorated school shark green_weights, green_sch = prorate*green_weight.

6. Data range checking and outlier treatment

- Across all records for a fish_stock, identify core set of target species and retain associated records. Sort target species by catch and retain all target species for BLL, and retain top 20 target species for SN.
- Check and exclude catch outliers for each trip-start_date record: calculate log(catch) and the median and standard deviation of log(catch) separately for all combinations of primary_method, form_type and vessel_id; and deem all records with catches greater than the median + 3.5 standard deviations as outliers, which are discarded (deleted). We used this method because we were unable to reproduce the results of the method described in Appendix E of Starr & Kendrick (2016).
- Check and impute effort values separately for each primary_method and form_type combination. This is done with considered plausible effort range(s), from expert knowledge and examination of the frequency distribution of effort. Effort medians by vessel_ids were calculated, and any effort values that were outside of the specified ranges were replaced with their corresponding vessel medians. Where the imputed median was also out of range, the field was replaced with an NA (thereby excluded from CPUE analyses).

APPENDIX B

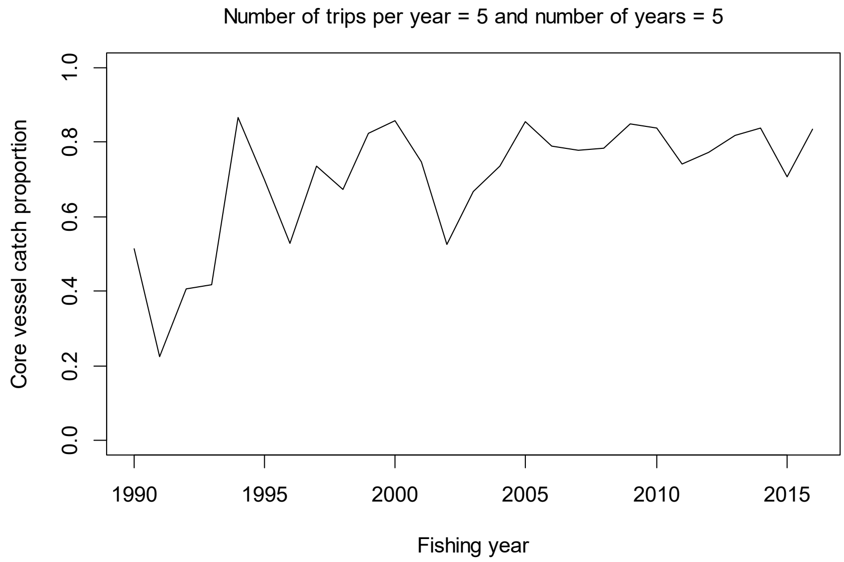

Figure 58: Proportion of catch included in the school shark N/1E bottom longline CPUE data set, after application of the data selection criteria, by fishing year.

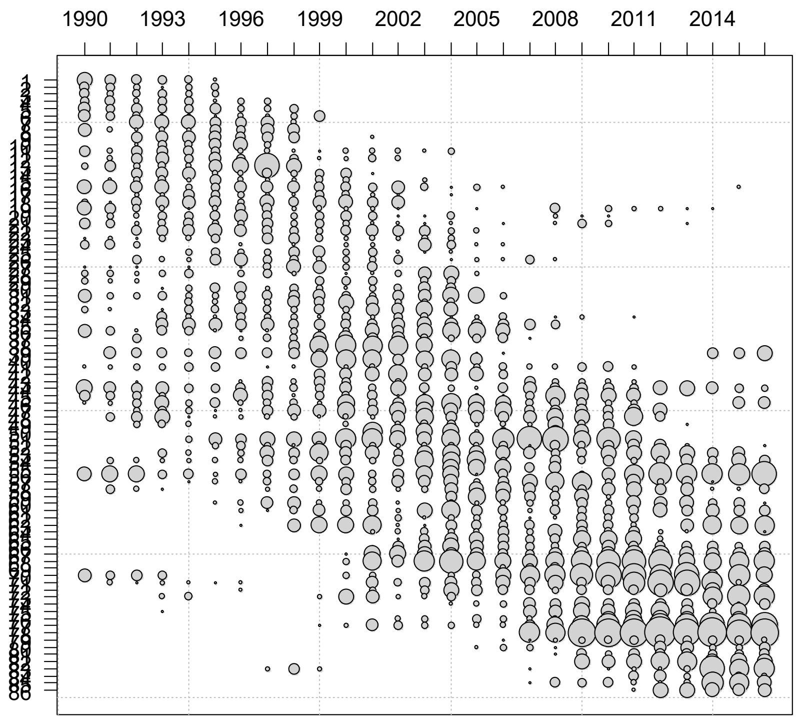

Figure 59: Core vessel summary by fishing year for school shark N/1E bottom longline. Bubble size proportional to effort by each vessel, normalised within each fishing year.

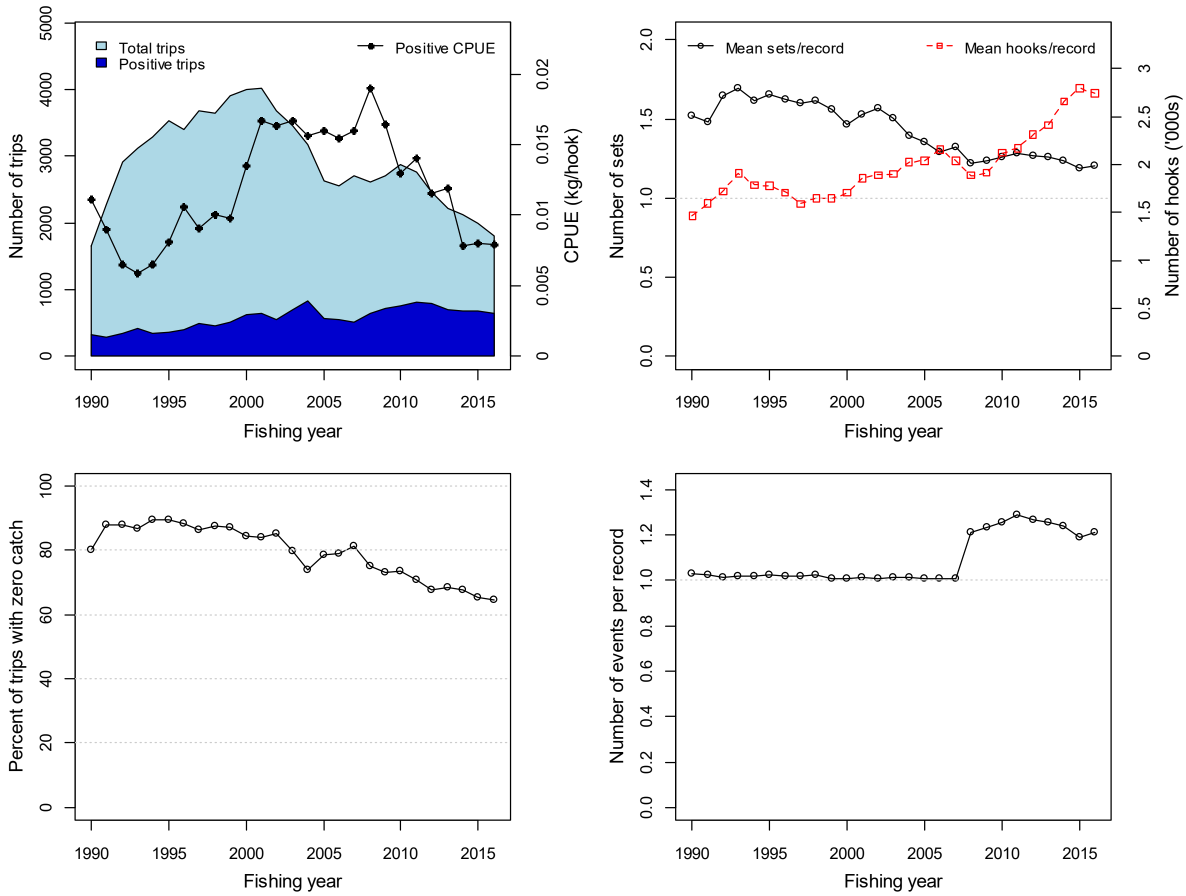

Figure 60: Core vessel summary plots by fishing year for school shark N/1E bottom longline: upper left panel, total trips (light blue) and trips with school shark catches (dark blue), overlaid with median annual arithmetic CPUE for all trips with positive catch; upper right panel, mean number of sets and mean number of hooks per set per daily effort-effort-stratum record; lower left panel, proportion of trips with no catch of school shark; lower right panel, mean number of events per daily-effort-stratum record.

Table 8: School shark N/1E bottom longline - Selected predictors for the lognormal CPUE model, showing the total and additional deviance explained.

Predictor	df	Total Dev. Expl. (%)	Additional Dev. Expl. (%)
Fishing year	26	4.6	4.6
Vessel	85	32.4	27.8
Target species	4	38.0	5.6
Statistical area	15	40.3	2.3

Table 9: School shark N/1E bottom longline - Selected predictors for the binomial CPUE model, showing the total and additional deviance explained.

Predictor	df	Total Dev. Expl. (%)	Additional Dev. Expl. (%)
Fishing year	26	3.6	3.6
Vessel	85	13.0	9.3
Target species	4	16.0	2.7

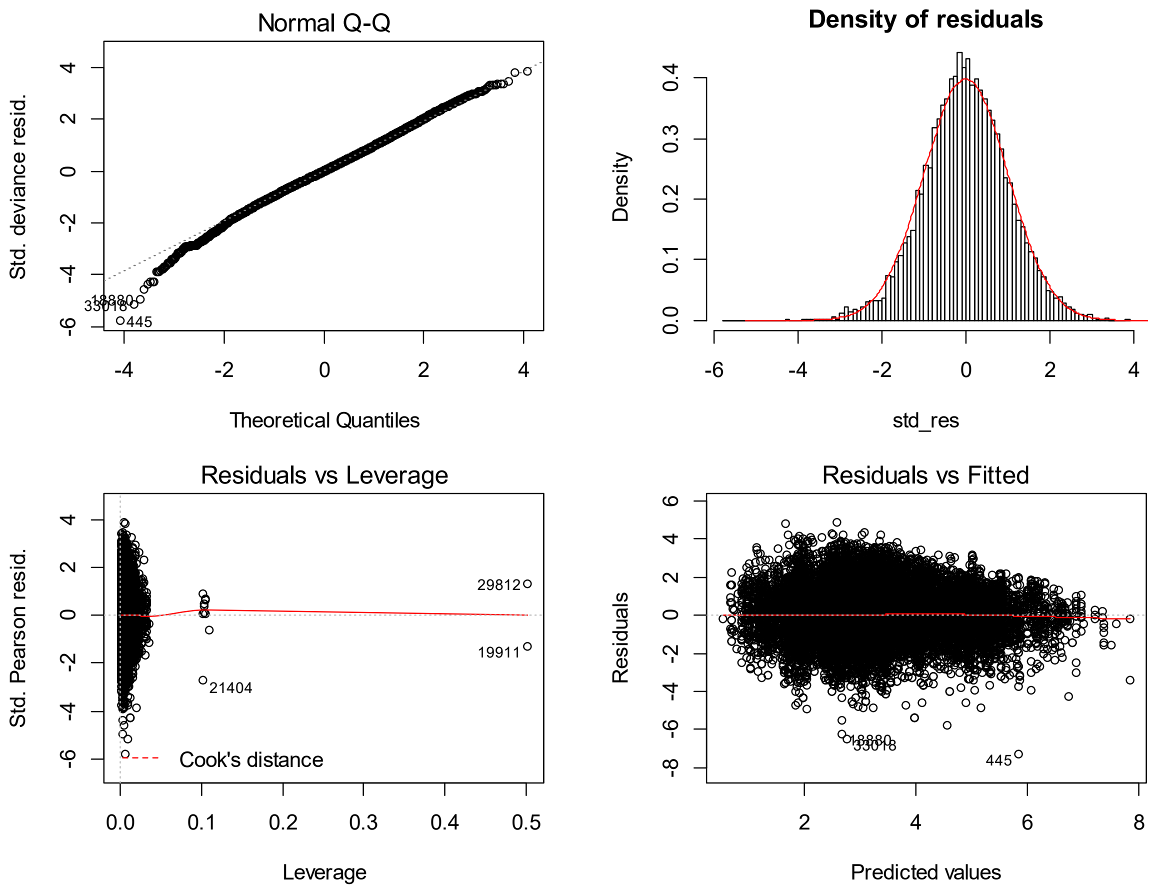

Figure 61: Diagnostic plots for the fit of the lognormal model for school shark N/1E bottom longline. Upper left panel, q-q plot of standardised residuals; upper right panel, histogram of standardised residuals compared to lognormal distribution (red line); lower left panel, residuals versus leverage plot; lower right panel, standardised residuals plotted against the predicted model catch.

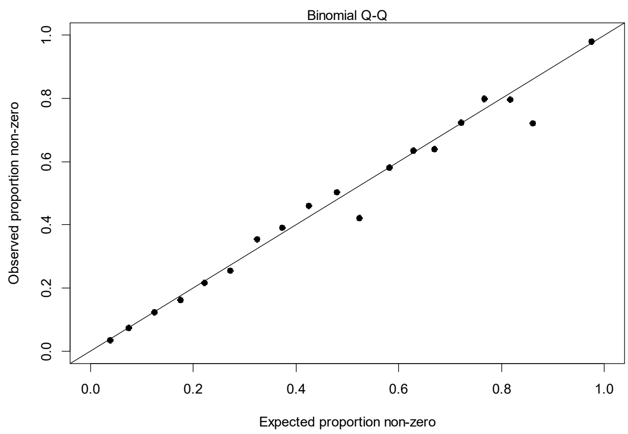

Figure 62: School shark N/1E bottom longline, diagnostic (q-q) plot for the binomial model.

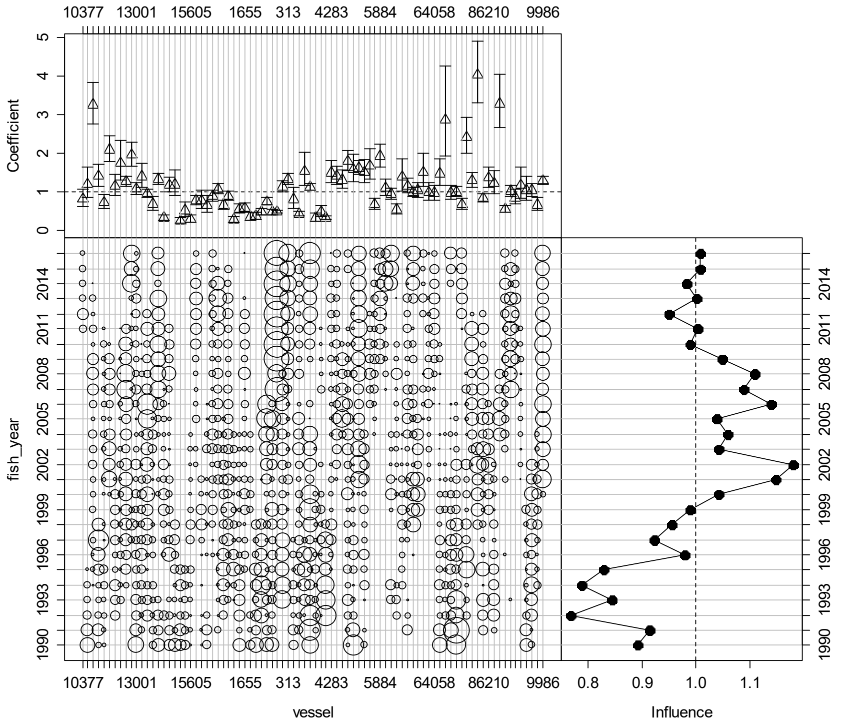

Figure 63: Vessel influence plot for the lognormal model for school shark N/1E bottom longline. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

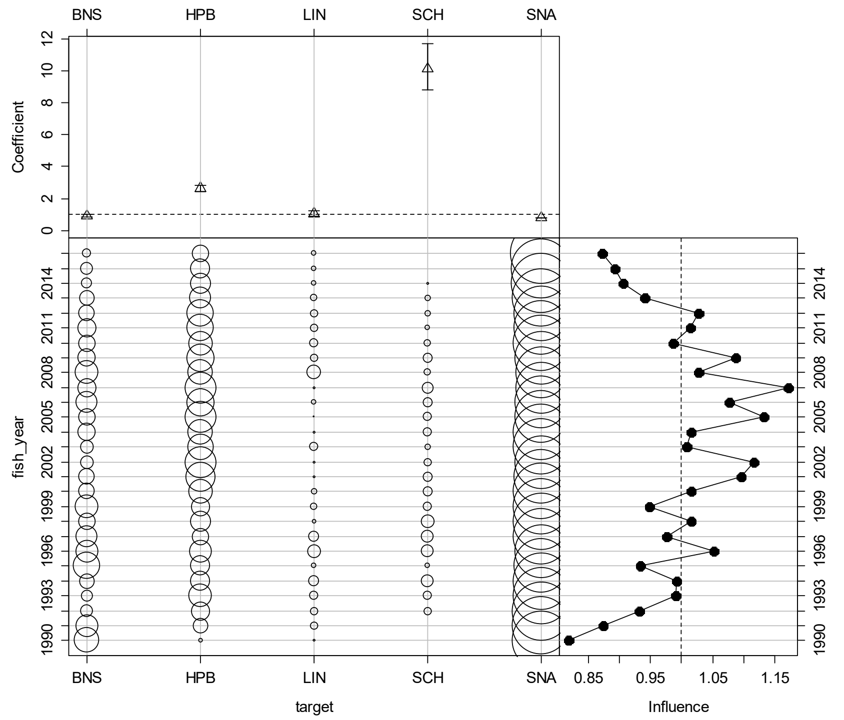

Figure 64: Target species influence plot for the lognormal model for school shark N/1E bottom longline. Top panel, the coefficient estimates for each target species; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

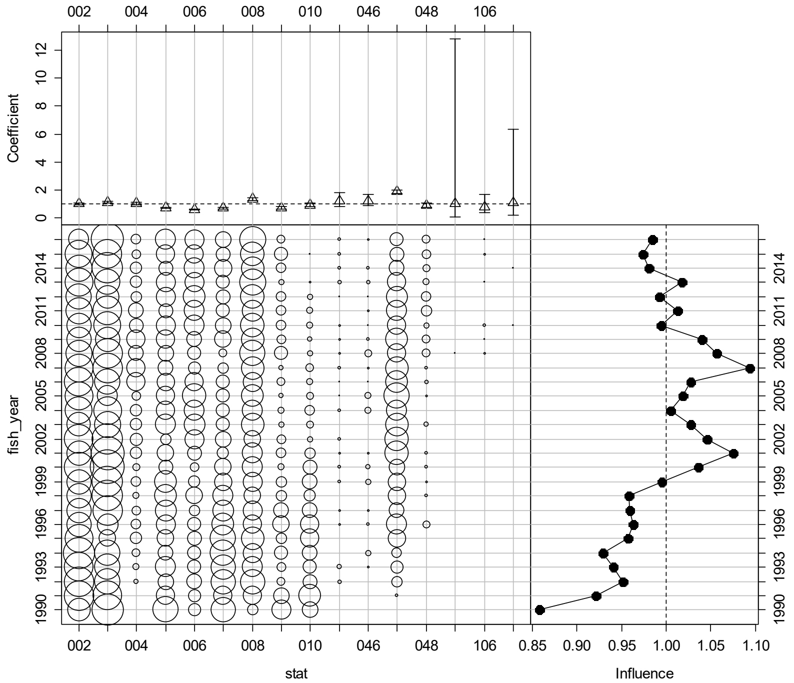

Figure 65: Statistical area influence plot for the lognormal model for school shark N/1E bottom longline. Top panel, the coefficient estimates for each statistical area; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

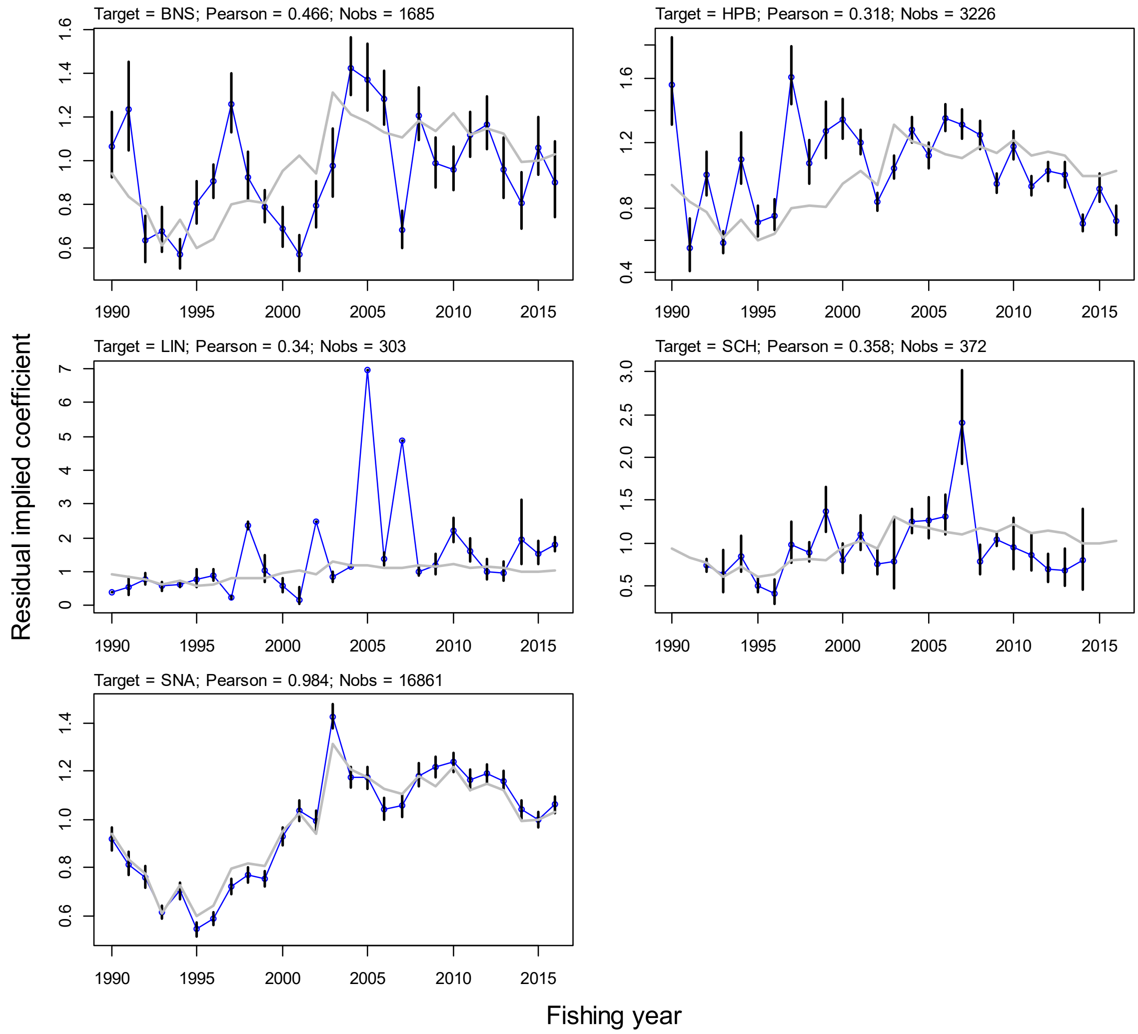

Figure 66: Residual implied coefficients for fishing year – target species interaction (not offered) for the school shark N/1E bottom longline CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.

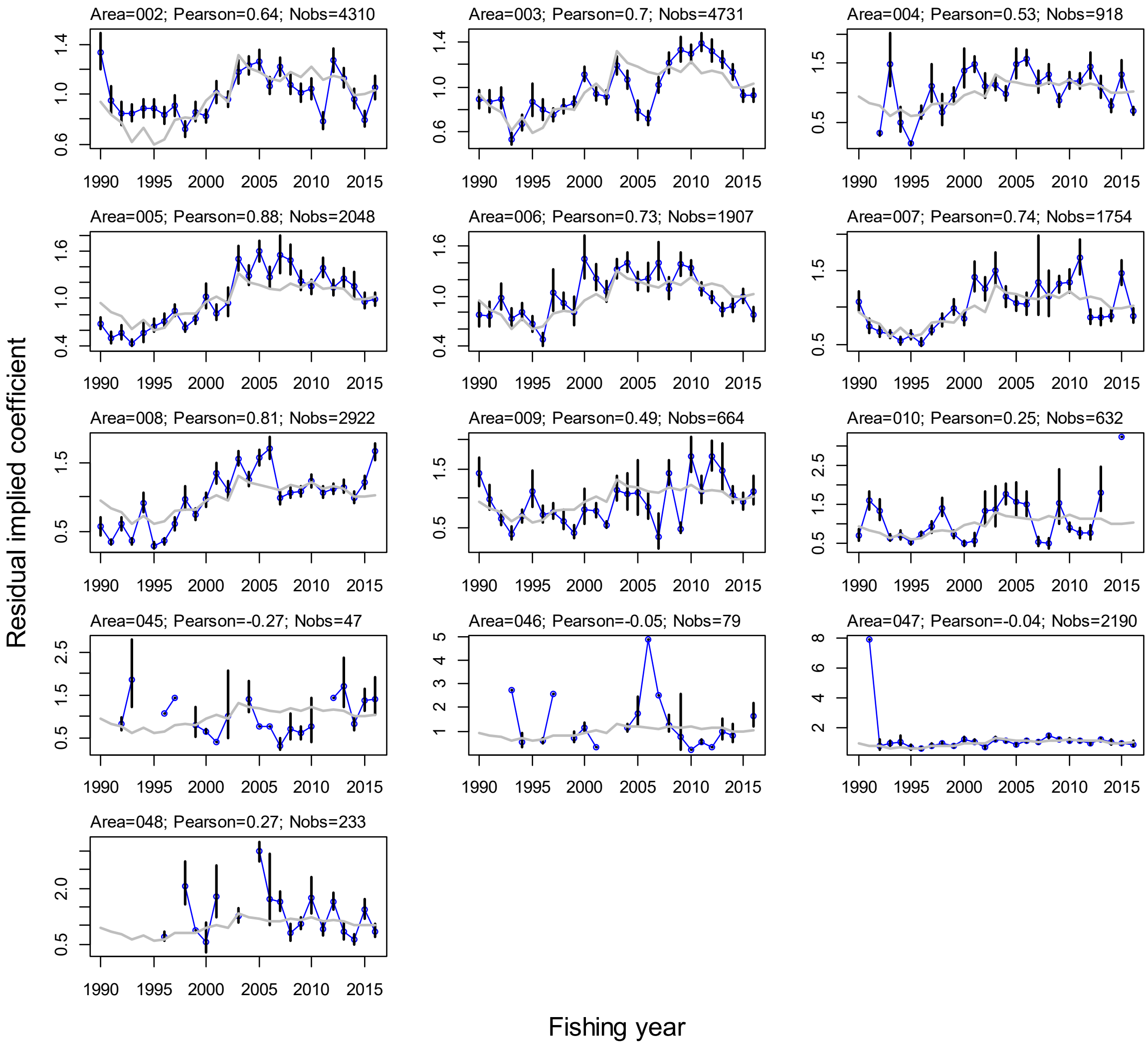

Figure 67: Residual implied coefficients for fishing year – statistical area interaction (not offered) for the school shark N/1E bottom longline CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.

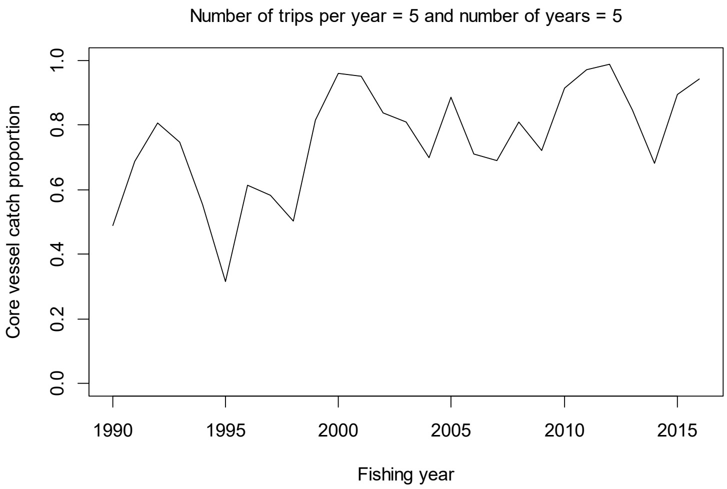

Figure 68: Proportion of catch included in the school shark N/1E setnet CPUE data set, after application of the data selection criteria, by fishing year.

