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Tini a Tangaroa

Fishery description and CPUE for ling *(Genypterus blacodes)* off the west coast South Island (LIN 7WC), 1986–87 to 2018–19

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Characterisations and CPUE abundance indices for observed trawl and commercial bottom longline ling fisheries off the west coast of the South Island (LIN 7WC) were updated to incorporate data for fishing years 1986–87 to 2018–19. The 2018–19 observed ling catch taken by trawl from off the west coast of the South Island has remained relatively consistent with that recorded in previous years, with catches increasing from the lowest levels in 2007–08 and 2008–09. An 850-tonne peak in observed trawl catches occurred in 2012–13 with observed catch totals in all subsequent years remaining above 500 tonnes. LIN 7WC bottom longline catches have remained relatively consistent since 2012–13. The spatial distribution of the ling fisheries has not changed substantially since the last assessment in 2015–16. Overall, in both the trawl and line fisheries, the line catch distribution has remained relatively consistent over time.

CPUE indices for the west coast of the South Island (LIN 7WC) commercial trawl, based on the observed catch, and for the target longline fisheries were revised and updated.

The LIN 7WC standardised trawl CPUE index suggest abundance gradually declined between 1998–99 and 2008–09 but progressively increased thereafter. Several standardisation models were run using the trawl fishery CPUE data, principally to investigate alternative ways to account for spatial heterogeneity in the data. The overall trends for all indices were similar to those in previous analyses. However, the final accepted trawl CPUE standardisation model is thought to better account for spatial variation in the data.

LIN 7WC target bottom longline fishery CPUE has gradually increased over time; however, the derived bottom longline standardised CPUE index may not provide a valid measure of ling relative abundance due to fisher behaviour optimising catch rates, thus leading to hyperstability.

1. INTRODUCTION

This document reports on Specific Objectives 1 and 2 of Project LIN201903, which has an overall objective "*To carry out a stock assessment of ling (Genypterus blacodes) from the west coast of the South Island including estimating biomass and sustainable yields*". It includes a descriptive analysis of the commercial catch and effort data for ling from LIN 7 and analyses of the standardised catch-per-unit-effort (CPUE) with the addition of data up to the end of the 2018–19 fishing year.

The Specific Objectives of this project were:

1. *To carry out a descriptive analysis of the commercial catch and effort data for ling from WCSI in preparation for the quantitative stock assessment*
2. *To complete a standardised catch and effort analysis from the relevant ling fisheries, including both longline and trawl fishing methods*
3. *To complete a stock assessment of the WCSI ling stock including estimating biomass, sustainable yields and status of the stock, and projecting biomass and stock status trajectories as required to support management*

Earlier descriptive analyses of commercial catch and effort data for ling were completed for the fishing years 1989–90 to 1998–99 (Horn 2001) and from 1989–90 to 2004–05 (Horn 2007b) and 1989–90 to 2012–13 (Ballara & Horn 2015, Dunn et al. 2013) and 1989–90 to 2015–16 (Dunn & Ballara 2019). The work presented here updates an analysis by Dunn & Ballara (2019) and includes data to the fishing year 2018–19 (fishing years run 1 October – 30 September). Horn (2007b) provided a detailed description of the methods used to extract and summarise Fisheries New Zealand landings data.

Analyses updating series of CPUE indices from 1) Fisheries New Zealand observed bottom trawl by-catch fisheries targeting hoki and hake, and 2) commercial bottom longline fisheries targeting ling off the west coast of the South Island (WCSI) are presented here. CPUE analyses of these fisheries were most recently reported by Dunn & Ballara (2019). The WCSI longline fisheries, along with the Sub-Antarctic, east coast of the South Island, Chatham Rise, Cook Strait, and the Bounty Plateau line fisheries account for over 95% of the line-caught ling. The principal lining method in all areas is bottom longline. The accepted CPUE series are used as inputs into stock assessments. However, the WCSI bottom longline CPUE series have not been used in previous assessments because they are considered unlikely to index stock abundance (Dunn et al. 2013, Dunn & Ballara 2019, Fisheries New Zealand 2019).

2. METHODS

2.1 Characterisation and fishery description

Catch-effort, daily processed, and landed data were extracted from the Fisheries New Zealand Enterprise Data Warehouse (EDW) (extract 12649B) and consisted of all fishing and landing events associated with a set of fishing trips that reported a positive catch or landing of hoki, hake, or ling during fishing years 1989–90 to 2018–19. The extract included all fishing recorded by the Electronic Reporting System (ERS); Trawl Catch, Effort and Processing Returns (TCEPRs); Trawl Catch Effort returns (TCERs); Catch, Effort and Landing Returns (CELRs); LCER (Lining Catch Effort Return); LTCER (Lining Trip Catch Effort Return); NCELR (Netting Catch Effort Landing Return); and by high seas versions of these forms.

The extracted data were groomed and stratified to derive the datasets required for the characterisation and CPUE analyses using a variation of the data processing method developed by Starr (2007) as implemented by Manning et al. (2004), with refinements by Blackwell et al. (2005) and Manning (2007), and further modifications for this study in accordance with the steps outlined by Ballara (2014). If the error could not be resolved the record was removed from the data set. Missing fields for statistical area were calculated from positions where these were available. Transposition of some data fields was carried out where the errors were clear (e.g., bottom depth and depth of net, or number of hooks and number of sets).

The fishing methods examined were deepwater bottom trawl, deepwater midwater trawl, inshore bottom trawl, inshore midwater trawl, and bottom longline. The distinction between deepwater and inshore trawls was not based on depth or position, but on the form type that the catch was reported on. TCEPR records were classified as deepwater; CELR and TCER records were classified as inshore.

The catch data from the statistical areas were combined so that the groupings generally approximated the various administrative ling stocks, with two major exceptions. The Bounty Plateau section of LIN 6 was examined separately because it is believed to contain a distinct biological stock (Horn 2005), and a Cook Strait area comprising parts of LIN 2 and LIN 7 was created. The fishery areas are labelled in this section as North North Island (North NI), East North Island (East NI), East South Island (East SI), Chatham, Southland, Sub-Antarctic, Bounty, West South Island (West SI), and Cook Strait (Figure 1, Table 1).

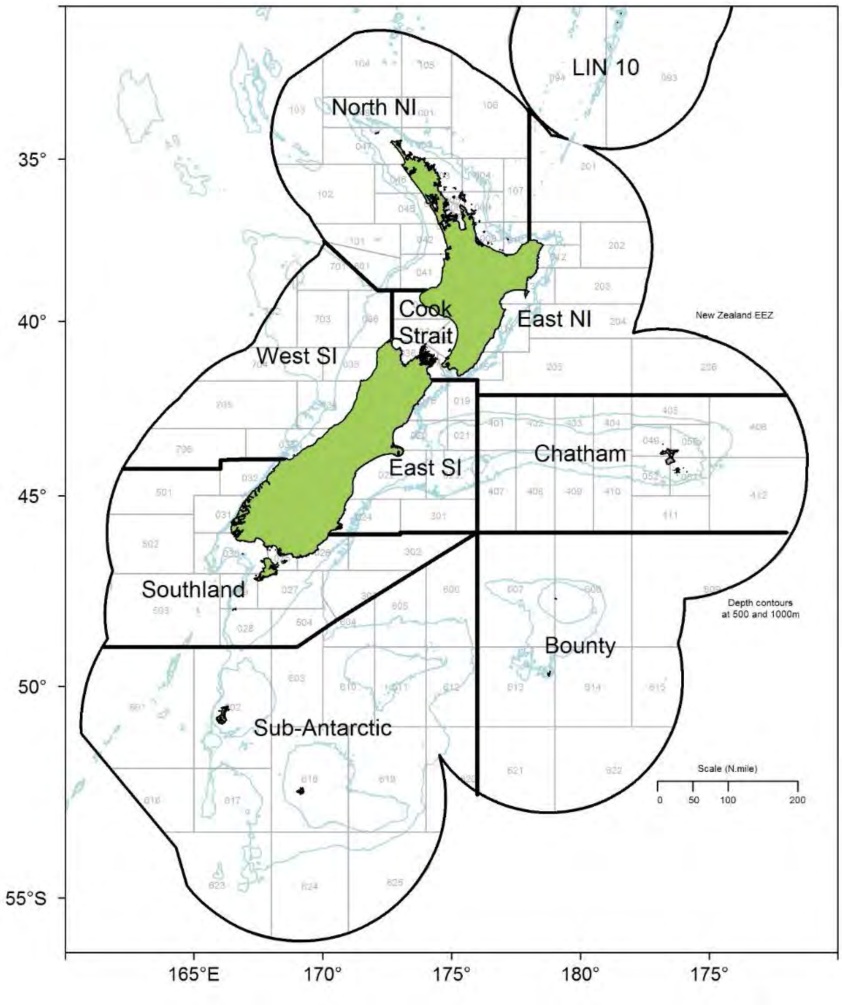

Figure 1: Definitions of geographical areas used in the analyses (based on statistical areas). See Table 1 for the administrative ling stocks they approximate.

Table 1: Definitions of geographical areas used in the fisheries descriptive analyses (based on statistical areas), and the administrative ling stocks they approximate. For a plot of statistical areas, see Figure 1.

Area	Statistical Areas	Administrative stock	Assessment stock
North NI	041–048, 001–010, 101–110, 801	LIN 1	–
East NI	011–015, 201–206	LIN 2	–
East SI	018–024, 301	LIN 3	LIN 3 & 4
Chatham	049–052, 401–412	LIN 4	LIN 3 & 4
Southland	025–031, 302, 303, 501–504	LIN 5	LIN 5 & 6
Sub-Antarctic	601–606, 610–612, 616–620, 623–625	Part of LIN 6	LIN 5 & 6
Bounty	607–609, 613–615, 621, 622	Part of LIN 6	LIN 6B
West SI	032–036, 701–706	Part of LIN 7	LIN 7WC
Cook Strait	016, 017, 037–040	Parts of LIN 2 & 7	LIN 7CK

2.2 CPUE analysis

2.2.1 Observed trawl fishery

Catch and effort data, collected under the Fisheries New Zealand observer programme, were available from 1986–87 to 2018–19. The timing of LIN 7WC trawl fishery varied slightly between years, but most ling catches were taken between May and October, often with a peak from June to September. Data for the CPUE analyses were selected for midwater (MW) and bottom trawl (BT) effort from the main catch months of June to September, and covered fishing years 1986–87 to 2018–19and Statistical Areas 034–036. Records were excluded if tow catch weights were greater than 10 t (assumed to be an error), bottom depths were not within 150–900 m (known depth range of ling), and duration of trawling was not within 0.2–15 hours (durations outside of this range were assumed to be errors). Midwater trawl records were either accepted as 'midwater trawl' (MW) or reclassified as 'midwater trawl fished on the bottom' (MB) if reported net depth was within 5 m of the reported bottom depth.

Data from vessels that fished infrequently were excluded by selecting data only from 'core' vessels. Core vessels were vessels that together reported at least 80% of the Fisheries New Zealand observed ling catch, were involved in the fishery for two or more years, completed at least 20 tows in a year, and targeted hoki or hake at the tow level of resolution (Figure 2).

Standardised catch-per-unit-effort (CPUE) analyses were carried out by fitting generalised linear models (GLMs) to CPUE, using the stepwise multiple regression technique described by Francis (2001). Four different models were used to standardise CPUE: (1) a normal model for the natural log of the non-zero ling catch (kilograms) tows, with a normal error distribution and identity link function; (2) a binomial model which estimated the probability of a non-zero catch, with a binomial response and logit link function; (3) a combined delta-lognormal model which estimated catch rates from all tows (including those with zero catch) by combining results from the normal and binomial models; and (4) a negative binomial model which was used to investigate the non-zero catches. The coefficient of variation (CV) of the estimates were estimated analytically for (1) and (2), and for (3) was calculated using a bootstrap procedure (Francis 2001).

The predictor covariate fishing year was forced into the models (because it is mandatory for an abundance index) and other variables tested for inclusion. The effects of different spatial covariates on the CPUE index were investigated. The previous analysis (Dunn & Ballara 2019) offered the model both latitude and longitude as spatial covariates. However, due to the spatial distribution of the fishery along the west coast of the South Island, latitude and longitude are likely to be confounded – as a vessel fishes at higher latitudes, it is also fishing relatively parallel to the coastline, and therefore changing its longitudinal position too. With this in mind, separate CPUE indices were produced using different spatial covariates in each model: Model A) latitude and longitude (to be comparable with Dunn &

Ballara 2019); Model B) latitude only; Model C) statistical area; and Model D) fishery split latitudinally into 3 defined areas: North, Canyon, and South (Figure 3). CPUE indices for each of these three areas were also produced, but not reported here because the area definitions were arbitrary and may not be an accurate representation of how to split the data spatially. An additional CPUE index (Model E) was produced where no seasonality covariates were offered to the model (i.e., excluding day of year and month). All models A–E used data from fishing years 1986–87 to 2018–19. A sixth CPUE index (Model F) was produced using data from fishing years 2009–10 to 2018–19 for bottom trawl method only, where data from twin trawlers were considered more reliable and were fitted with latitude offered as the only spatial covariate (i.e., longitude was excluded as a covariate). A stepwise forward procedure was used to select additional predictor covariates, and they were entered into the model in the order which gave the maximum decrease in the Akaike Information Criterion (AIC). Covariates were accepted into the final model if they explained at least 1% of the deviance. Predictors were either categorical or continuous, with continuous variables offered as third- or fourth-order polynomials (Table 2). The year indices were standardised to the mean and presented in canonical form (Francis 1999). Interaction terms (with method) were also offered. Model fits were investigated using standard residual diagnostics. Annual unstandardised (raw) CPUE indices were calculated as the mean of the catch per tow (kilograms).

The influence of each covariate accepted into the models was described by coefficient distribution influence (CDI) plots (Bentley et al. 2012). These plots show the combined effect of (a) the expected catch for each level of the variable (model coefficients) and (b) the distribution of the levels of the variable in each year, and therefore describe the influence that the variable has on the unstandardised CPUE that is accounted for by the standardisation.

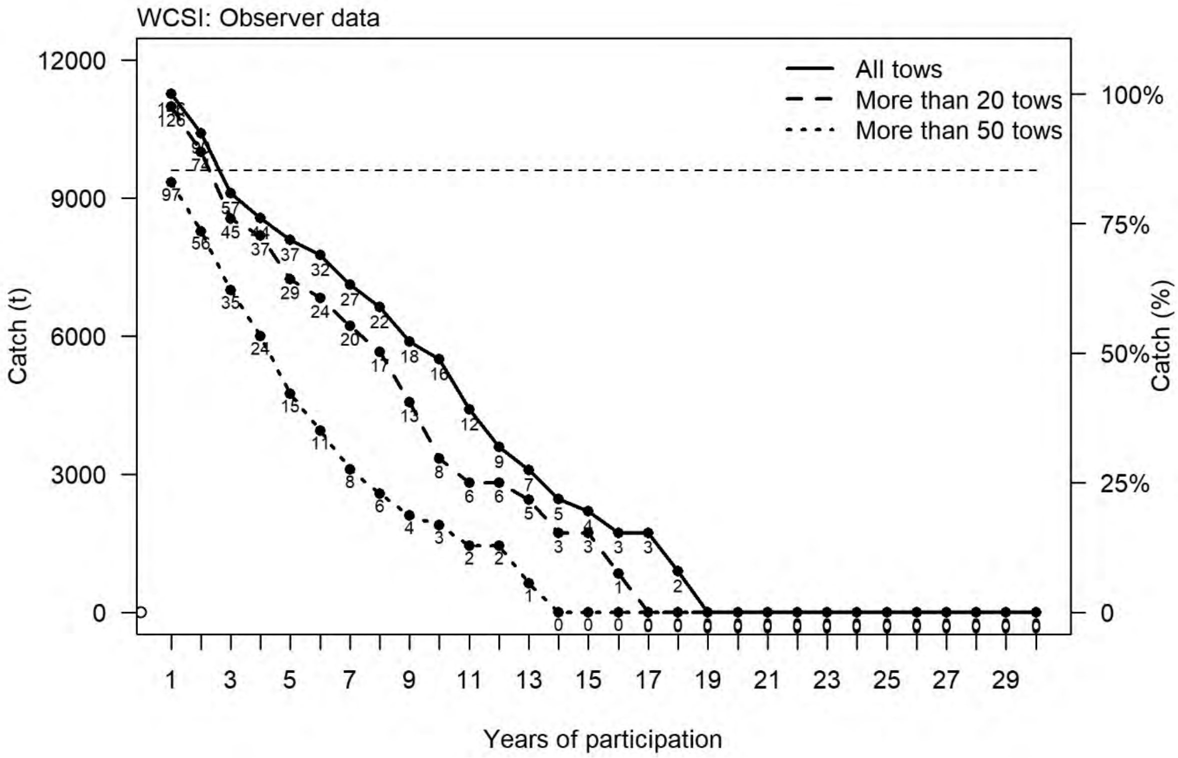

Figure 2: LIN 7WC trawl fishing catches by years of participation in the fishery for all individual vessels, where yearly participation was defined as all tows, more than 20 tows, more than 50 tows. Horizontal dotted line denotes where 80% of the yearly observed catch was taken. Trawl fishery year defined as June-September.

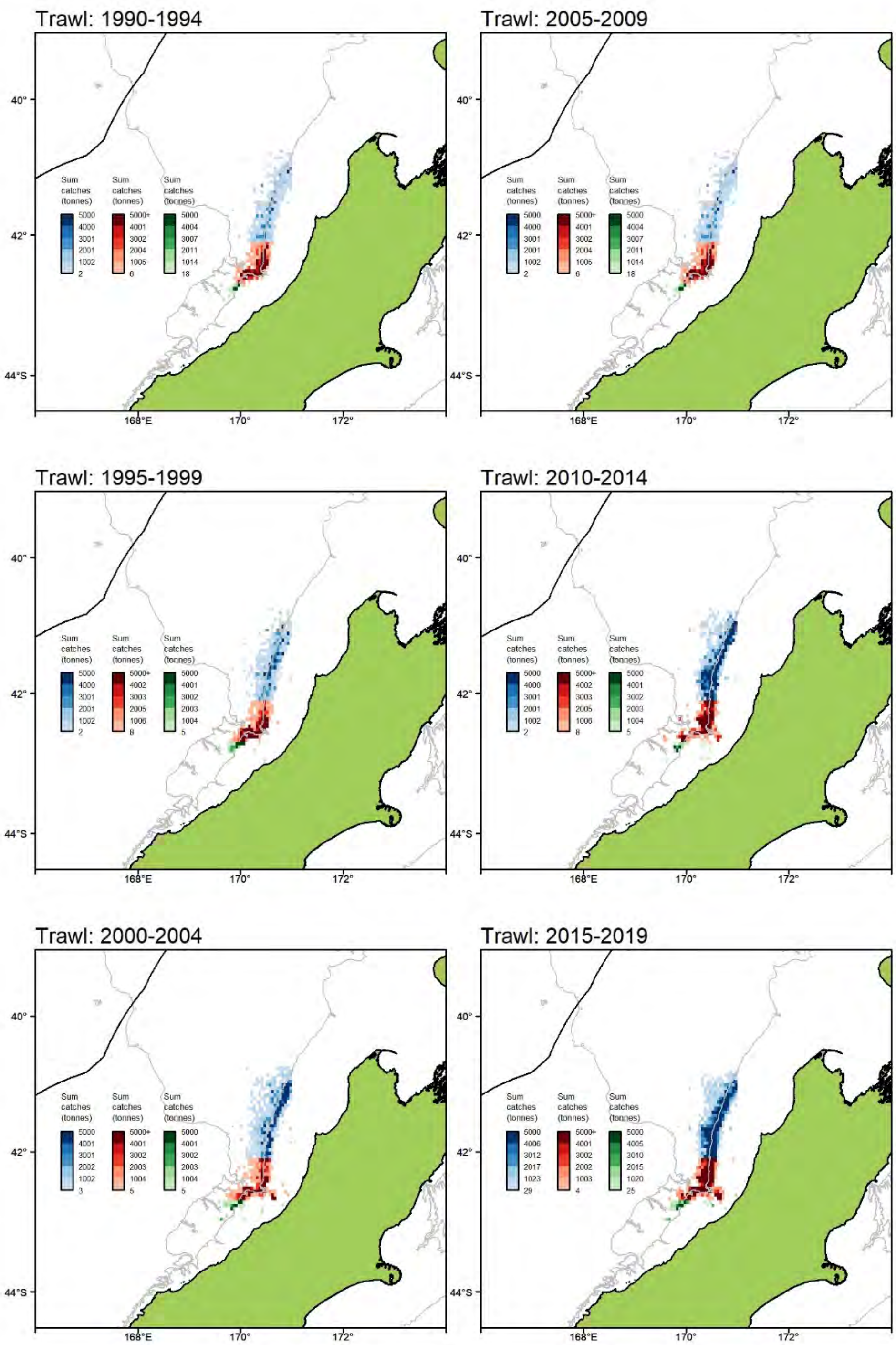

Figure 3: LIN 7WC trawl density plots of ling catches by fishing years (labelled as year-ending), where catches were split into arbitrary areas: North (blue), Canyon (red), and South (green).

Table 2: Summary of predictors offered in the CPUE models for the trawl fishery. Model run codes are a) latitude and longitude (to be comparable with last analysis); b) latitude only; c) statistical area; d) fishery spilt latitudinally into 3 defined areas: North, Canyon and South; e) no seasonality; and f) 2009–10 to 2018–19 latitude only.

Variable	Type	Description	Model Run
Trawl fisheries			
Year	Categorical	Fishing year, or June-September	a), b), c), d), e), f)
Month	Categorical	Month of year	a), b), c), d), f)
Statistical area	Categorical	Statistical area for the set or tow	a), b)
Vessel	Categorical	Unique vessel identifier	a), b), c), d), e), f)
Day of year	Continuous	Julian day, starting at 1 on 1 January	a), b), c), d), f)
Method	Categorical	Trawl method (bottom trawl, midwater trawl on bottom, midwater trawl)	a), b), c), d), e)
Subareas	Categorical	Subareas North, South, and Canyon, where Canyon was defined as being between latitudes -42.1° and -42.7°, and between 169.1° and 171° longitude	d), e)
Twin trawl	Categorical	Vessel did or did not use a twin trawl	a), b), c), d), e), f)
Number of nets	Categorial	Number of nets used in a trawl	a)
Headline height	Continuous	Distance between trawl headline and groundrope (m)	a), b), c), d), e), f)
Duration	Continuous	Tow duration, in hours	a), b), c), d), e), f)
Start time	Continuous	Start time of tow, 24-hour clock	a), b), c), d), e), f)
Mid time	Continuous	Time at the midpoint of the tow, 24-hour clock	a)
Depth bottom	Continuous	Bottom depth (m)	a), b), c), d), e), f)
Depth net	Continuous	Depth of groundrope (m)	a)
Latitude	Continuous	Start latitude of tow	a), b), f)
Longitude	Continuous	Start longitude of tow	a)

2.2.2 Line Fishery

Commercial catch data for the line fishery were available from 1 October 1989 and analysed by calendar year rather than fishing year, because of a seasonal trend of higher catch rates in most ling line fisheries running across the fishing year boundary, from about June to December (see Horn 2007a). This is believed to produce a more representative CPUE index, because all catches from a given fishing season are included in a single year, rather than being spread (and mixed) across two fishing years. Some line vessels recorded individual set data on CELR forms, but most vessels reported a day's fishing on a single CELR form. If uncorrected, this would bias CPUE analyses because those vessels recording individual events would contribute about four times as many records per day. Consequently, all line data for CELR, LTCER, and LCER forms were condensed (catches, hooks, and sets summed for each vessel, day, and statistical area) to ensure that each record represented total catch and effort per statistical area per day.

The estimated catch of the top five species *per day* (which can comprise multiple *sets*) can be reported on the CELR form, whereas the estimated catch of the top eight species *per set* can be reported on the LCER and LTCER forms. If there was more than one set recorded in a day, the estimated catch of numerous (up to 30) species may be reported for a single day of fishing on LCER and LTCER forms, compared with five species on CELR forms. This can result in small catches being reported on LCER and LTCER records that would not have been recorded had CELR forms been used. Therefore, the daily aggregate estimated catch of ling was only included with the LCER or LTCER daily aggregate effort record if ling was ranked amongst the top five species (by weight) for a given unique combination of vessel/day/statistical area. As a result of this correction, there were 425 vessel-day-statistical area aggregate records removed from the dataset. Data were accepted from the CELR, LCER, LTCER, and ERS forms for target ling and line method BLL (bottom longline) for calendar years 1990–2019, for Statistical Areas 032–034. Records were excluded if catches were outside the range 1–35 000 kg, and the total number of hooks was outside the range 20–10 000. Core vessels were defined as having completed at least 20 daily records per year over five years. This was a different selection criterion to that used in the previous analysis where the criterion was 50 daily records per year. The change in the core vessel criteria was made to include those vessels that together reported at least 80% of the estimated catch. The 50 daily records selection criterion meant that less than 75% on the estimated catch was reported by core vessels (Figure 4). The change had little noticeable effect on the resulting CPUE index.