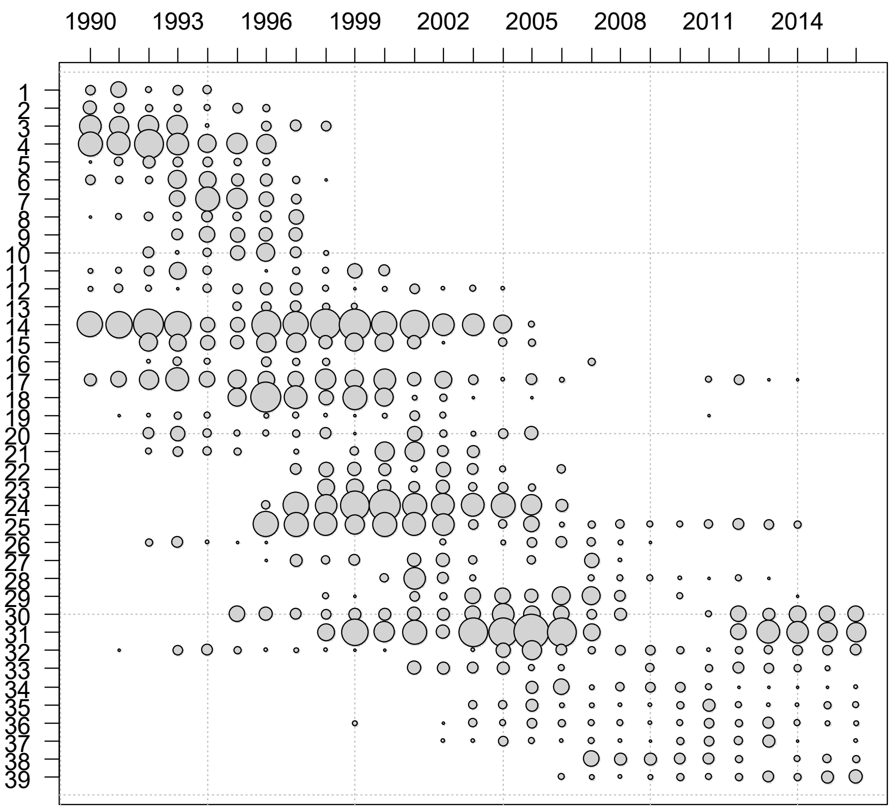

Figure 69: Core vessel summary by fishing year for school shark N/1E setnet. Bubble size proportional to effort by each vessel, normalised within each fishing year.

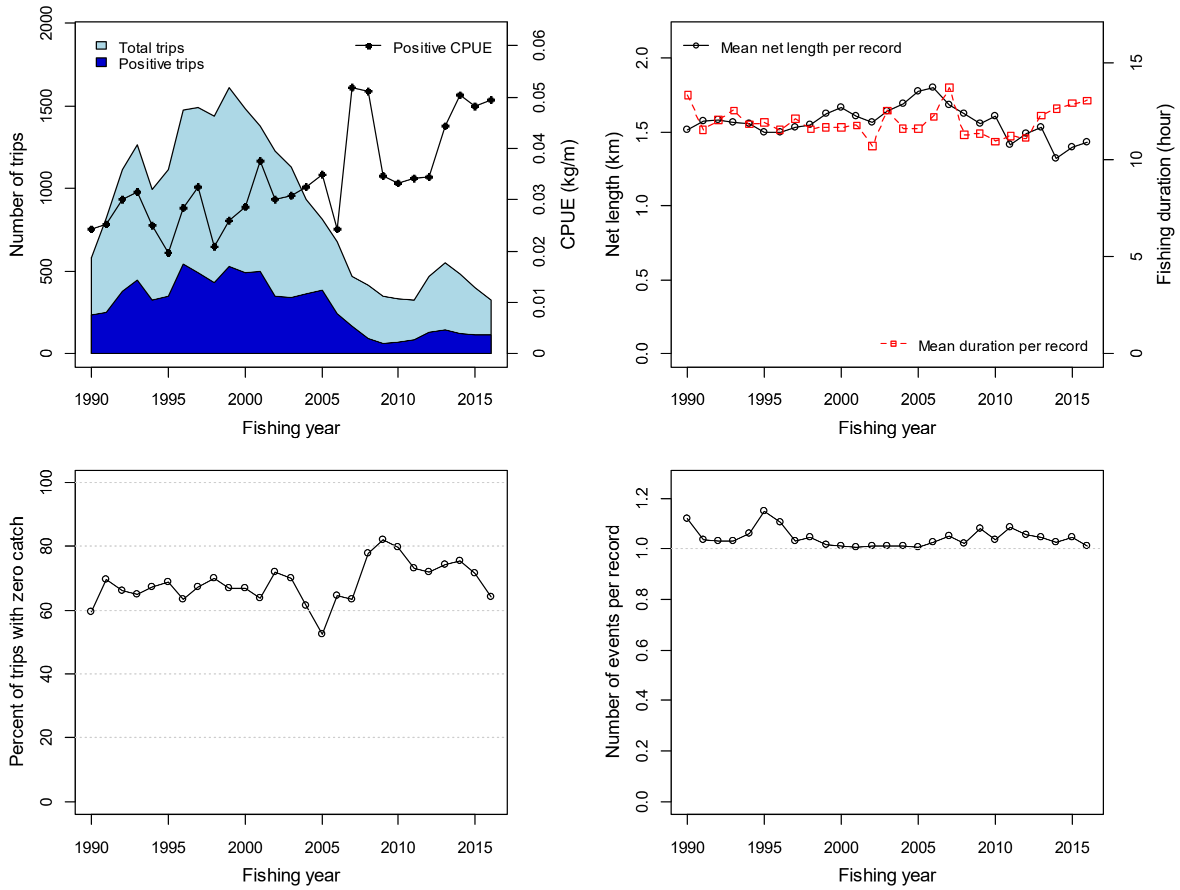

Figure 70: Core vessel summary plots by fishing year for school shark N/1E setnet: upper left panel, total trips (light blue) and trips with school shark catches (dark blue), overlaid with median annual arithmetic CPUE for all trips with positive catch; upper right panel, mean number of sets and mean number of hooks per set per daily effort-effort-stratum record; lower left panel, proportion of trips with no catch of school shark; lower right panel, mean number of events per daily-effort-stratum record.

Table 10: School shark N/1E setnet - Selected predictors for the lognormal CPUE model, showing the total and additional deviance explained.

Predictor	df	Total Dev. Expl. (%)	Additional Dev. Expl. (%)
Fishing year	26	3.0	3.0
Vessel	38	22.7	19.7
Target species	4	29.6	6.9

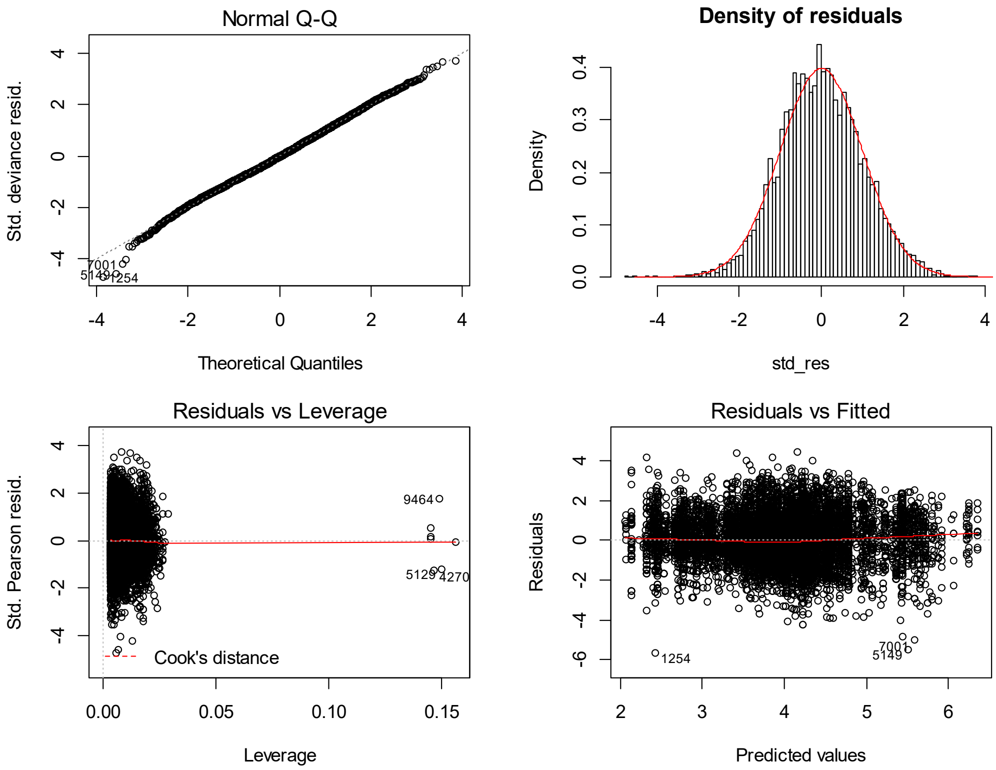

Figure 71: Diagnostic plots for the fit of the lognormal model for school shark N/1E setnet. Upper left panel, q-q plot of standardised residuals; upper right panel, histogram of standardised residuals compared to lognormal distribution (red line); lower left panel, residuals versus leverage plot; lower right panel, standardised residuals plotted against the predicted model catch.

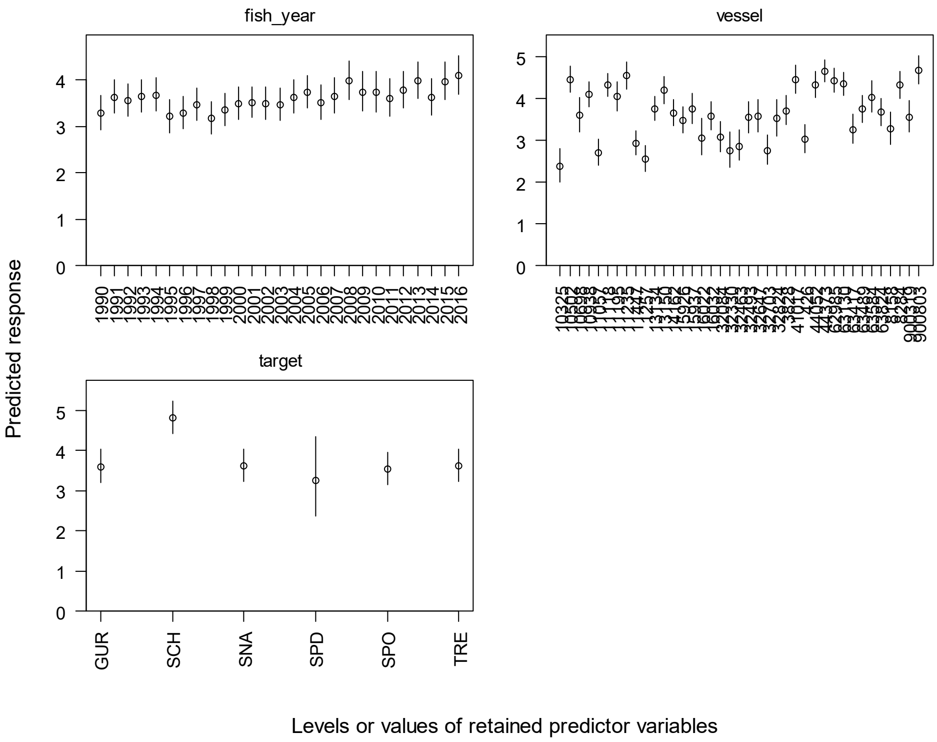

Figure 72: School shark N/1E setnet, predicted effects of the variables selected in the final lognormal CPUE model.

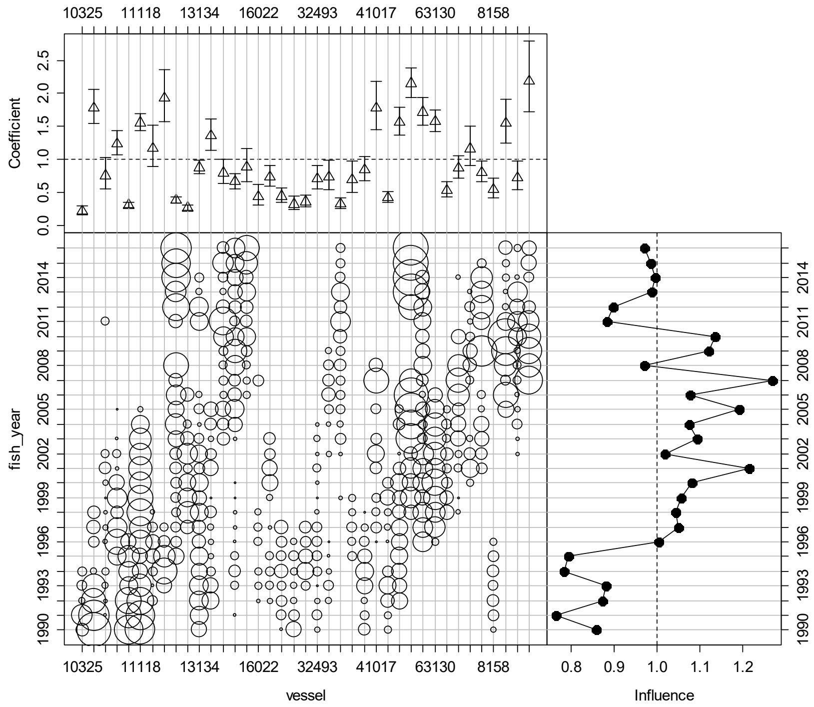

Figure 73: Vessel influence plot for the lognormal model for school shark N/1E setnet. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

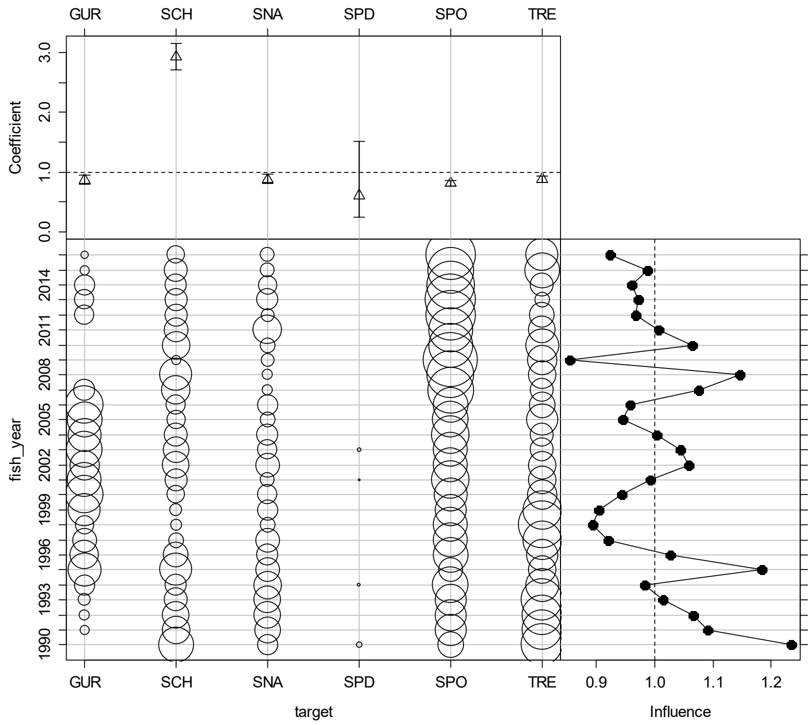

Figure 74: Target species influence plot for the lognormal model for school shark N/1E setnet. Top panel, the coefficient estimates for each target species; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

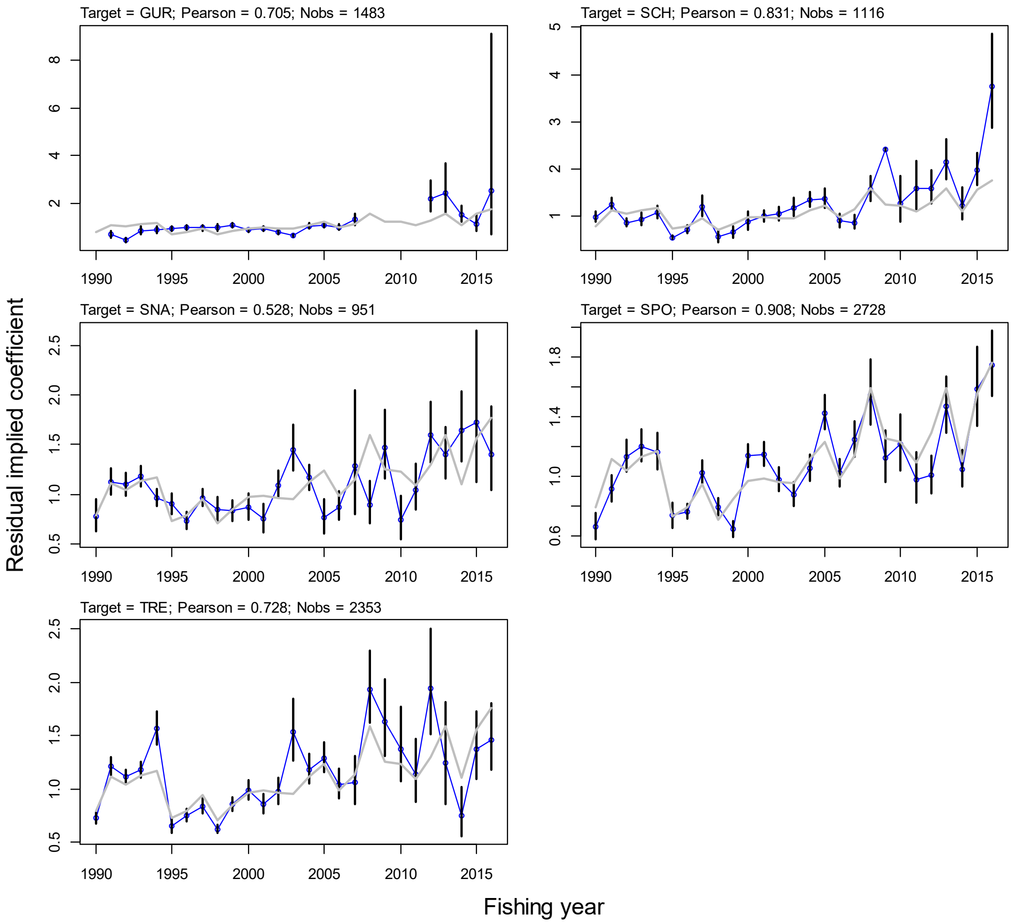

Figure 75: Residual implied coefficients for fishing year – target species interaction (not offered) for the school shark N/1E setnet CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.

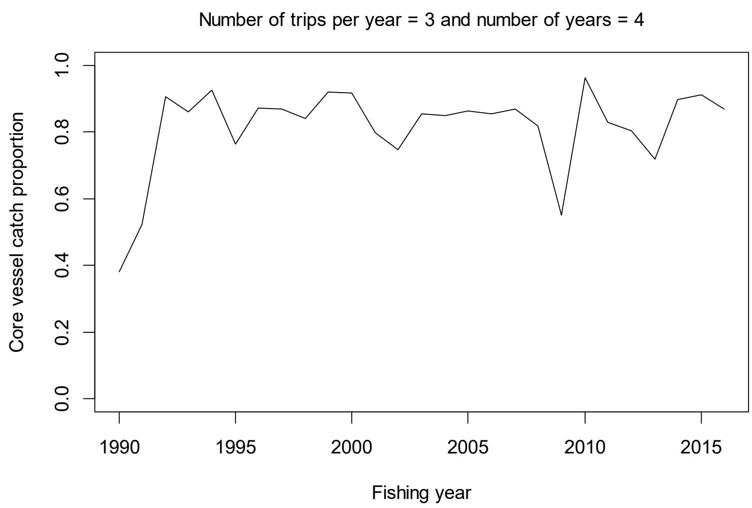

Figure 76: Proportion of catch included in the school shark 2/3N bottom longline CPUE data set, after application of the data selection criteria, by fishing year.

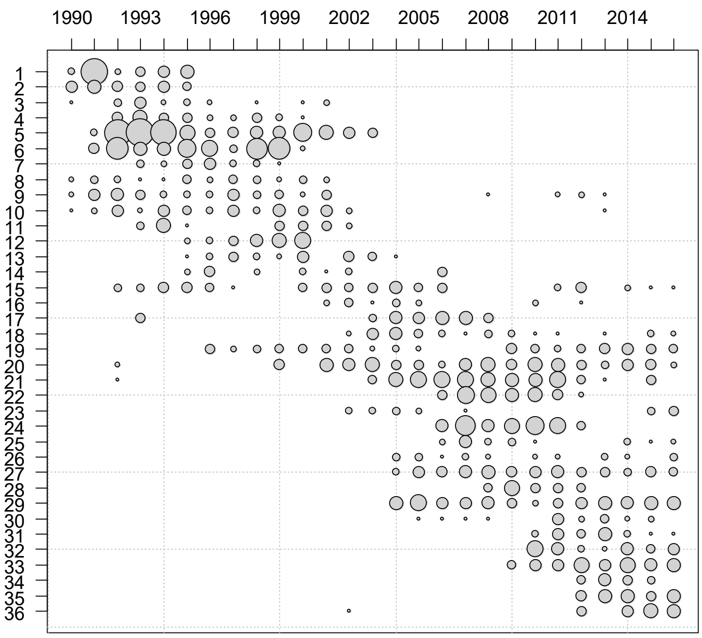

Figure 77: Core vessel summary by fishing year for school shark 2/3N bottom longline. Bubble size proportional to effort by each vessel, normalised within each fishing year.

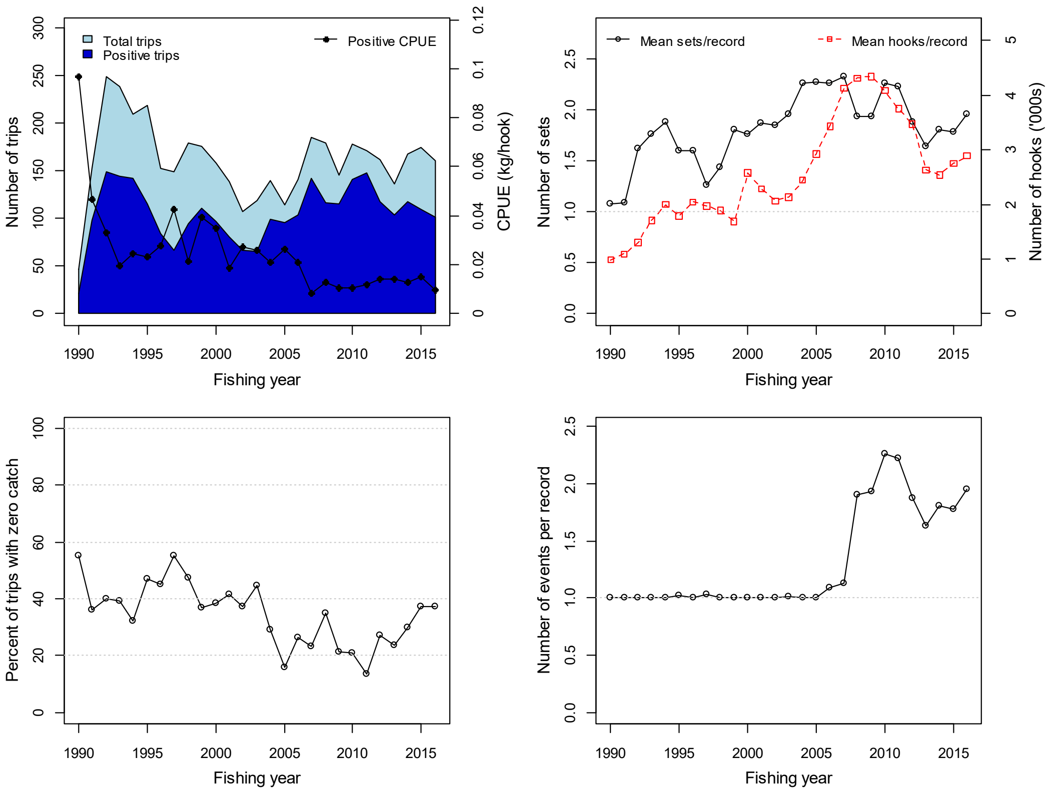

Figure 78: Core vessel summary plots by fishing year for school shark 2/3N bottom longline: upper left panel, total trips (light blue) and trips with school shark catches (dark blue), overlaid with median annual arithmetic CPUE for all trips with positive catch; upper right panel, mean number of sets and mean number of hooks per set per daily effort-effort-stratum record; lower left panel, proportion of trips with no catch of school shark; lower right panel, mean number of events per daily-effort-stratum record.

Table 11: School shark 2/3N bottom longline - Selected predictors for the lognormal CPUE model, showing the total and additional deviance explained.

Predictor	df	Total Dev. Expl. (%)	Additional Dev. Expl. (%)
Fishing year	26	2.0	2.0
Target species	4	19.8	17.8
Vessel	35	24.0	4.2
Statistical area	4	27.6	3.6
Number of hooks	3	29.0	1.4

Table 12: School shark 2/3N bottom longline - Selected predictors for the binomial CPUE model, showing the total and additional deviance explained.

Predictor	df	Total Dev. Expl. (%)	Additional Dev. Expl. (%)
Fishing year	26	1.0	1.0
Target species	4	6.0	5.0
Vessel	35	9.0	4.0
Statistical area	4	10.0	1.0

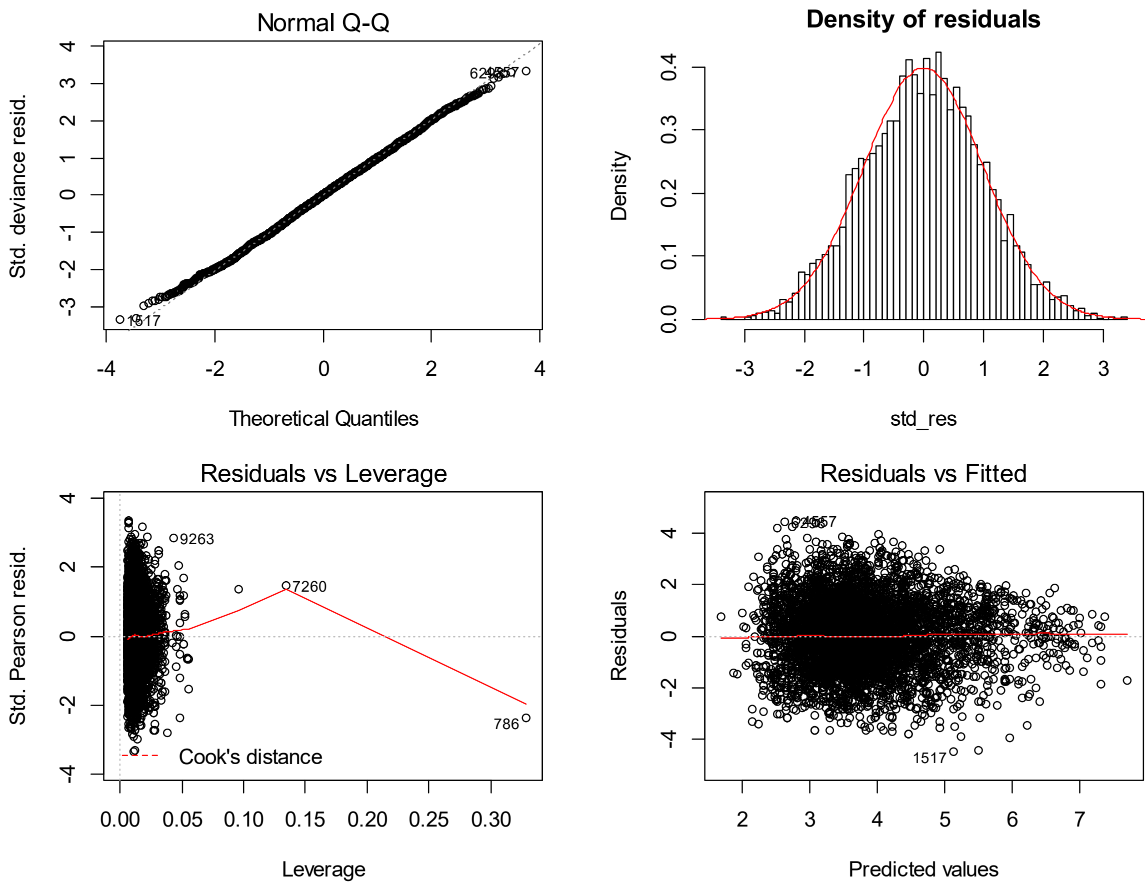

Figure 79: Diagnostic plots for the fit of the lognormal model for school shark 2/3N bottom longline. Upper left panel, q-q plot of standardised residuals; upper right panel, histogram of standardised residuals compared to lognormal distribution (red line); lower left panel, residuals versus leverage plot; lower right panel, standardised residuals plotted against the predicted model catch.