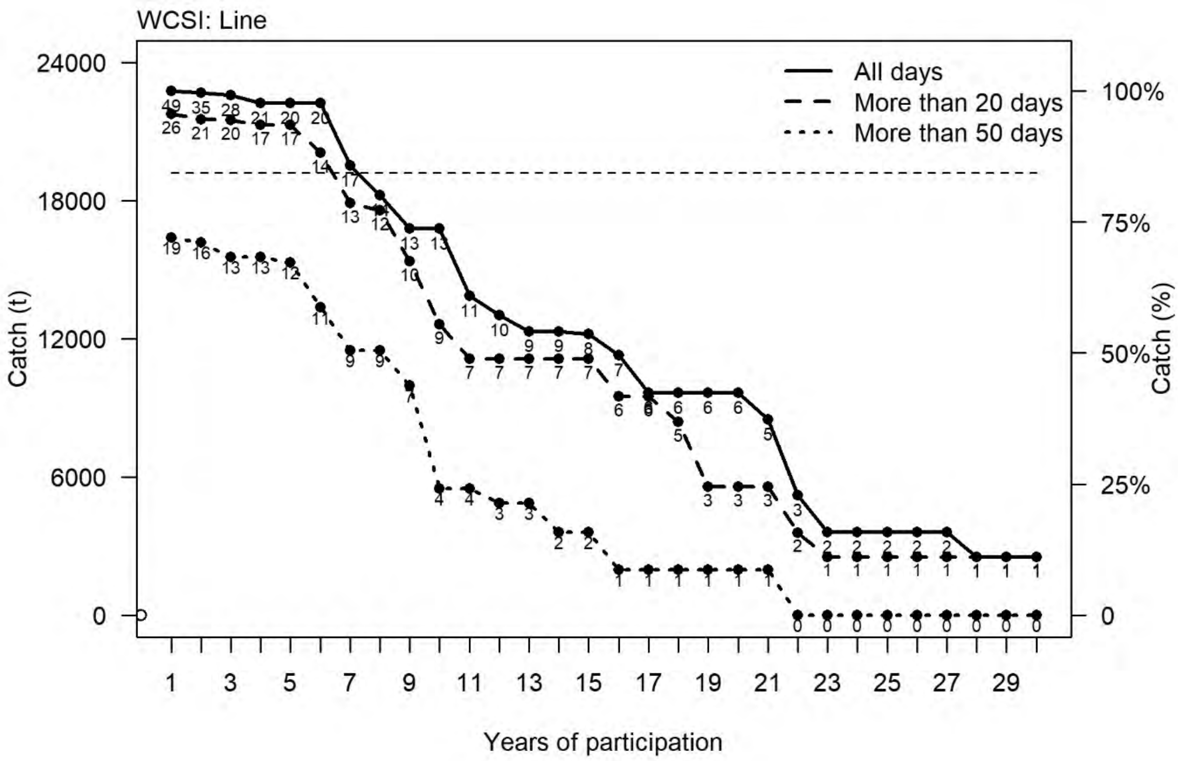

Figure 4: LIN 7WC bottom longline fishing catches by years of participation in the fishery for all individual vessels, where yearly participation was defined as all days, more than 20 days, more than 50 days. Horizontal dotted line denotes where 80% of the yearly estimated catch was taken.

CPUE standardisation for the bottom longline fishery used a lognormal model, because only 1.3% (n=194) of records had zero ling catch and were subsequently removed from the data. An examination of the zero catch records showed that most represented either duplicated records (two records for a particular day, one with and one without catches) or obvious mistakes (two- or three-days fishing with no ling catch). Because of the relatively high number of hooks fished in any set, a zero catch of ling in any set that is genuinely targeting ling is likely to result either from some gear malfunction or from exploratory fishing.

The predictor covariate calendar year was forced into the model (because it is mandatory for an abundance index) and other variables tested for inclusion. The response variable was the natural log of the estimated daily catch per statistical area. Catch per day (rather than catch per hook) was used as the unit of CPUE because the relationship between catch per hook and the number of hooks set per day has been shown to be non-linear (Horn 2002). Explanatory variables offered to the model are listed in Table 3. Total hooks per day and number of sets per day were offered untransformed and log-transformed. Annual unstandardised (raw) CPUE indices were calculated as the mean of the catch per vessel-day. CDI plots were used to describe the influence of each covariate accepted into the model. Data for 2019 were only available to September 2019; however, the inclusion of a seasonal covariate should adjust the index value for 2019 for any seasonal bias this might introduce.

Table 3: Summary of predictors offered in the CPUE models for the bottom longline fishery.

Variable	Type	Description
Line fisheries		
Year	Categorical	Calendar year
Month	Categorical	Month of year
Statistical area	Categorical	Statistical area for the set or tow
Vessel	Categorical	Unique vessel identifier
Day of year	Continuous	Julian day, starting at 1 on 1 January
Method	Categorical	Fishing method (bottom longline, trot line, dahn line)
Total hooks	Continuous	Number of hooks set per day in a statistical area
Log(Total hooks)	Continuous	Logarithm of variable Total hooks
Number of sets	Continuous	Number of sets per day in a statistical area
Log(Number of sets)	Continuous	Logarithm of variable Number of sets

3. RESULTS

3.1 LIN 7WC trawl fishery

Over the period 1989–90 to 2018–19, the LIN 7WC trawl catch was mainly taken as bycatch in the hoki target fishery (Table 4). The amount of ling caught in hake or ling target tows increased from 2005, with a decrease in the amount of ling taken by the hake target fishery after 2015–16 (Table 4, Figure 5). In general, most ling are caught between May and October, often with a peak from June to September (Table 5, Figure 5).

A progressive decline in the ling midwater trawl catch, evident from 1989–90 (Figure 5), is likely due to the declining use of this method in the regional hoki and hake fisheries.

Mean duration, distance, speed, and depth per tow decreased after about 2003–04 (Figure 6); this can be attributed in part to the increased bottom trawl catches since 2001–02 by Korean vessels targeting hake and to changes in midwater and bottom trawl vessel participation. Mean bottom depth has decreased by approximately 100 m since the beginning of the time series, which may be attributable to a longitudinal shift in the fishery as vessels move latitudinally north and south relatively parallel to the coast, as well as there being an increase in catches from inshore areas since 2004–05 (Figure 6, Figure 7). Most of the trawl catch was taken in Statistical Areas 034–035 (Figure 8). The greatest density of catches has been taken along the 200 m isobath and within the Hokitika Canyon since the 1989–90 fishing year (Figure 7).

Prior to core vessel selection Fisheries New Zealand observer data set comprised 31 277 tow records from 147 vessels, with 21.6% of the vessel tow records reporting no ling catch (Table 6). Most of the trawl effort involved vessels greater than 28 m in length (Table 7). Overall, the Fisheries New Zealand observer coverage was a good representation of the majority of the catches of the fleet, although coverage was relatively poor for small vessels (under 28 m) and in Statistical Area 033 (Figure 8).

The core CPUE data included 88.8% of the total observed catch. A total of 74 vessels were included in the core trawl data set, with 26 933 tows (Table 6). The proportion of zero catch tows decreased over time, to less than 10% of records in the last 2 years of the series (Table 6).

Table 4: LIN 7WC trawl catch (t) by target species for fishing years 1989–90 to 2018–19.

Fishing year	Hake	Hoki	Ling	Other
1989–90	1	1 628	59	92
1990–91	<1	1 030	59	63
1991–92	25	659	95	125
1992–93	43	729	123	143
1993–94	35	714	20	86
1994–95	20	1 427	21	151
1995–96	11	1 293	16	129
1996–97	16	1 209	41	169
1997–98	23	1 517	7	85
1998–99	41	1 684	4	160
1999–00	26	1 681	13	100
2000–01	13	2 035	0	56
2001–02	22	1 847	8	45
2002–03	41	1 496	21	45
2003–04	52	1 566	31	46
2004–05	69	1 058	79	92
2005–06	159	1 147	70	75
2006–07	153	544	76	187
2007–08	227	322	197	112
2008–09	204	347	165	205
2009–10	125	555	213	154
2010–11	209	742	251	155
2011–12	124	847	173	127
2012–13	154	1 073	111	132
2013–14	145	1 085	107	116
2014–15	205	1 225	86	72
2015–16	99	1 335	105	146
2016–17	61	1 553	159	101
2017–18	35	1 513	110	54
2018–19	35	1 086	119	133

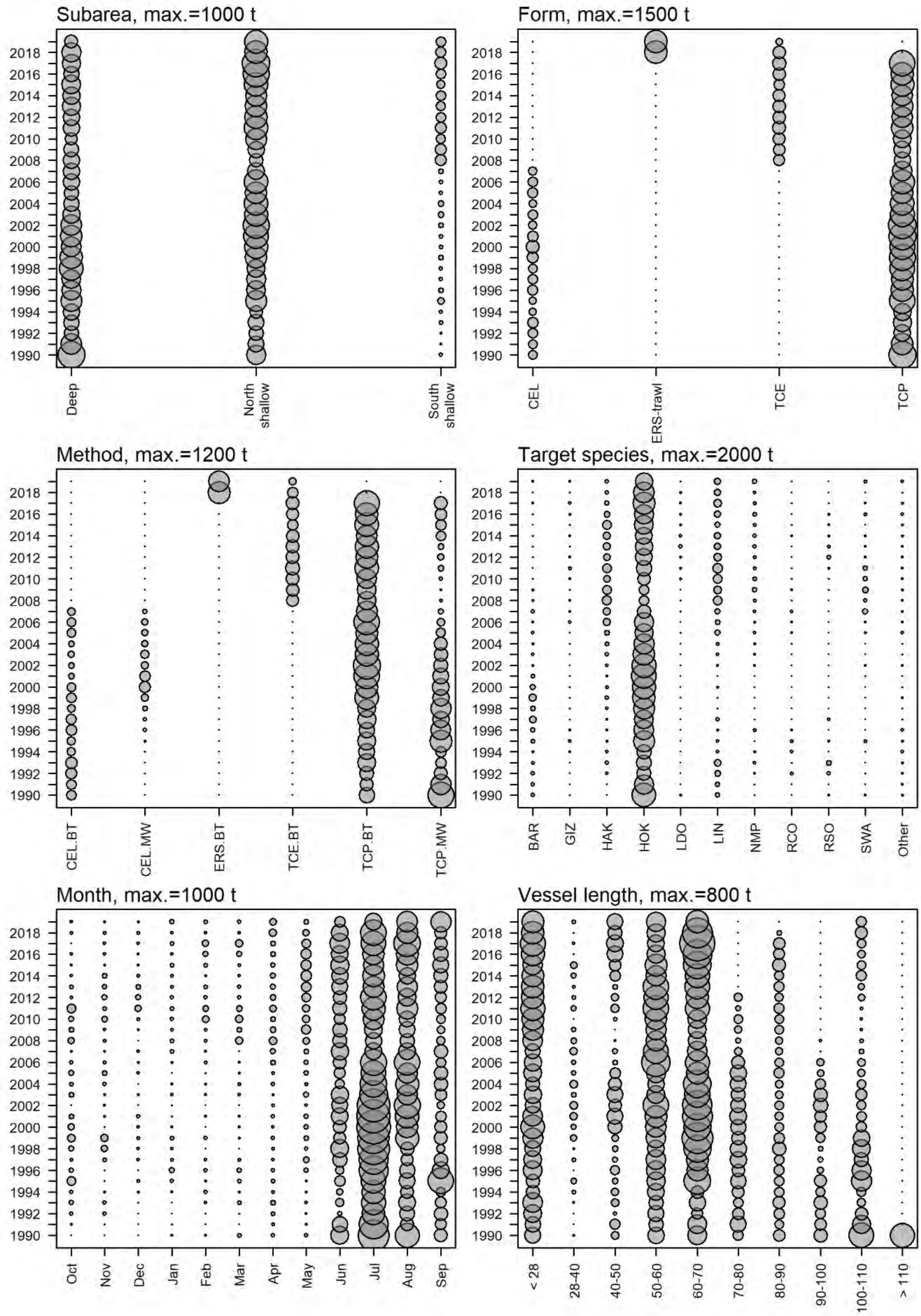

Figure 5: LIN 7WC trawl distribution of annual catch by subarea (different to arbitrary areas defined in Figure 3), form type, fishing method (by form type), target species, month, and vessel length. Circle size is proportional to catch; maximum circle size is indicated in the heading of each plot. Species codes: BAR, barracouta; GIZ, giant stargazer; HAK, hake; HOK, hoki; LDO, lookdown dory; LIN, ling; NMP, tarakihi; RCO, red cod; RSO, gemfish; SWA, silver warehou.

Table 5: LIN 7WC ling trawl catch (t) by month for fishing years 1989–90 to 2018–19.

	Month												
Fishing Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1989–90	1	<1	<1	3	3	13	11	12	269	810	527	131	1780
1990–91	4	2	<1	2	1	1	9	5	190	684	150	103	1151
1991–92	13	11	1	1	<1	1	13	3	29	490	192	149	903
1992–93	17	11	2	1	5	13	21	7	64	546	231	119	1038
1993–94	10	4	5	3	12	5	8	4	45	509	165	85	855
1994–95	66	2	9	11	4	13	15	5	102	589	237	567	1619
1995–96	17	2	<1	26	10	15	11	17	53	754	261	281	1449
1996–97	8	15	7	9	7	8	7	29	173	808	169	196	1435
1997–98	25	32	6	6	<1	<1	9	11	264	944	263	72	1631
1998–99	56	43	8	12	10	4	10	21	136	900	539	150	1889
1999–00	33	2	6	2	1	3	6	17	165	999	446	140	1820
2000–01	19	4	11	2	2	3	12	18	248	1098	578	109	2104
2001–02	1	3	<1	2	1	1	8	6	204	1004	640	53	1922
2002–03	20	4	5	6	3	7	6	25	251	717	426	133	1603
2003–04	15	11	<1	3	5	8	11	8	72	846	556	161	1695
2004–05	26	20	7	1	1	4	9	18	108	539	405	161	1298
2005–06	11	8	3	5	9	3	21	17	139	584	576	75	1451
2006–07	4	4	6	14	2	1	25	22	243	254	246	140	960
2007–08	31	9	1	14	8	41	48	38	193	246	171	58	857
2008–09	22	7	5	9	8	22	29	70	185	314	202	48	921
2009–10	24	30	7	10	39	41	20	62	138	395	217	61	1047
2010–11	59	15	35	13	27	31	40	43	188	466	349	92	1358
2011–12	9	24	24	11	10	12	31	60	156	574	259	101	1272
2012–13	15	16	21	7	14	12	26	77	381	406	362	133	1469
2013–14	7	21	7	9	4	7	26	106	287	600	214	165	1453
2014–15	3	4	2	14	13	8	16	95	348	451	435	199	1588
2015–16	5	7	3	6	26	24	22	85	311	444	565	187	1685
2016–17	1	6	6	13	34	45	19	75	369	560	617	128	1874
2017–18	8	8	7	6	6	7	46	36	286	714	469	117	1712
2018–19	6	5	5	17	14	11	38	20	165	349	418	324	1373
Total	536	330	199	238	279	364	573	1012	5762	18594	10885	4438	43212

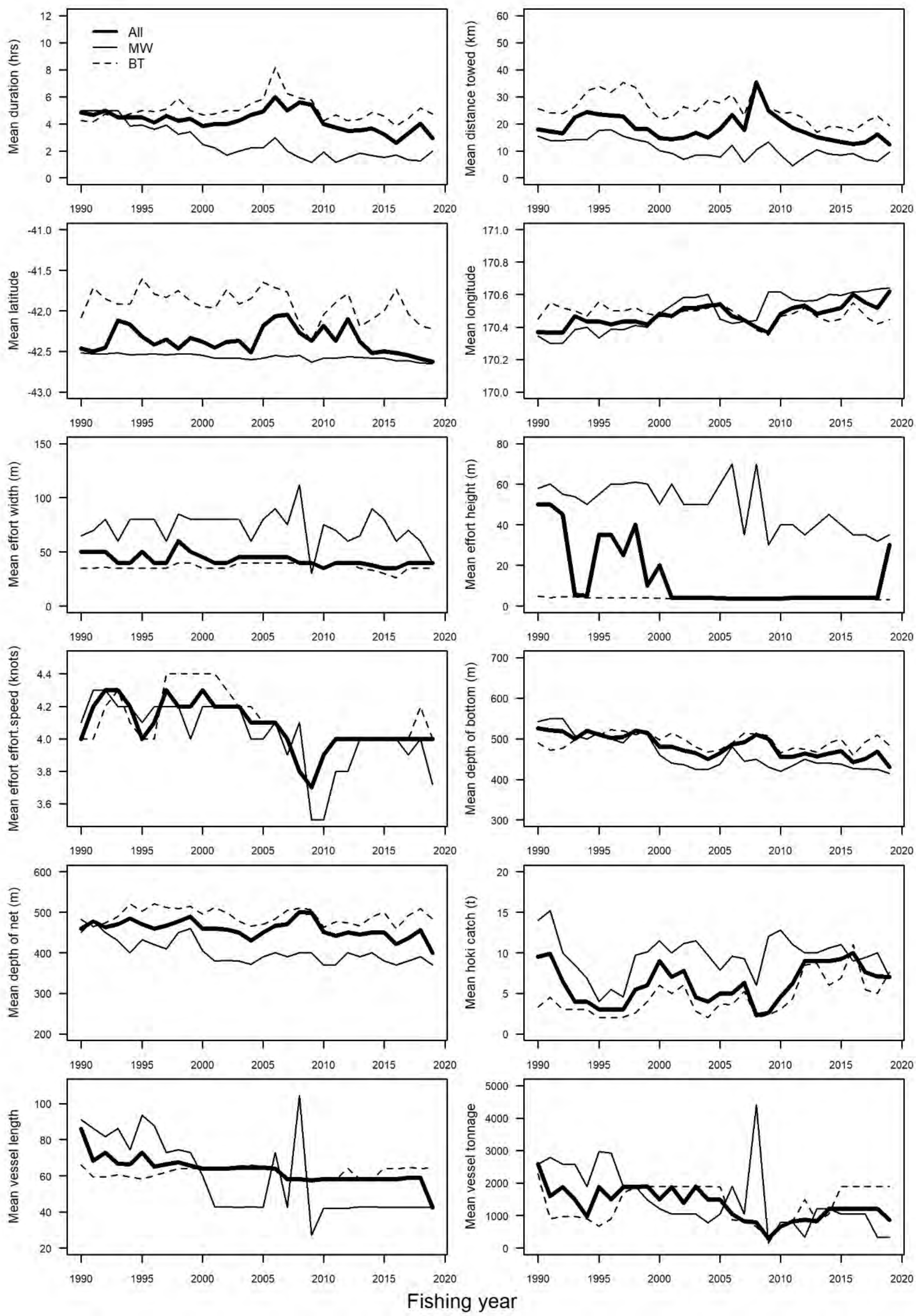

Figure 6: LIN 7WC trawl; means of effort variables by fishing year for tows targeting hoki for all tows (All), bottom tows (BT), and midwater tows (MW).

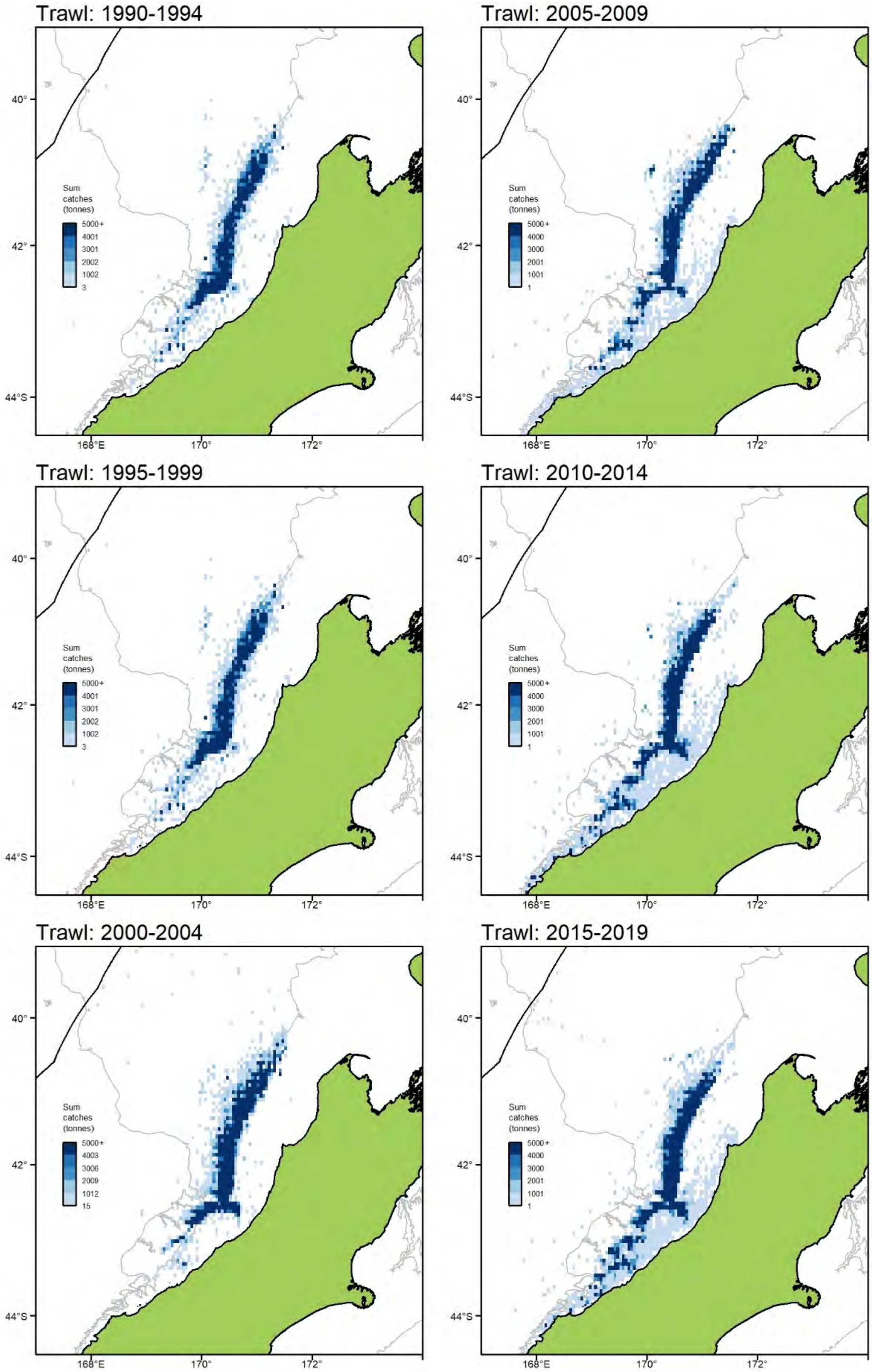

Figure 7: Density plots of LIN 7WC commercial ling catches by trawls by fishing year (labelled by year-ending) or combined fishing year groups.

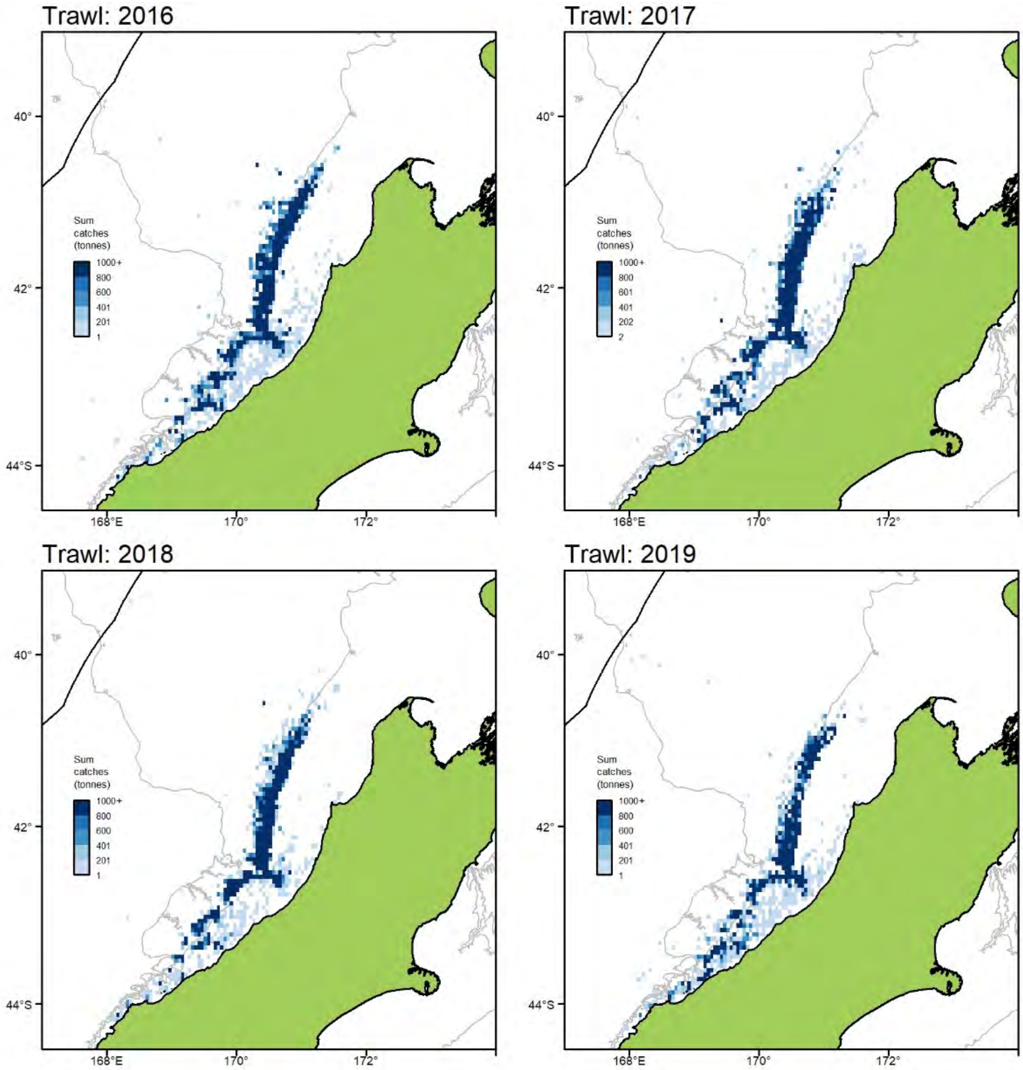

Figure 7 (continued): Density plots of LIN 7WC commercial ling catches by trawls for fishing years (labelled by year-ending) or combined fishing year groups.

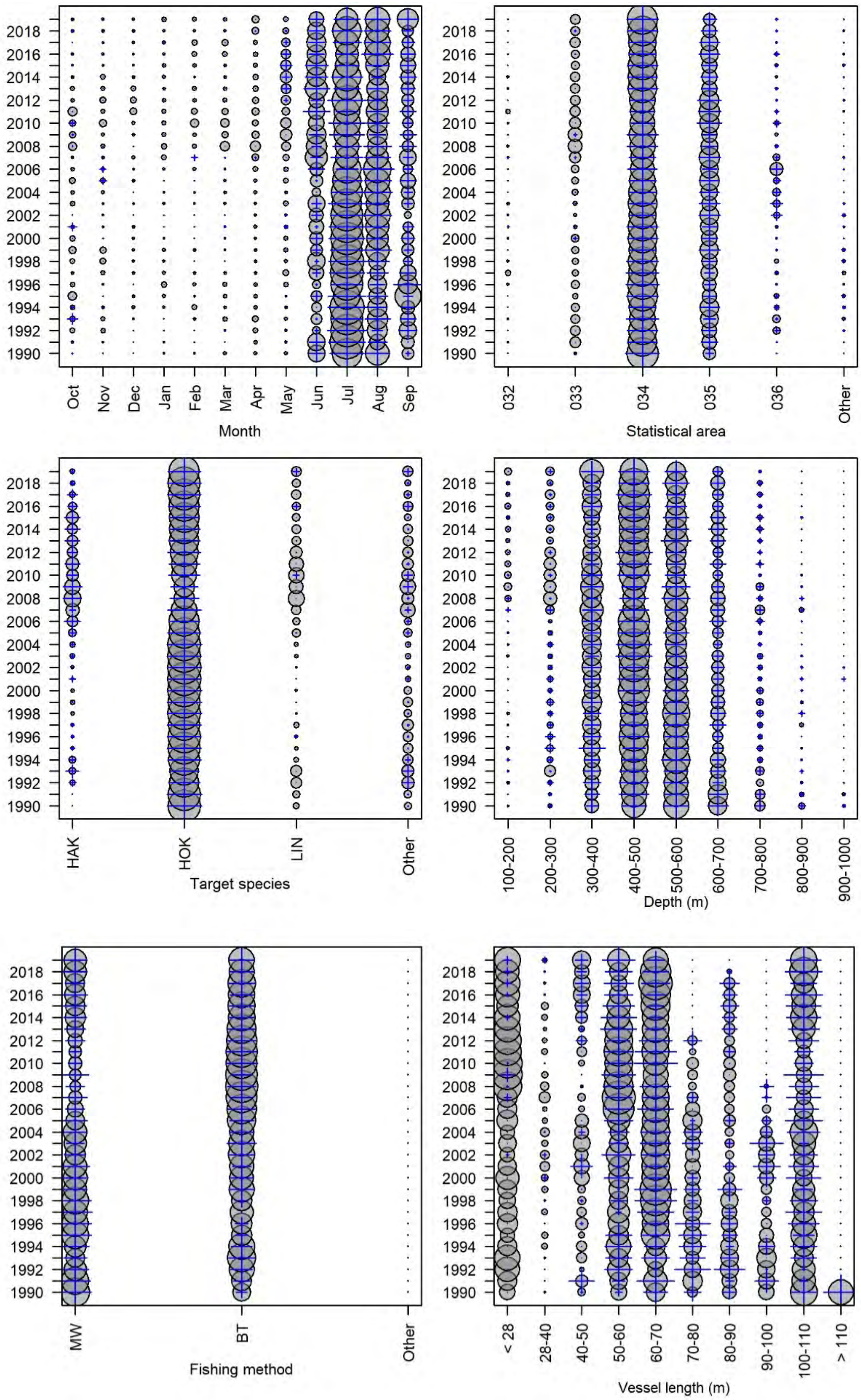

Figure 8: Representativeness of observer sampling of ling catch for LIN 7WC. Circles show the proportion of target catch by month within a fishing year and other main variables. Crosses show the proportion of observed target catch for the same cells. Representation is demonstrated by how closely the cross dimensions match the circle diameter. Fishing years are labelled by year-ending.

Table 6: Fisheries New Zealand observer data summary for all vessels and for core vessels included in the final LIN 7WC trawl CPUE standardisation datasets.

	All vessels					Core vessels				
Fishing Year	No. vessels	Catch (t)	Tows	Prop. zeros	CPUE	No. vessels	Catch (t)	Tows	Prop. zeros	CPUE
1986–87	25	238.7	1 326	0.44	0.18	10	150.8	771	0.42	0.20
1986–87	22	684.8	1 721	0.30	0.40	13	597.2	1 462	0.27	0.41
1988–89	14	458.0	964	0.30	0.48	6	268.4	581	0.24	0.46
1989–90	14	558.6	1 234	0.16	0.45	8	368.4	885	0.11	0.42
1990–91	14	204.6	764	0.30	0.27	6	133.5	413	0.29	0.32
1991–92	12	123.2	474	0.31	0.26	4	99.5	252	0.17	0.39
1992–93	15	157.0	576	0.47	0.27	7	77.7	333	0.39	0.23
1993–94	15	130.2	708	0.51	0.18	7	93.1	455	0.42	0.20
1994–95	9	188.3	655	0.15	0.29	6	88.1	350	0.17	0.25
1995–96	15	262.9	831	0.21	0.32	10	220.6	662	0.19	0.33
1996–97	12	122.3	440	0.34	0.28	7	111.1	366	0.27	0.30
1997–98	16	284.0	670	0.22	0.42	10	272.0	580	0.23	0.47
1998–99	14	284.7	862	0.21	0.33	12	279.2	838	0.21	0.33
1999–00	17	281.8	824	0.28	0.34	12	267.7	783	0.29	0.34
2000–01	21	243.5	795	0.19	0.31	13	222.5	706	0.17	0.32
2001–02	16	441.6	1 040	0.16	0.42	14	439.0	1 024	0.16	0.43
2002–03	13	149.2	621	0.23	0.24	13	149.2	621	0.23	0.24
2003–04	16	429.0	1 126	0.12	0.38	13	377.0	1 020	0.12	0.37
2004–05	13	265.7	911	0.11	0.29	12	263.9	903	0.11	0.29
2005–06	15	242.6	858	0.16	0.28	10	222.9	803	0.15	0.28
2006–07	16	66.4	332	0.36	0.20	9	44.0	277	0.33	0.16
2007–08	14	82.5	425	0.27	0.19	7	72.4	366	0.21	0.20
2008–09	16	62.3	342	0.28	0.18	7	52.5	285	0.27	0.18
2009–10	14	116.1	402	0.16	0.29	7	107.3	350	0.15	0.31
2010–11	11	180.4	433	0.20	0.42	10	176.3	427	0.19	0.41
2011–12	16	297.9	693	0.19	0.43	12	265.8	650	0.16	0.41
2012–13	17	875.5	1 680	0.10	0.52	16	874.4	1 671	0.10	0.52
2013–14	17	666.1	1 574	0.13	0.42	15	664.2	1 559	0.12	0.43
2014–15	20	662.0	1 713	0.12	0.39	18	659.6	1 689	0.12	0.39
2015–16	17	589.8	1 456	0.12	0.41	15	583.7	1 429	0.12	0.41
2016–17	20	531.5	1 451	0.10	0.37	18	485.4	1 324	0.10	0.37
2017–18	28	790.3	1 949	0.07	0.41	18	735.7	1 800	0.06	0.41
2018–19	24	590.0	1 427	0.08	0.41	18	555.9	1 298	0.07	0.43
Total		11 261.5	31 277				9 979	26 933		

Table 7: LIN 7WC Fisheries New Zealand observed catch and effort (numbers of tows and fishing duration) for vessels under 28 m and at least 28 m overall length, by fishing year.

	All vessels						Core vessels					
Fishing	Catches (t)		Total number of tows		Total duration (hrs)		Catches (t)		Total number of tows		Total duration (hrs)	
year	less28	28plus	less28	28plus	less28	28plus	less28	28plus	less28	28plus	less28	28plus
1989–90	155	1 625	1 073	9 860	10 320	43 204	-	85	-	1 033	-	3 387
1990–91	151	999	1 238	9 785	10 459	41 307	-	444	-	1 372	-	7 213
1991–92	195	708	1 899	7 987	19 173	31 669	-	217	-	621	-	3 153
1992–93	238	800	3 235	9 105	31 660	33 358	-	315	-	785	-	4 130
1993–94	114	741	2 229	11 509	20 658	41 349	-	112	-	477	-	2 507
1994–95	118	1 501	1 957	11 161	19 046	44 161	-	86	-	215	-	1 056
1995–96	216	1 232	2 125	8 820	20 727	36 914	-	78	-	547	-	2 115
1996–97	201	1 234	2 772	10 520	27 223	46 477	-	93	-	782	-	2 838
1997–98	157	1 474	1 745	10 139	16 041	44 027	-	88	-	423	-	2 267
1998–99	253	1 636	2 438	9 740	24 406	39 609	-	221	-	813	-	3 374
1999–00	348	1 471	2 161	8 930	21 432	33 677	-	111	-	501	-	1 960
2000–01	250	1 853	2 299	9 781	22 713	37 158	-	272	-	754	-	3 089
2001–02	155	1 767	1 738	8 617	15 388	32 919	-	279	-	1 066	-	4 400
2002–03	185	1 418	1 919	8 464	19 086	38 633	-	268	-	1 096	-	3 340
2003–04	123	1 572	2 032	7 000	19 998	33 371	-	222	-	855	-	3 392
2004–05	200	1 098	2 105	5 409	22 376	26 830	-	439	-	1 222	-	5 090
2005–06	190	1 261	2 248	4 965	23 556	28 255	-	149	-	803	-	4 285
2006–07	135	825	2 360	3 975	25 756	23 422	-	377	-	1 164	-	4 816
2007–08	246	611	5 993	3 218	27 199	18 362	-	264	-	1 016	-	3 577
2008–09	285	636	6 328	2 757	28 144	17 690	-	223	-	940	-	3 993
2009–10	317	730	6 836	2 754	27 785	12 809	-	44	-	415	-	1 807
2010–11	364	994	5 616	3 594	22 240	16 000	-	72	-	461	-	1 989
2011–12	347	925	5 815	3 726	24 214	15 500	-	53	-	392	-	1 650
2012–13	341	1 128	5 786	3 768	24 153	15 562	-	107	-	413	-	1 754
2013–14	333	1 121	6 238	4 553	26 463	19 361	-	176	-	529	-	1 990
2014–15	262	1 325	6 131	5 610	25 570	23 355	-	266	-	775	-	2 680
2015–16	351	1 334	6 418	5 204	25 956	17 869	-	874	-	1 854	-	8 784
2016–17	408	1 466	6 604	5 522	27 305	23 131	7	657	30	1 749	45	9 085
2017–18	342	1 370	5 050	5 106	20 340	21 378	-	660	-	1 929	-	10 183
2018–19	319	1 054	5 900	3 828	24 849	16 075	4	580	41	1 580	72	6 382
Total	7 299	35 909	110 288	205 407	674 236	873 432	11	7 832	71	26 582	117	116 286

3.1.1 Observer trawl 1986–87 to 2018–19 CPUE index based on tow-by-tow data with latitude offered as spatial covariate (Model B)

Based on the analyses presented below, and in Appendix 1 and 2, the Deepwater Working Group selected the combined index derived from observer tow-by-tow data, where 'latitude' is the offered as the only spatial covariate, as the 'preferred' index (Model B).

Binomial model

The binomial model explained 22.26% of the deviance, with bottom depth explaining just over 5% (Table 8). Bottom depth tended to flatten the CPUE index in all years, with the exception of 1994–95, when bottom depth had little effect (Figure 9). The model fit was good, although the residual plot suggests a failure of the binomial model homogeneity of variance assumption (heteroscedasticity) (Figure 10). The binomial model indicated a gradual increase in success rate over time, although variability was minimal (Figure 9).

Table 8: Predictor and percentage of deviance explained for the final binomial model fit for 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as spatial covariate. Df, degrees of freedom; R^2, R squared.

Step	Df	R^2
Year	32	6.39
Bottom depth	3	11.63
Vessel	72	14.79
Method	2	18.05
Latitude	3	20.34
Method:Duration	12	22.26

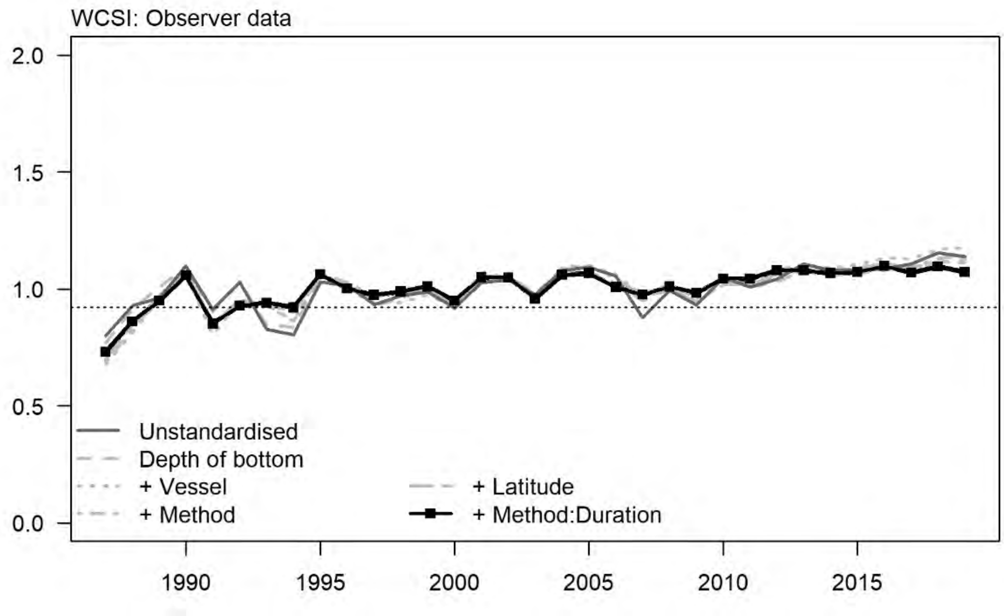

Figure 9: Step plot for the fishing success (binomial) model for the 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate. Plot shows the year effect for the unstandardised model, and the effect after successive model predictors are added.

The vessel covariate had minimal influence except for a large negative influence in 1992–93, where catches taken by vessels in that year were larger than catches taken by the same vessels in other years (Figure 11). Where catches taken were concentrated around -42.5 degrees, latitude had a greater positive influence (Figure 12). In years where catches were more widely distributed (both North and South, although little catch was taken South of -42.5 degrees), latitude had a greater negative influence on CPUE, as observed in 1994 and 2010 (Figure 12). The concentration of catches around -42.5 degrees is consistent with the target hoki fishery fishing the Hokitika Canyon. Highest catches were concentrated at bottom depths between 390 and 550 m (Figure 13), consistent with fishing the Hokitika Canyon, which has an average depth of around 400 m. Consistent again with ling catches being taken as by-catch in the hoki fishery, bottom trawling had a greater positive influence on CPUE and suggested this method was more likely to take relatively larger ling catches than midwater trawls both in midwater and on the bottom (Figure 14).

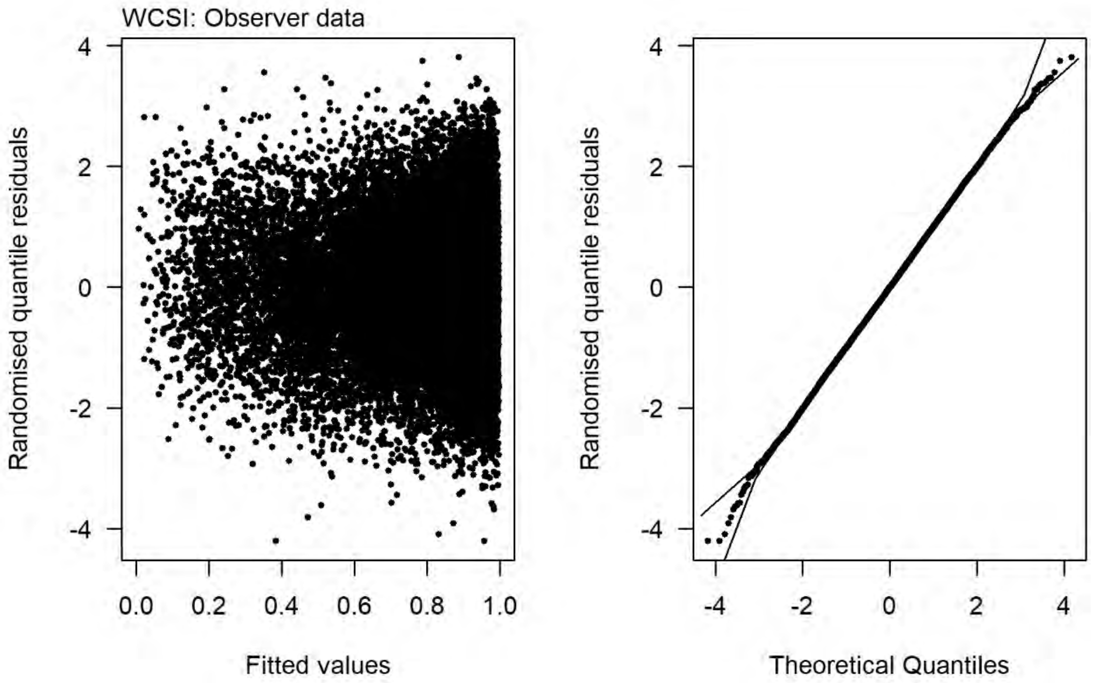

Figure 10: Residuals (left panel) and normal quantile plot (right panel) for the binomial model fit for the 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate.

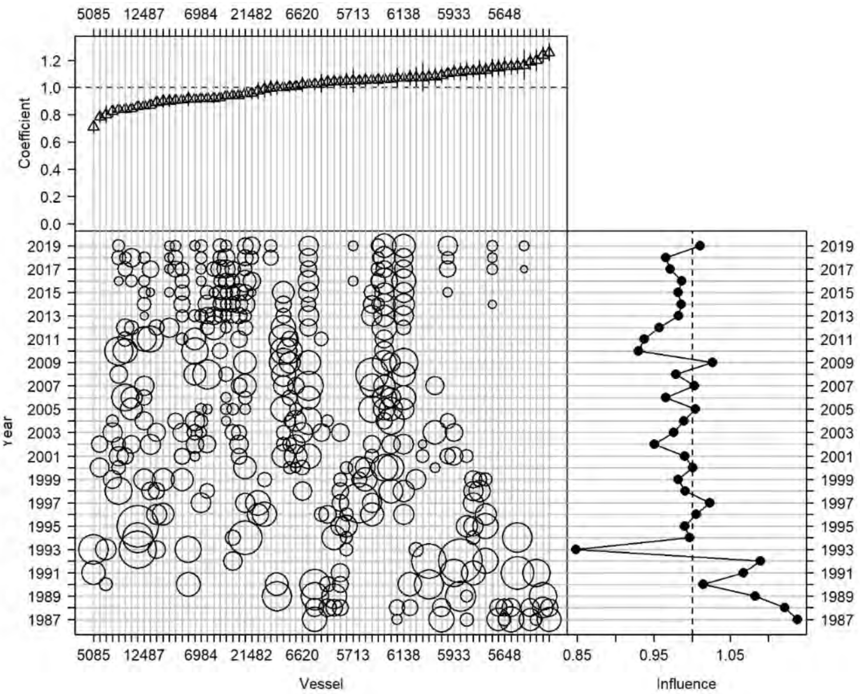

Figure 11: Vessel influence plot for the fishing success (binomial) model for the 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of tows, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

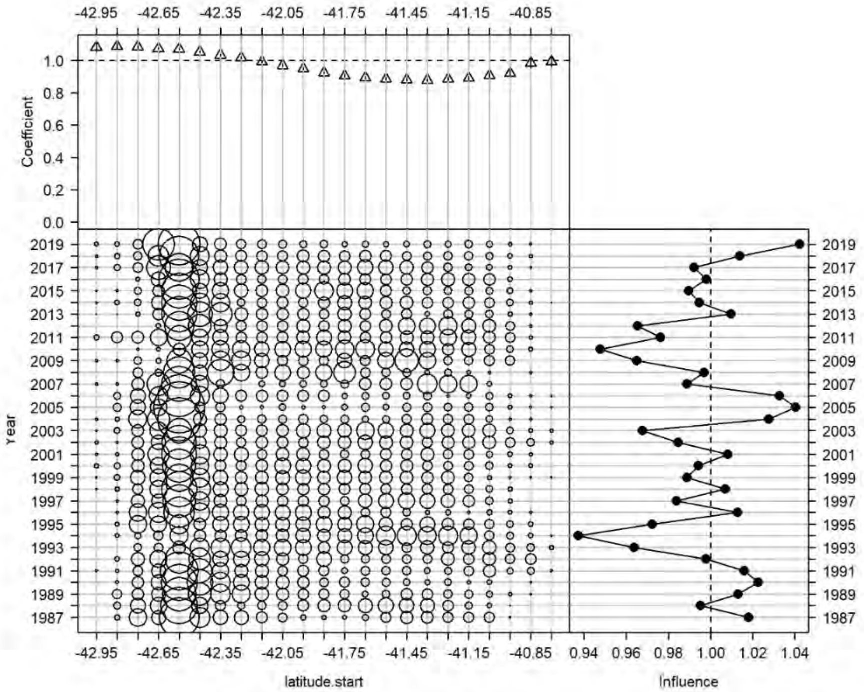

Figure 12: Latitude influence plot for the fishing success (binomial) model for the 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate. Top panel, the coefficient estimates for latitude; bottom left panel, the number of tows, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