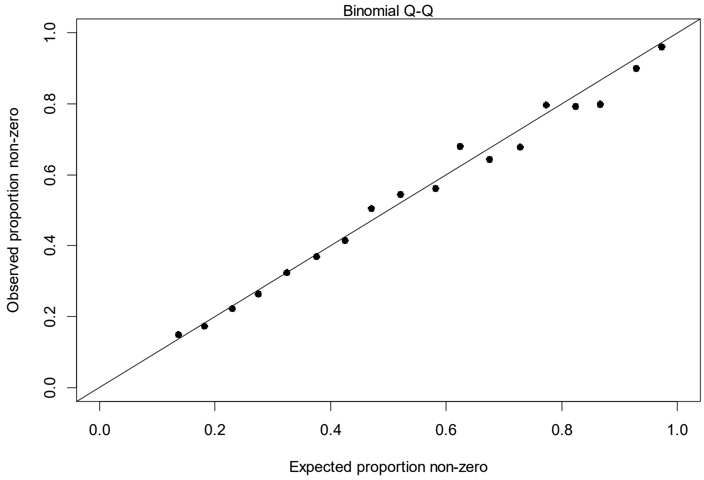

Figure 80: School shark 2/3N bottom longline, diagnostic (q-q) plot for the binomial model.

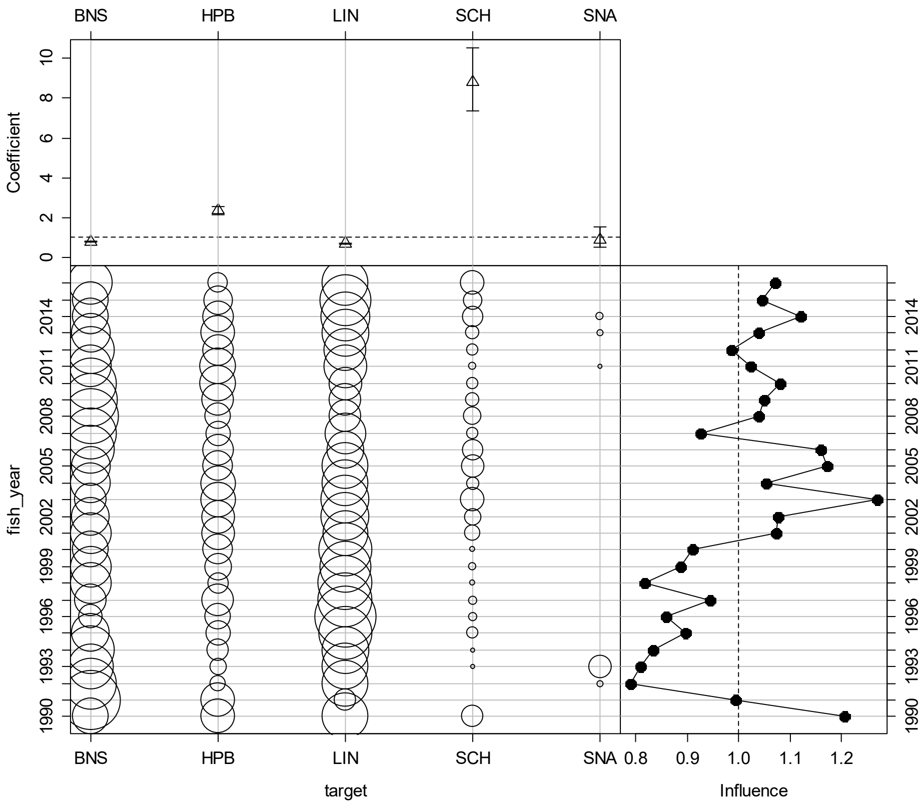

Figure 81: Target species influence plot for the lognormal model for school shark 2/3N bottom longline. Top panel, the coefficient estimates for each target species; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

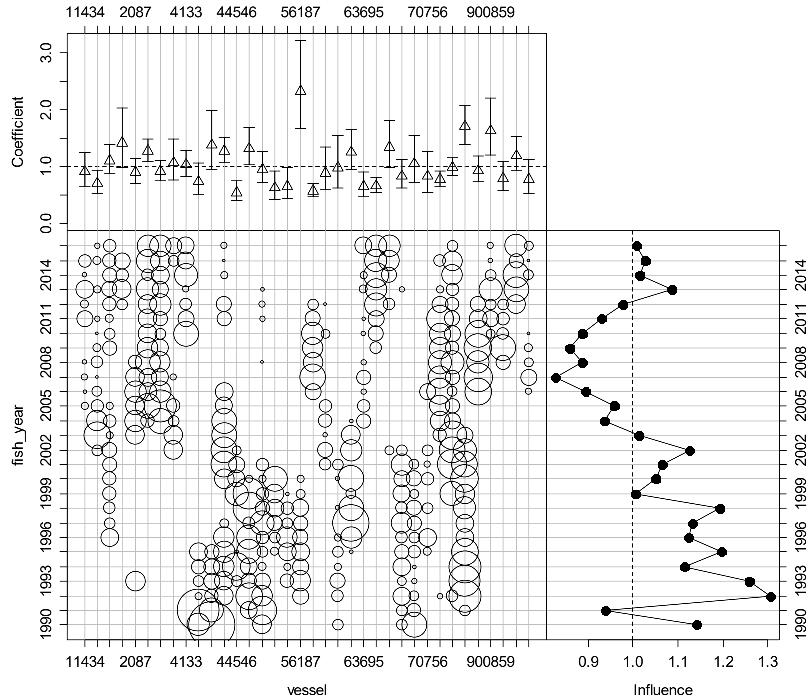

Figure 82: Vessel influence plot for the lognormal model for school shark 2/3N bottom longline. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

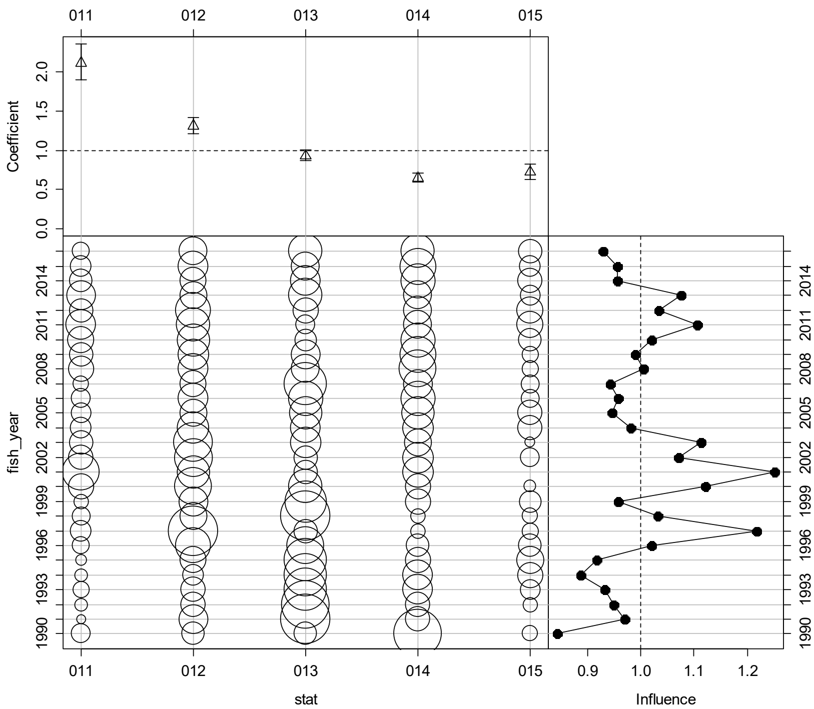

Figure 83: Statistical area influence plot for the lognormal model for school shark 2/3N bottom longline. Top panel, the coefficient estimates for each statistical area; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

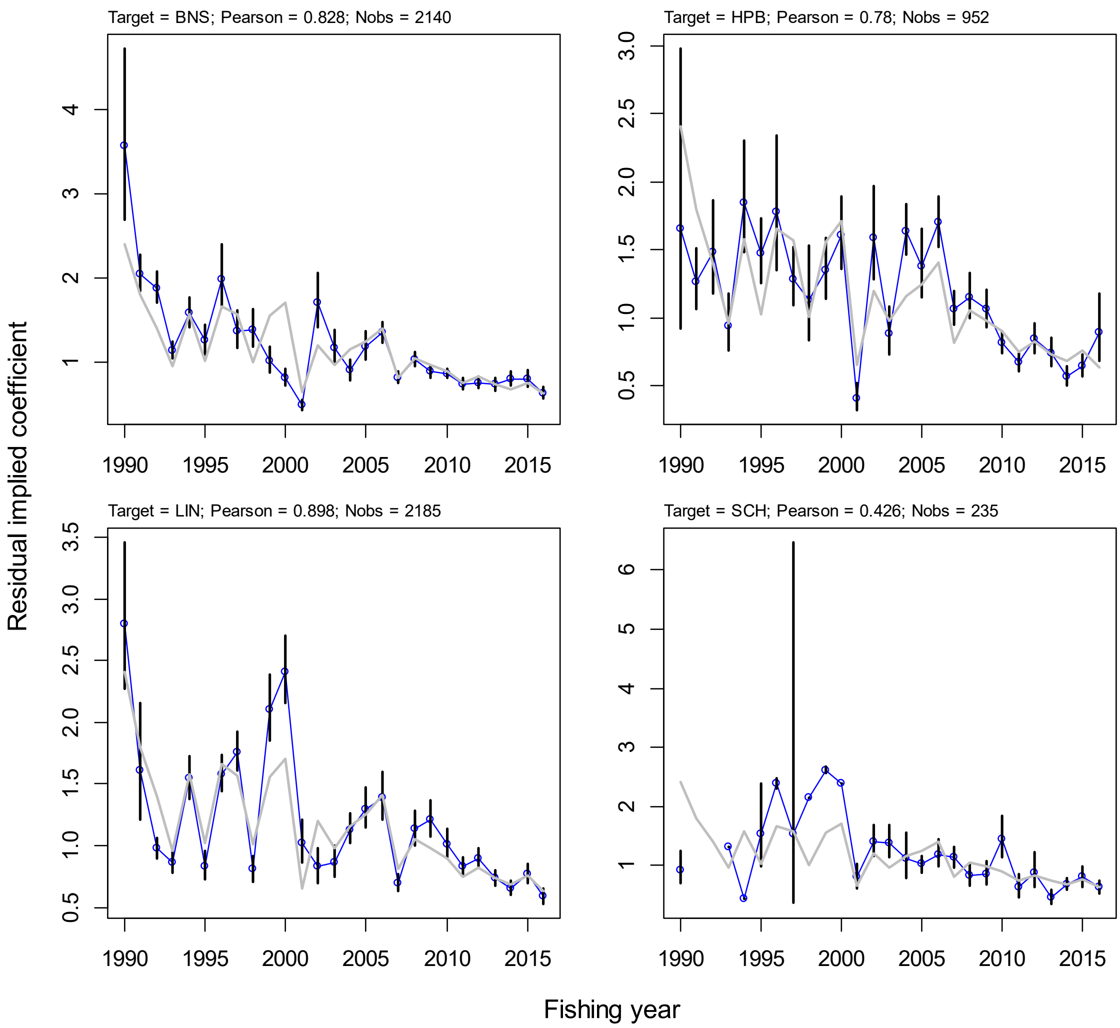

Figure 84: Residual implied coefficients for fishing year – target species interaction (not offered) for the school shark 2/3N bottom longline CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.

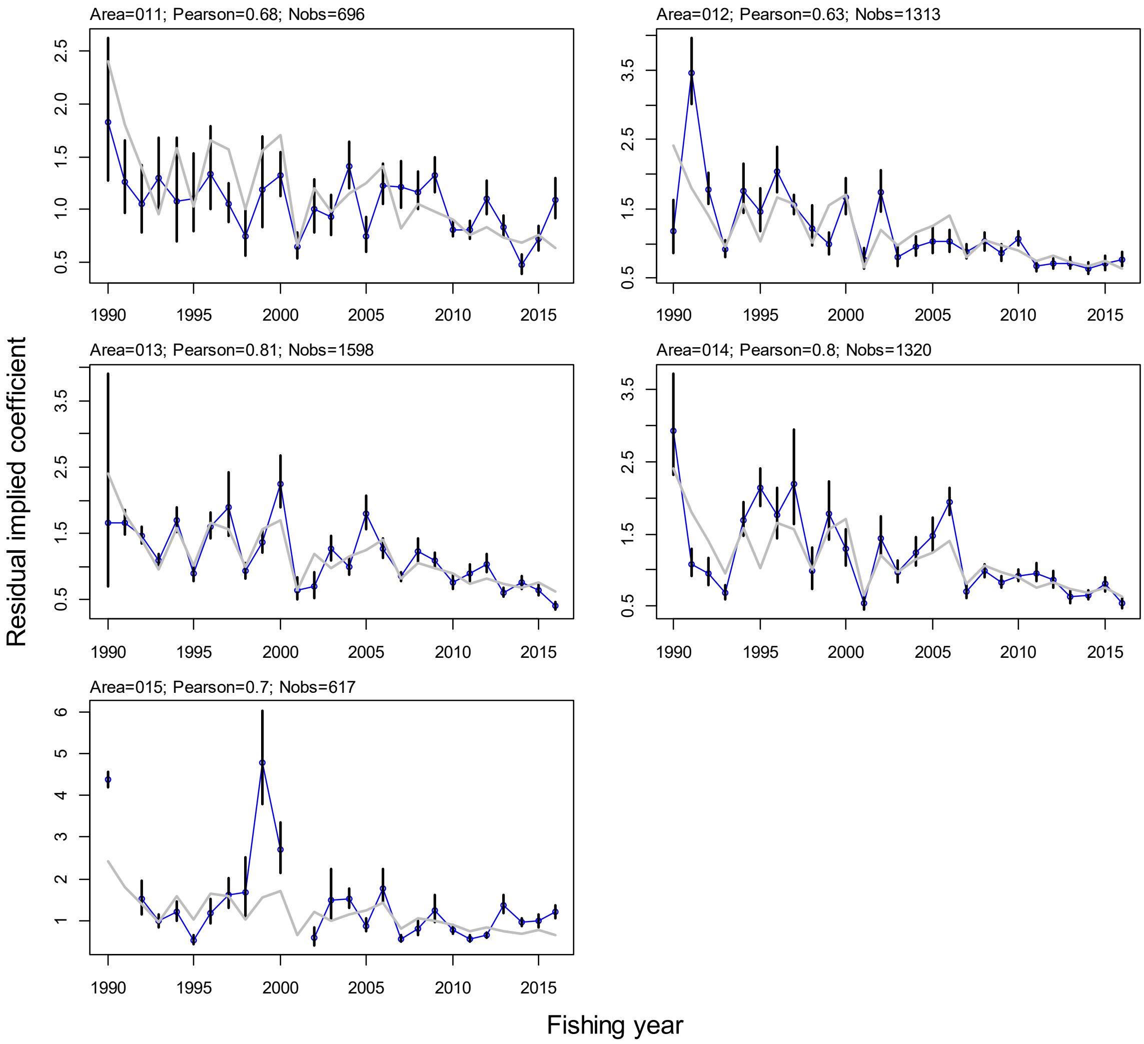

Figure 85: Residual implied coefficients for fishing year – statistical area interaction (not offered) for the school shark 2/3N bottom longline CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.

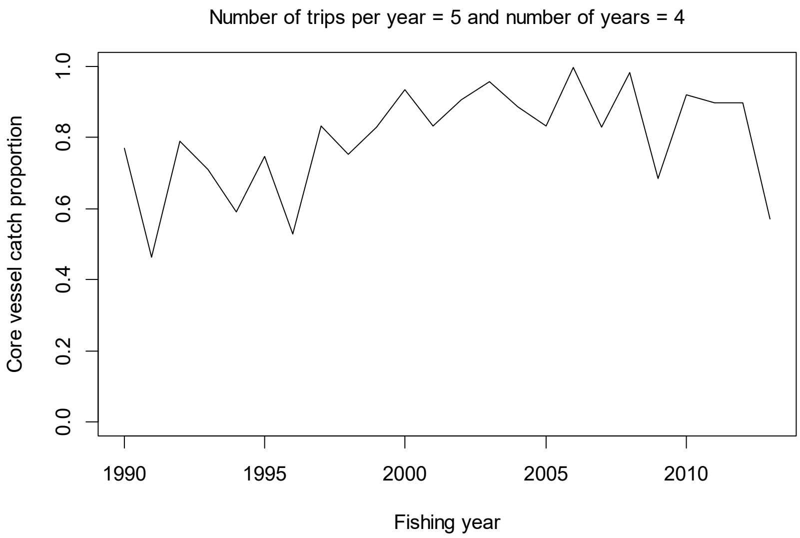

Figure 86: Proportion of catch included in the school shark 2/3N setnet CPUE data set, after application of the data selection criteria, by fishing year.

Figure 87: Core vessel summary by fishing year for school shark 2/3N setnet. Bubble size proportional to effort by each vessel, normalised within each fishing year.

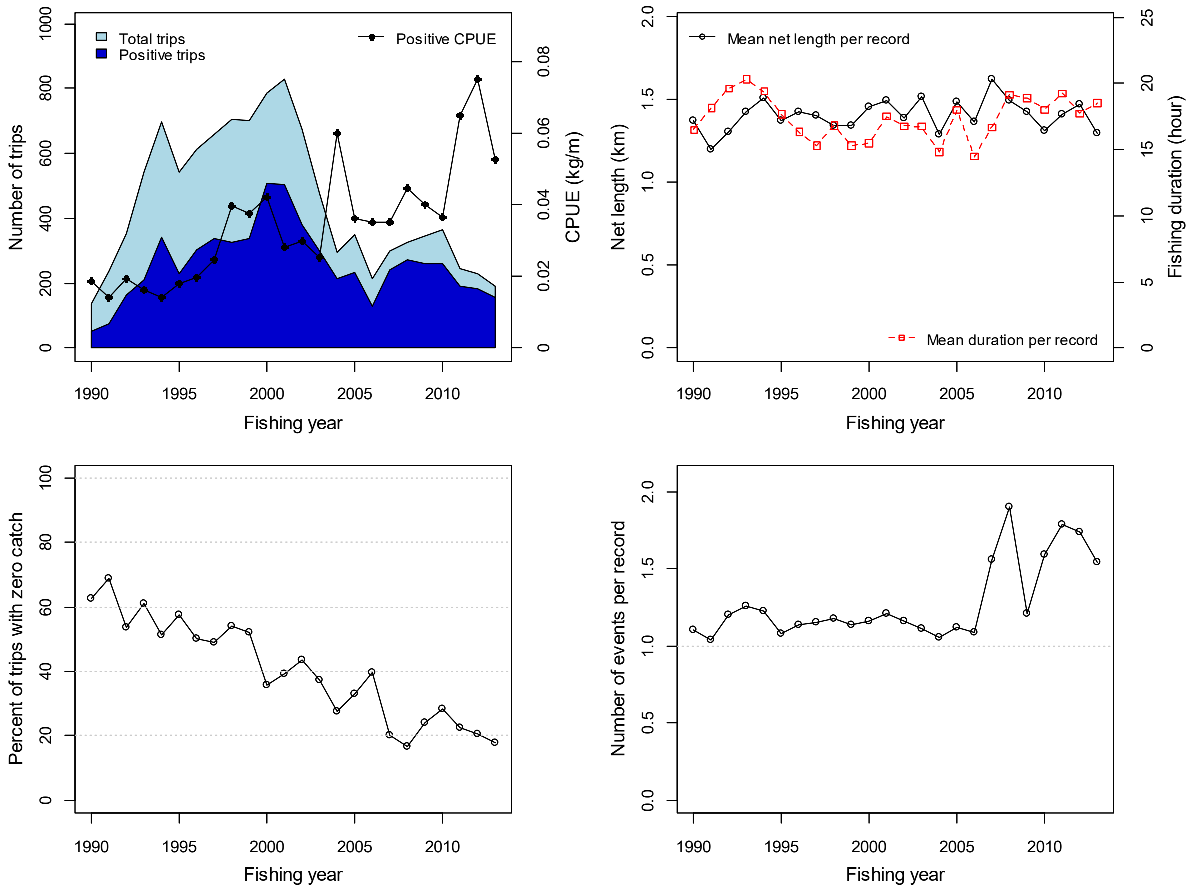

Figure 88: Core vessel summary plots by fishing year for school shark 2/3N setnet: upper left panel, total trips (light blue) and trips with school shark catches (dark blue), overlaid with median annual arithmetic CPUE for all trips with positive catch; upper right panel, mean number of sets and mean number of hooks per set per daily effort-effort-stratum record; lower left panel, proportion of trips with no catch of school shark; lower right panel, mean number of events per daily-effort-stratum record.

Table 13: School shark 2/3N setnet - Selected predictors for the lognormal CPUE model, showing the total and additional deviance explained.

Predictor	df	Total Dev. Expl. (%)	Additional Dev. Expl. (%)
Fishing year	23	6.0	6.0
Vessel	32	27.4	21.4
Target species	3	31.6	4.2
Statistical area	8	33.1	1.5

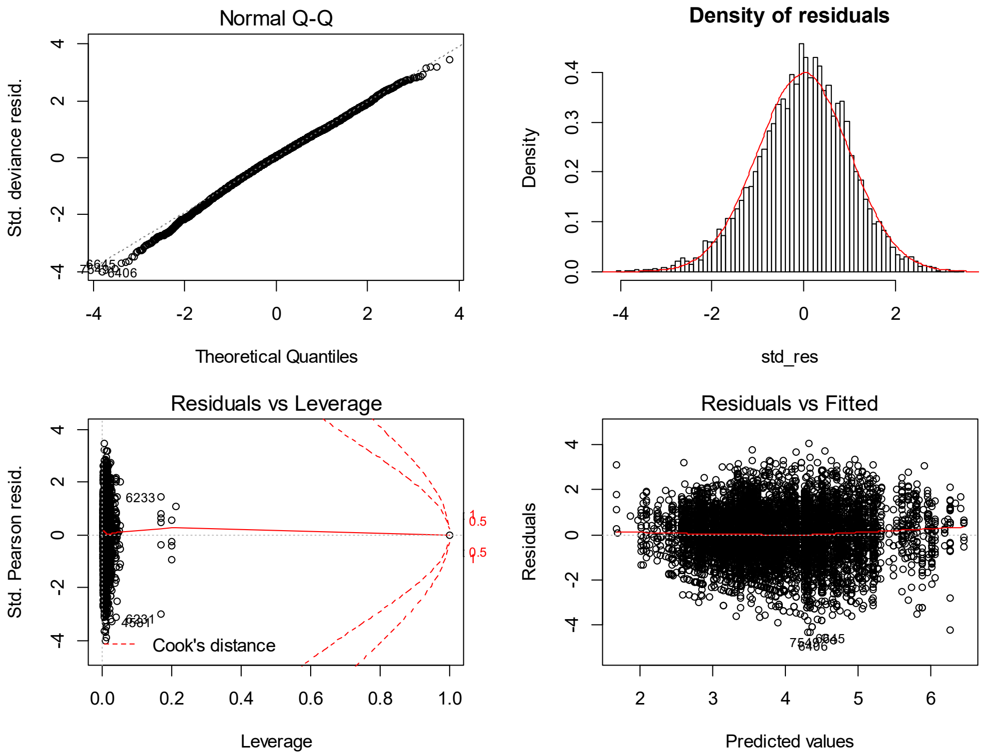

Figure 89: Diagnostic plots for the fit of the lognormal model for school shark 2/3N setnet. Upper left panel, q-q plot of standardised residuals; upper right panel, histogram of standardised residuals compared to lognormal distribution (red line); lower left panel, residuals versus leverage plot; lower right panel, standardised residuals plotted against the predicted model catch.

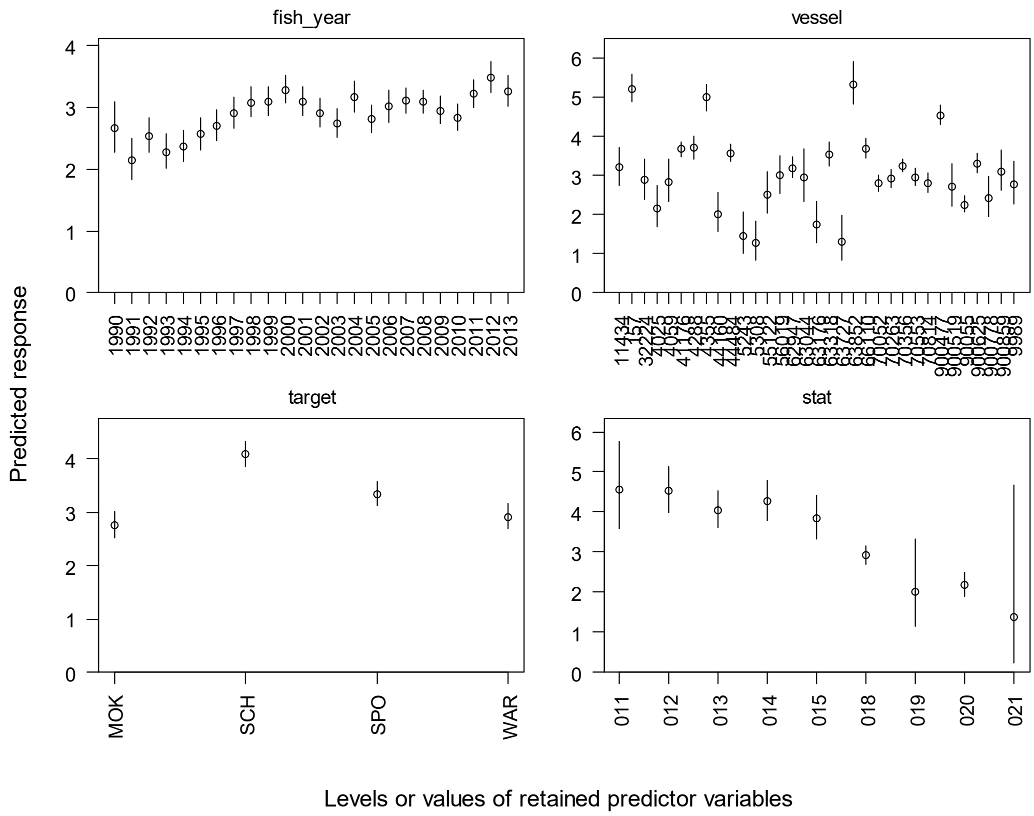

Figure 90: School shark 2/3N setnet, predicted effects of the variables selected in the final lognormal CPUE model.