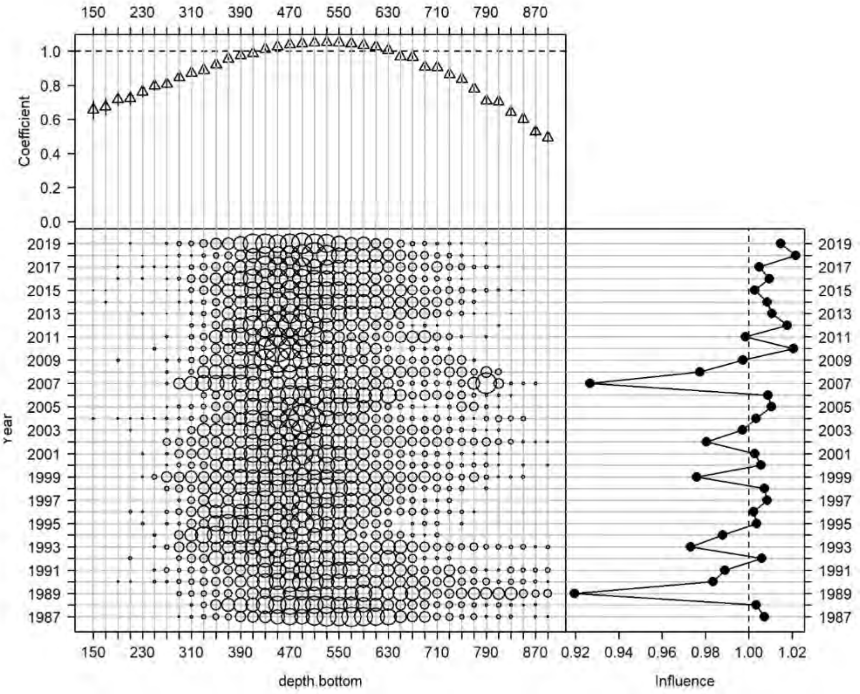

Figure 13: Bottom depth influence plot for the fishing success (binomial) model for the 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate. Top panel, the coefficient estimates for bottom depth; bottom left panel, the number of tows, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

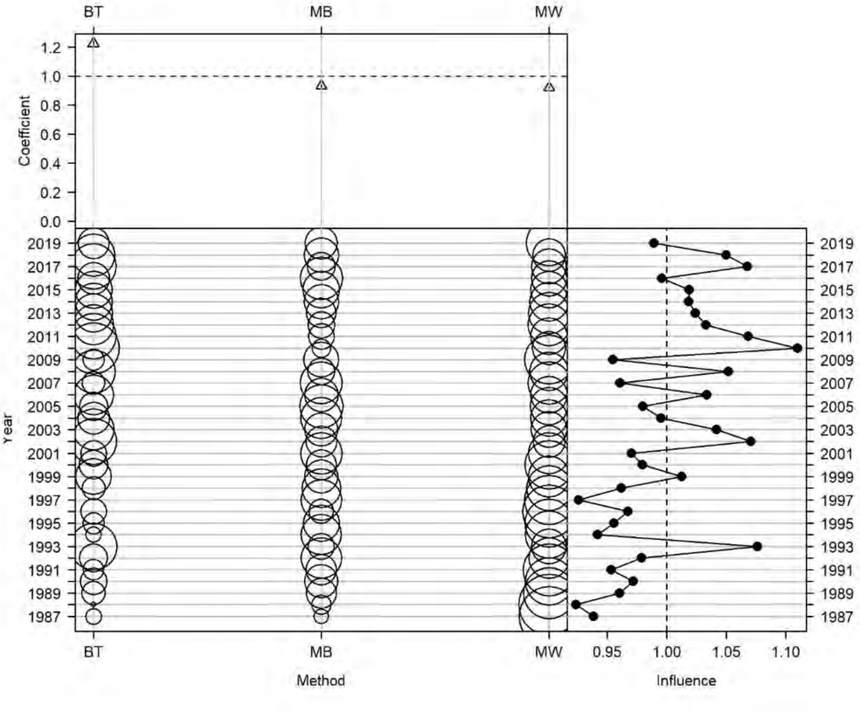

Figure 14: Gear method influence plot for the fishing success (binomial) model for the 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate. Top panel, the coefficient estimates for each gear method; bottom left panel, the number of tows, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

Lognormal model

The non-zero catch (normal) model explained 30.37% of the deviance, of which about 6% was explained by the vessel covariate (Table 9). The vessel predictor tended to decrease the CPUE between 1999–00 and 2014–15, increase the CPUE in years pre-2000s, and had little effect in the last 4 years (Figure 15). The non-zero catch rate showed a general increase over time to a peak in 1999–00, a decrease until 2008–09, followed by an increase in non-zero catches back to pre-2000 levels (Figure 15). The model fit was good, although the extremes did not fit well (Figure 16). The residuals suggest small catches are expected but are overestimated when predicted by the model (Figure 16).

Table 9: Predictor and percentage of deviance explained for the final lognormal model fit for the 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate. Df, degrees of freedom; R^2, R squared.

Step	Df	R^2
Year	32	5.72
Vessel	72	10.96
Method	2	17.82
Latitude	3	21.58
Bottom depth	3	25.48
Day of year	3	28.35
Method:Duration	12	30.37

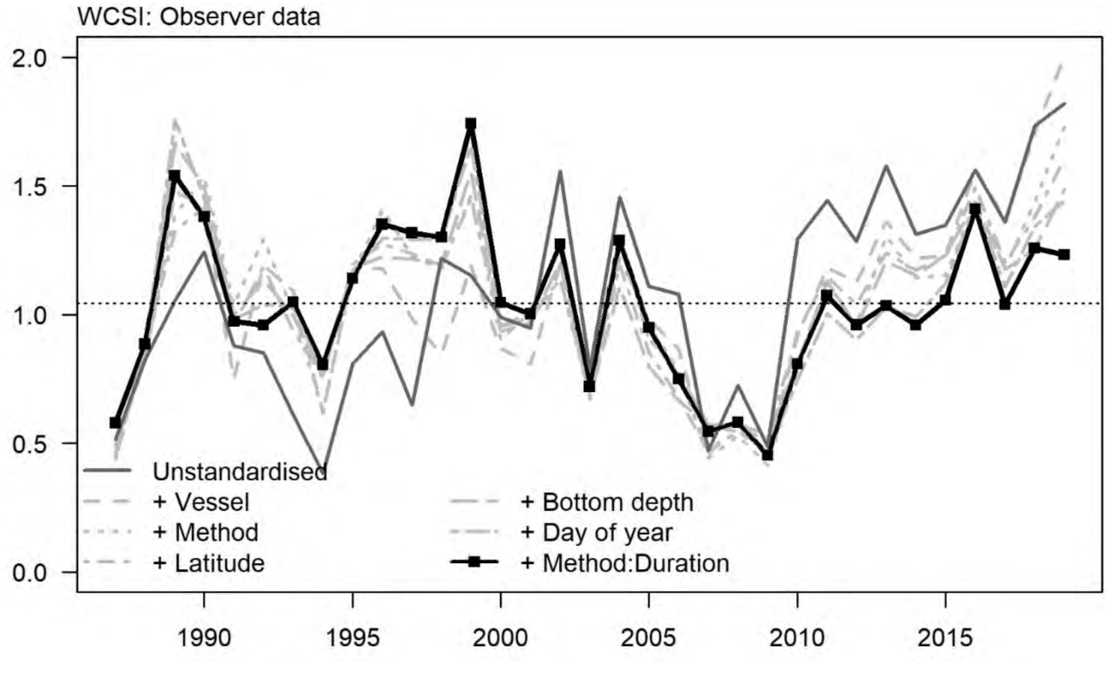

Figure 15: Step plot for the non-zero catch rate (lognormal) model for the 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate. Plot shows the year effect for the unstandardised model, and the effect after successive model predictors are added.

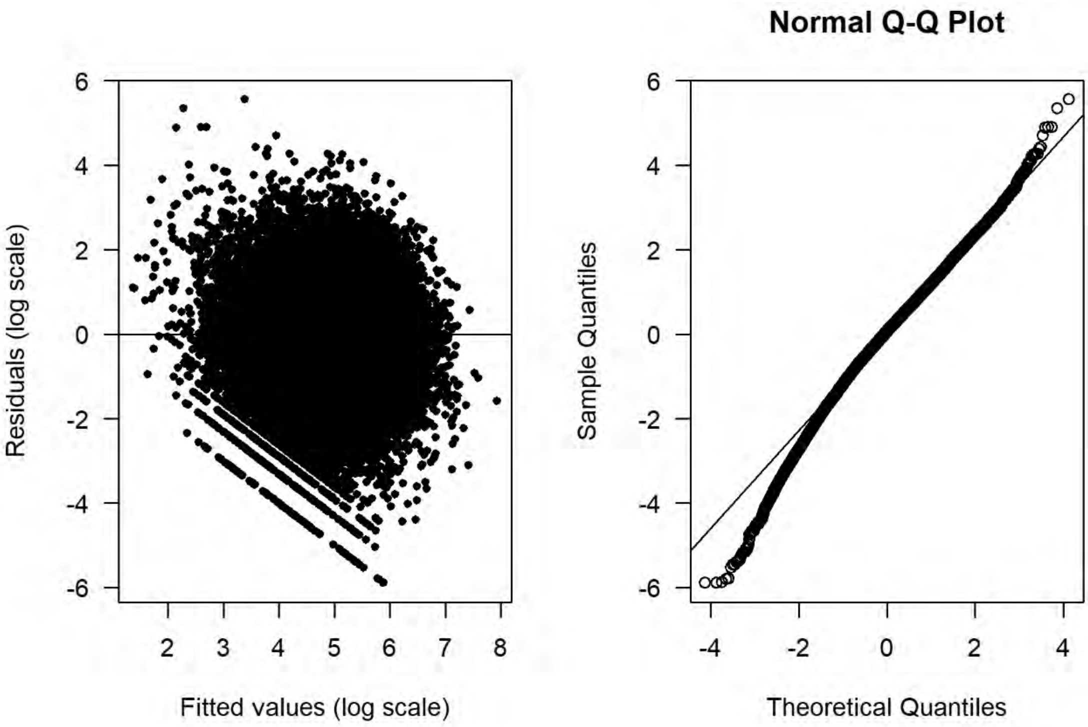

Figure 16: Residuals (left panel) and normal quantile plot (right panel) for the lognormal model fit for the 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate.

The vessel covariate had minimal influence except for a large negative influence in 1992–93, where catches taken by those vessels in the fishery in that year were relatively larger than catches taken by the same vessels in other years (Figure 17). Where catches taken were concentrated around -42.5 degrees, latitude had a greater positive influence (Figure 18). In years where catches were more widely distributed, latitude had a greater negative influence on CPUE, as observed in 1994 and 2010 (Figure 18). Highest catches were concentrated at bottom depths between 390 and 550 m (Figure 19), consistent with the target hoki fishery fishing the Hokitika Canyon. Bottom trawling had a greater positive influence on CPUE and indicated that this method was more likely to take relatively larger ling catches than midwater trawls both in midwater and on the bottom (Figure 20). Although 'day of year' had little overall influence on the lognormal CPUE, shifts in fishery behaviour to fishing slightly earlier in the fishing year demonstrated a more positive influence on CPUE (Figure 21).

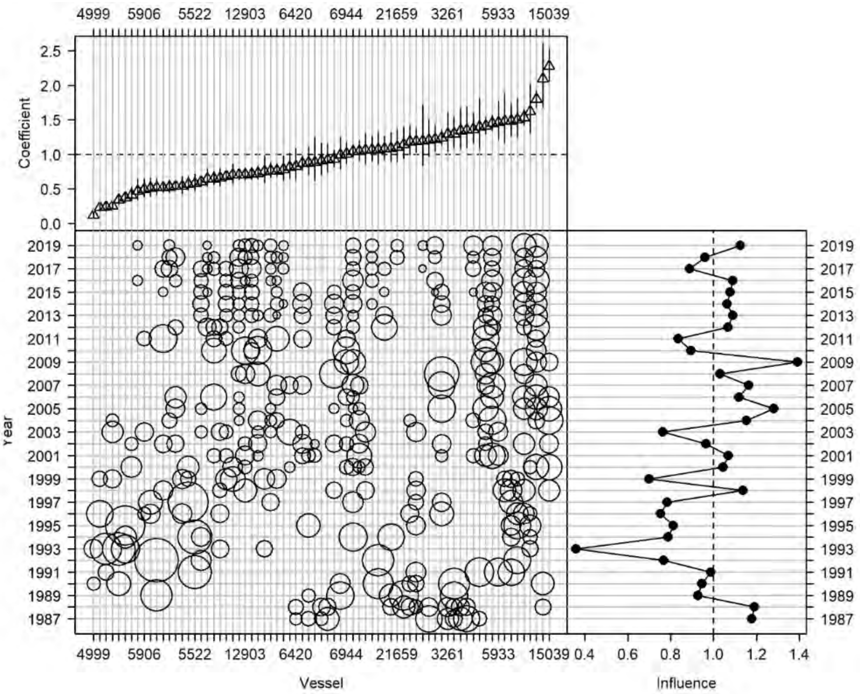

Figure 17: Vessel influence plot for the non-zero catch rate (lognormal) model for the 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of tows, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

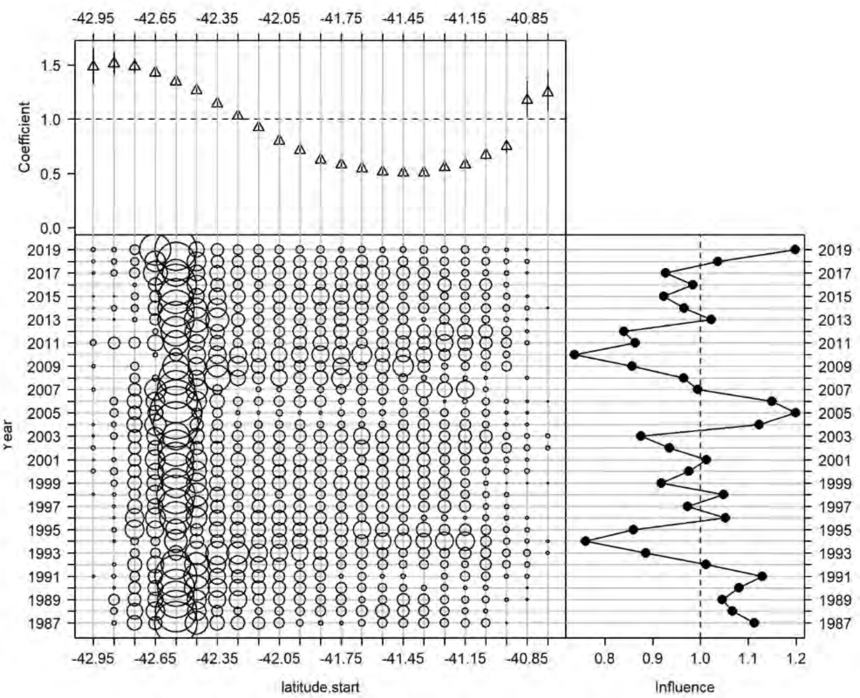

Figure 18: Latitude influence plot for the non-zero catch rate (lognormal) model for the 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate. Top panel, the coefficient estimates for latitude; bottom left panel, the number of tows, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

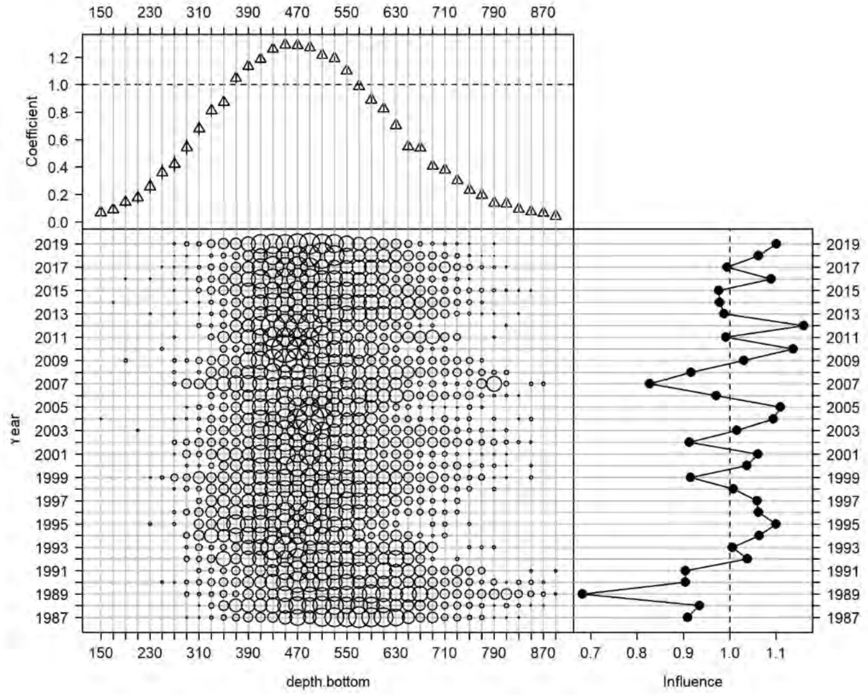

Figure 19: Bottom depth influence plot for the non-zero catch rate (lognormal) model for the 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate. Top panel, the coefficient estimates for bottom depth; bottom left panel, the number of tows, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

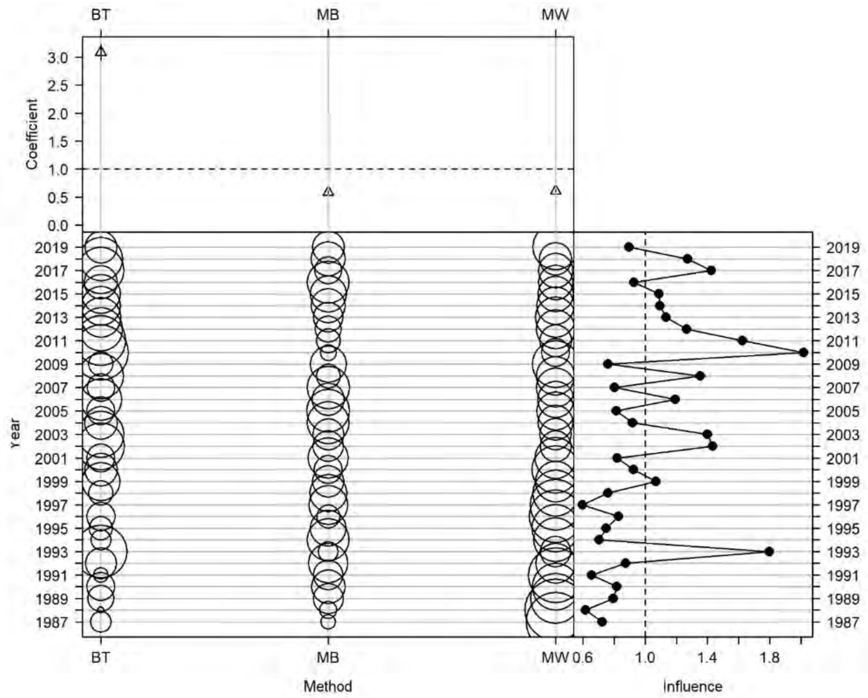

Figure 20: Gear method influence plot for the non-zero catch rate (lognormal) model for the 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate. Top panel, the coefficient estimates for each gear method; bottom left panel, the number of tows, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

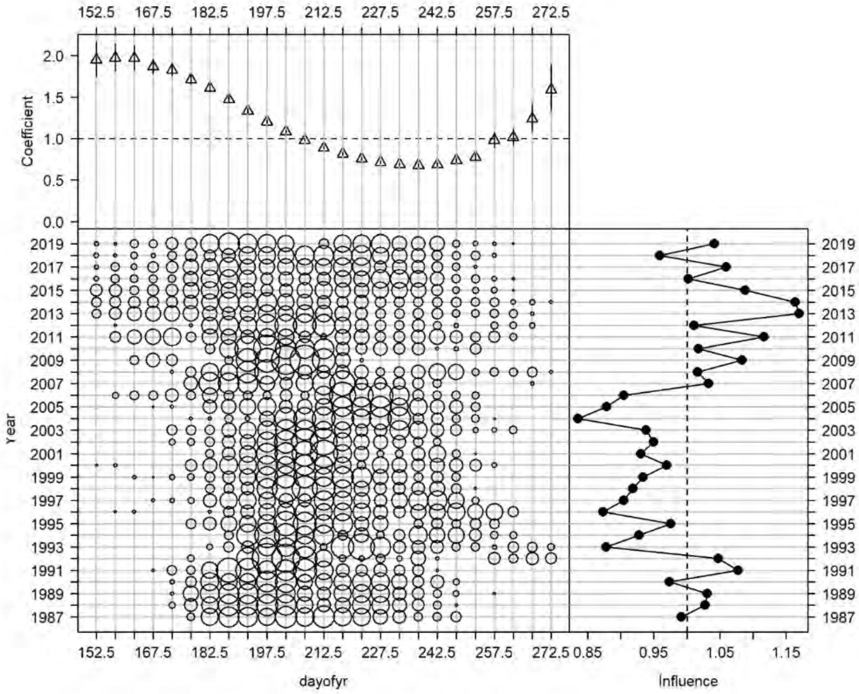

Figure 21: Day of year influence plot for the non-zero catch rate (lognormal) model for the 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate. Top panel, the coefficient estimates for day of the year; bottom left panel, the number of tows, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

Delta-lognormal combined model

The combined index was primarily driven by the patterns seen in the lognormal index, particularly after 1999–00, when the binomial model indicated a fishing success rate of almost 100% (Figure 22).

Negative Binomial model

An analysis of the quantile residuals on the negative binomial model (Appendix 1) suggested an imbalance of too many negative residuals for observations with low predicted values and too many positive residuals when the predicted value was high. A zero inflation test also demonstrated the negative binomial model was not appropriate for these data, because the model underestimated the true number of zero catches (see Figure 41 and Figure 42 in Appendix 1). Given these issues, the combined model index was considered preferable to the negative binomial as an index of ling abundance.

Model B derived index comparisons with those from alternative spatial covariate models and those from previous assessments

There was little difference between the combined model B index (Figure 44 in Appendix 1) and the combined model A index (Figure 62 in Appendix 2, Figure 23, Figure 24). Model A differed from B in that it included both latitude and longitude as offered spatial covariates as was done in the 2016 analyses (Figure 23, Figure 24), although the latter reduced the peak in CPUE in 1996–97 observed in all previous analyses (Figure 25, Figure 26). The combined CPUE indices were more similar to those estimated by Ballara & Horn (2015) than those estimated by Dunn & Ballara (2019) which was much more variable and estimated a substantial increase in CPUE in later years (Figure 26). When compared with the CPUE estimated for years post-2008–09 (Appendix 2), the combined index was flatter from 2008–09 to 2014–15 and was estimated as being slightly higher after 2015 (Figure 27, Figure 28). The bootstrap procedure estimated the very low coefficient of variation (CV) of less than 10% (Table 10).

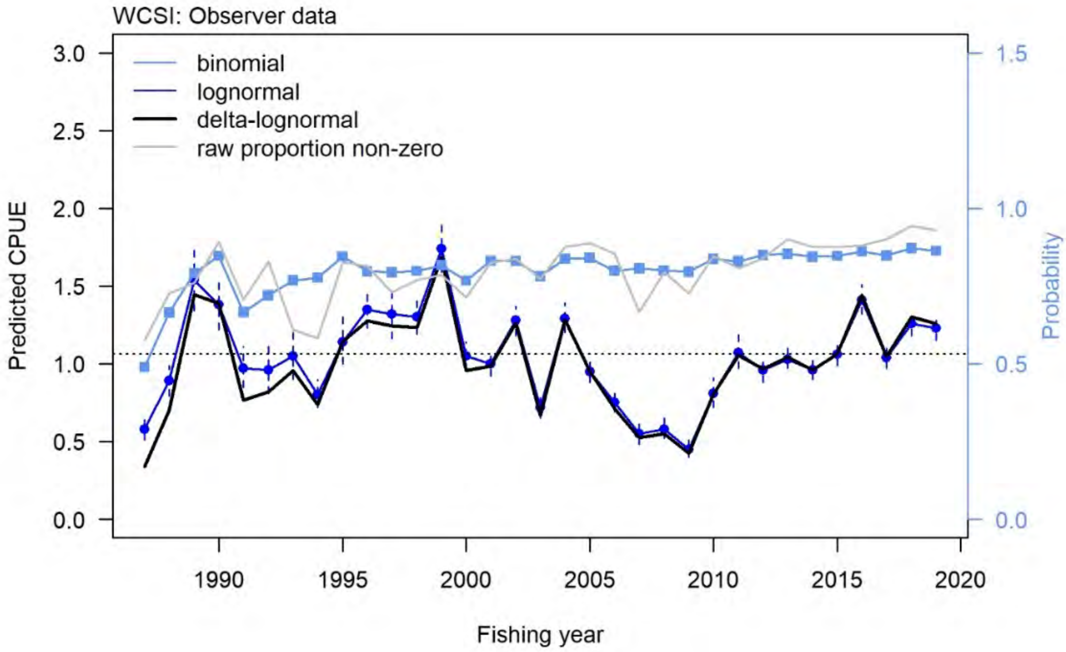

Figure 22: Comparison of the binomial, lognormal and combined CPUE indices for the 1986–87 to 2018–19 CPUE for observer tow-by-tow data with latitude offered as the spatial covariate (Model B) and the raw proportion of non-zero tows. Bars indicate 95% confidence intervals.