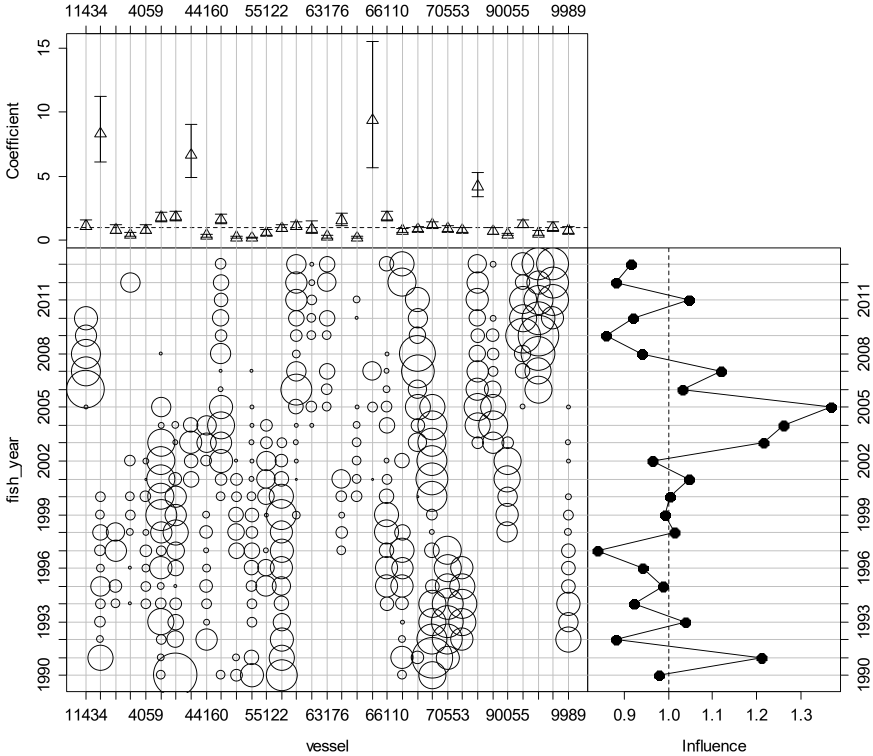

Figure 91: Vessel influence plot for the lognormal model for school shark 2/3N setnet. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

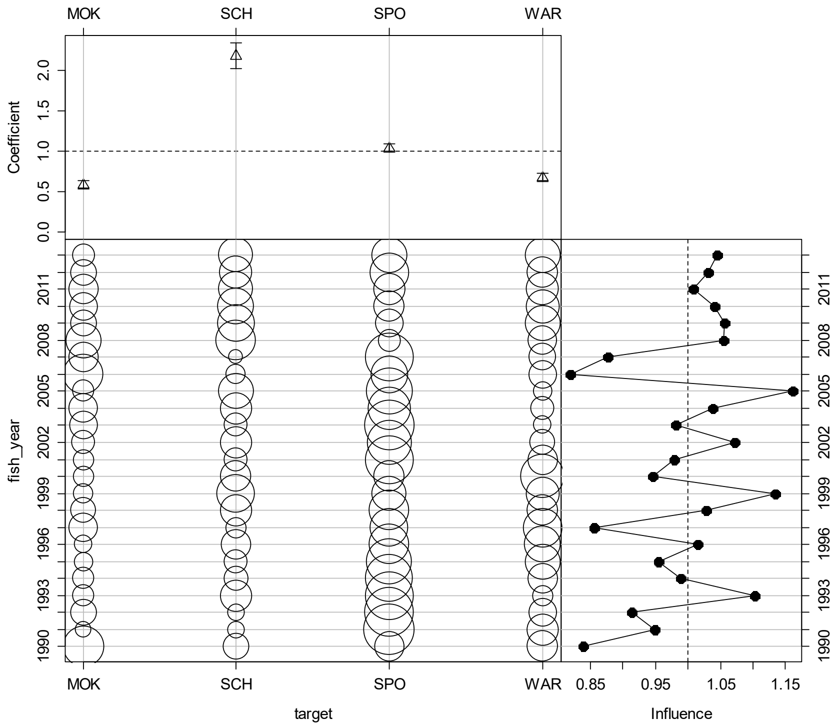

Figure 92: Target species influence plot for the lognormal model for school shark 2/3N setnet. Top panel, the coefficient estimates for each target species; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

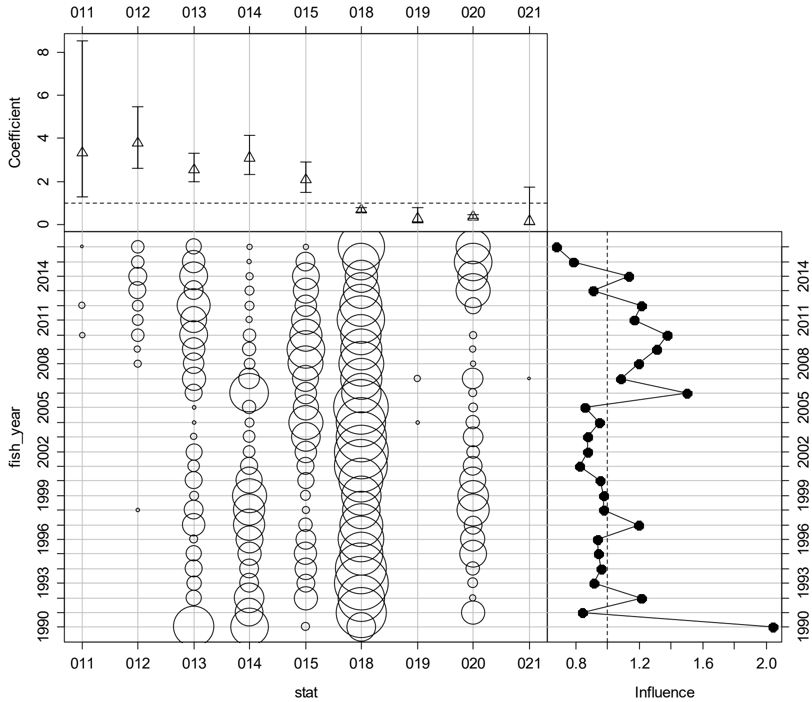

Figure 93: Statistical area influence plot for the lognormal model for school shark 2/3N setnet. Top panel, the coefficient estimates for each statistical area; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

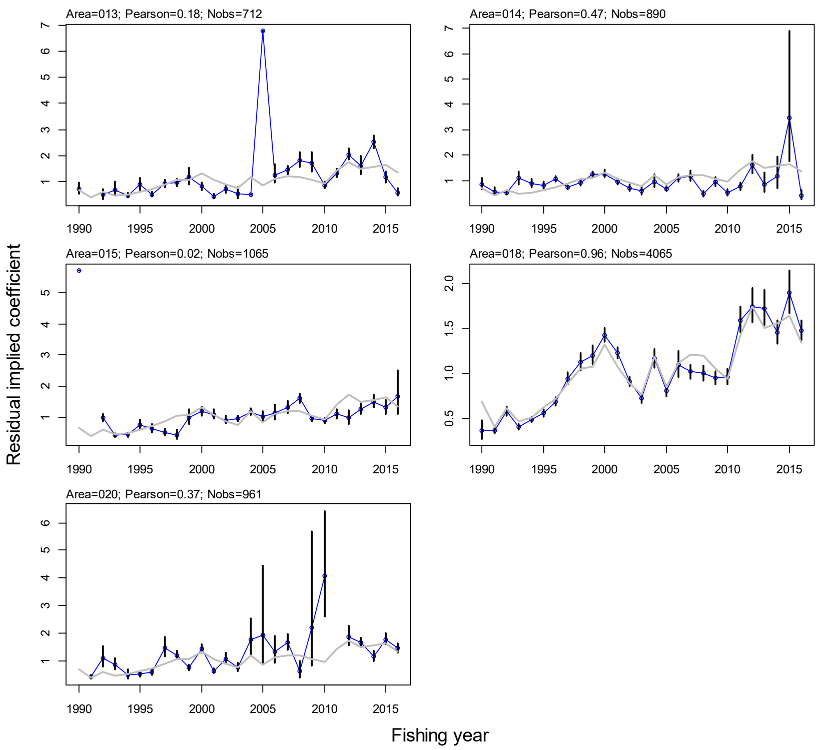

Figure 94: Residual implied coefficients for fishing year – statistical area interaction (not offered) for the school shark 2/3N setnet CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.

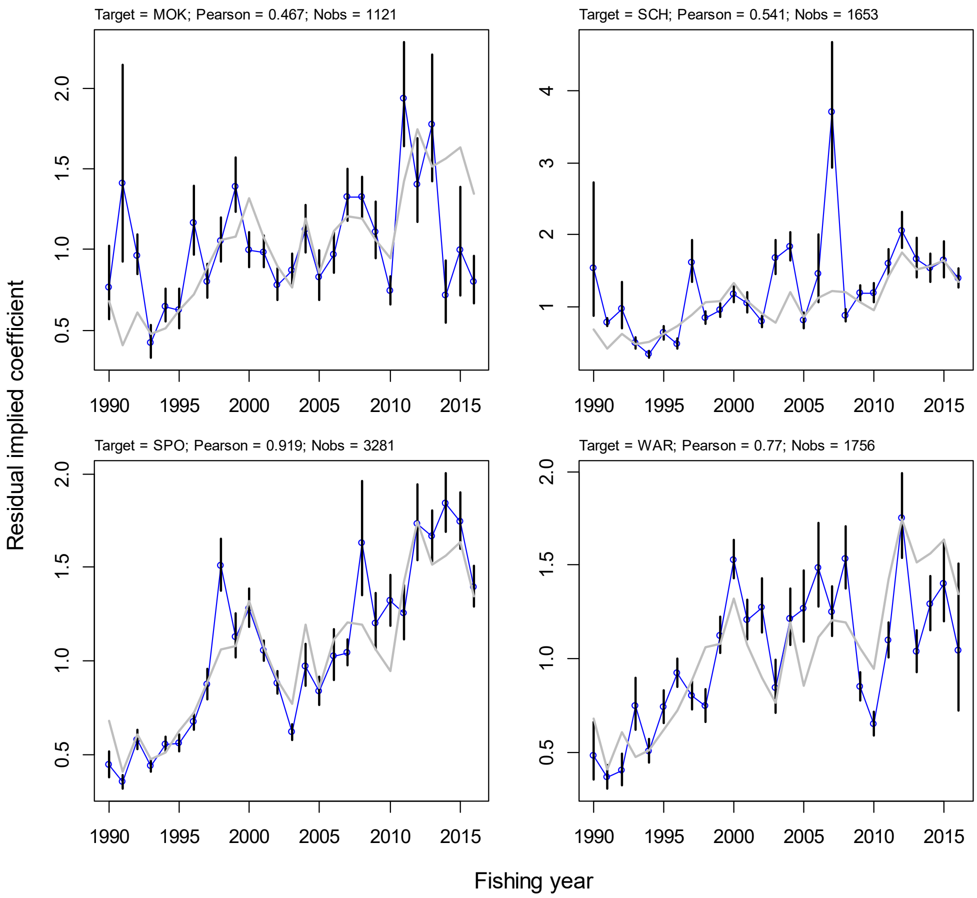

Figure 95: Residual implied coefficients for fishing year – target species interaction (not offered) for the school shark 2/3N setnet CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.

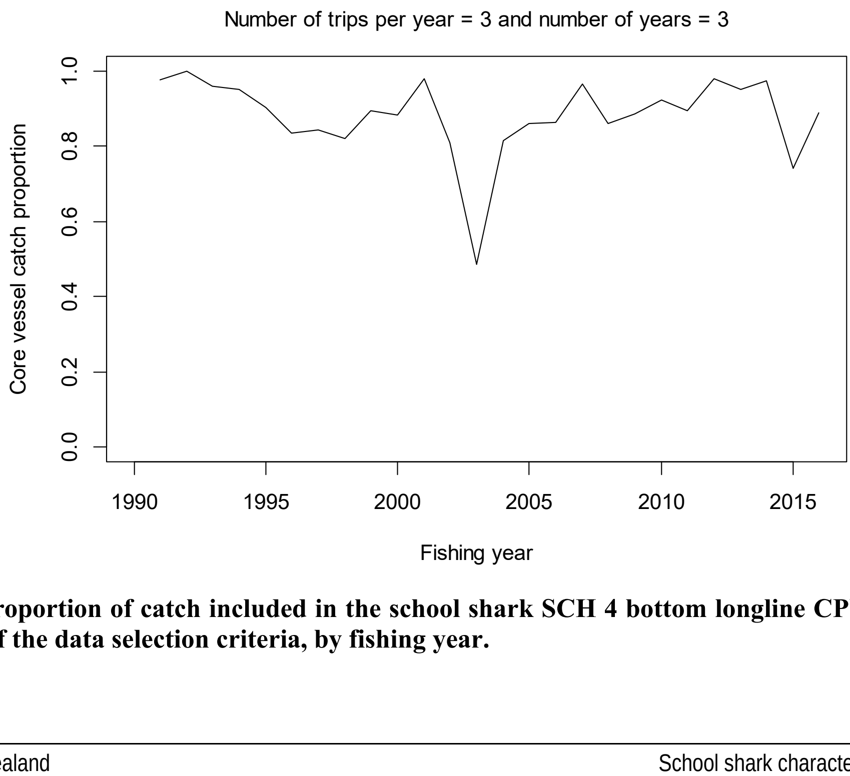

Figure 96: Proportion of catch included in the school shark SCH 4 bottom longline CPUE data set, after application of the data selection criteria, by fishing year.

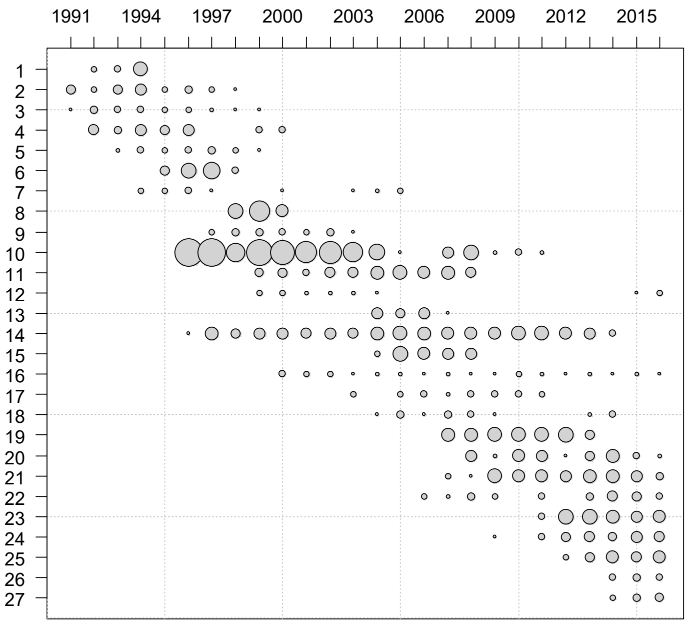

Figure 97: Core vessel summary by fishing year for school shark SCH 4 bottom longline. Bubble size proportional to effort by each vessel, normalised within each fishing year.

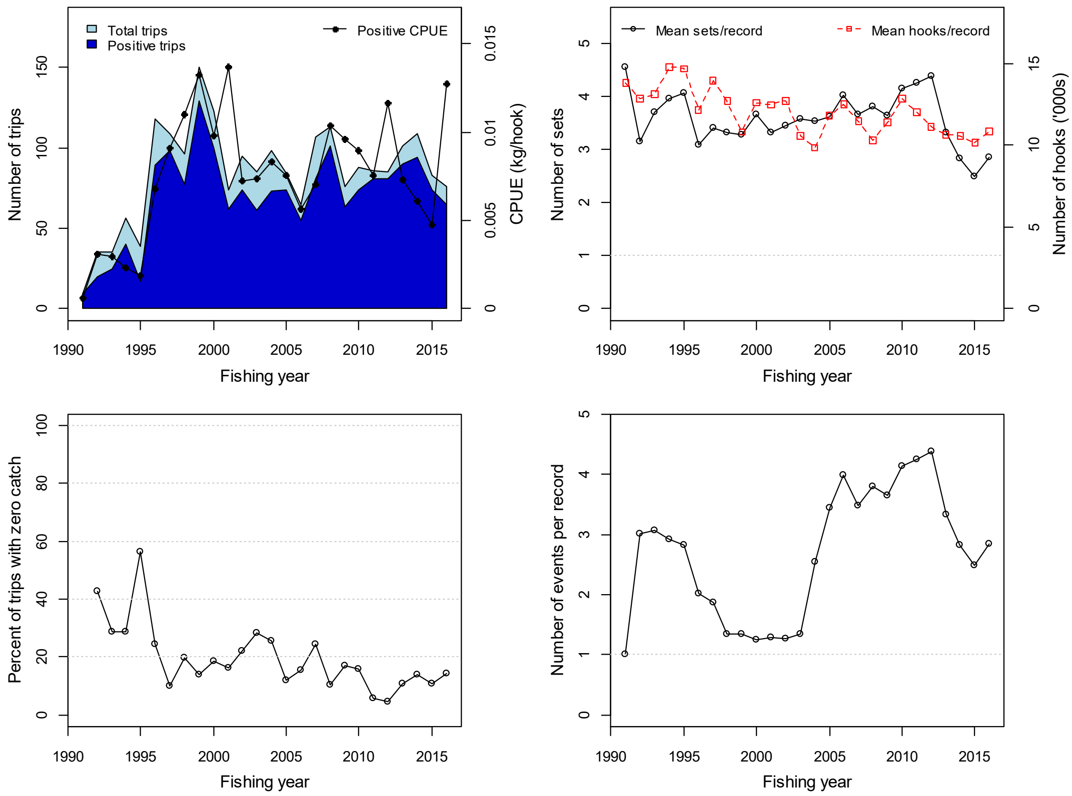

Figure 98: Core vessel summary plots by fishing year for school shark SCH 4 bottom longline: upper left panel, total trips (light blue) and trips with school shark catches (dark blue), overlaid with median annual arithmetic CPUE for all trips with positive catch; upper right panel, mean number of sets and mean number of hooks per set per daily effort-effort-stratum record; lower left panel, proportion of trips with no catch of school shark; lower right panel, mean number of events per daily-effort-stratum record.

Table 14: School shark SCH 4 bottom longline - Selected predictors for the lognormal CPUE model, showing the total and additional deviance explained.

Predictor	df	Total Dev. Expl. (%)	Additional Dev. Expl. (%)
Fishing year	25	7.0	7.0
Vessel	26	24.0	17.0
Target species	3	32.3	8.3
Statistical area	16	35.3	3.0
Number of hooks	3	36.0	0.7

Table 15: School shark SCH 4 bottom longline - Selected predictors for the binomial CPUE model, showing the total and additional deviance explained.

Predictor	df	Total Dev. Expl. (%)	Additional Dev. Expl. (%)
Fishing year	26	2.0	2.0
Target species	4	9.0	7.0
Vessel	35	12.0	5.0
Statistical area	4	14.0	2.0

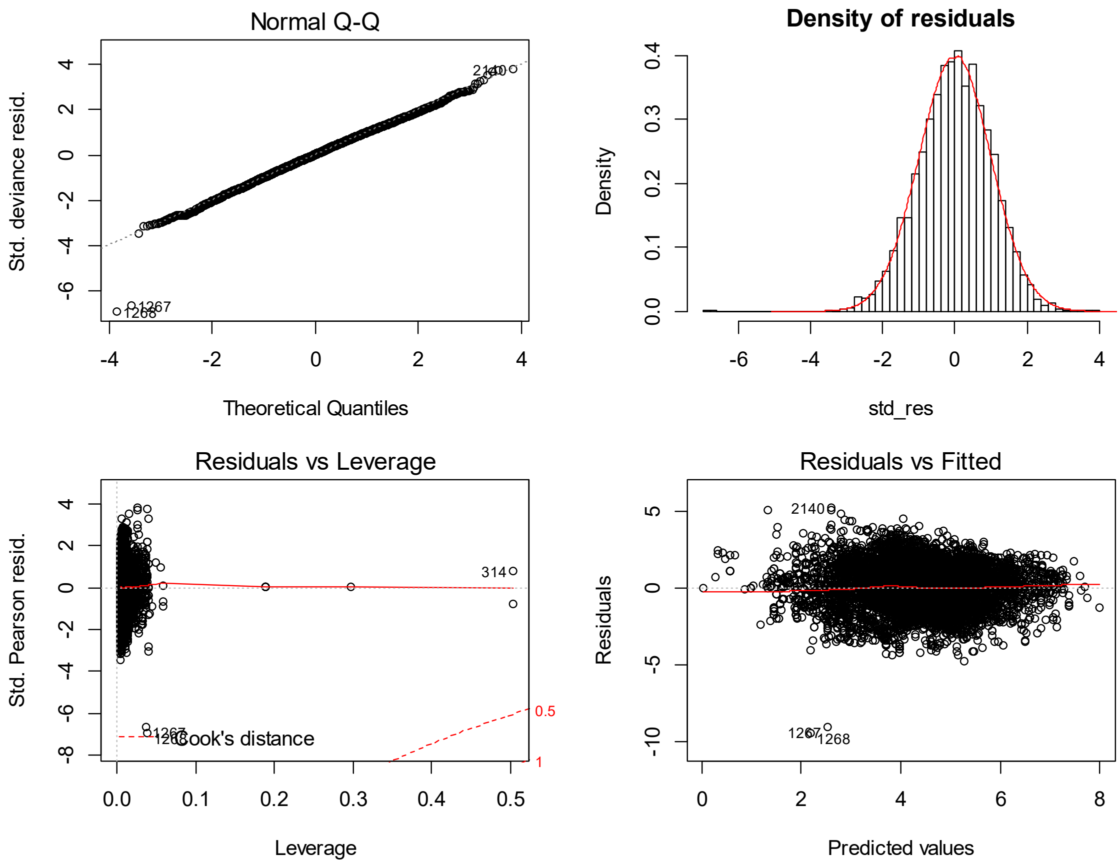

Figure 99: Diagnostic plots for the fit of the lognormal model for school shark SCH 4 bottom longline. Upper left panel, q-q plot of standardised residuals; upper right panel, histogram of standardised residuals compared to lognormal distribution (red line); lower left panel, residuals versus leverage plot; lower right panel, standardised residuals plotted against the predicted model catch.

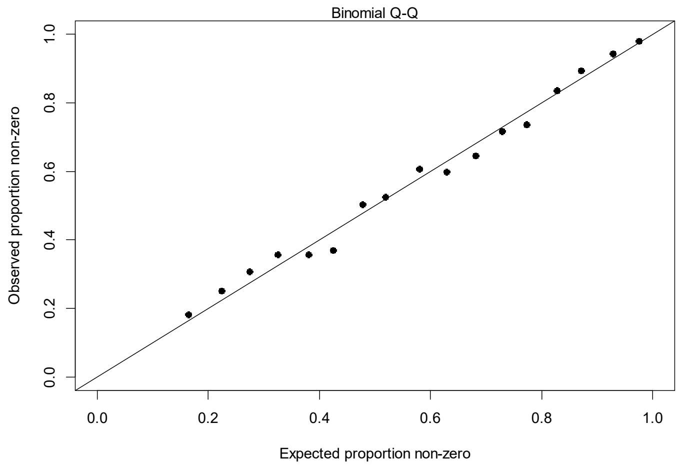

Figure 100: School shark SCH 4 bottom longline, diagnostic (q-q) plot for the binomial model.

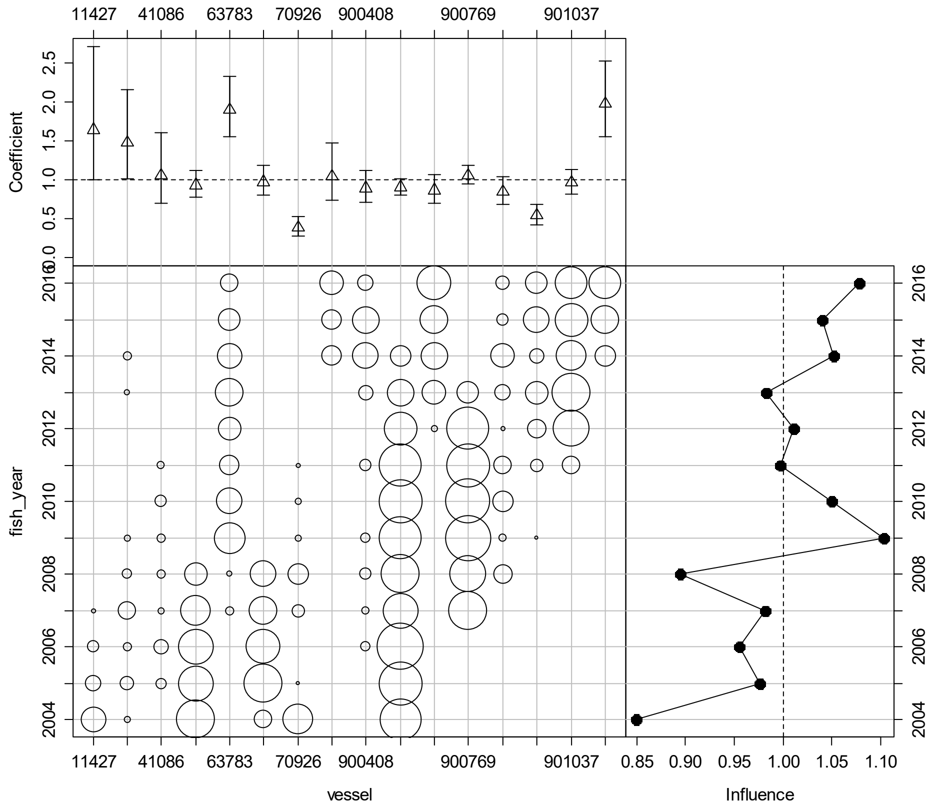

Figure 101: Vessel influence plot for the lognormal model for school shark SCH 4 bottom longline. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

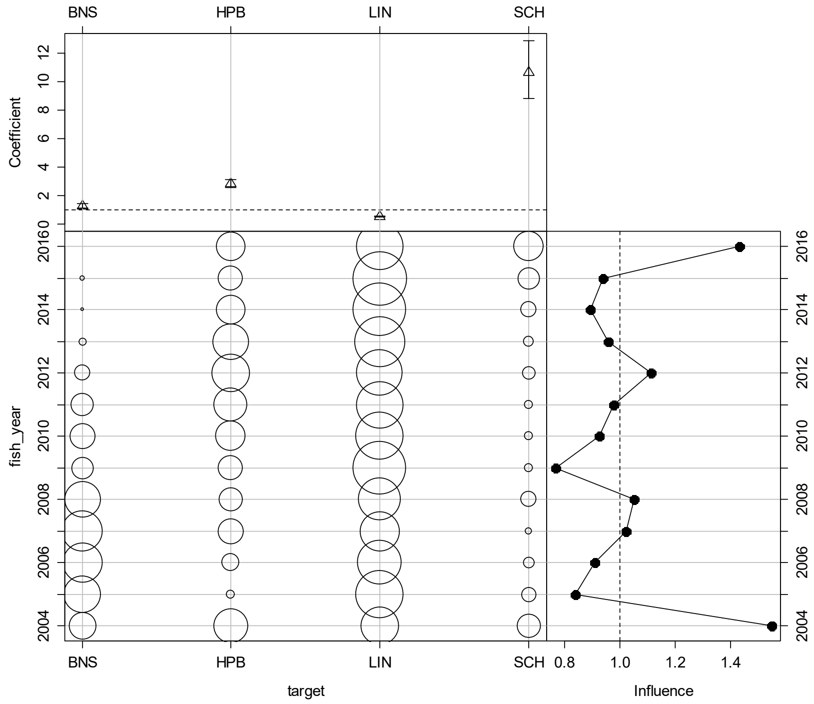

Figure 102: Target species influence plot for the lognormal model for school shark SCH 4 bottom longline. Top panel, the coefficient estimates for each target species; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

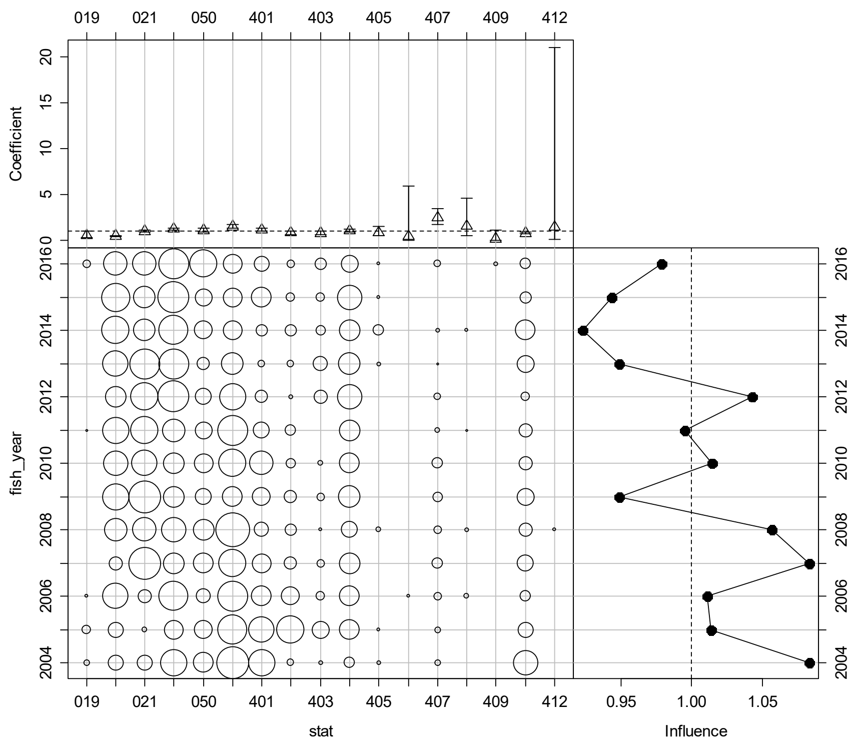

Figure 103: Statistical area influence plot for the lognormal model for school shark SCH 4 bottom longline. Top panel, the coefficient estimates for each statistical area; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

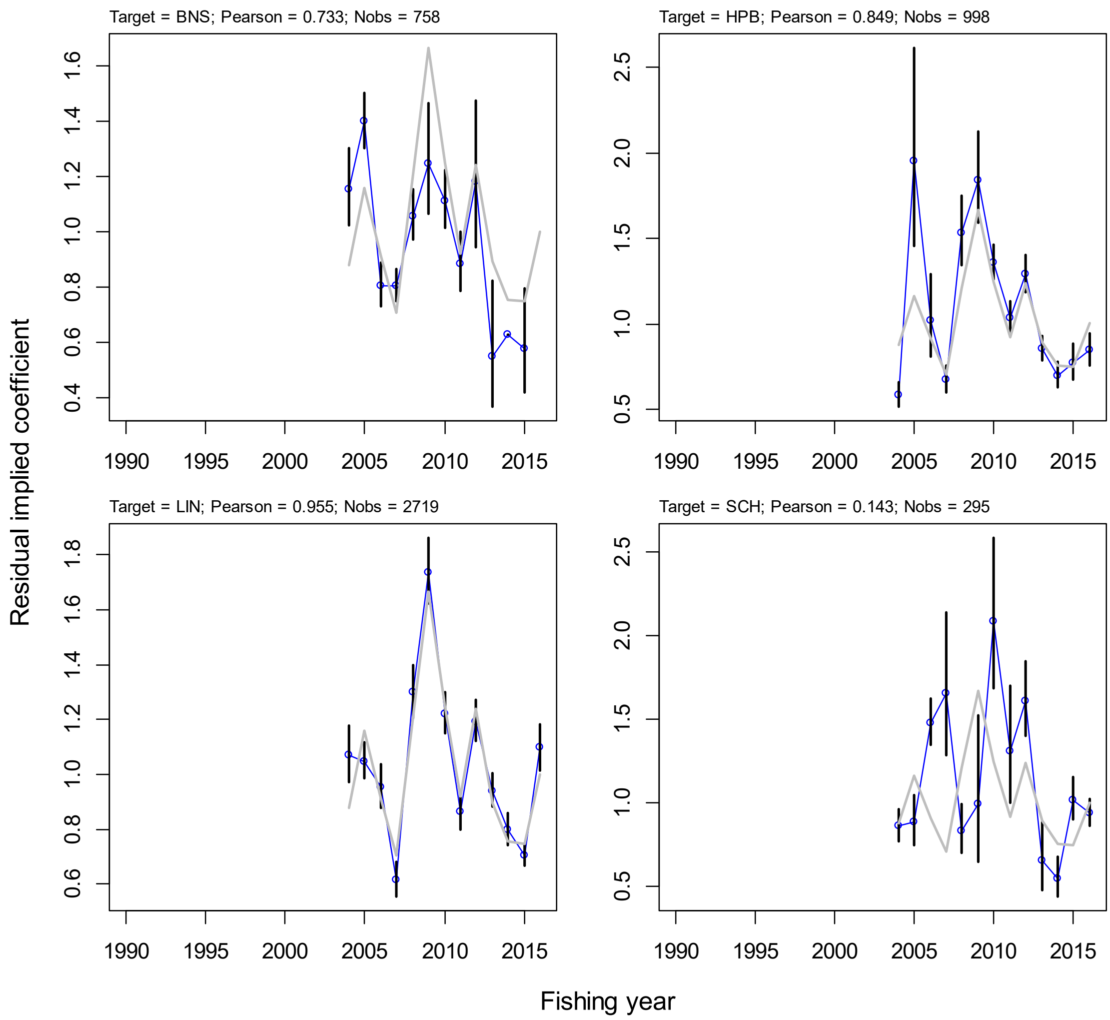

Figure 104: Residual implied coefficients for fishing year – target species interaction (not offered) for the school shark SCH 4 bottom longline CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.

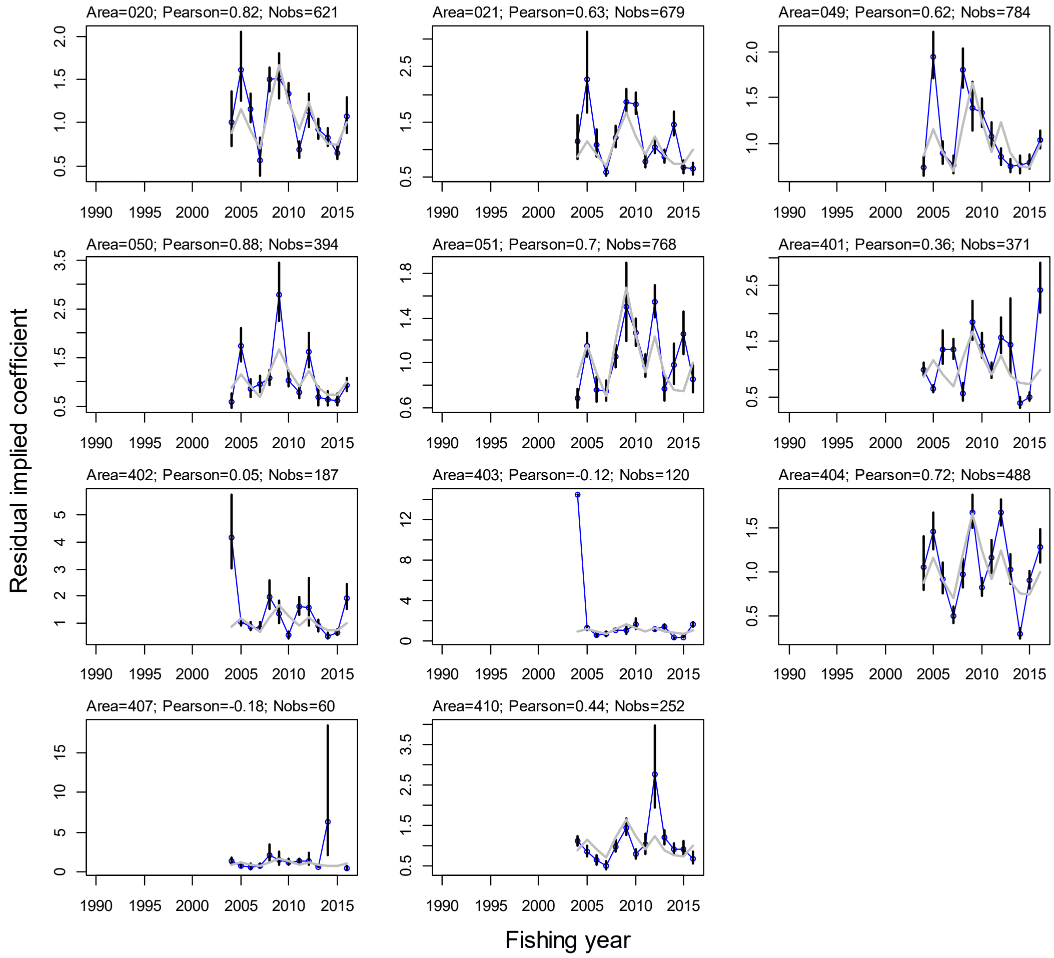

Figure 105: Residual implied coefficients for fishing year – statistical area interaction (not offered) for the school shark SCH 4 bottom longline CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.

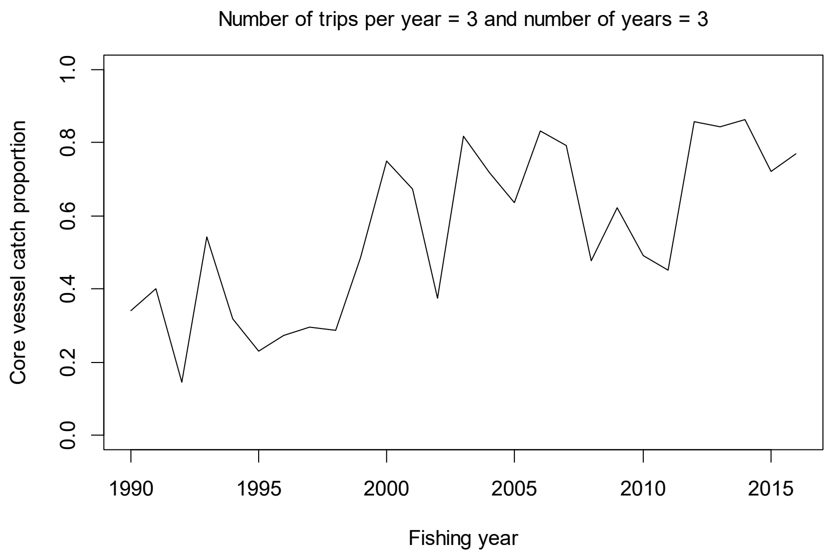

Figure 106: Proportion of catch included in the school shark 3S/5 bottom longline CPUE data set, after application of the data selection criteria, by fishing year.

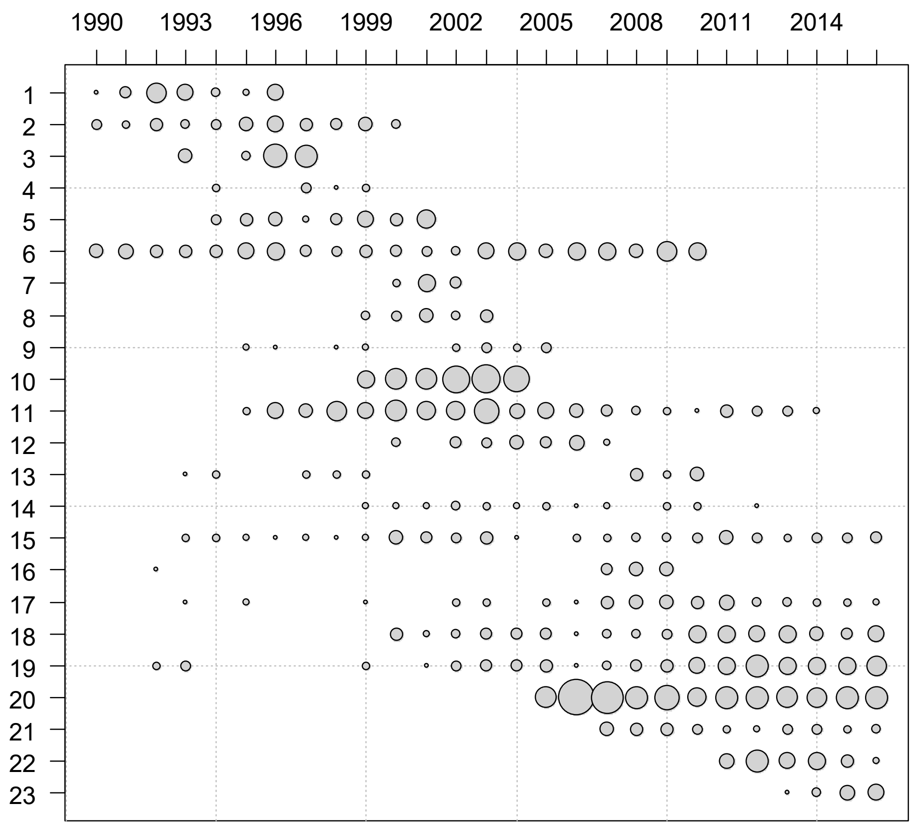

Figure 107: Core vessel summary by fishing year for school shark 3S/5 bottom longline. Bubble size proportional to effort by each vessel, normalised within each fishing year.

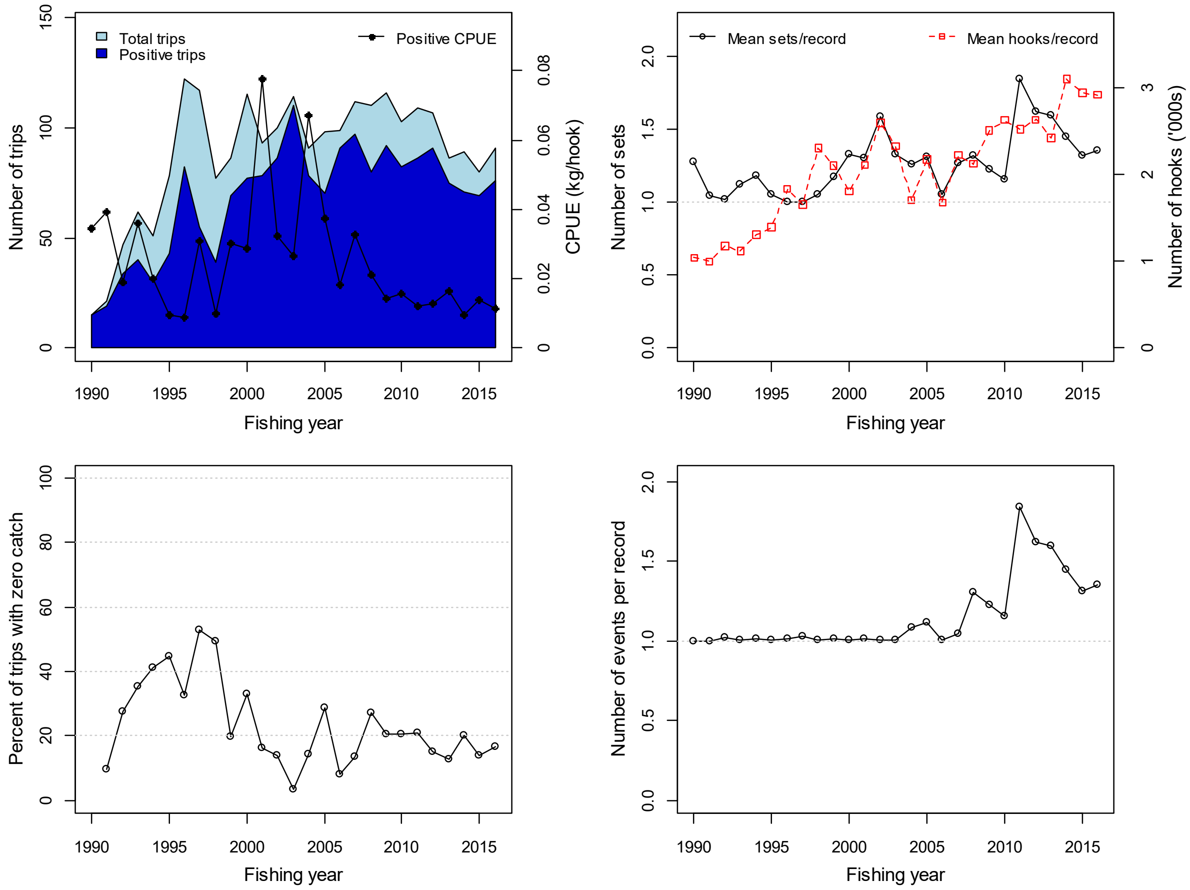

Figure 108: Core vessel summary plots by fishing year for school shark 3S/5 bottom longline: upper left panel, total trips (light blue) and trips with school shark catches (dark blue), overlaid with median annual arithmetic CPUE for all trips with positive catch; upper right panel, mean number of sets and mean number of hooks per set per daily effort-effort-stratum record; lower left panel, proportion of trips with no catch of school shark; lower right panel, mean number of events per daily-effort-stratum record.

Table 16: School shark 3S/5 bottom longline - Selected predictors for the lognormal CPUE model, showing the total and additional deviance explained.

Predictor	df	Total Dev. Expl. (%)	Additional Dev. Expl. (%)
Fishing year	26	5.0	5.0
Target species	3	25.1	20.1
Vessel	22	31.5	6.4
Statistical area	11	36.2	4.7
Number of hooks	3	37.0	0.8

Table 17: School shark 3S/5 bottom longline - Selected predictors for the binomial CPUE model, showing the total and additional deviance explained.

Predictor	df	Total Dev. Expl. (%)	Additional Dev. Expl. (%)
Fishing year	26	4.0	4.0
Target species	3	9.0	7.0
Vessel	22	11.0	2.0

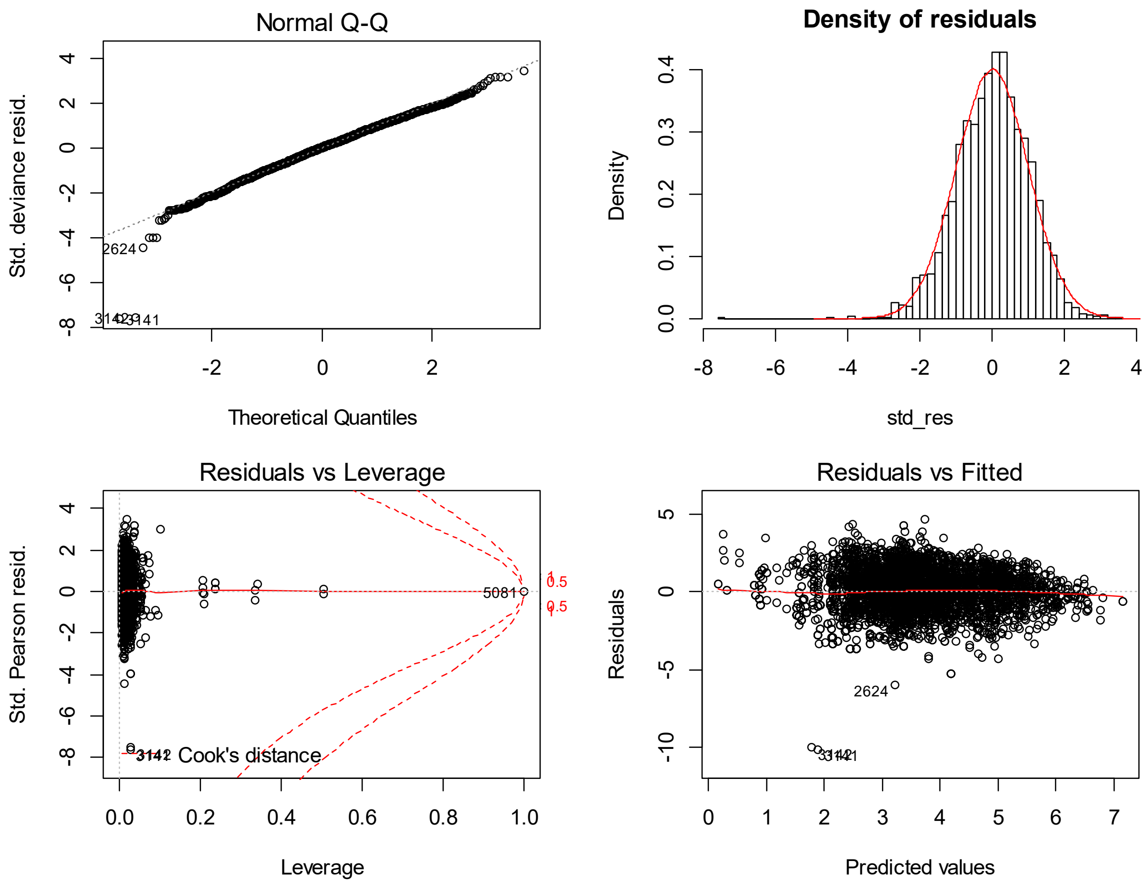

Figure 109: Diagnostic plots for the fit of the lognormal model for school shark 3S/5 bottom longline. Upper left panel, q-q plot of standardised residuals; upper right panel, histogram of standardised residuals compared to lognormal distribution (red line); lower left panel, residuals versus leverage plot; lower right panel, standardised residuals plotted against the predicted model catch.

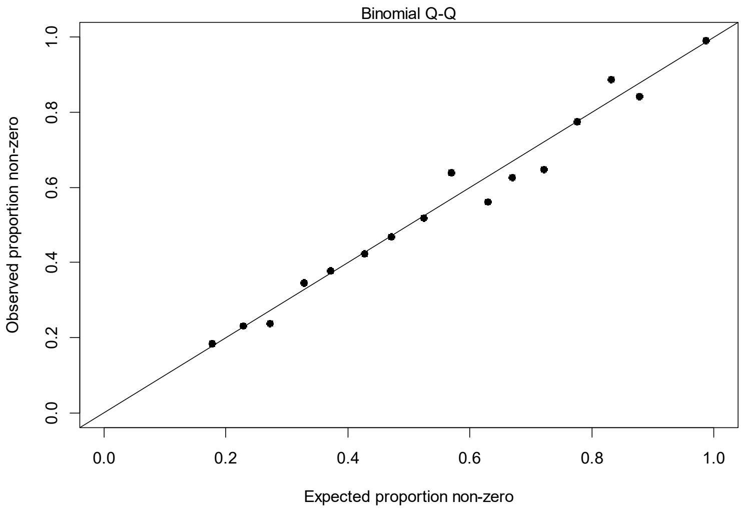

Figure 110: School shark 3S/5 bottom longline, diagnostic (q-q) plot for the binomial model.

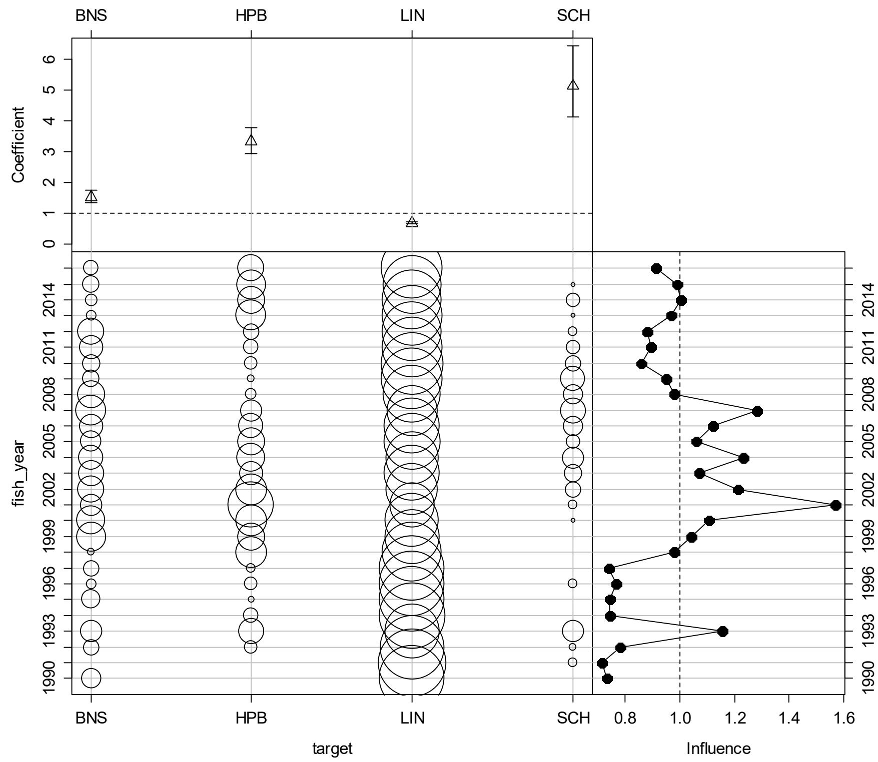

Figure 111: Target species influence plot for the lognormal model for school shark 3S/5 bottom longline. Top panel, the coefficient estimates for each target species; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

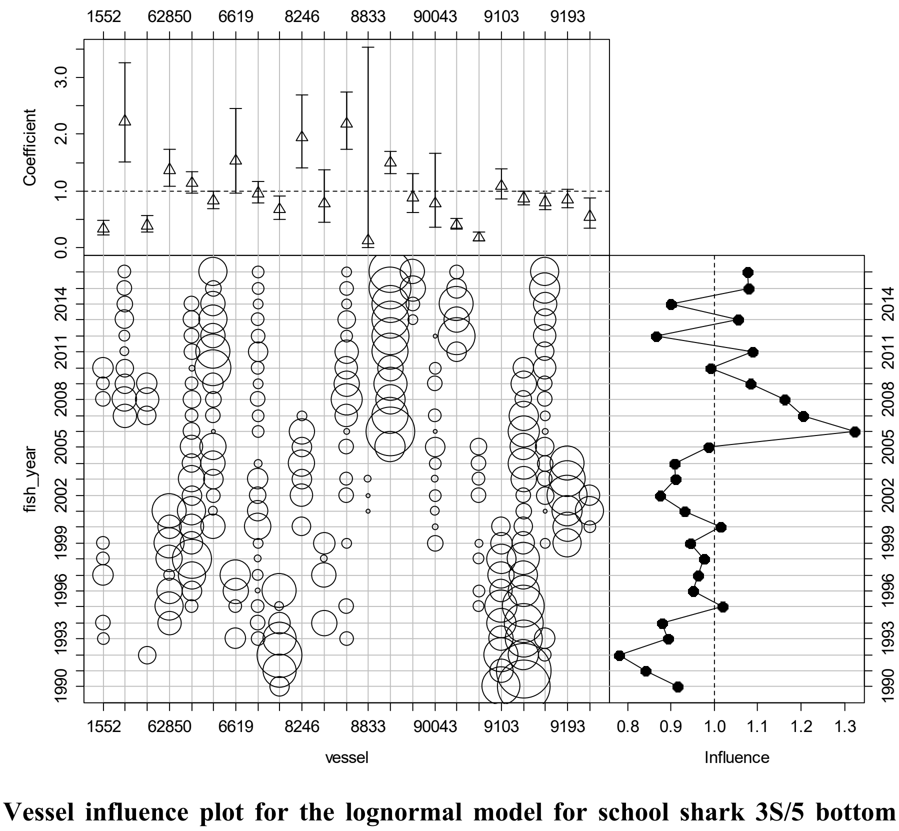

Figure 112: Vessel influence plot for the lognormal model for school shark 3S/5 bottom longline. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

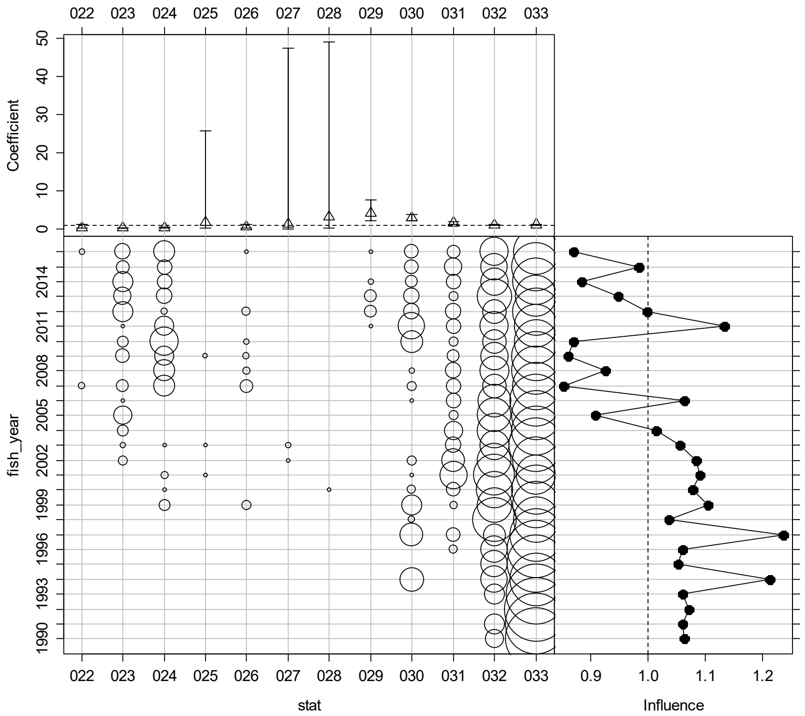

Figure 113: Statistical area influence plot for the lognormal model for school shark 3S/5 bottom longline. Top panel, the coefficient estimates for each statistical area; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

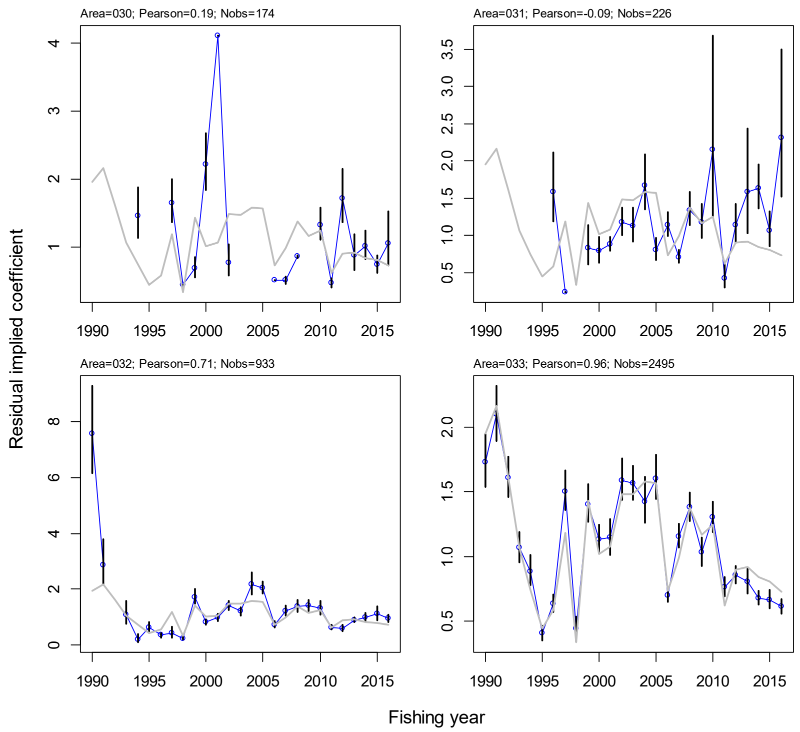

Figure 114: Residual implied coefficients for fishing year – statistical area interaction (not offered) for the school shark 3S/5 bottom longline CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.