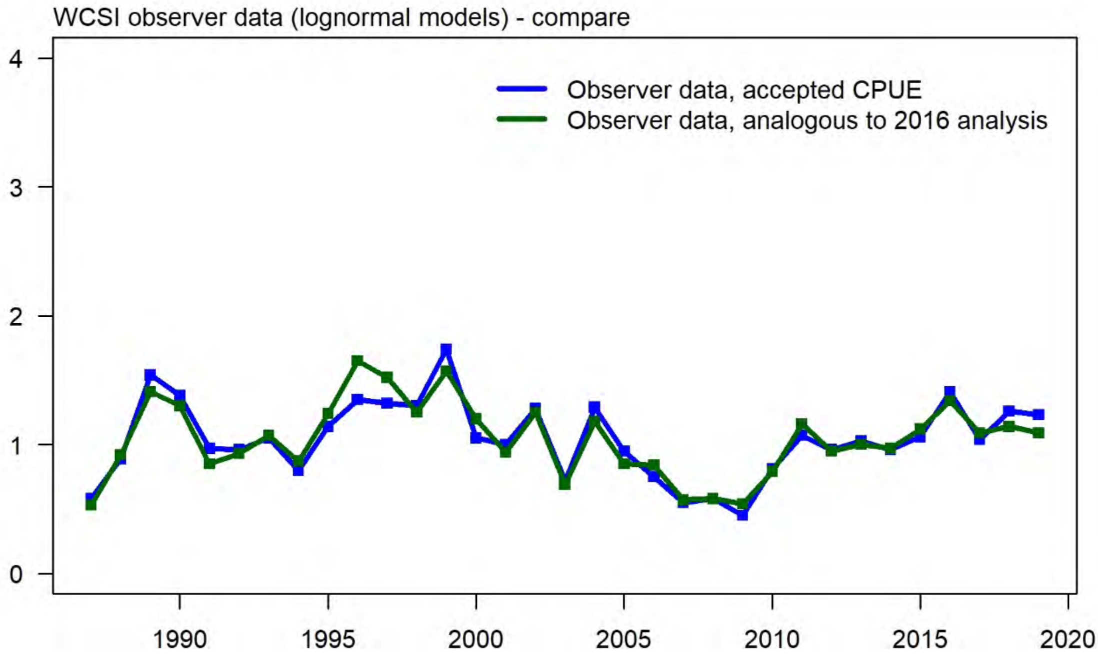

Figure 23: Comparison of the lognormal CPUE index for the 1986–87 to 2018–19 CPUE for observer tow-by-tow data with latitude offered as the spatial covariate and the lognormal CPUE for the 1986–87 to 2018–19CPUE for observer tow-by-tow data with latitude and longitude offered as spatial covariates (Figure 61 in Appendix 2).

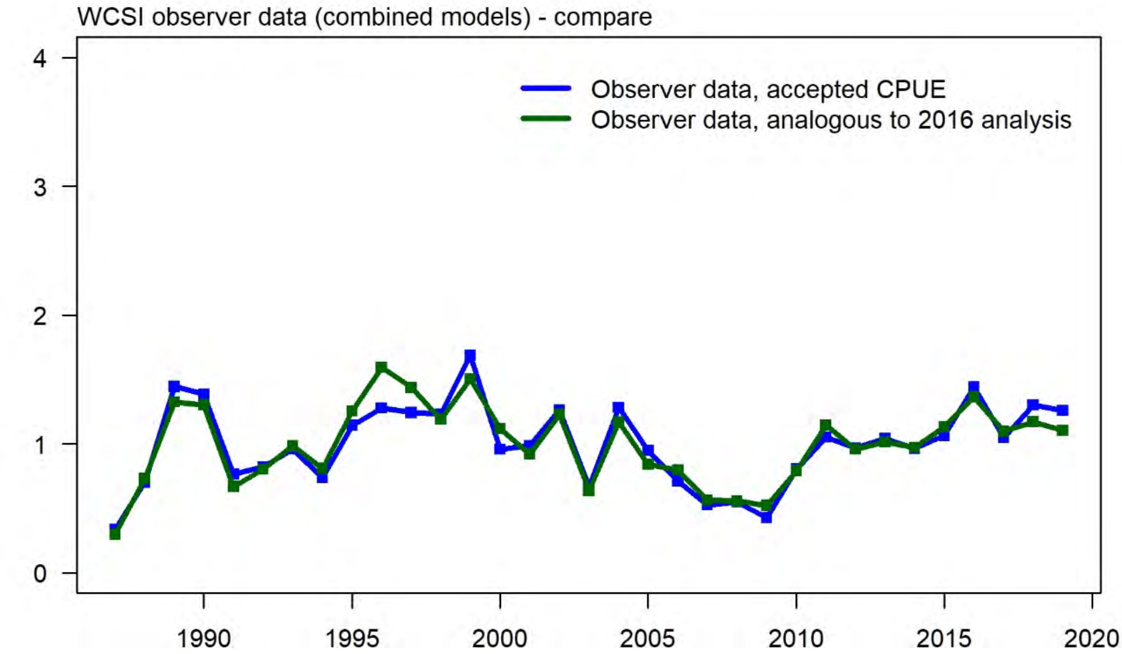

Figure 24: Comparison of the combined CPUE index for the 1986–87 to 2018–19 CPUE for observer tow-by-tow data with latitude offered as the spatial covariate and the combined CPUE for the 1986–87 to 2018–19CPUE for observer tow-by-tow data with latitude and longitude offered as spatial covariates (Figure 62 in Appendix 2).

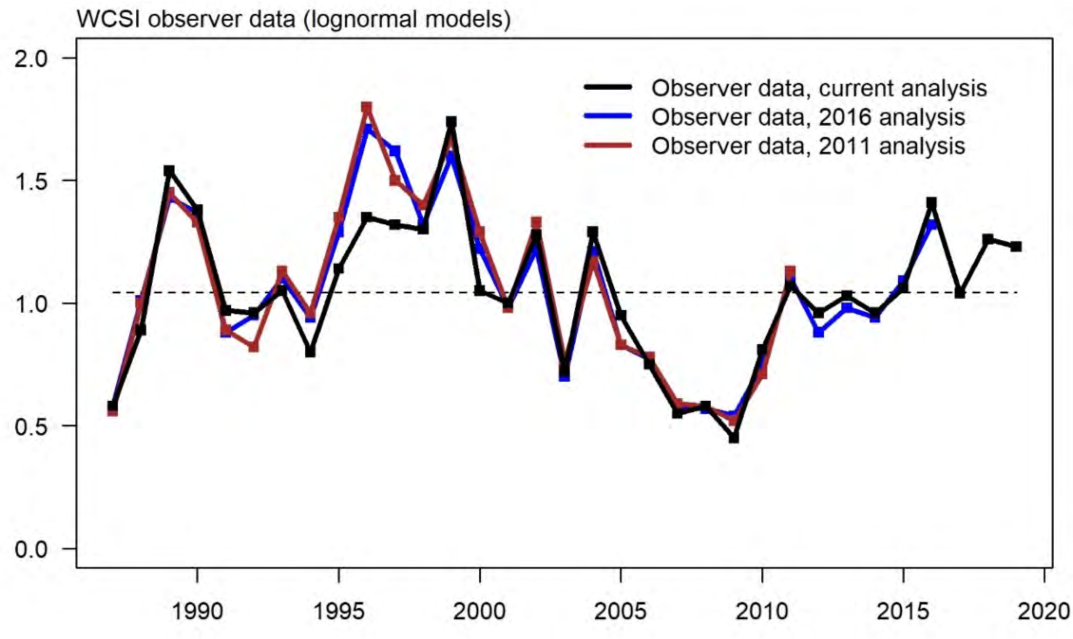

Figure 25: Comparison of the lognormal CPUE index for the 1986–87 to 2018–19 CPUE for observer tow-by-tow data with latitude offered as the spatial covariate and the CPUE indices produced in 2016 (Dunn & Ballara 2019) and 2011 (Ballara & Horn 2015).

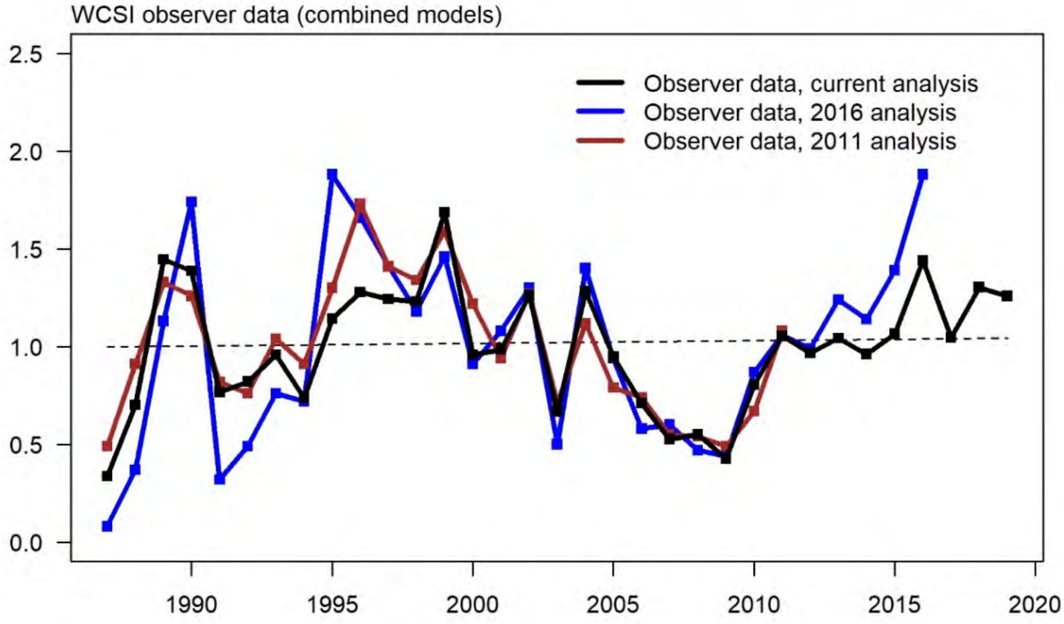

Figure 26: Comparison of the combined CPUE index for the 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate and the CPUE indices produced in 2016 (Dunn & Ballara 2019) and 2011 (Ballara & Horn 2015).

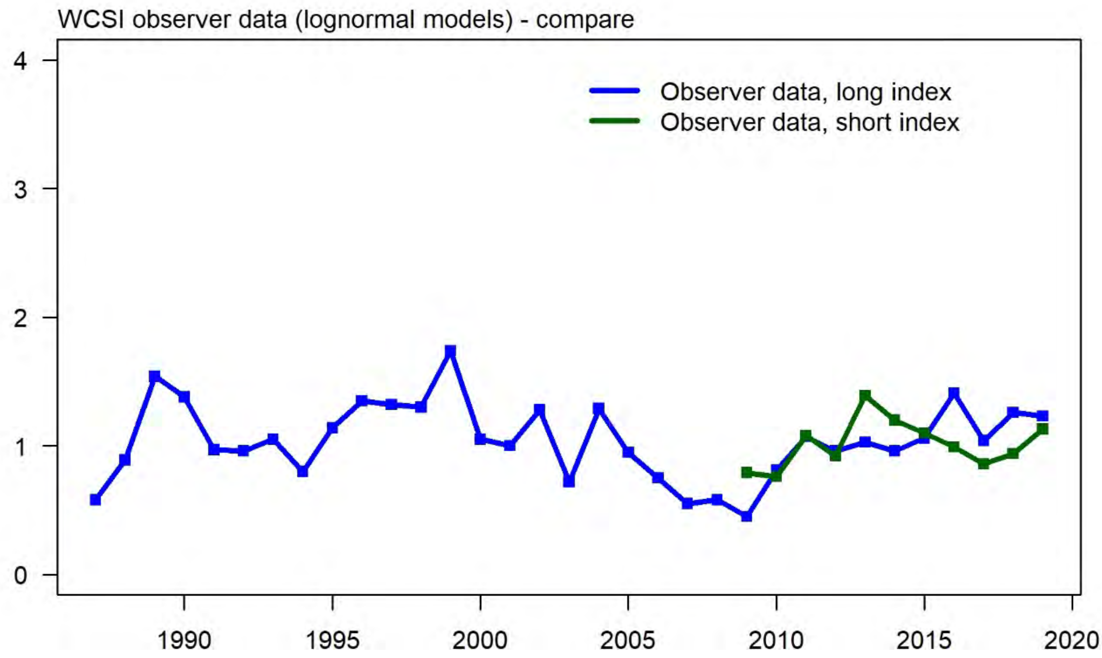

Figure 27: Comparison of the lognormal CPUE index for the 1986–87 to 2018–19 CPUE for observer tow-by-tow data with latitude offered as the spatial covariate and the lognormal CPUE for the 2008-09 to 2018–19 CPUE for observer tow-by-tow data with latitude offered as the spatial covariate (Figure 122 in Appendix 2).

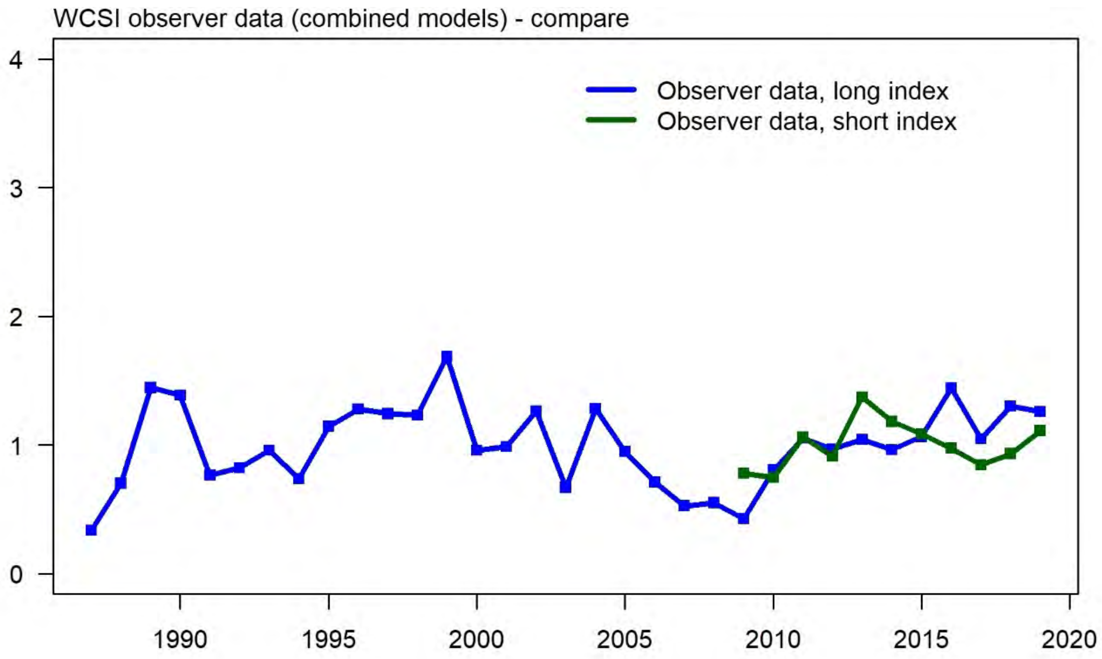

Figure 28: Comparison of the combined CPUE index for the 1986–87 to 2018–19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate and the combined CPUE for the 2008-09 to 2018-19 CPUE for observed tow-by-tow data with latitude offered as the spatial covariate (Figure 123 in Appendix 2).

Table 10: CPUE standardised year indices and estimated coefficient of variation (CV) for the 1986–87 to 2018–19 CPUE for observer tow-by-tow data with latitude offered as the spatial covariate (Model B).

	Lognormal		Binomial		Combined	
Fishing year	Index	CV	Index	CV	Index	CV
1986–87	0.58	0.07	0.56	0.0020	0.34	0.07
1987–88	0.89	0.06	0.76	0.0011	0.70	0.06
1988–89	1.54	0.07	0.91	0.0006	1.45	0.07
1989–90	1.38	0.06	0.97	0.0003	1.39	0.06
1990–91	0.97	0.07	0.76	0.0011	0.77	0.07
1991–92	0.96	0.08	0.83	0.0010	0.82	0.08
1992–93	1.05	0.08	0.88	0.0007	0.96	0.08
1993–94	0.80	0.06	0.89	0.0006	0.74	0.06
1994–95	1.14	0.07	0.97	0.0003	1.14	0.07
1995–96	1.35	0.05	0.92	0.0005	1.28	0.05
1996–97	1.32	0.06	0.91	0.0005	1.24	0.06
1997–98	1.30	0.05	0.92	0.0005	1.23	0.05
1998–99	1.74	0.04	0.94	0.0004	1.69	0.04
1999–2000	1.05	0.04	0.88	0.0006	0.96	0.04
2000–01	1.00	0.04	0.95	0.0004	0.99	0.04
2001–02	1.28	0.04	0.95	0.0004	1.26	0.04
2002–03	0.72	0.05	0.90	0.0006	0.67	0.05
2003–04	1.29	0.04	0.96	0.0003	1.28	0.04
2004–05	0.95	0.04	0.96	0.0003	0.95	0.04
2005–06	0.75	0.04	0.92	0.0005	0.71	0.04
2006–07	0.55	0.06	0.93	0.0005	0.53	0.06
2007–08	0.58	0.06	0.92	0.0005	0.55	0.06
2008–09	0.45	0.06	0.91	0.0005	0.42	0.06
2009–10	0.81	0.06	0.96	0.0004	0.80	0.06
2010–11	1.07	0.05	0.95	0.0004	1.05	0.05
2011–12	0.96	0.04	0.98	0.0003	0.97	0.04
2012–13	1.03	0.03	0.98	0.0003	1.04	0.03
2013–14	0.96	0.03	0.97	0.0003	0.96	0.03
2014–15	1.06	0.03	0.97	0.0003	1.06	0.03
2015–16	1.41	0.03	0.99	0.0002	1.44	0.03
2016–17	1.04	0.03	0.97	0.0003	1.05	0.03
2017–18	1.26	0.03	1.00	0.0002	1.30	0.03
2018–19	1.23	0.03	0.99	0.0002	1.26	0.03

3.2 LIN 7WC line fishery

Since 1990, the LIN 7WC bottom longline fishery has been predominantly (about 96%) a ling target fishery (Figure 29). The LIN 7 WC bottom longline fishery operates all year round, although, prior to 2009, the July to November period had typically higher monthly catches (Table 11, Figure 29). Most of the ling bottom longline catch was taken in Statistical Areas 032–034 (Figure 29), by vessels using fewer than 5000 hooks/day (Figure 30). In recent years, mean hooks/day and mean vessel size appears to have increased (Figure 30).

Before core vessel selection, the groomed 30-year bottom longline dataset contained 18 955 records from 49 vessels that fished (Table 12). Most of the catch and effort data came from inshore vessels less than 28 m in length (Table 13). As with the trawl fishery, highest catches are taken from canyon areas (Figure 31). An increase of catches taken north of the Hokitika Canyon occurred after 2016 (Figure 32). The proportion of the total estimated catch included in the 'core' CPUE data set 84.1% for line catch. A total of 17 'core' vessels were included for the line fishery CPUE analyses which account for 84.1% of the reported LIN 7WC bottom longline catch. The proportion of zero catches in the longline dataset was virtually nil, therefore zero catch records were removed from the dataset as these were likely to be errors in either reporting, exploratory fishing, or gear malfunctions (see Section 2.2).

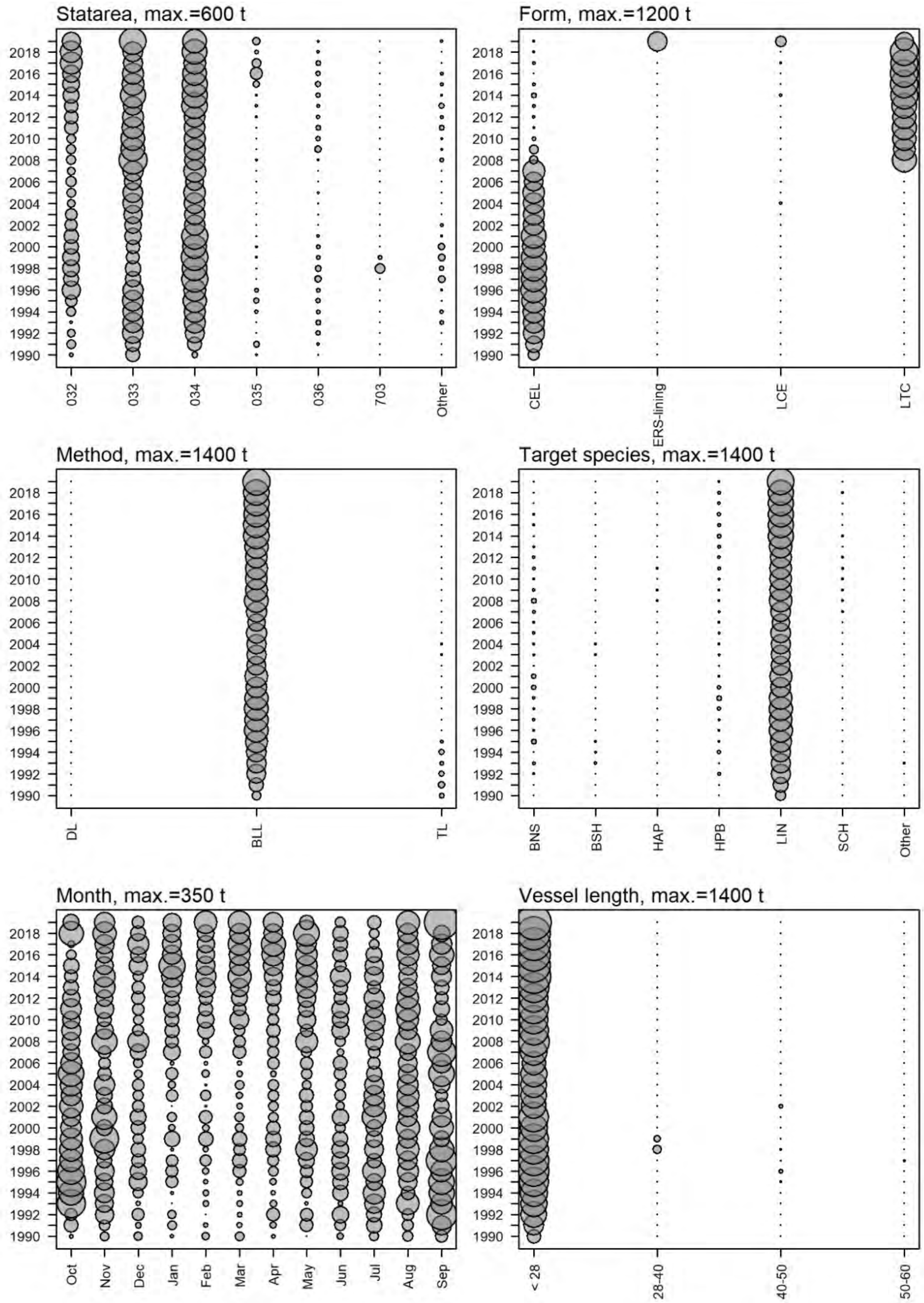

Figure 29: LIN 7WC line distribution of ling catch by fishing year, area, form type, fishing method (by form type), target species, month of fishing year, and vessel length. Circle size is proportional to catch; maximum circle size is indicated in the heading of each plot. BNS, bluenose; BSH, seal shark; HAP, hāpuku; HPB, hāpuku and bass; LIN, ling; SCH, school shark.

Table 11: LIN 7WC estimated ling line catch (t) by month, for fishing years from 1990 to 2019.