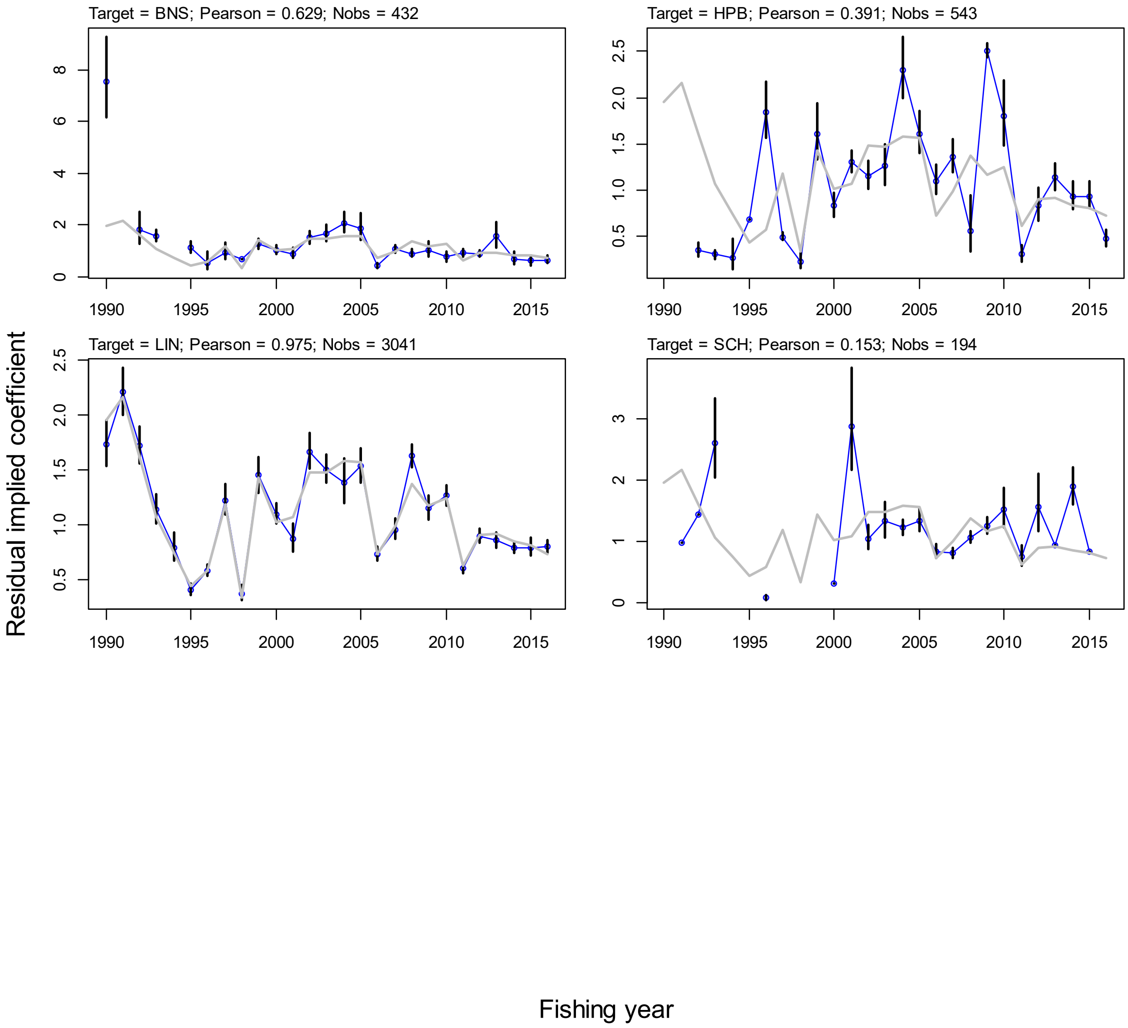

Figure 115: Residual implied coefficients for fishing year – target species interaction (not offered) for the school shark 3S/5 bottom longline CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.

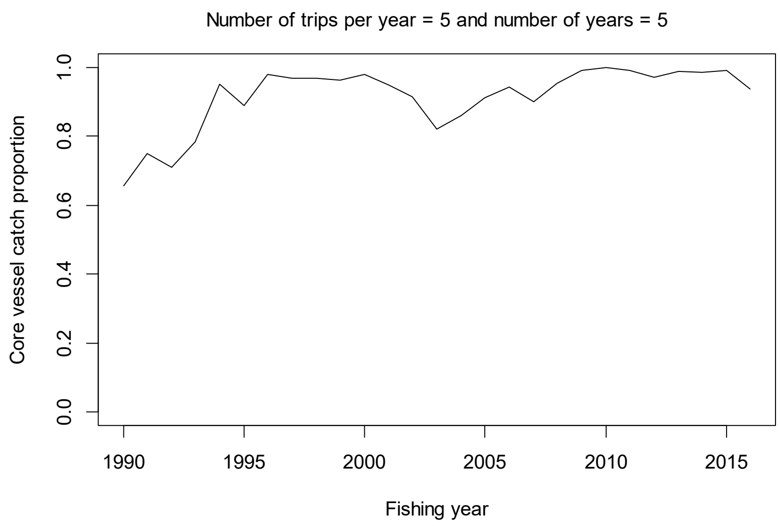

Figure 116: Proportion of catch included in the school shark 3S/5 setnet CPUE data set, after application of the data selection criteria, by fishing year.

Figure 117: Core vessel summary by fishing year for school shark 3S/5 setnet. Bubble size proportional to effort by each vessel, normalised within each fishing year.

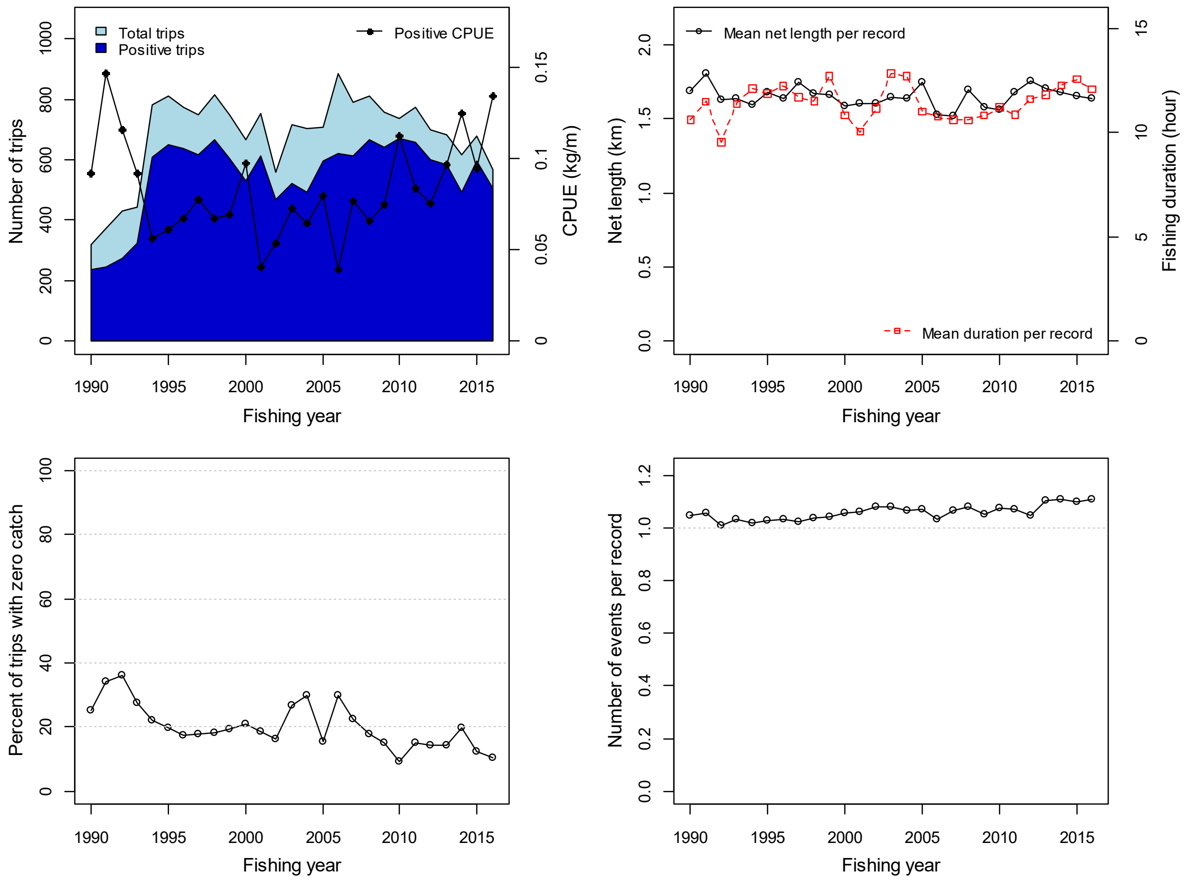

Figure 118: Core vessel summary plots by fishing year for school shark 3S/5 setnet: upper left panel, total trips (light blue) and trips with school shark catches (dark blue), overlaid with median annual arithmetic CPUE for all trips with positive catch; upper right panel, mean number of sets and mean number of hooks per set per daily effort-effort-stratum record; lower left panel, proportion of trips with no catch of school shark; lower right panel, mean number of events per daily-effort-stratum record.

Table 18: School shark 3S/5 setnet - Selected predictors for the lognormal CPUE model, showing the total and additional deviance explained.

Predictor	df	Total Dev. Expl. (%)	Additional Dev. Expl. (%)
Fishing year	26	1.0	1.0
Vessel	40	54.0	53.0
Target species	3	58.5	4.5
Statistical area	11	59.8	1.3

Table 19: School shark 3S/5 setnet - Selected predictors for the binomial CPUE model, showing the total and additional deviance explained.

Predictor	df	Total Dev. Expl. (%)	Additional Dev. Expl. (%)
Fishing year	26	2.0	2.0
Vessel	40	13.0	11.0
Target species	3	17.0	4.0

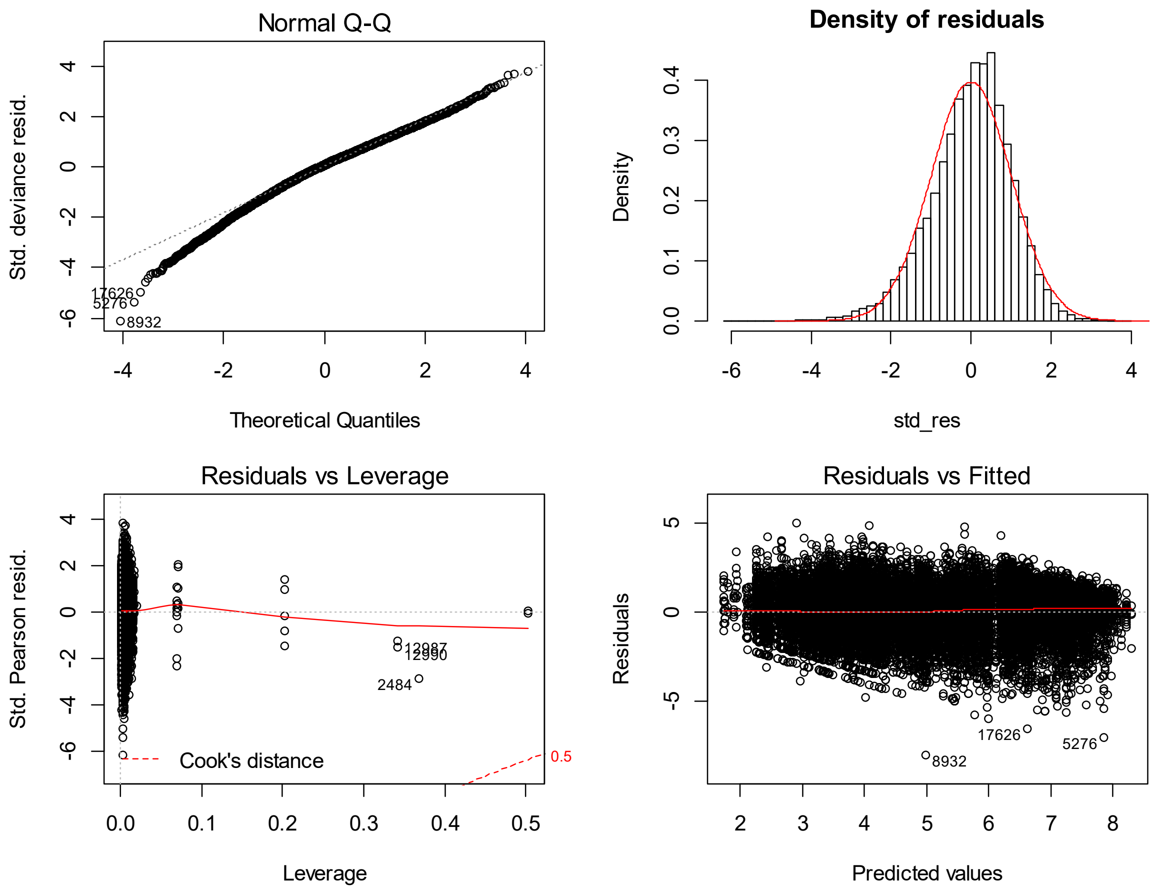

Figure 119: Diagnostic plots for the fit of the lognormal model for school shark 3S/5 setnet. Upper left panel, q-q plot of standardised residuals; upper right panel, histogram of standardised residuals compared to lognormal distribution (red line); lower left panel, residuals versus leverage plot; lower right panel, standardised residuals plotted against the predicted model catch.

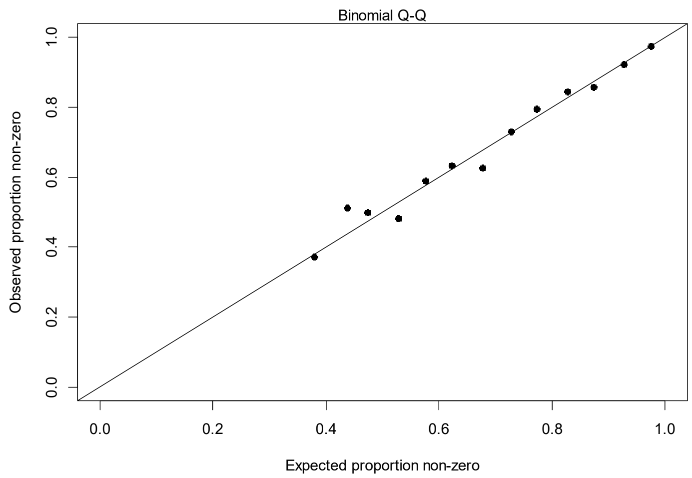

Figure 120: School shark 3S/5 setnet, diagnostic (q-q) plot for the binomial model.

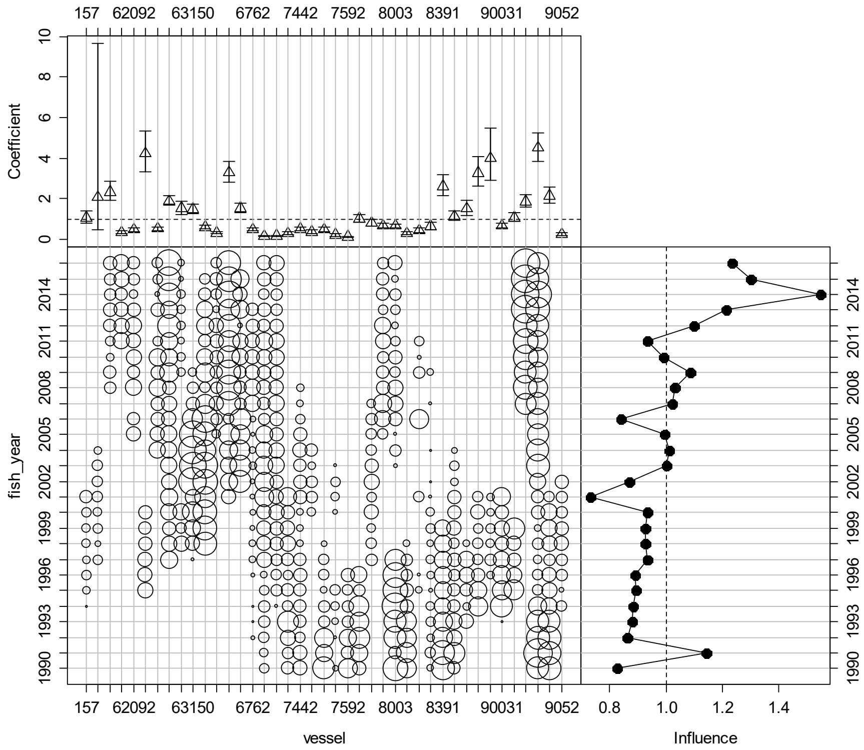

Figure 121: Vessel influence plot for the lognormal model for school shark 3S/5 setnet. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

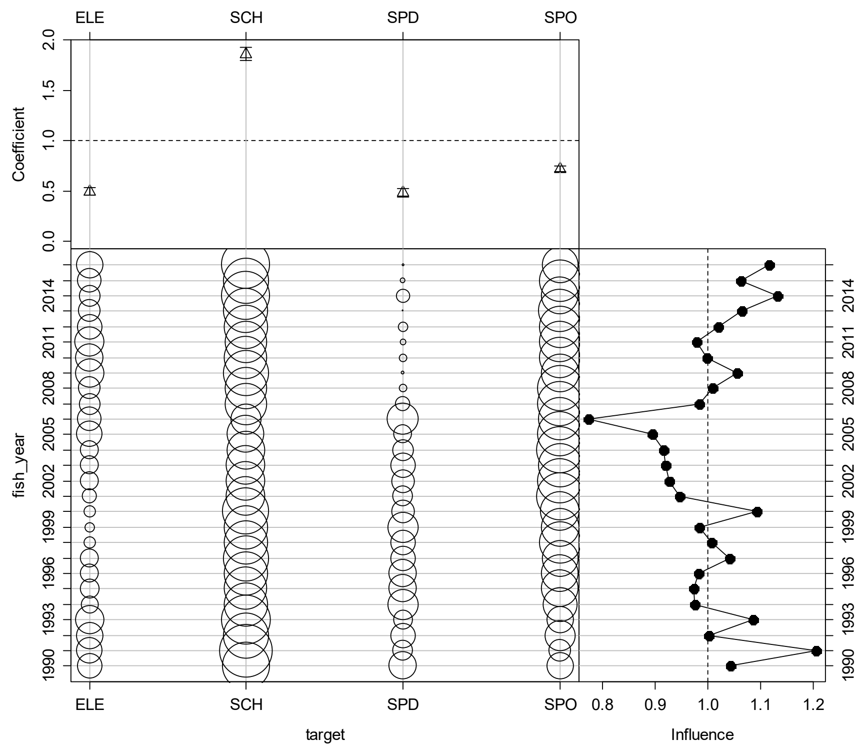

Figure 122: Target species influence plot for the lognormal model for school shark 3S/5 setnet. Top panel, the coefficient estimates for each target species; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

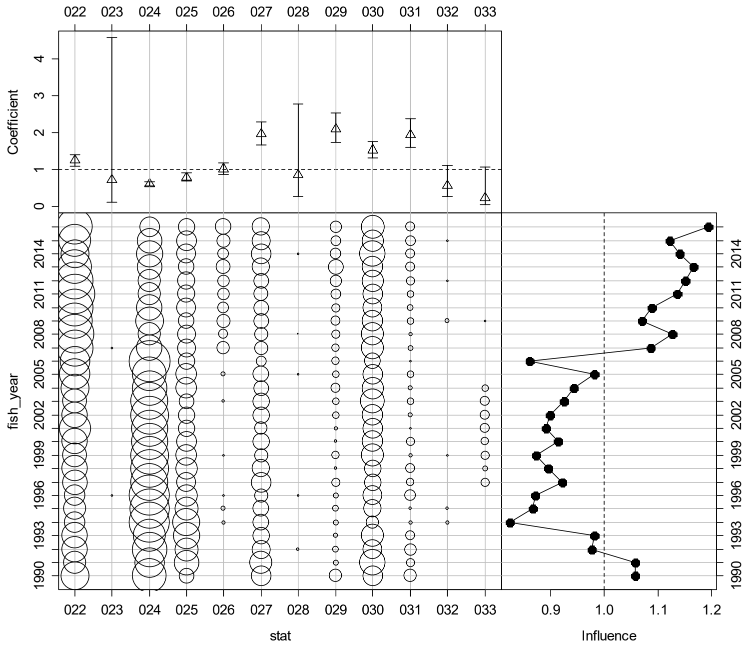

Figure 123: Statistical area influence plot for the lognormal model for school shark 3S/5 setnet. Top panel, the coefficient estimates for each statistical area; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

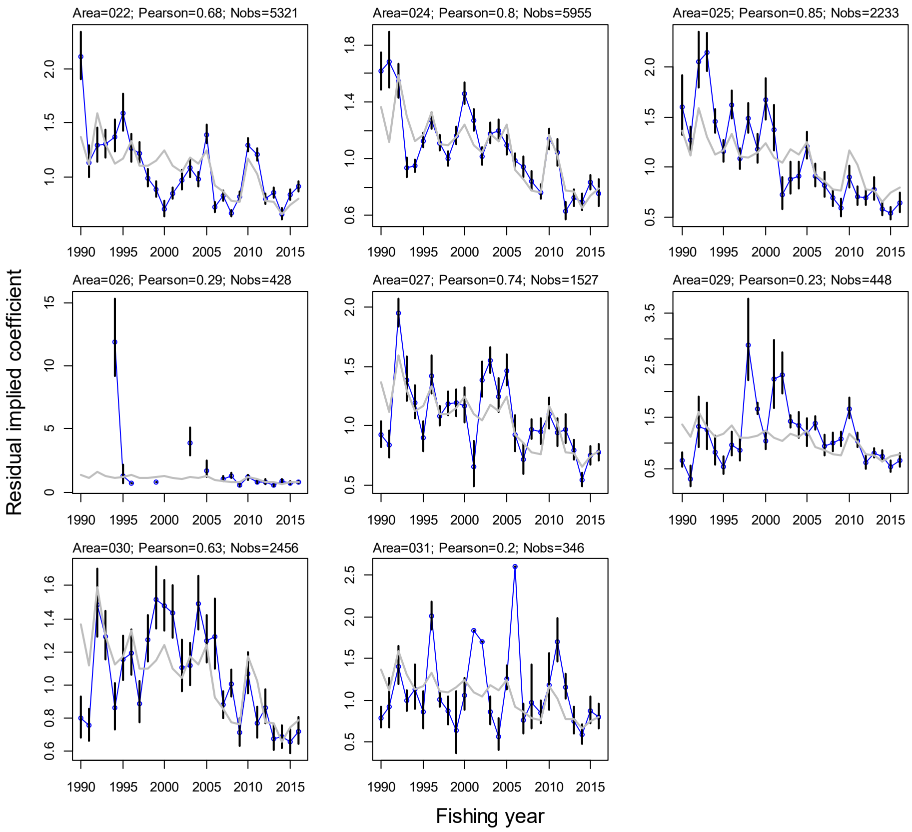

Figure 124: Residual implied coefficients for fishing year – statistical area interaction (not offered) for the school shark 3S/5 setnet CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.

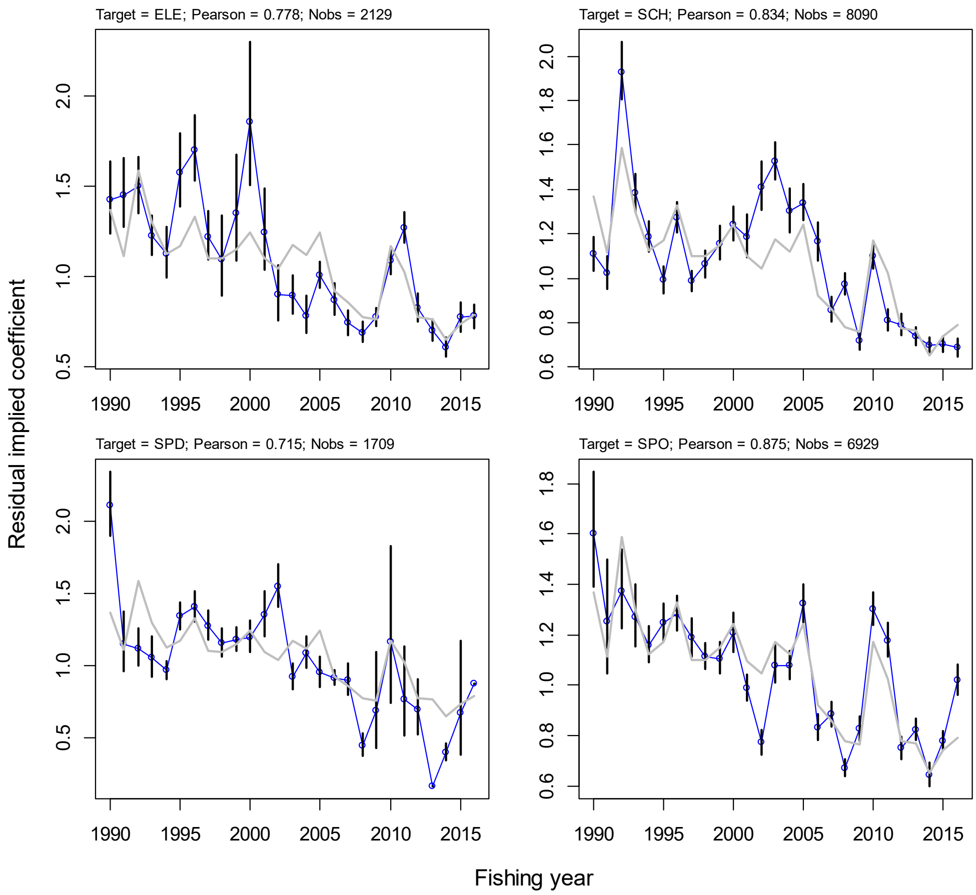

Figure 125: Residual implied coefficients for fishing year – target species interaction (not offered) for the school shark 3S/5 setnet CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.

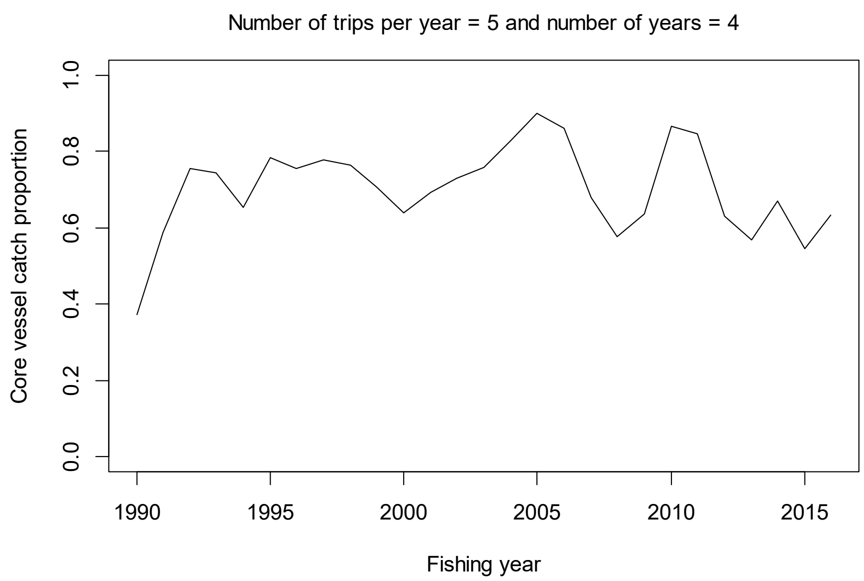

Figure 126: Proportion of catch included in the school shark 7/8/1W bottom longline CPUE data set, after application of the data selection criteria, by fishing year.

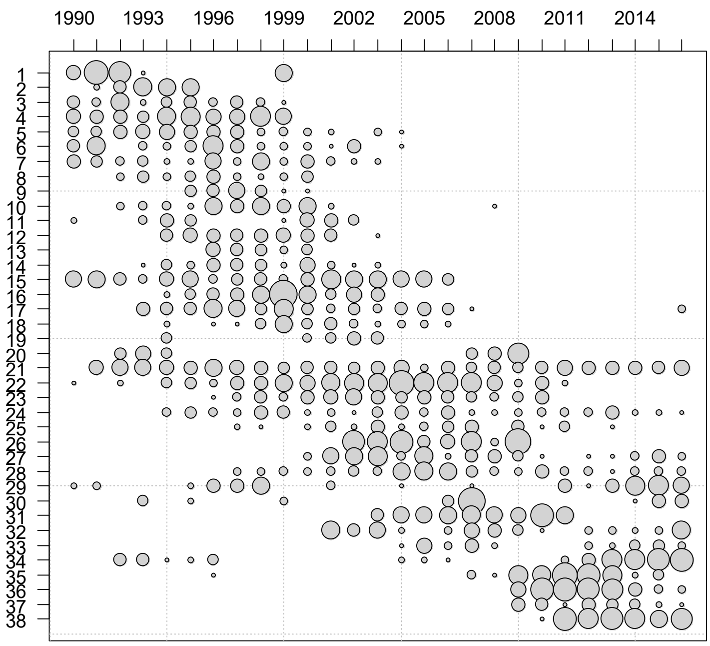

Figure 127: Core vessel summary by fishing year for school shark 7/8/1W bottom longline. Bubble size proportional to effort by each vessel, normalised within each fishing year.

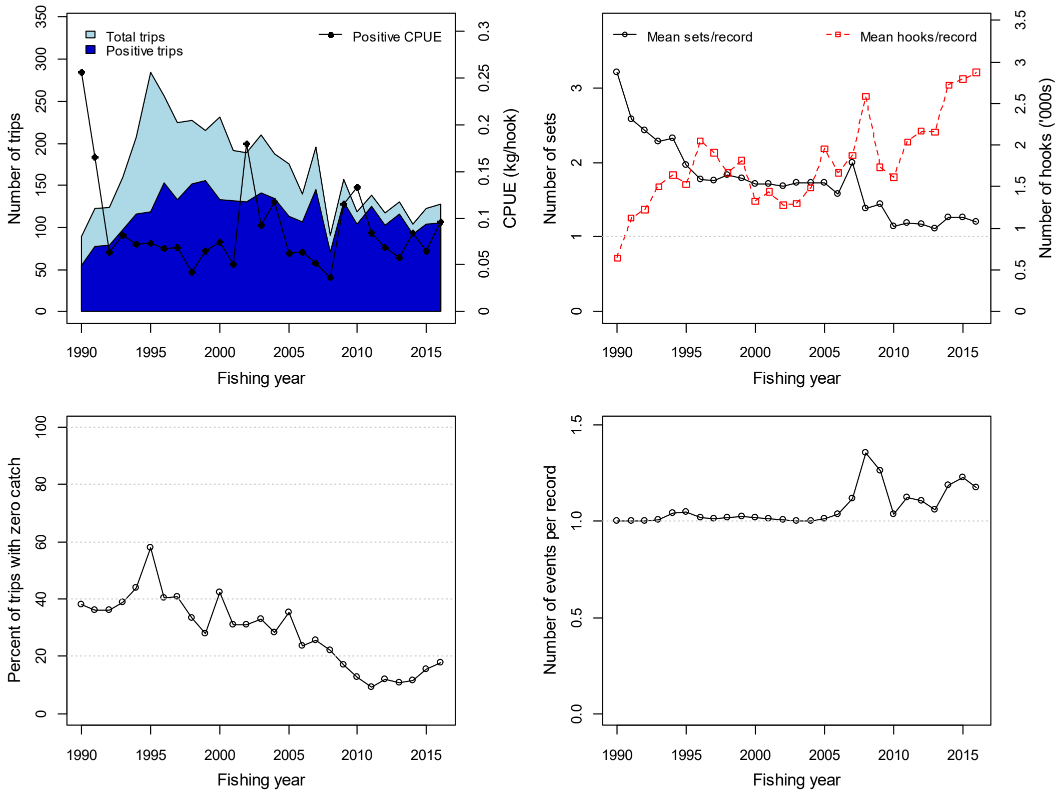

Figure 128: Core vessel summary plots by fishing year for school shark 7/8/1W bottom longline: upper left panel, total trips (light blue) and trips with school shark catches (dark blue), overlaid with median annual arithmetic CPUE for all trips with positive catch; upper right panel, mean number of sets and mean number of hooks per set per daily effort-effort-stratum record; lower left panel, proportion of trips with no catch of school shark; lower right panel, mean number of events per daily-effort-stratum record.

Table 20: School shark 7/8/1W bottom longline - Selected predictors for the lognormal CPUE model, showing the total and additional deviance explained.

Predictor	df	Total Dev. Expl. (%)	Additional Dev. Expl. (%)
Fishing year	26	2.0	2.0
Target species	4	42.4	40.4
Vessel	37	49.0	6.6
Number of hooks	3	52.0	3.0
Statistical area	12	52.6	0.6

Table 21: School shark 7/8/1W bottom longline - Selected predictors for the binomial CPUE model, showing the total and additional deviance explained.

Predictor	df	Total Dev. Expl. (%)	Additional Dev. Expl. (%)
Fishing year	26	3.0	3.0
Target species	4	20.0	17.0
Vessel	37	24.0	4.0

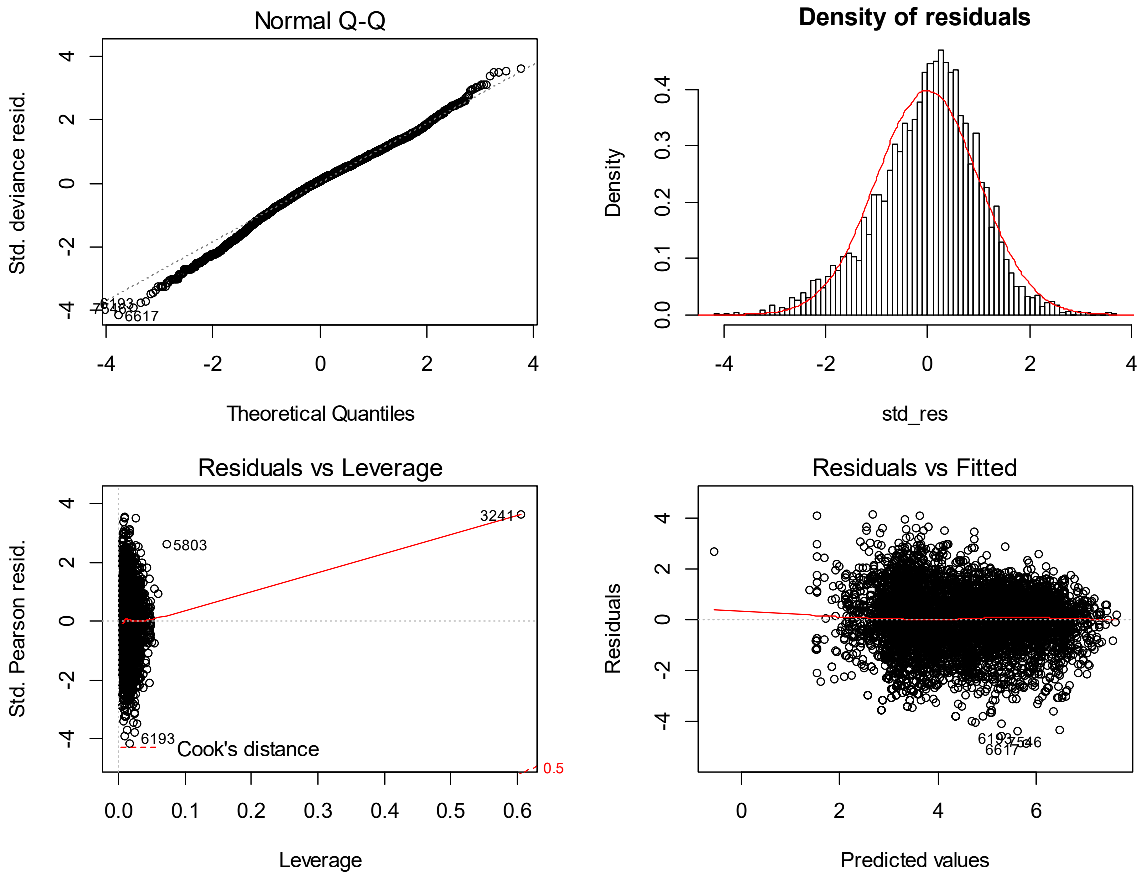

Figure 129: Diagnostic plots for the fit of the lognormal model for school shark 7/8/1W bottom longline. Upper left panel, q-q plot of standardised residuals; upper right panel, histogram of standardised residuals compared to lognormal distribution (red line); lower left panel, residuals versus leverage plot; lower right panel, standardised residuals plotted against the predicted model catch.

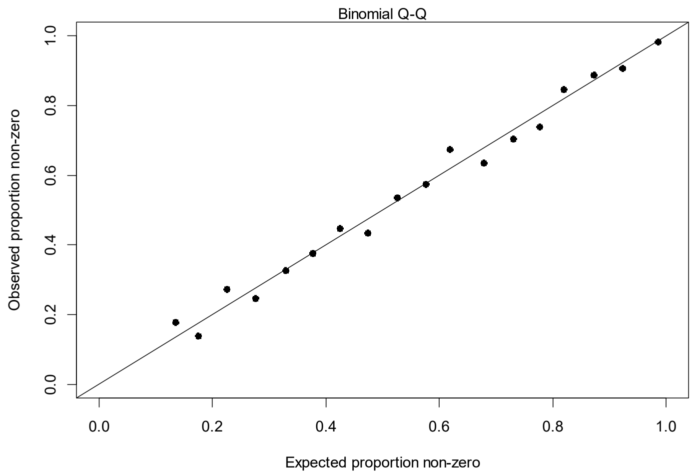

Figure 130: School shark 7/8/1W bottom longline, diagnostic (q-q) plot for the binomial model.

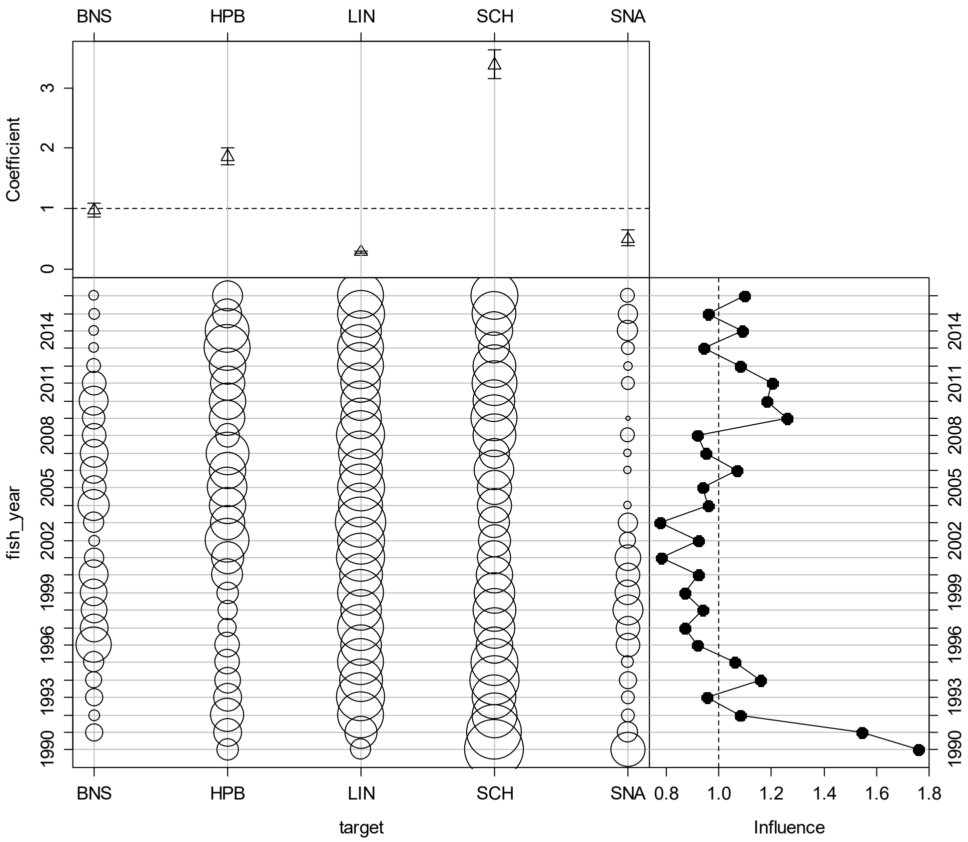

Figure 131: Target species influence plot for the lognormal model for school shark 7/8/1W bottom longline. Top panel, the coefficient estimates for each target species; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

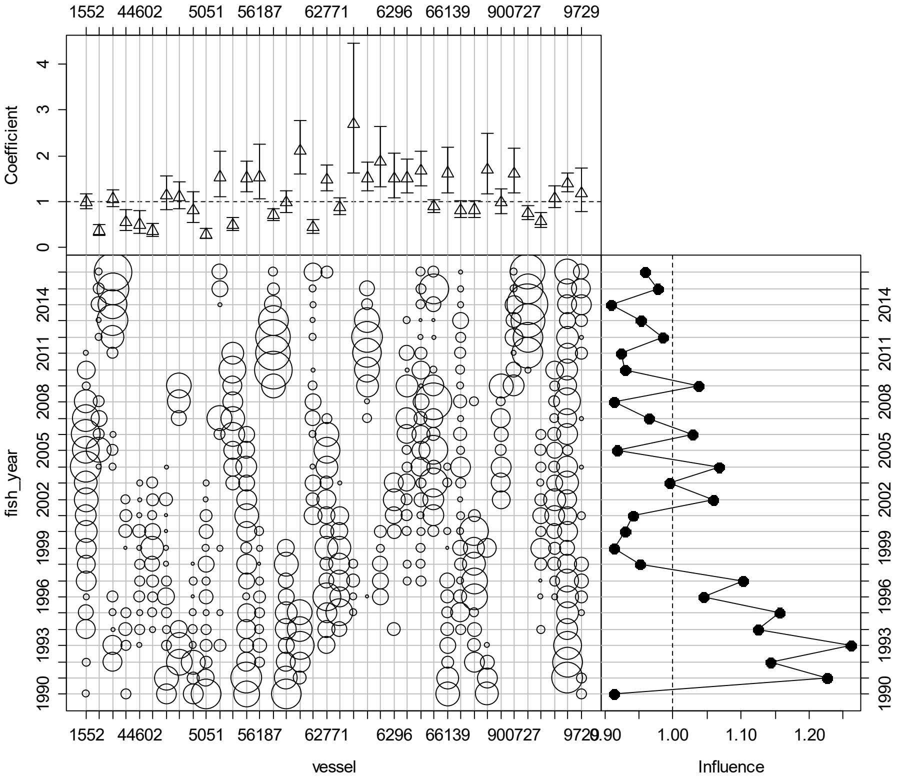

Figure 132: Vessel influence plot for the lognormal model for school shark 7/8/1W bottom longline. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

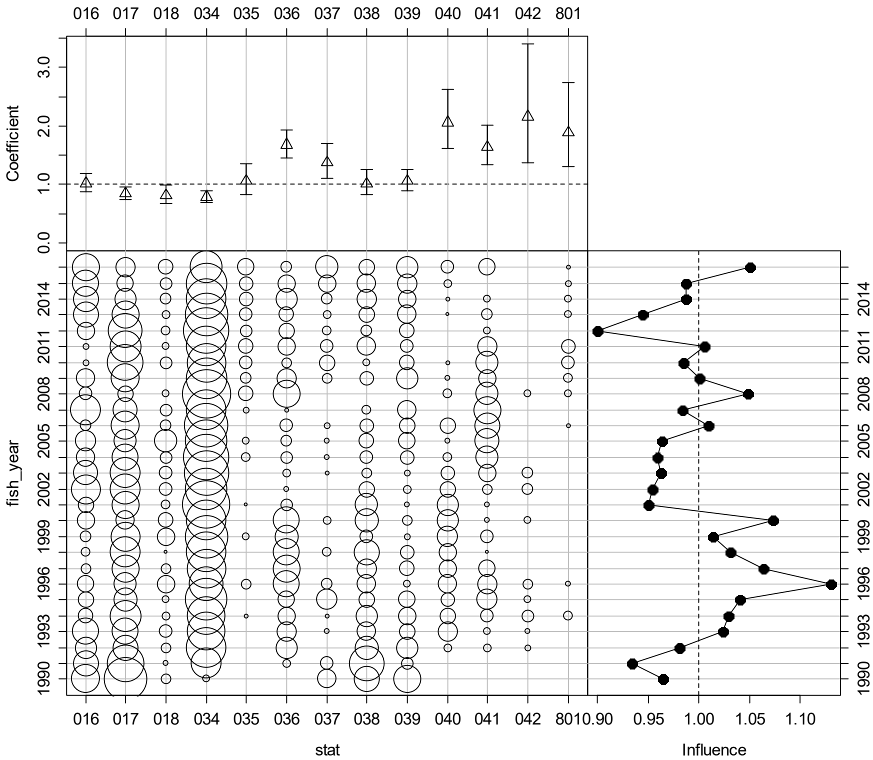

Figure 133: Statistical area influence plot for the lognormal model for school shark 7/8/1W bottom longline. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

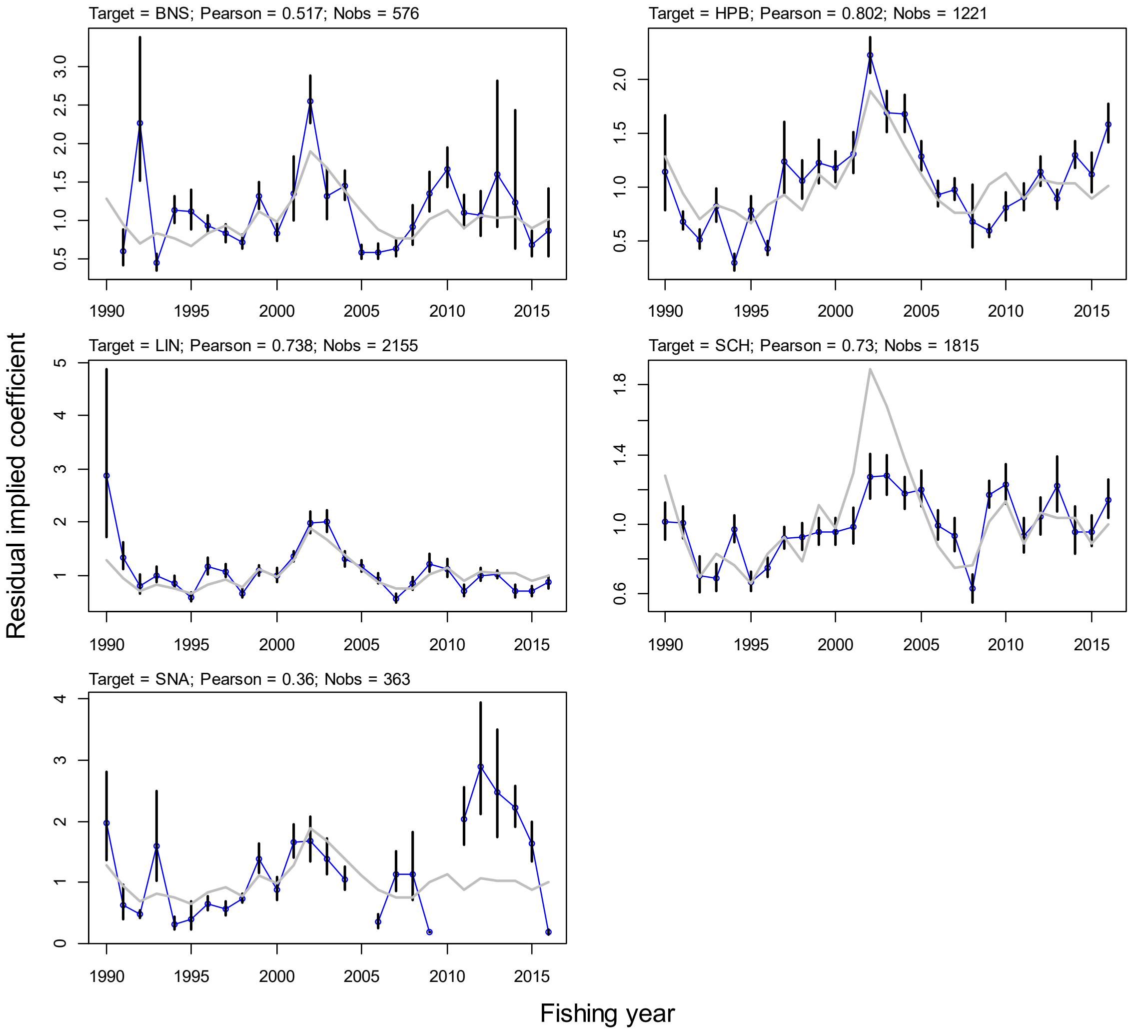

Figure 134: Residual implied coefficients for fishing year – target species interaction (not offered) for the school shark 7/8/1W bottom longline CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.

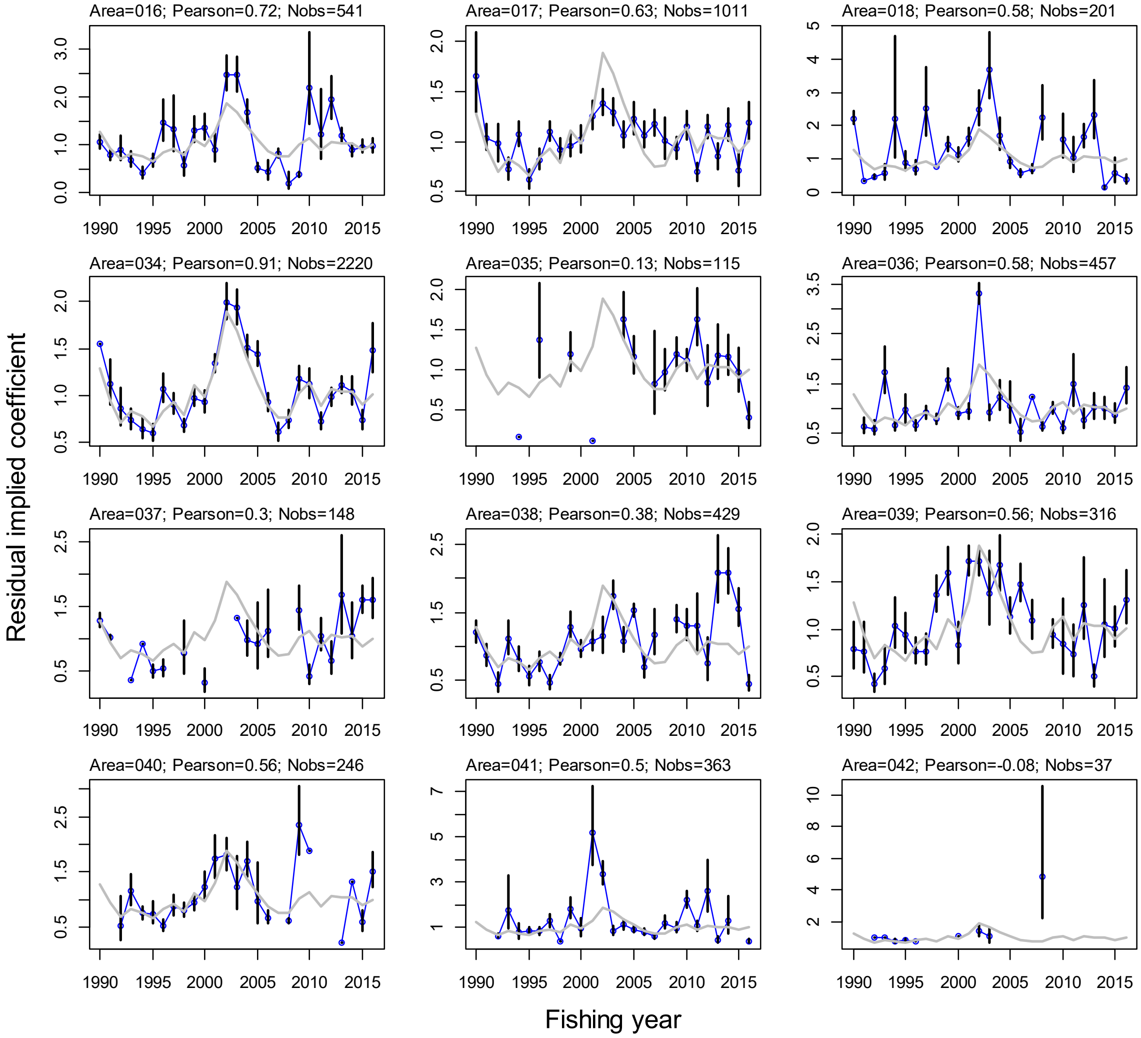

Figure 135: Residual implied coefficients for fishing year – statistical area interaction (not offered) for the school shark 7/8/1W bottom longline CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.