Fishing												Month	
year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1989–90	5	22	20	4	16	20	4	<1	12	25	28	41	197
1990–91	54	32	11	22	6	8	12	48	35	63	34	102	428
1991–92	40	89	41	19	<1	7	48	43	74	61	37	234	691
1992–93	207	87	6	<1	11	10	13	4	7	98	137	128	708
1993–94	161	106	29	3	11	8	6	26	64	133	50	165	761
1994–95	218	79	85	41	6	14	11	41	63	72	89	171	889
1995–96	183	99	72	40	11	47	26	43	81	137	123	128	991
1996–97	139	61	49	37	34	57	34	70	76	59	96	247	958
1997–98	144	110	55	3	8	36	62	125	76	95	136	157	1 008
1998–99	129	213	28	64	58	56	65	66	61	71	93	68	972
1999–2000	115	68	55	11	13	19	49	59	28	72	144	151	784
2000–01	92	163	67	23	47	24	25	58	72	151	94	101	917
2001–02	143	70	38	<1	1	11	26	37	18	123	128	62	659
2002–03	112	69	29	37	28	12	31	54	34	110	130	40	686
2003–04	130	109	37	15	1	22	31	21	26	98	113	78	682
2004–05	173	50	17	41	14	10	10	31	41	65	102	173	728
2005–06	118	39	23	5	5	6	38	44	52	39	93	101	562
2006–07	74	43	67	79	40	47	33	30	14	38	73	208	745
2007–08	84	165	120	45	11	36	35	132	28	83	158	113	1 010
2008–09	102	81	34	55	75	35	51	43	83	100	89	139	887
2009–10	79	54	25	52	75	93	35	88	67	133	125	35	864
2010–11	113	96	36	74	52	43	35	69	82	82	152	68	902
2011–12	79	72	46	56	50	69	63	90	44	108	128	43	848
2012–13	62	121	44	100	98	89	63	127	58	47	92	57	957
2013–14	45	124	29	121	109	143	88	131	110	96	89	105	1 190
2014–15	66	87	92	182	96	102	105	119	39	91	92	86	1 157
2015–16	26	73	64	99	85	120	139	125	62	68	130	157	1 149
2016–17	14	101	119	96	80	138	155	107	56	25	122	112	1 127
2017–18	152	140	62	84	78	112	95	171	65	27	106	74	1 165
2018–19	69	111	41	91	135	137	107	58	27	51	143	312	1 283
Total	3 128	2 734	1 441	1 499	1 254	1 531	1 495	2 060	1 555	2 421	3 126	3 656	25 905

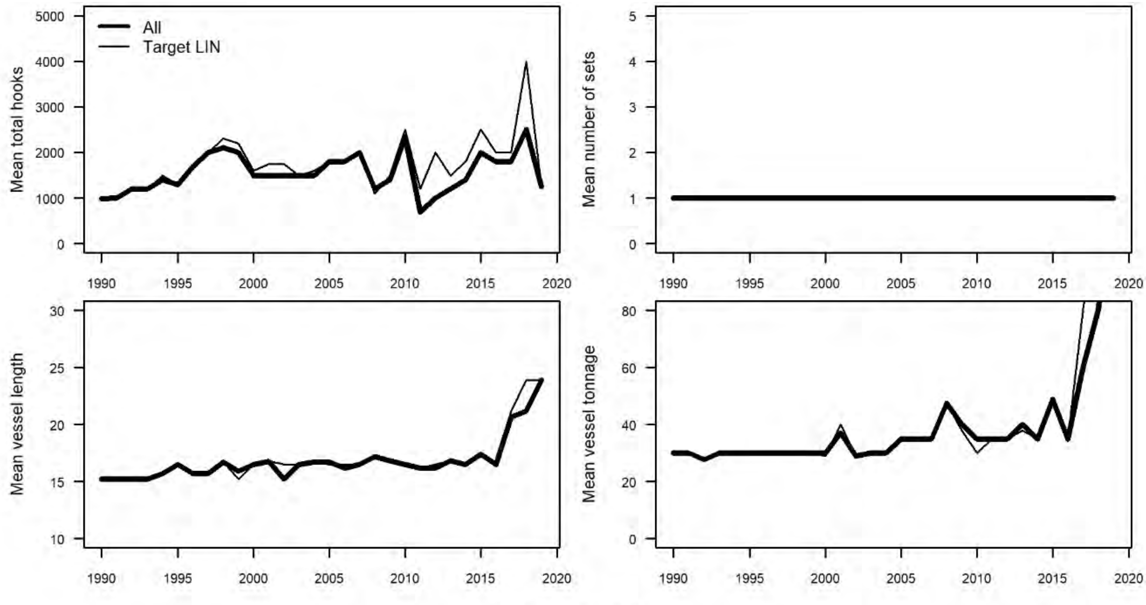

Figure 30: LIN 7WC line means of effort variables by fishing year for vessels targeting all species (other than ling) or ling by line methods.

Table 12: Summary for all vessels and for core vessels included in the final LIN 7WC target longline CPUE standardisation datasets.

	All vessels					Core vessels				
Calendar year	No. vessels	Catch	Days	Prop. zeros	CPUE	No. vessels	Catch	Days	Prop. zeros	CPUE
1990	16	247.7	342	0.01	0.72	3	168.3	180	0	0.94
1991	17	500.1	530	0.01	0.94	4	272	256	0	1.06
1992	22	820.8	744	0	1.1	7	589.4	430	0	1.37
1993	18	683.6	595	0	1.15	8	573.1	404	0	1.42
1994	22	847.2	655	0	1.29	8	659.5	430	0	1.53
1995	23	857.8	683	0	1.26	9	733.9	493	0	1.49
1996	25	773.0	685	0.04	1.13	8	682.6	525	0	1.3
1997	23	824.1	674	0.03	1.22	8	710.3	462	0	1.54
1998	18	933.5	658	0.07	1.42	8	853	537	0	1.59
1999	20	803.3	663	0.08	1.21	8	681.4	484	0	1.41
2000	22	866.7	708	0	1.22	10	691.8	514	0	1.35
2001	20	845.6	673	0	1.26	9	702.4	480	0	1.46
2002	18	615.4	543	0	1.13	9	605.6	445	0	1.36
2003	20	753.3	636	0	1.18	9	686.4	519	0	1.32
2004	21	641.6	550	0	1.17	9	527.2	390	0	1.35
2005	20	666.8	786	0	0.85	9	631.1	589	0	1.07
2006	13	566.7	566	0	1	6	468	410	0	1.14
2007	15	928.9	711	0	1.31	9	861.6	536	0	1.61
2008	18	850.6	643	0	1.32	7	706.1	420	0	1.68
2009	18	825.0	652	0	1.27	8	683.2	447	0	1.53
2010	16	947.3	678	0	1.4	7	780.3	477	0	1.64
2011	13	836.0	621	0	1.35	6	712.9	436	0	1.64
2012	15	870.0	698	0	1.25	6	730.6	466	0	1.57
2013	13	925.1	587	0	1.58	6	790.8	381	0	2.08
2014	17	1 237.1	689	0	1.8	6	1 069.6	454	0	2.36
2015	16	1 074.9	650	0	1.65	7	915.1	444	0	2.06
2916	15	1 216.3	675	0	1.8	6	1 009.4	474	0	2.13
2017	16	1 246.1	609	0	2.05	5	1 038.1	398	0	2.61
2018	14	1 032.4	472	0.02	2.19	5	884.2	356	0	2.48
2019	8	1 057.9	376	0	2.81	4	863.9	283	0	3.05

Table 13: LIN 7WC catches and effort for vessels under 28 m (less28) and at least 28 m (28plus) overall length.

	All Vessels						Core Vessels					
Calendar	Catches (t)		Total number of days		Total number of sets		Catches (t)		Total number of days		Total number of sets	
year	less28	28plus	less28	28plus	less28	28plus	less28	28plus	less28	28plus	less28	28plus
1990	197	0	317	0	452	0	168	0	180	0	230	0
1991	428	0	509	0	598	0	272	0	256	0	266	0
1992	690	1	742	2	848	2	589	0	427	0	448	0
1993	708	<1	656	1	826	1	573	0	404	0	477	0
1994	760	1	709	1	962	1	660	0	430	0	518	0
1995	885	4	751	3	909	6	734	0	493	0	495	0
1996	971	20	913	7	1 059	25	683	0	522	0	531	0
1997	948	9	985	8	1 202	8	710	0	462	0	464	0
1998	924	84	792	62	984	173	853	0	537	0	550	0
1999	921	51	931	20	1 227	57	681	0	484	0	533	0
2000	784	<1	826	2	1 172	2	692	0	514	0	617	0
2001	915	1	868	1	1 107	1	702	0	480	0	580	0
2002	641	17	629	3	860	5	606	0	445	0	553	0
2003	686	0	718	0	977	0	686	0	519	0	650	0
2004	680	2	735	2	950	2	527	0	390	0	463	0
2005	728	0	867	0	1 272	0	631	0	589	0	689	0
2006	559	2	744	1	917	1	468	0	410	0	411	0
2007	745	0	732	0	1 005	0	862	0	535	0	721	0
2008	1 010	0	825	0	1 230	0	706	0	419	0	640	0
2009	887	0	763	0	1 176	0	683	0	445	0	523	0
2010	864	0	667	0	842	0	780	0	475	0	535	0
2011	902	0	772	0	1 502	0	713	0	429	0	741	0
2012	848	0	737	0	1 302	0	731	0	461	0	671	0
2013	955	2	673	37	1 029	149	791	0	379	0	541	0
2014	1 190	1	788	17	1 232	48	1 070	0	449	0	595	0
2015	1 157	<1	729	19	992	61	915	0	442	0	528	0
2916	1 147	2	759	11	1 020	31	1 009	0	473	0	604	0
2017	1 127	<1	674	3	977	18	1 038	0	396	0	513	0
2018	1 165	0	594	0	825	0	884	0	356	0	432	0
2019	1 283	0	514	0	1 144	0	864	0	278	0	668	0

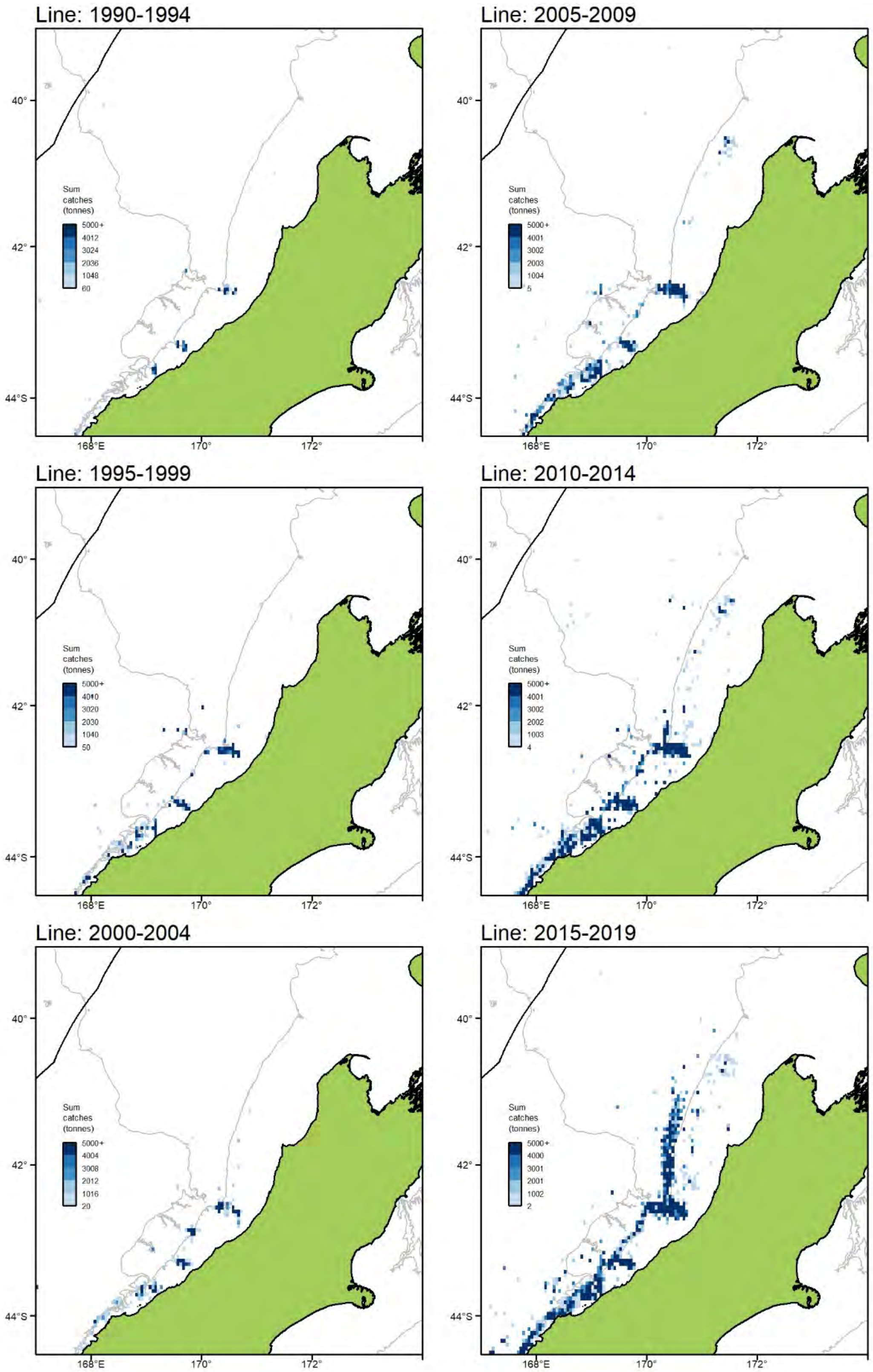

Figure 31: LIN 7WC line density plots of ling catches by fishing years (labelled as year-ending).

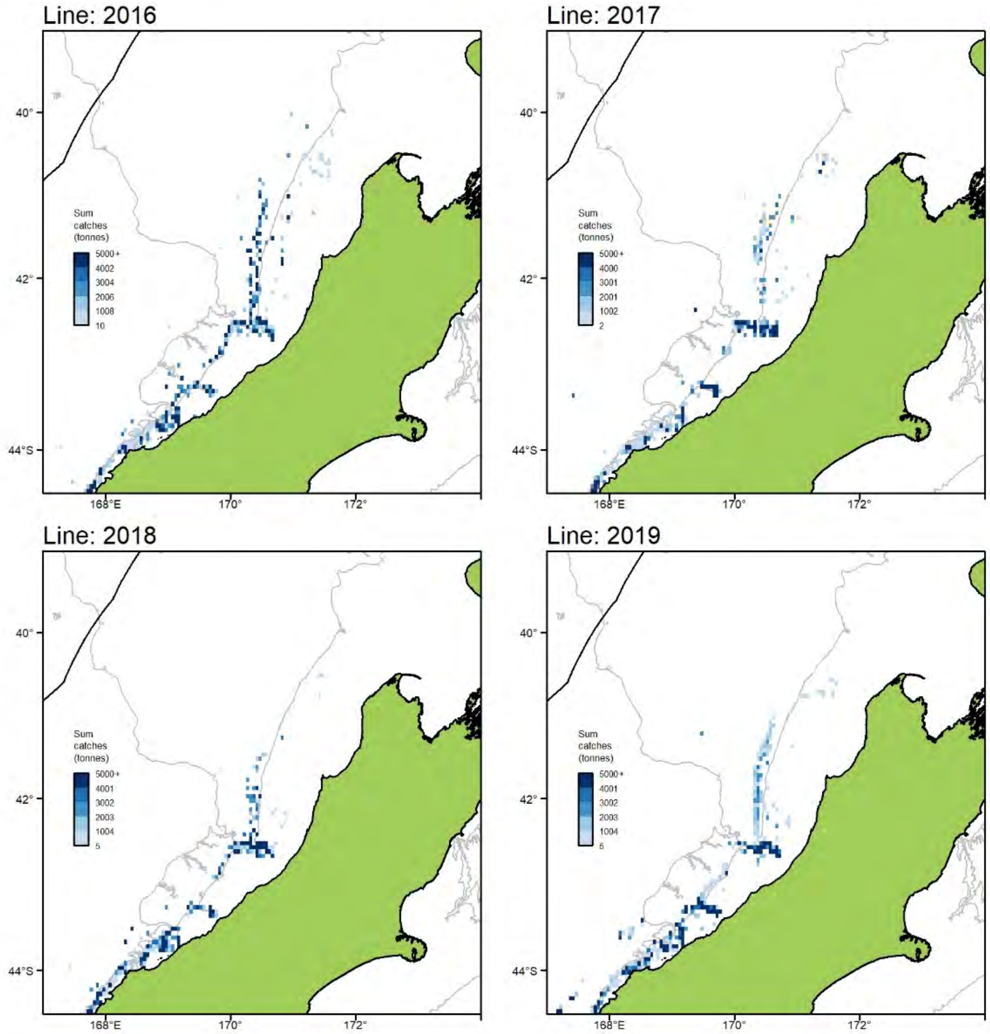

Figure 31 (continued): LIN 7WC line density plots of ling catches by fishing years (labelled as year-ending).

3.2.1 Target LIN 7WC bottom longline 1990–2019 calendar year CPUE index

The lognormal positive catch model accounted for 40.17% of the observational deviance, of which about 15% was explained by the total hook number covariate (Table 14). The total hooks predictor tended to increase the CPUE before 1995, decrease the CPUE in years after 2005, and had little effect in the 10 years in between (Figure 32). The fit of the model was good, although the extremes at the lower end were not well captured (Figure 33). The model residuals suggest small catches are expected but are overestimated when predicted by the model (Figure 33). The lognormal model indicated a gradual increase in CPUE over time (Figure 32).

Table 14: Predictor and percentage of deviance explained for the final lognormal model fit for the 1990–2019 CPUE for commercial line fishery. Df, degrees of freedom; R^2, R squared.

Step	Df	R^2
Year	29	8.30
Log(Total Hooks)	3	23.58
Month	11	32.84
Vessel	16	40.17

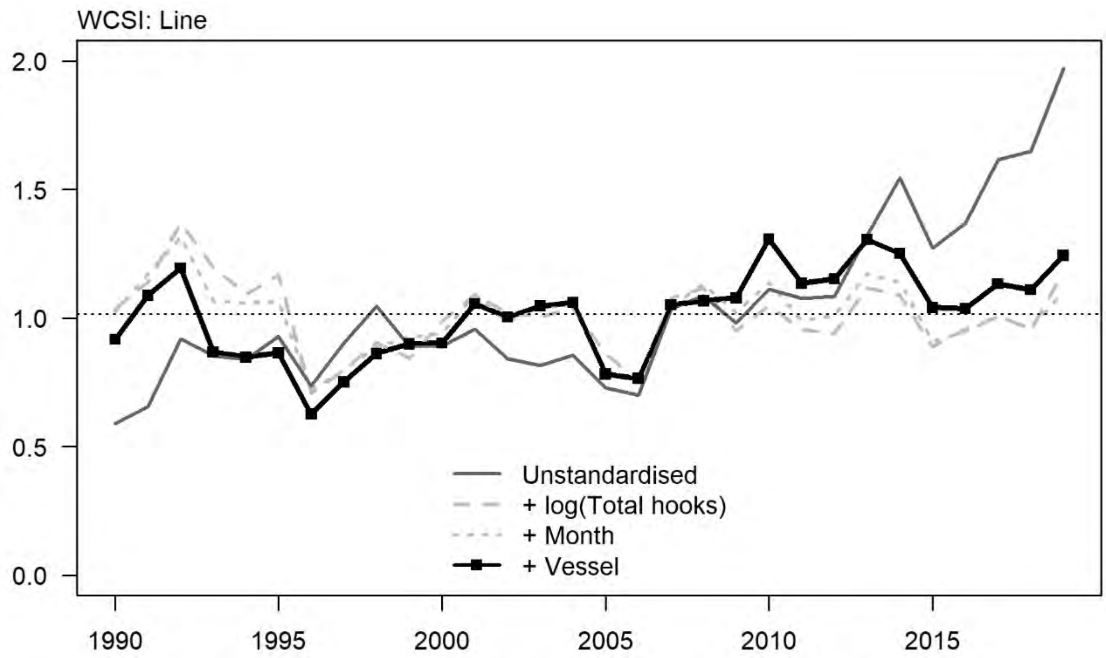

Figure 32: Step plot for the non-zero catch rate (lognormal) model for the 1990–2019 CPUE for commercial line fishery. Plot shows the year effect for the unstandardised model, and after successive model predictors are added.

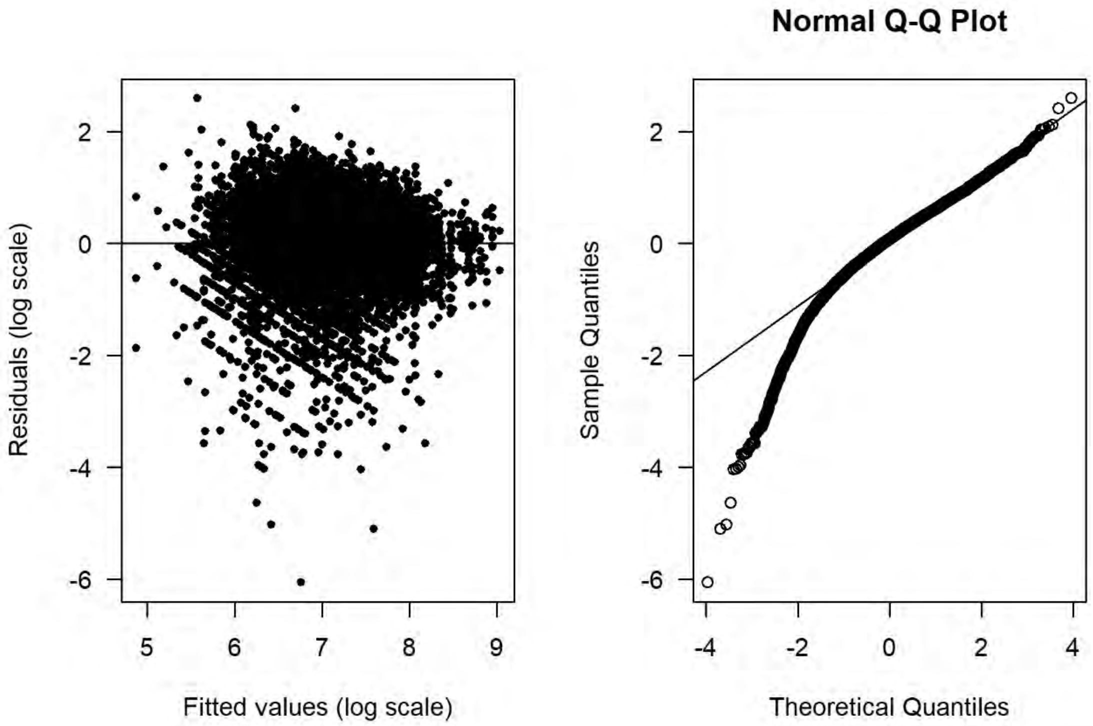

Figure 33: Residuals (left panel) and normal quantile plot (right panel) for the lognormal model fit for the 1990–2019 CPUE for commercial line fishery.

Total hook number has increased over time, particularly since the mid-2000s, with higher catch rates with more hooks set (Figure 34). Month had little overall influence on CPUE, although higher coefficients were estimated for August through October (Figure 35). However, catch rates taken during these months have decreased since the mid-2000s, with catches being distributed more consistently year-round. The vessel covariate had minimal influence although there were fewer vessels in the fleet after 2010 (Figure 36). There is some positive influence in some years where vessels with higher predicted catch rates have higher effort (e.g., 1994) and negative where vessels with lower predicted catch rates have higher effort (e.g., 2010).

The line CPUE estimated here was comparable with those estimated in Ballara & Horn (2015) and Dunn & Ballara (2019) and indicated a slight increase in CPUE since 2016 (Figure 37). The bootstrap procedure estimated the very low coefficient of variation (CV) of less than 10% (Table 15).

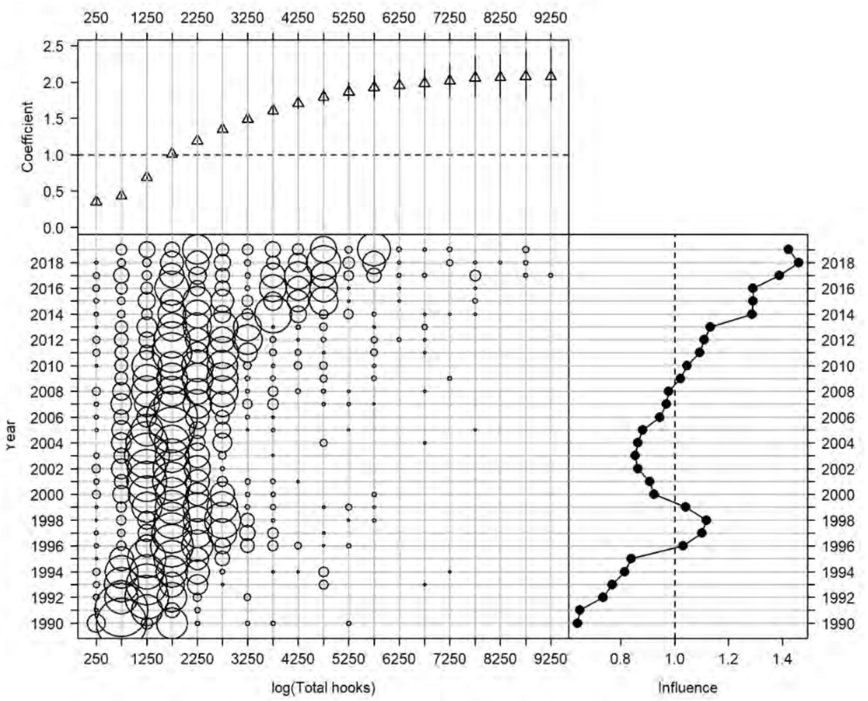

Figure 34: Total hooks influence plot for the non-zero catch rate (lognormal) model for the 1990–2019 CPUE for commercial line fishery. Top panel, the coefficient estimates for total hook numbers; bottom left panel, the number of sets, with bubble size proportional to the number of sets; right panel, the influence of the predictor on the year effect.

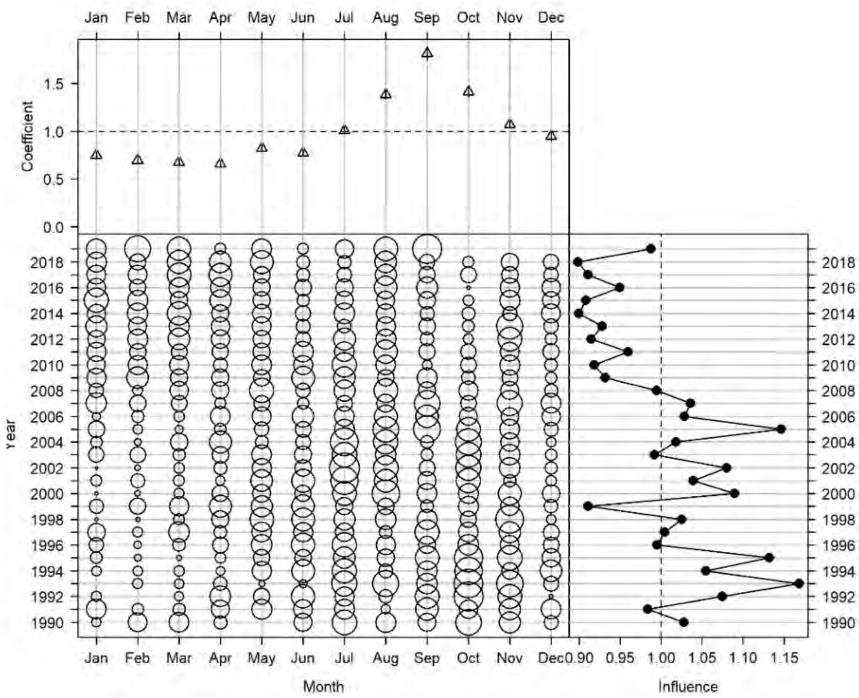

Figure 35: Month influence plot for the non-zero catch rate (lognormal) model for the 1990–2019 CPUE for commercial line fishery. Top panel, the coefficient estimates for each month of the calendar year; bottom left panel, the number of sets, with bubble size proportional to the number of sets; right panel, the influence of the predictor on the year effect.

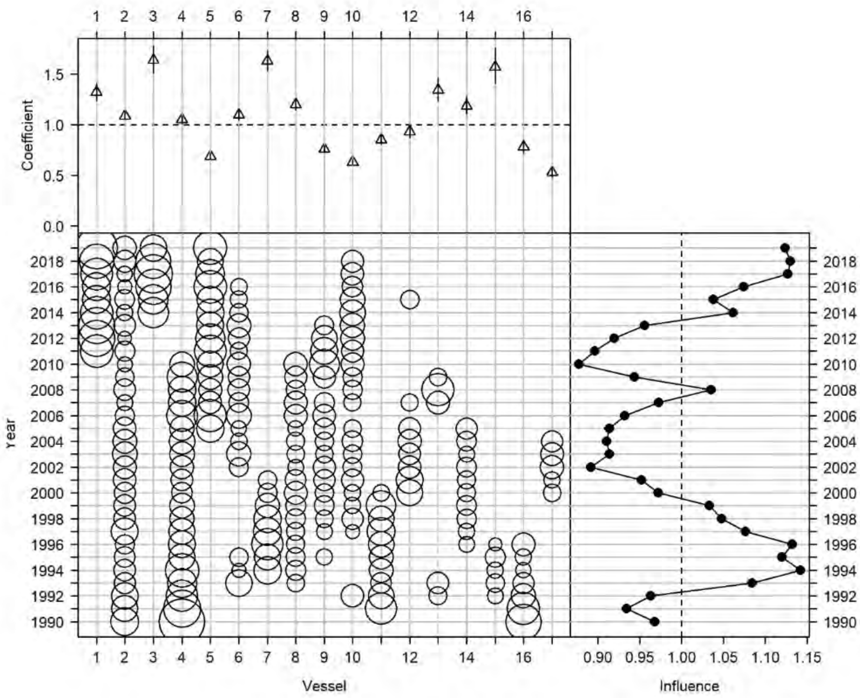

Figure 36: Vessel influence plot for the non-zero catch rate (lognormal) model for the 1990–2019 CPUE for commercial line fishery. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of sets, with bubble size proportional to the number of sets; right panel, the influence of the predictor on the year effect.

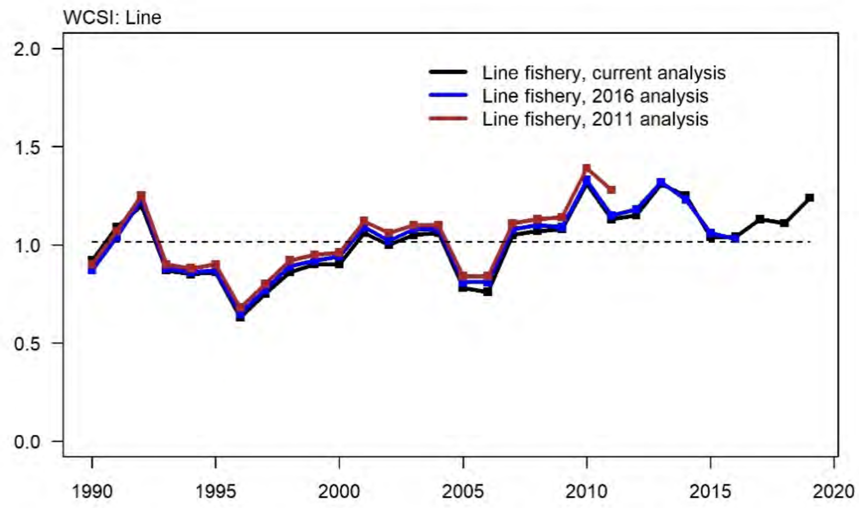

Figure 37: Comparison of the lognormal CPUE index for the 1990–2019 CPUE for commercial line fishery and the CPUE indices produced in 2016 (Dunn & Ballara 2019) and 2011 (Ballara & Horn 2015).

Table 15: CPUE standardised year indices and estimated coefficient of variation (CV) for the 1990–2019 calendar year CPUE for commercial line fishery.

Calendar year	Index	Lognormal CV
1990	0.92	0.08
1991	1.09	0.07
1992	1.20	0.05
1993	0.87	0.05
1994	0.85	0.05
1995	0.86	0.05
1996	0.63	0.05
1997	0.75	0.05
1998	0.86	0.05
1999	0.90	0.05
2000	0.90	0.05
2001	1.06	0.05
2002	1.00	0.05
2003	1.05	0.05
2004	1.06	0.05
2005	0.78	0.04
2006	0.76	0.05
2007	1.05	0.04
2008	1.07	0.05
2009	1.08	0.05
2010	1.31	0.05
2011	1.13	0.05
2012	1.15	0.05
2013	1.31	0.05
2014	1.25	0.05
2015	1.04	0.05
2016	1.04	0.05
2107	1.13	0.06
2018	1.11	0.06
2019	1.24	0.06

4. CPUE SUMMARY

The trend in the trawl CPUE indices, and the variables selected by the models, were not dissimilar to those produced by Dunn & Ballara (2019). However, the removal of the potentially confounding interaction between latitude and longitude did reduce the peak in CPUE around 1997–98. The lognormal trawl CPUE did not markedly change from the previous analysis, except for the reduction in CPUE in 1997–98, which was still observed when the model was offered the same covariates as were offered by Dunn & Ballara (2019). The combined index changed the most, with the trend more resembling that produced by Ballara & Horn (2015) as opposed to that produced by Dunn & Ballara (2019), irrespective of whether the model was offered the same covariates as by Dunn & Ballara (2019) or only offered latitude as the spatial covariate. Although the CPUE analysis produced by Dunn & Ballara (2019) was primarily driven by the binomial model, the addition of three years of data led to some instability in the binomial model, thus the lognormal model drove the trends observed in the combined index. The additional trawl data led to the inclusion of vessels that were not previously selected by the core vessel criteria, due to those vessels not being in the fleet for more than two years at the time of the previous analysis.

The line CPUE index and the variables selected by the model, did not change markedly from previous analyses (Dunn & Ballara 2019). This was expected given that most of the data set was the same, and the same covariates were offered to the model. Although the line CPUE series was updated here, Dunn et al. (2013) determined that the line CPUE may not provide a valid index of abundance. The index may be biased to some extent, because the fishery generally targets ling on clearly defined geological features using relatively short longlines that can be accurately placed. The accurate placement of fishing gear in optimal ling habitat could enable a degree of hyperstability in the CPUE indices. Also, some interactions with the trawl fishery in the same area could also lead to biases.

The accepted CPUE index for the trawl fishery was the combined (delta-lognormal) model where only latitude was offered as the spatial covariate for the entire observed time series (fishing years 1987–2019).

5. ACKNOWLEDGMENTS

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APPENDIX 1

Model B: 1987–2019 CPUE for observed tow-by-tow data with latitude offered as spatial covariate – negative binomial results

Table 16: Predictor and percentage of deviance explained for the negative binomial model fit for 1987–2019 CPUE for observed tow-by-tow data with latitude offered as spatial covariate. Df, degrees of freedom; R^2, R squared.

Step	Df	R^2
Year	32	6.39
Bottom depth	3	11.63
Vessel	72	14.79
Method	2	18.05
Latitude	3	20.34
Method:Duration	12	22.26

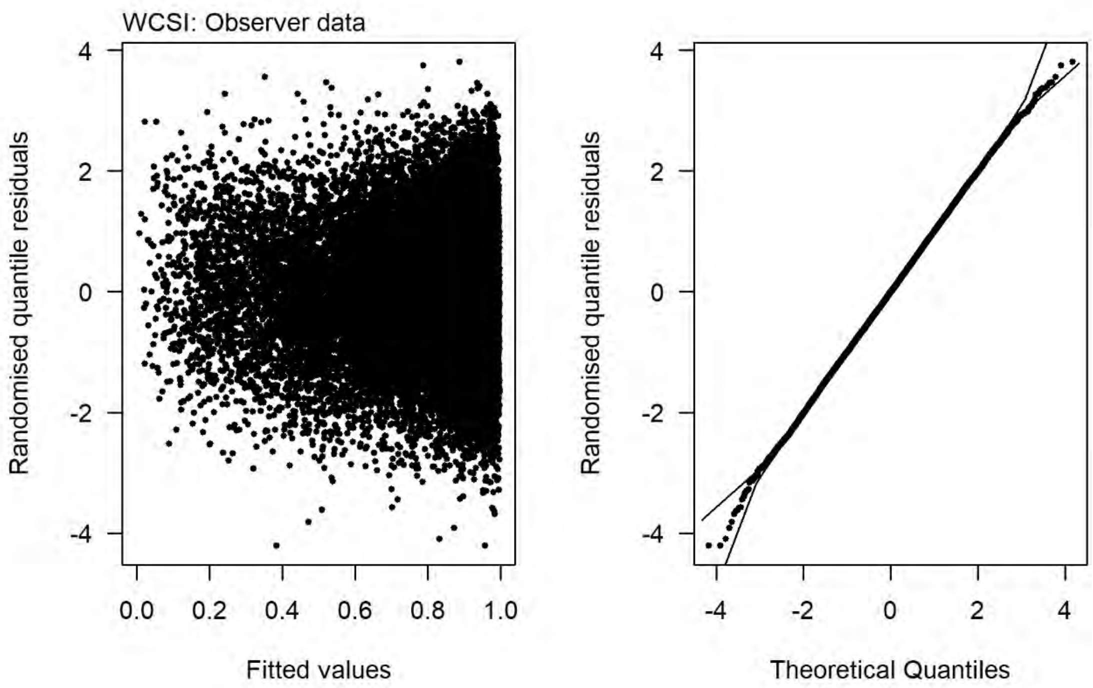

Figure 38: Residuals (left panel) and normal quantile plot (right panel) for the negative binomial model fit for the 1987–2019 CPUE for observed tow-by-tow data with latitude offered as spatial covariate.

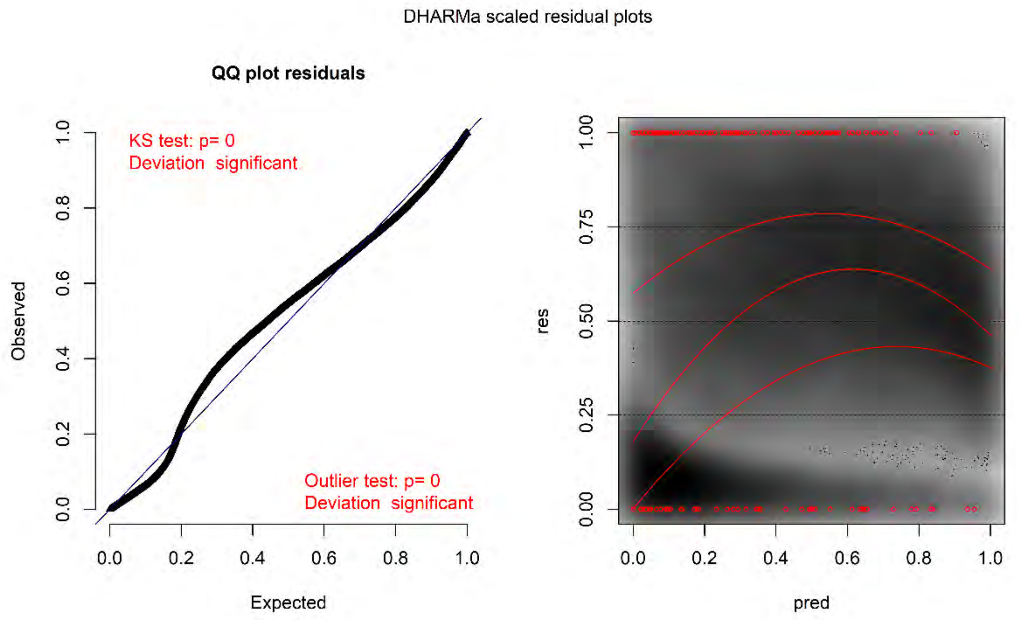

Figure 39: Normal quantile (left panel) and residuals plot (right panel) for the negative binomial model fit for the 1987–2019 CPUE for observed tow-by-tow data with latitude offered as spatial covariate.

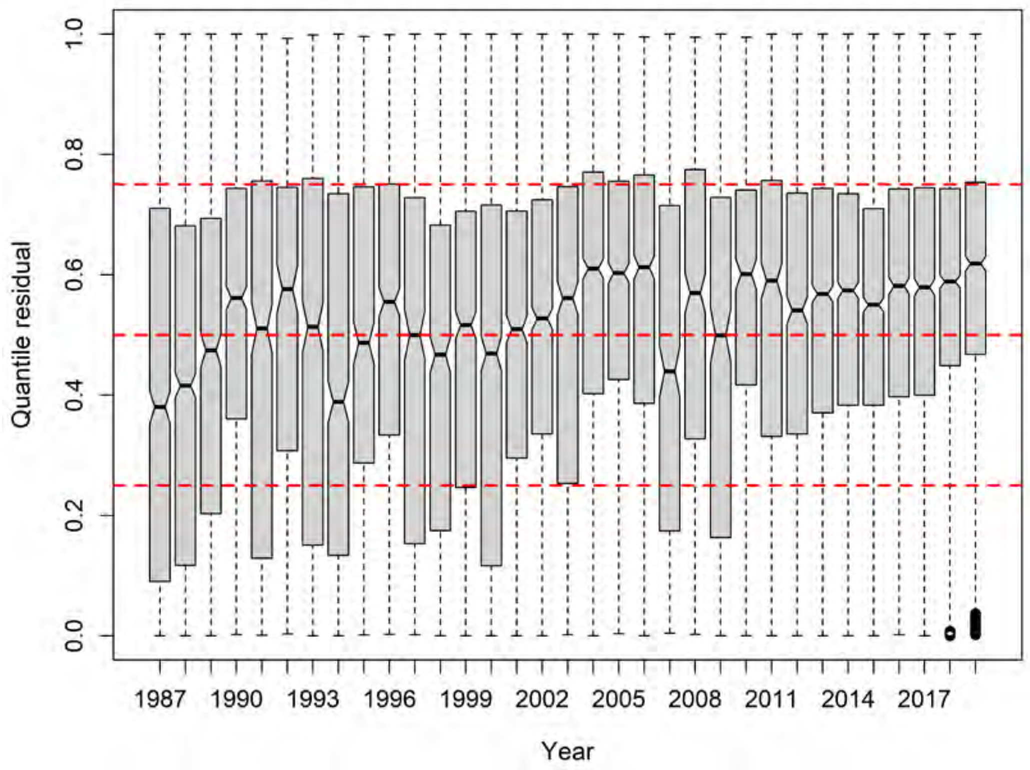

Figure 40: Quantile residual plot for the 1987–2019 CPUE for observed tow-by-tow data with latitude offered as spatial covariate for the negative binomial model.

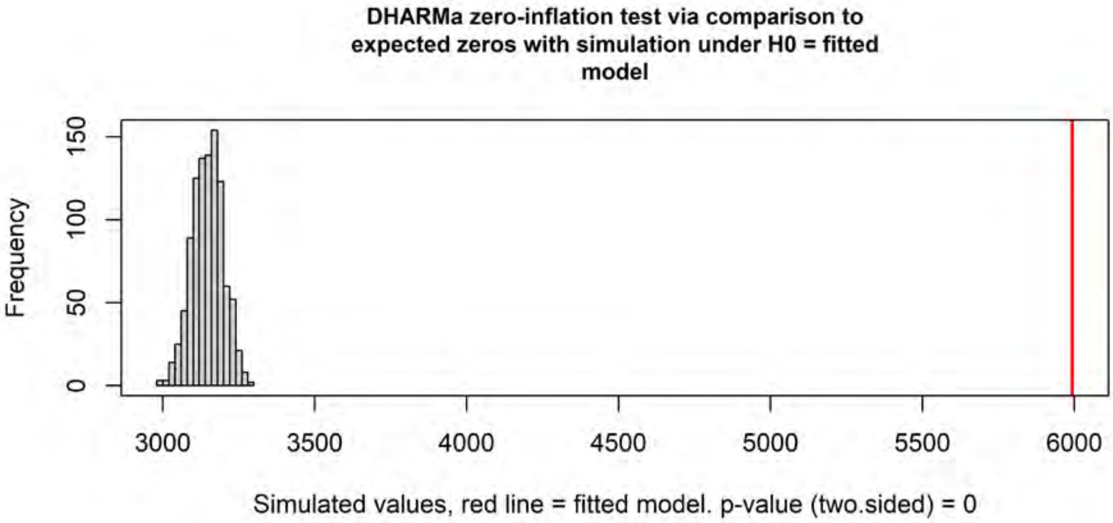

Figure 41: Zero inflation test for the 1987–2019 CPUE for observed tow-by-tow data with latitude offered as spatial covariate for the negative binomial model. Red line is the observed number of zeros in data. Grey bars are the fitted predicted zeros.

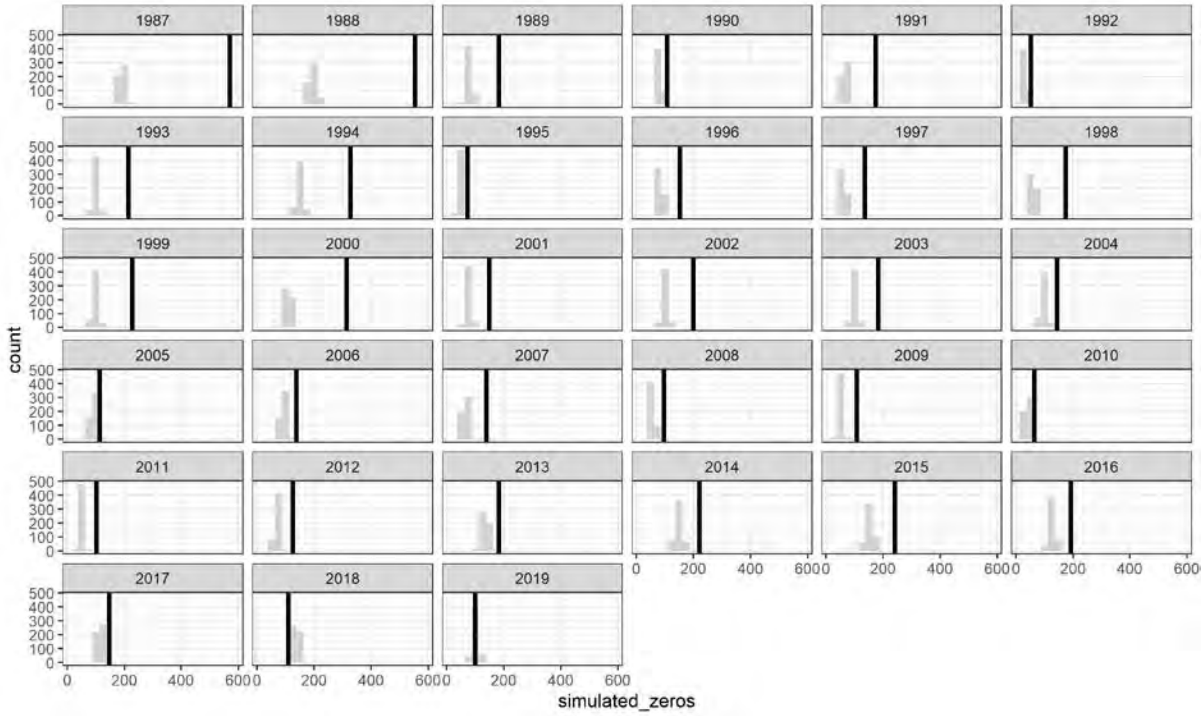

Figure 42: Zero inflation test by fishing year for the 1987–2019 CPUE for observed tow-by-tow data with latitude offered as spatial covariate for the negative binomial model. Black line is the observed number of zeros in data. Grey bars are the fitted predicted zeros.