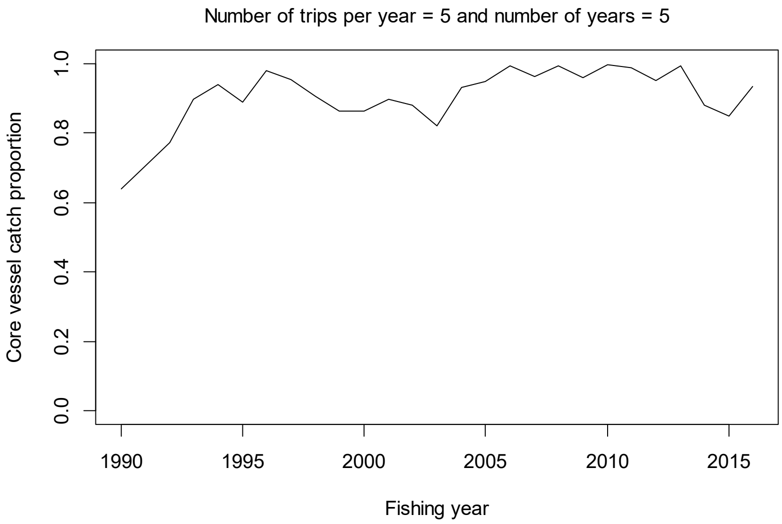

Figure 136: Proportion of catch included in the school shark 7/8/1W setnet CPUE data set, after application of the data selection criteria, by fishing year.

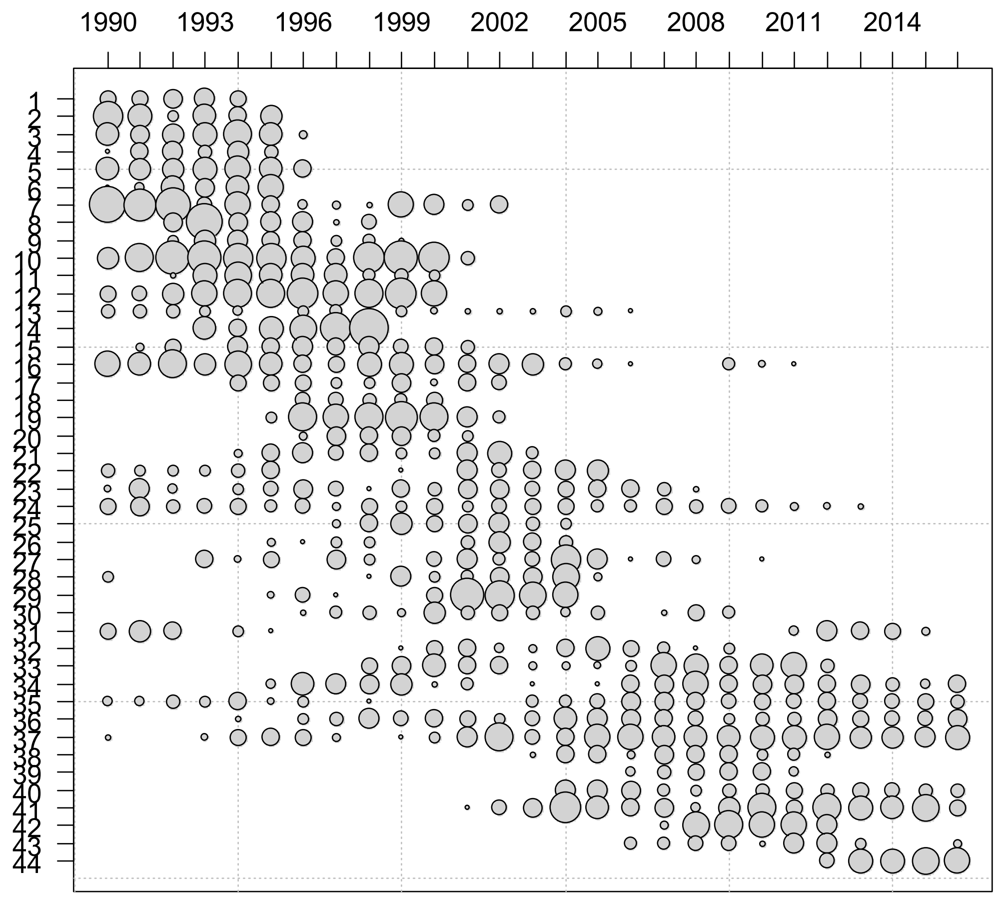

Figure 137: Core vessel summary by fishing year for school shark 7/8/1W setnet. Bubble size proportional to effort by each vessel, normalised within each fishing year.

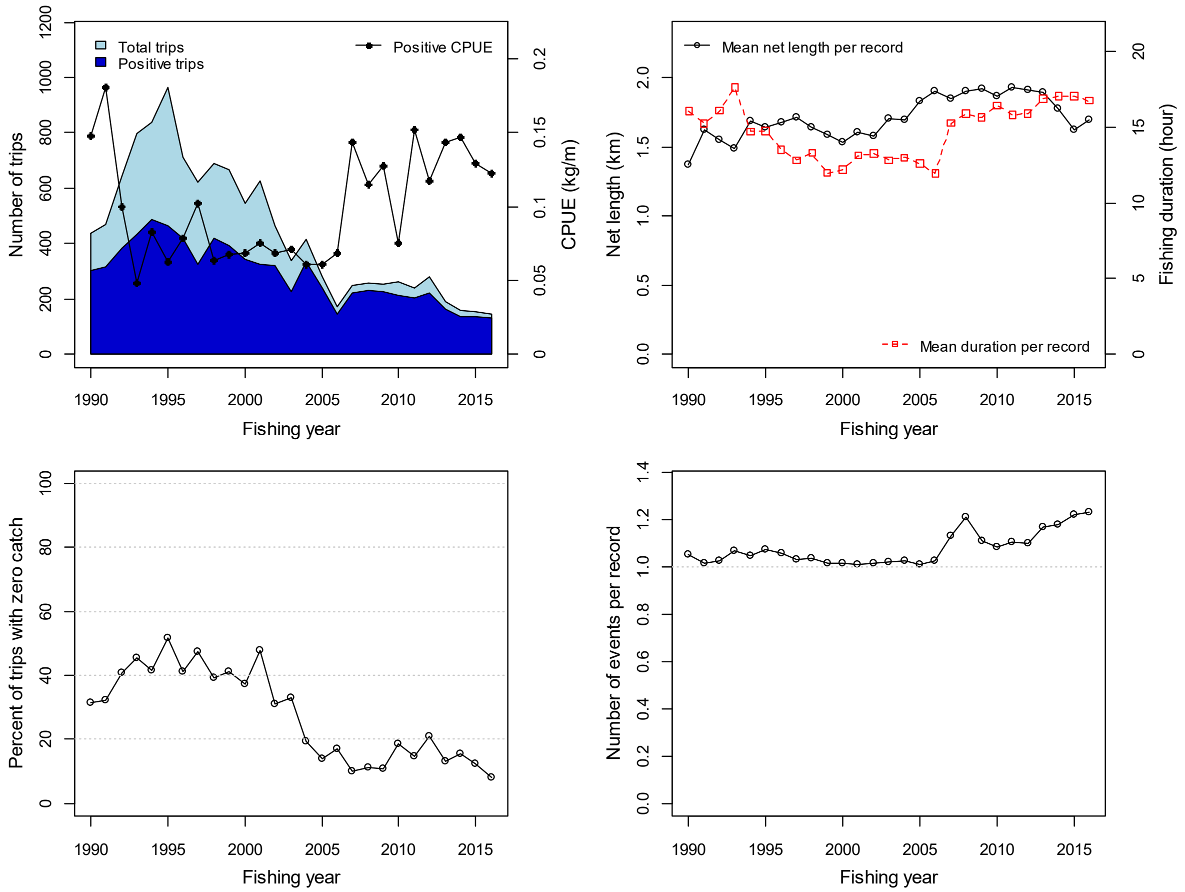

Figure 138: Core vessel summary plots by fishing year for school shark 7/8/1W setnet: upper left panel, total trips (light blue) and trips with school shark catches (dark blue), overlaid with median annual arithmetic CPUE for all trips with positive catch; upper right panel, mean number of sets and mean number of hooks per set per daily effort-effort-stratum record; lower left panel, proportion of trips with no catch of school shark; lower right panel, mean number of events per daily-effort-stratum record.

Table 22: School shark 7/8/1W setnet - Selected predictors for the lognormal CPUE model, showing the total and additional deviance explained.

Predictor	df	Total Dev. Expl. (%)	Additional Dev. Expl. (%)
Fishing year	26	3.0	3.0
Target species	5	30.4	27.4
Vessel	43	41.6	11.2
Statistical area	11	44.3	2.7

Table 23: School shark 7/8/1W setnet - Selected predictors for the binomial CPUE model, showing the total and additional deviance explained.

Predictor	df	Total Dev. Expl. (%)	Additional Dev. Expl. (%)
Fishing year	26	3.0	3.0
Target species	5	17.0	14.0
Vessel	43	23.0	6.0
Statistical area	11	24.0	1.0

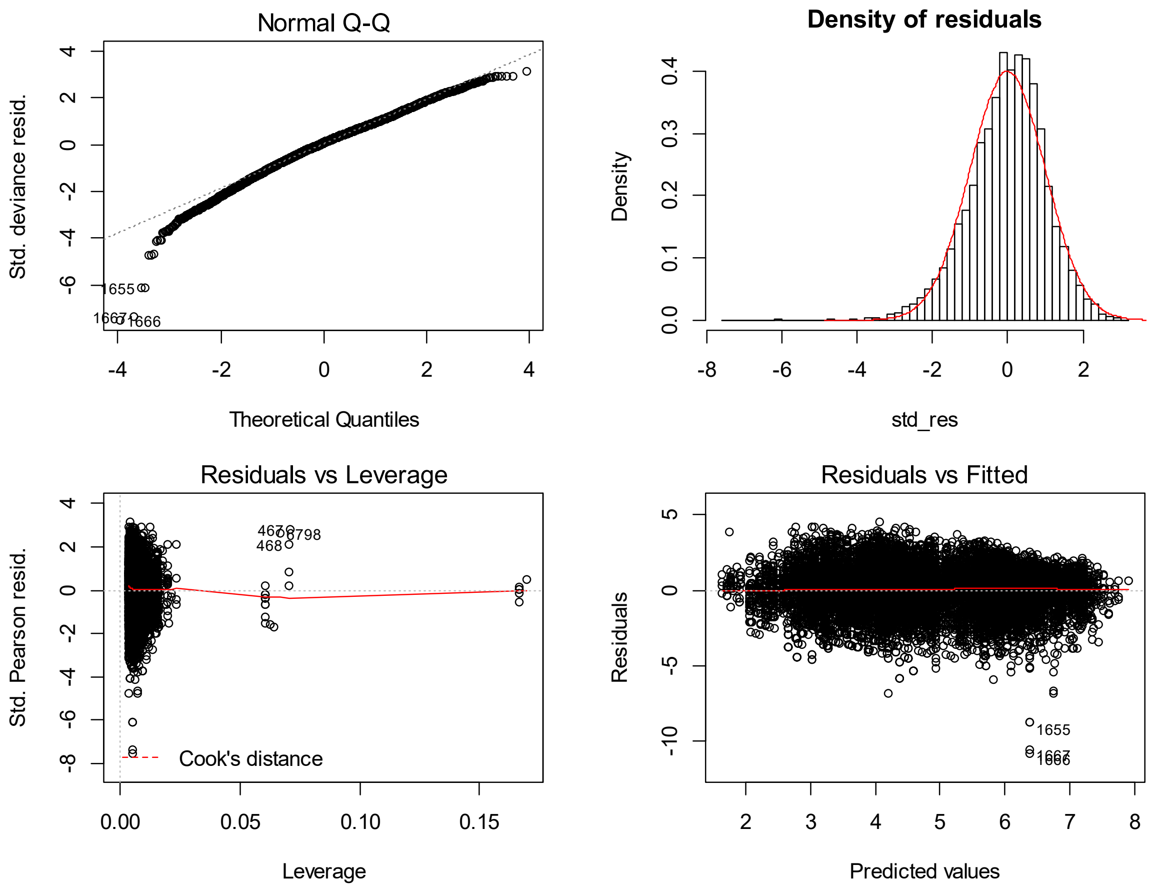

Figure 139: Diagnostic plots for the fit of the lognormal model for school shark 7/8/1W setnet. Upper left panel, q-q plot of standardised residuals; upper right panel, histogram of standardised residuals compared to lognormal distribution (red line); lower left panel, residuals versus leverage plot; lower right panel, standardised residuals plotted against the predicted model catch.

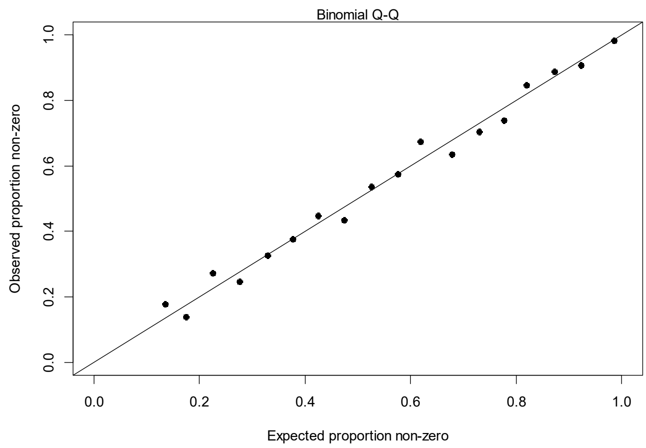

Figure 140: School shark 7/8/1W setnet, diagnostic (q-q) plot for the binomial model.

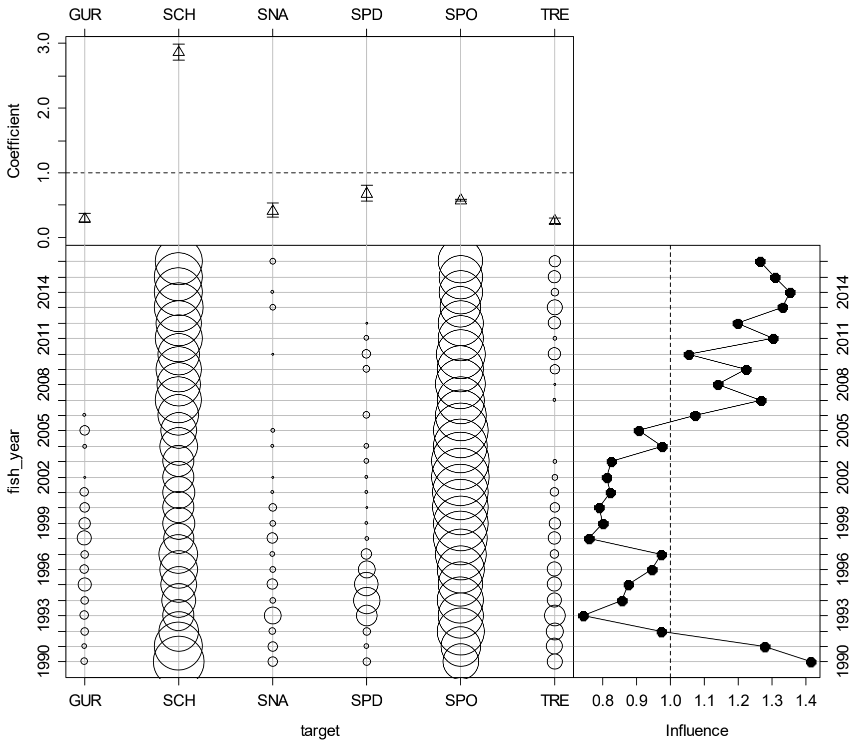

Figure 141: Target species influence plot for the lognormal model for school shark 7/8/1W setnet. Top panel, the coefficient estimates for each target species; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

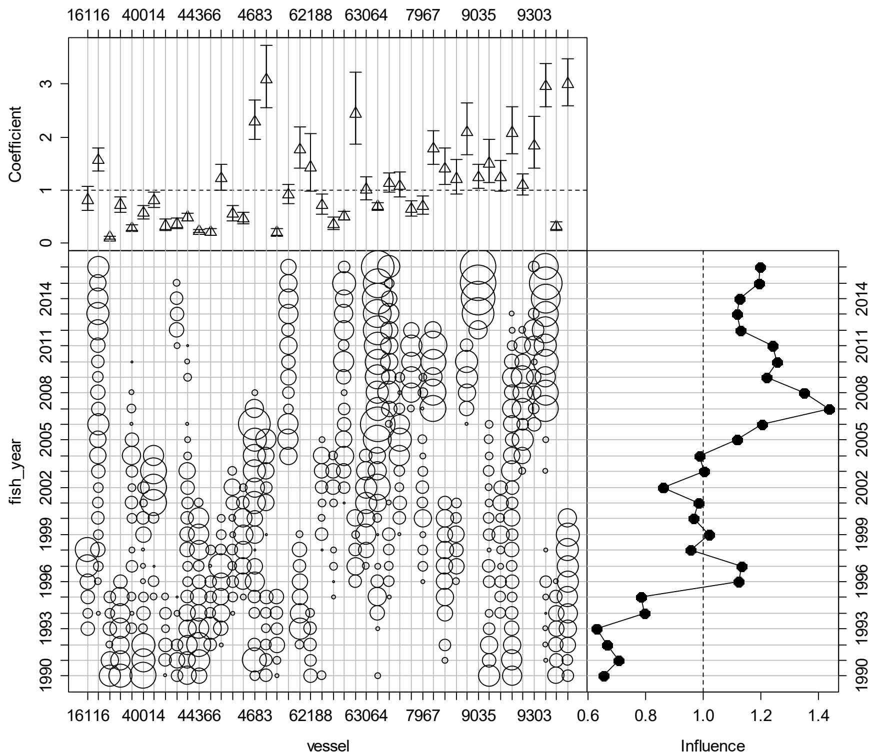

Figure 142: Vessel influence plot for the lognormal model for school shark 7/8/1W setnet. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

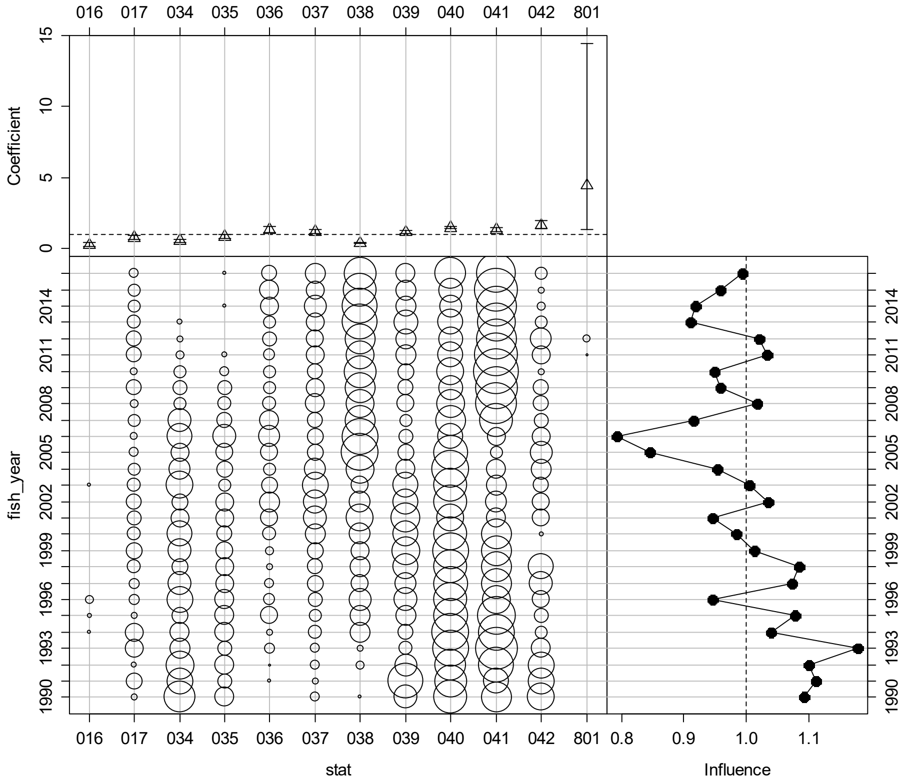

Figure 143: Statistical area influence plot for the lognormal model for school shark 7/8/1W setnet. Top panel, the coefficient estimates for each statistical area; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

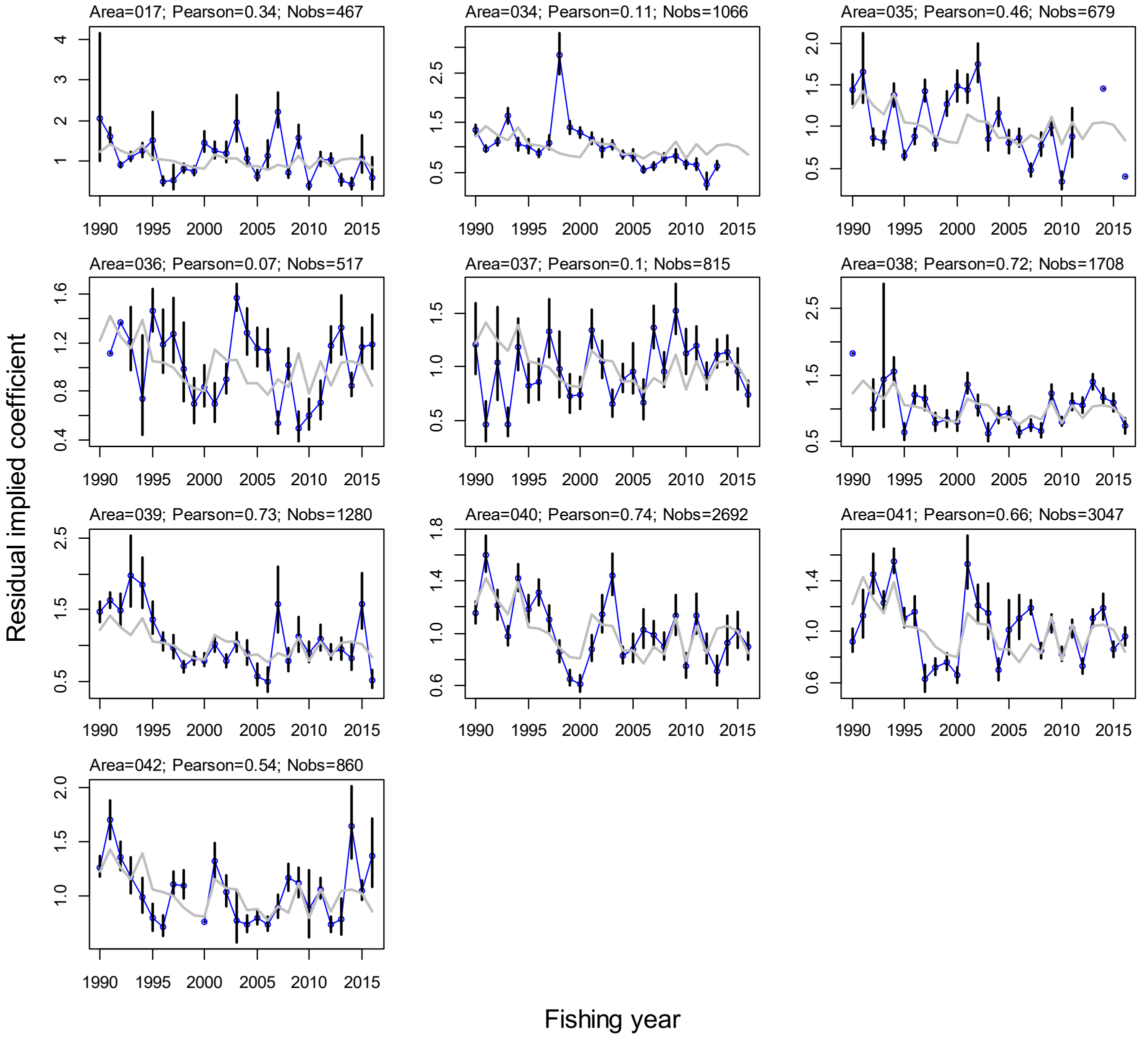

Figure 144: Residual implied coefficients for fishing year – statistical area interaction (not offered) for the school shark 7/8/1W setnet CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.

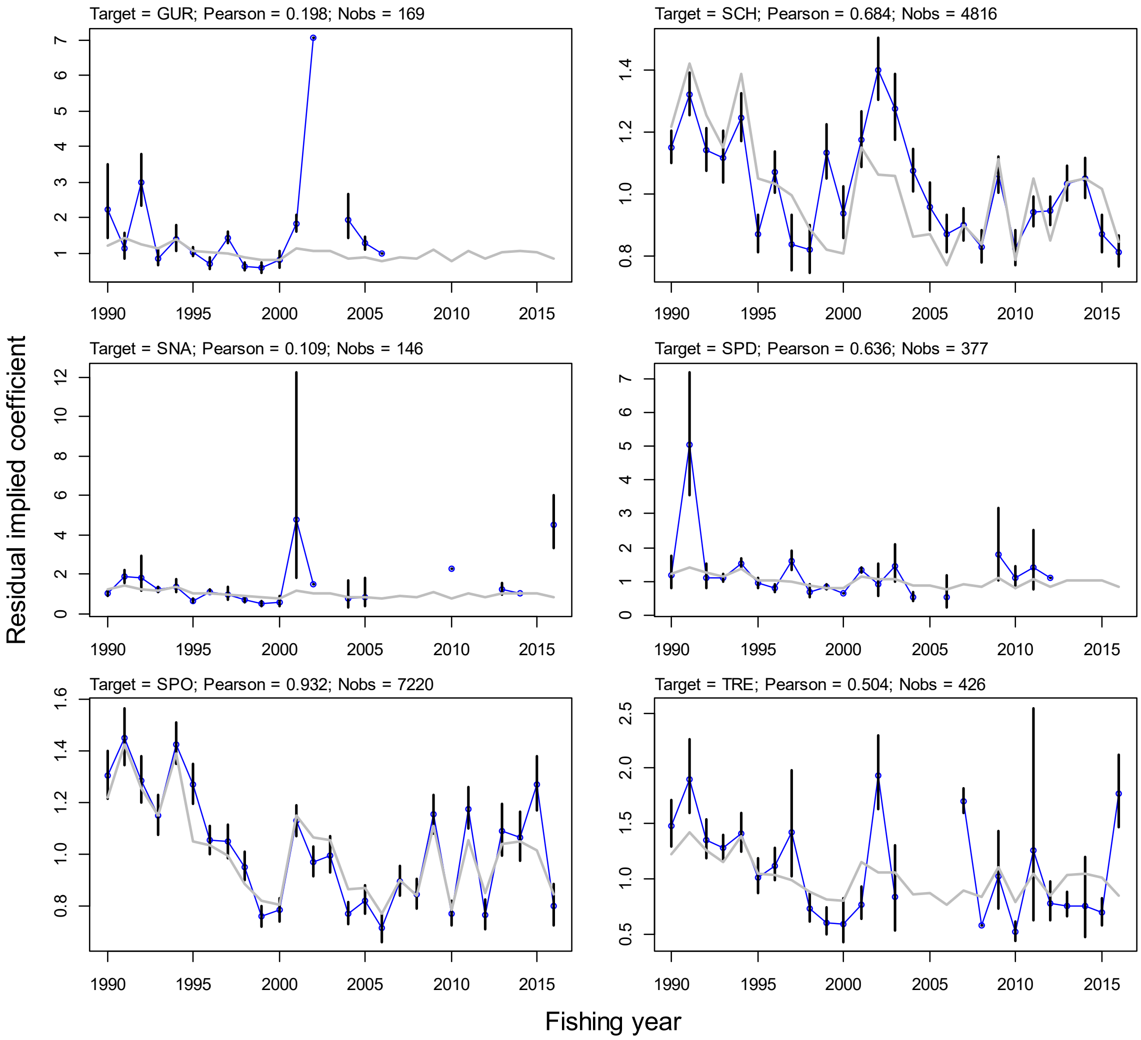

Figure 145: Residual implied coefficients for fishing year – target species interaction (not offered) for the school shark 7/8/1W setnet CPUE index. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an interaction term is fitted. Error bars indicate one standard error of the standardised residuals. Pearson's rho is reported for the correlation between the year index and the overall model index.