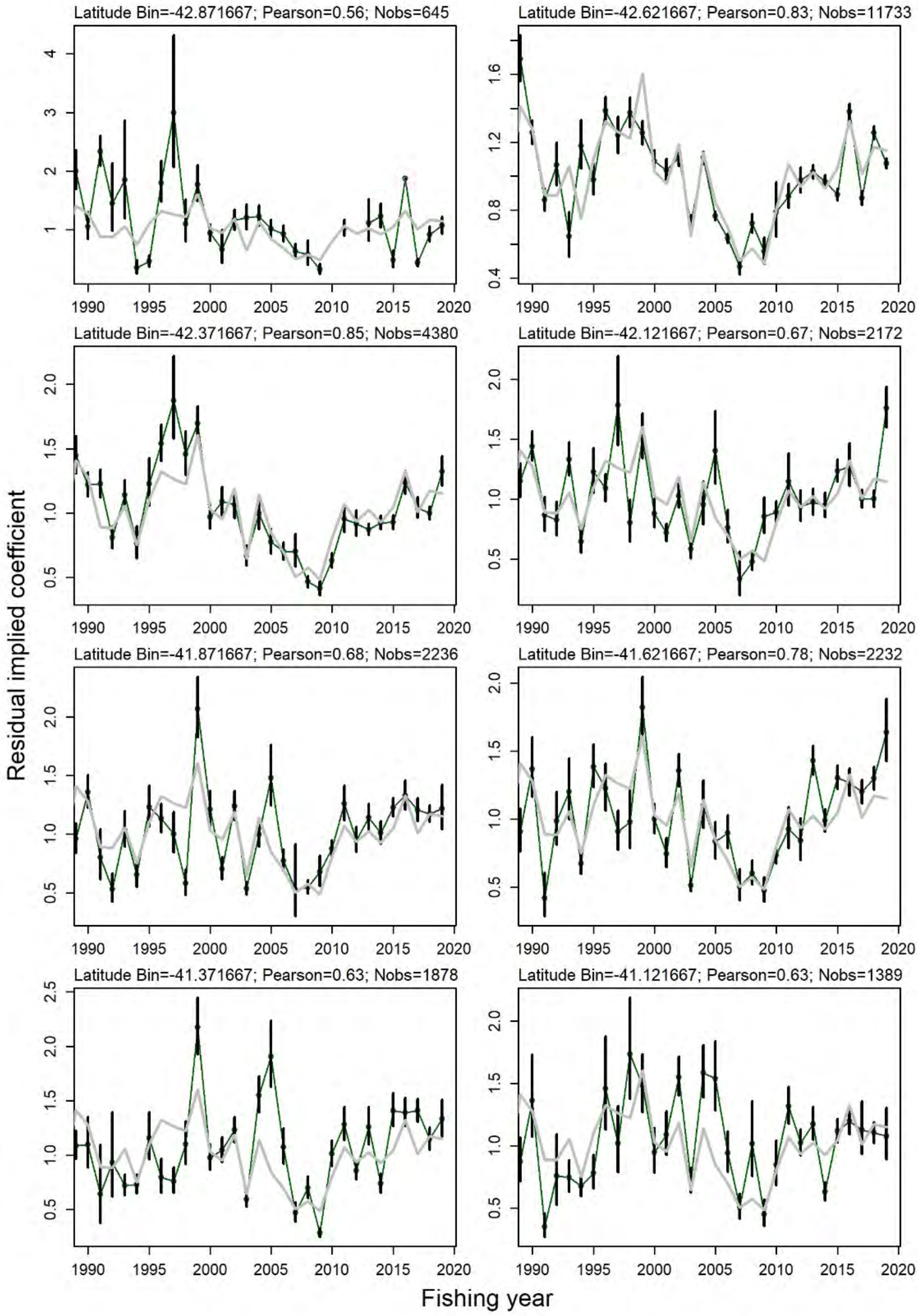

Figure 43: Implied residuals for 0.25 degree latitudinal bins for the 1987–2019 CPUE for observed tow-by-tow data with latitude offered as spatial covariate for the negative binomial model. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables. The grey line is the negative binomial CPUE index. The green line is the implied residual coefficient.

Table 17: CPUE standardised year index and estimated coefficient of variation (CV) for the 1987–2019 CPUE for observed tow-by-tow data with latitude offered as spatial covariate. Fishing year labelled as year-ending.

	Negative binomial	
Fishing year	Index	CV
1987	0.39	0.09
1988	0.98	0.08
1989	1.57	0.1
1990	1.54	0.09
1991	0.75	0.09
1992	1.03	0.12
1993	0.8	0.1
1994	0.64	0.07
1995	1.66	0.09
1996	1.14	0.07
1997	1.16	0.09
1998	1.73	0.07
1999	1.58	0.06
2000	0.9	0.06
2001	1.28	0.06
2002	1.22	0.05
2003	0.62	0.07
2004	1.12	0.05
2005	0.87	0.06
2006	0.75	0.06
2007	0.58	0.08
2008	0.52	0.08
2009	0.55	0.08
2010	0.72	0.08
2011	1.01	0.07
2012	1.2	0.06
2013	1.34	0.05
2014	1.12	0.05
2015	1.46	0.04
2016	1.52	0.05
2107	1.19	0.05
2018	1.13	0.05
2019	1.06	0.05

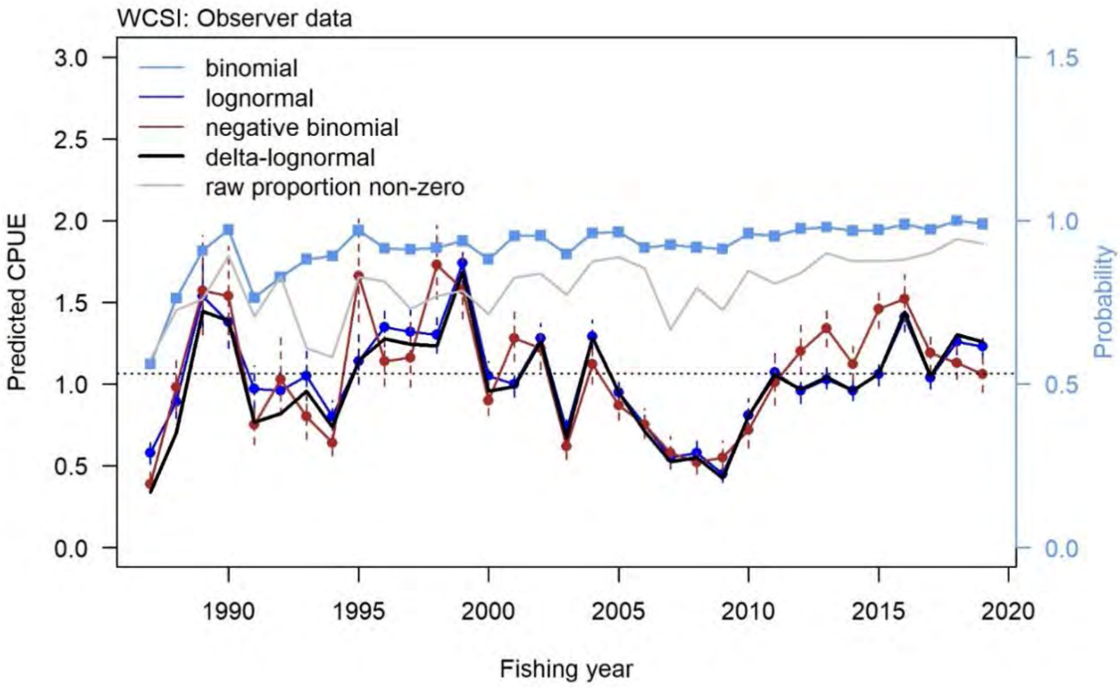

Figure 44: Comparison of the binomial, lognormal, negative binomial and combined CPUE indices for the 1987–2019 CPUE for observed tow-by-tow data with latitude offered as spatial covariate and the raw proportion of non-zero tows. Bars indicate 95% confidence intervals.

APPENDIX 2

Model A: 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates

Table 18: Predictor and percentage of deviance explained for the final binomial model fit for 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates. Df, degrees of freedom; R^2, R squared.

Step	Df	R^2
Year	32	6.39
Bottom depth	3	11.63
Vessel	72	14.79
Method	2	18.05
Latitude	3	20.34
Longitude	3	21.93
Method:Duration	12	24.38

Table 19: Predictor and percentage of deviance explained for the final lognormal model fit for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates. Df, degrees of freedom; R^2, R squared.

Step	Df	R^2
Year	32	5,72
Vessel	72	10.96
Method	2	17.87
Latitude	3	21.58
Day of year	3	23.20
Longitude	3	29.57
Method:Depth of net	9	33.49
Method:Duration	12	36.80

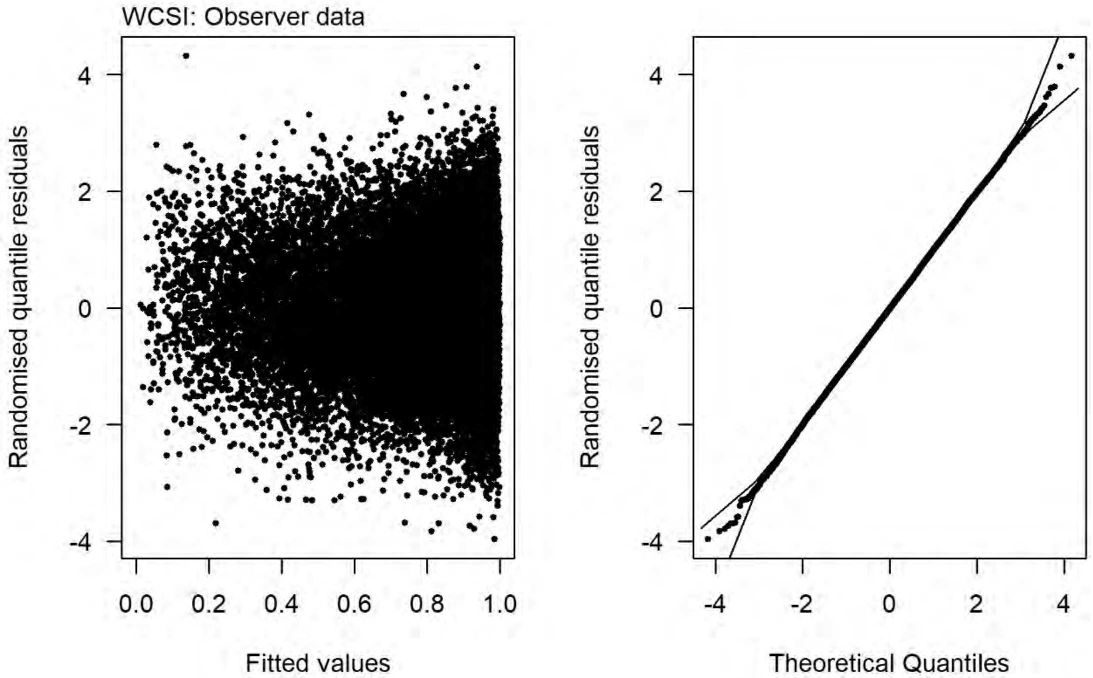

Figure 45: Residuals (left panel) and normal quantile plot (right panel) for the binomial model fit for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates.

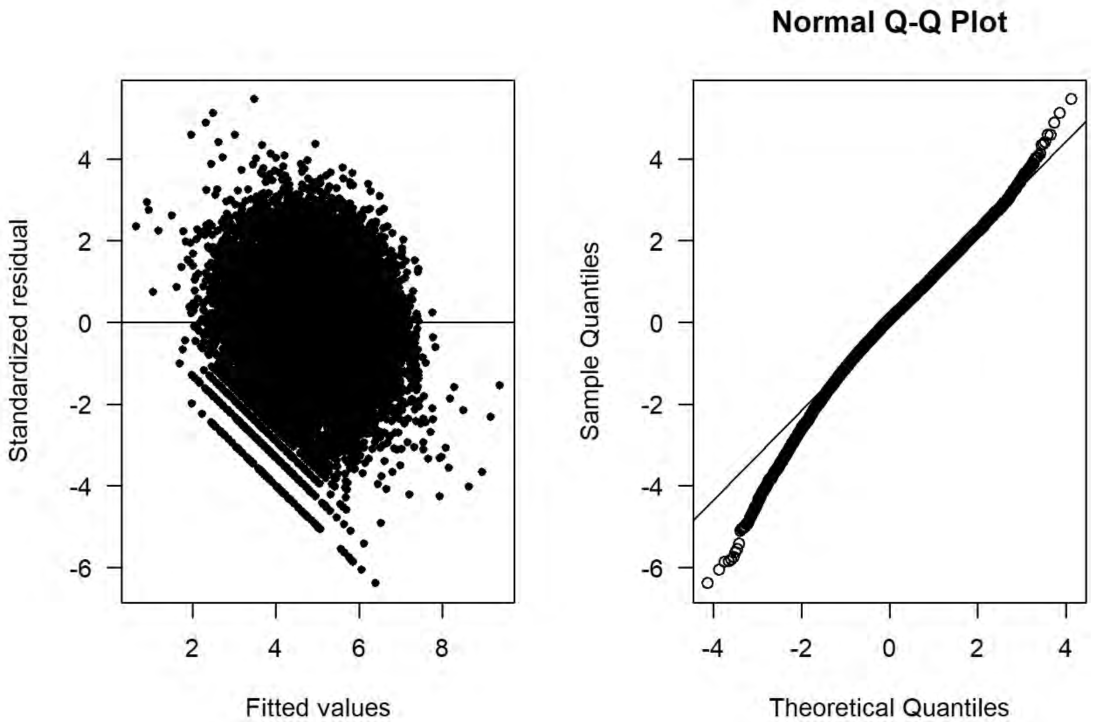

Figure 46: Residuals (left panel) and normal quantile plot (right panel) for the lognormal model fit for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates.

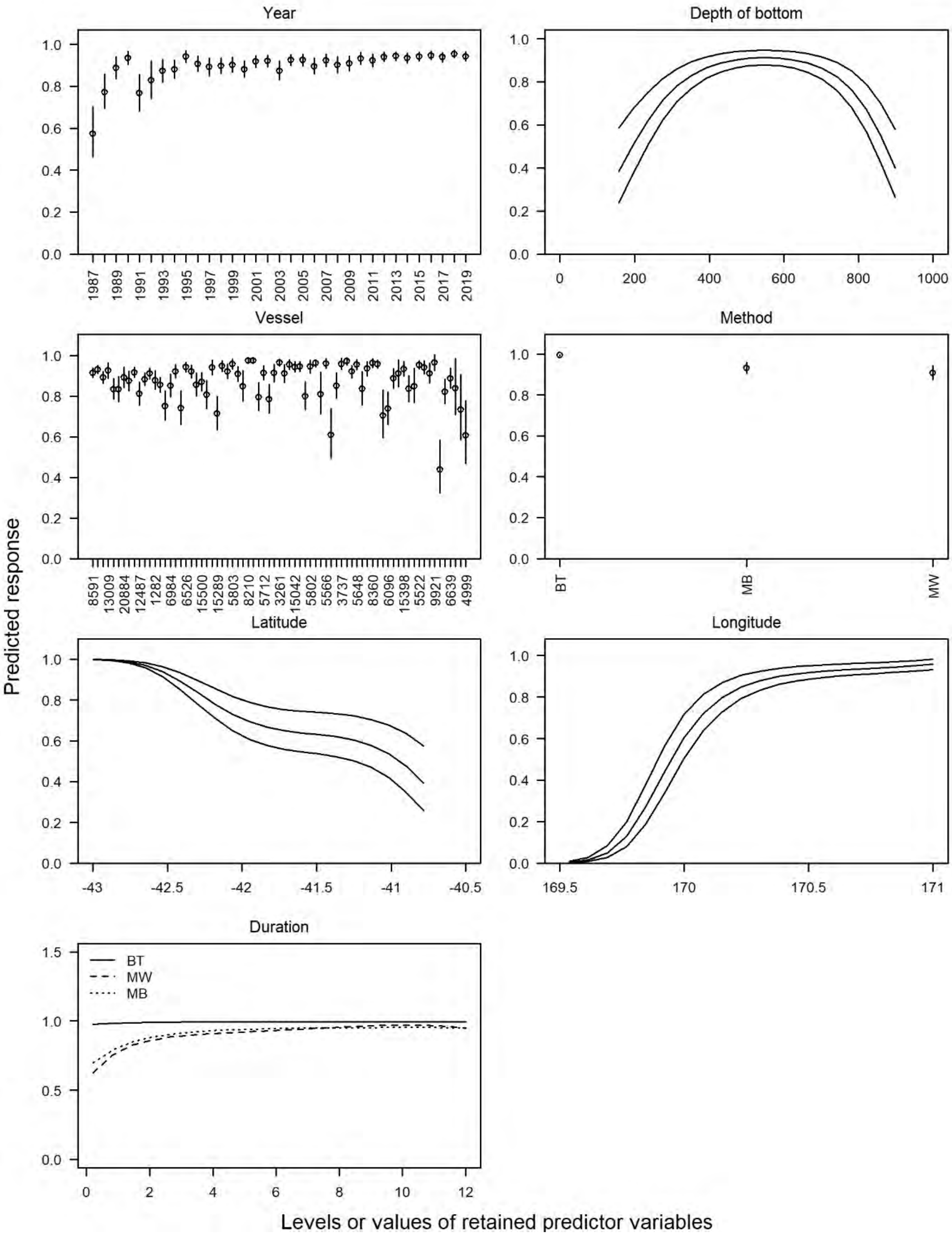

Figure 47: Model predictions for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates, by fishing year (labelled as year ending, i.e., 1991 means 1990–91) vessel, month, and fishing depth, for the binomial model made with all other predictors set to the median (fixed) values. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

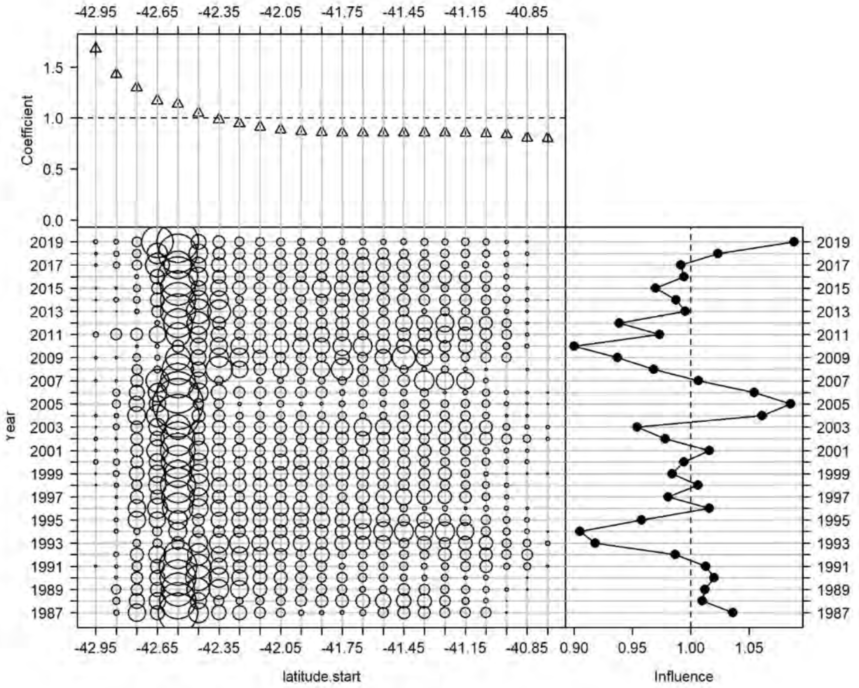

Figure 48: Latitude influence plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates. Top panel, the coefficient estimates for latitude; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

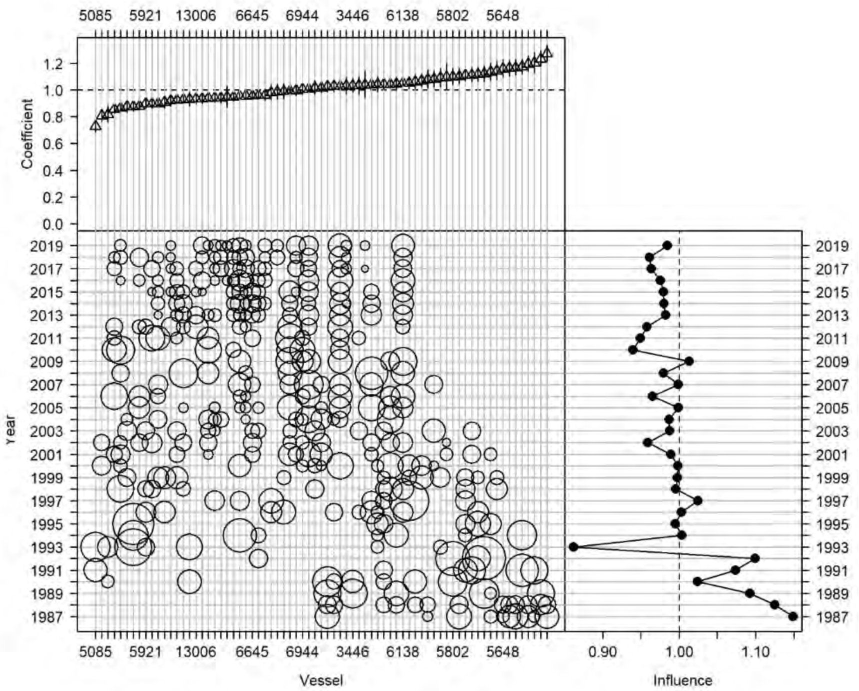

Figure 49: Vessel influence plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

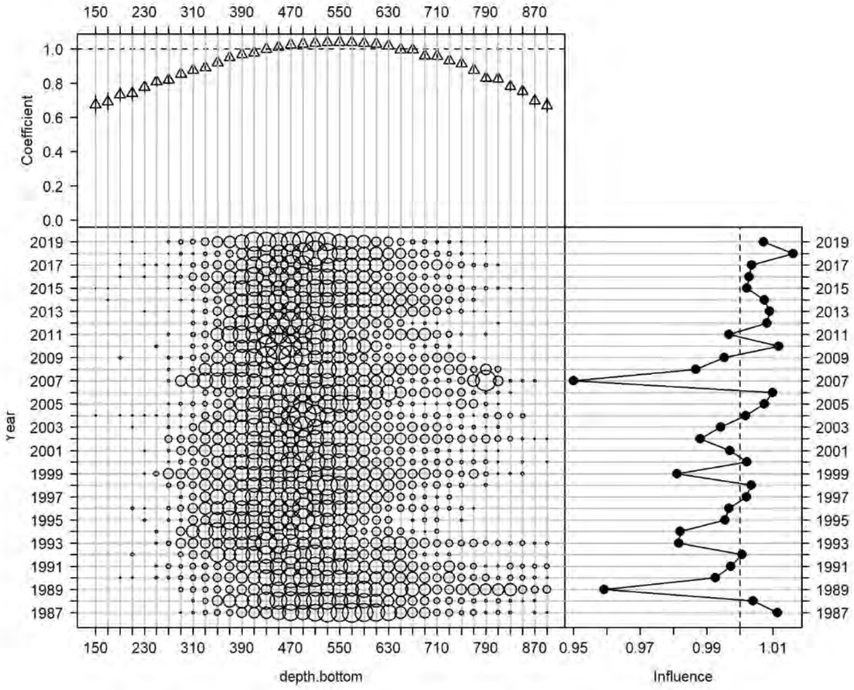

Figure 50: Bottom depth influence plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates. Top panel, the coefficient estimates for bottom depth; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

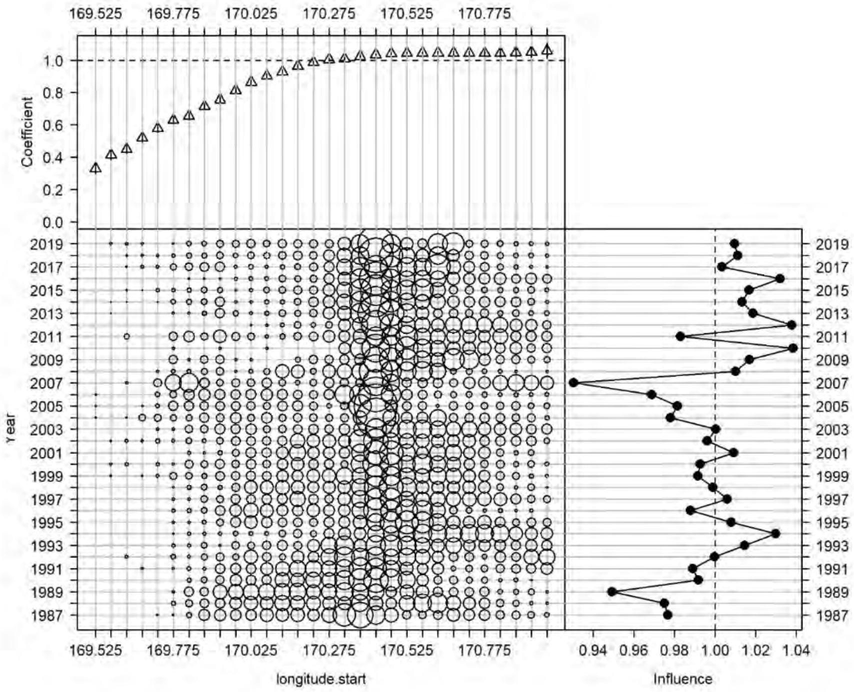

Figure 51: Longitude influence plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates. Top panel, the coefficient estimates for longitude; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

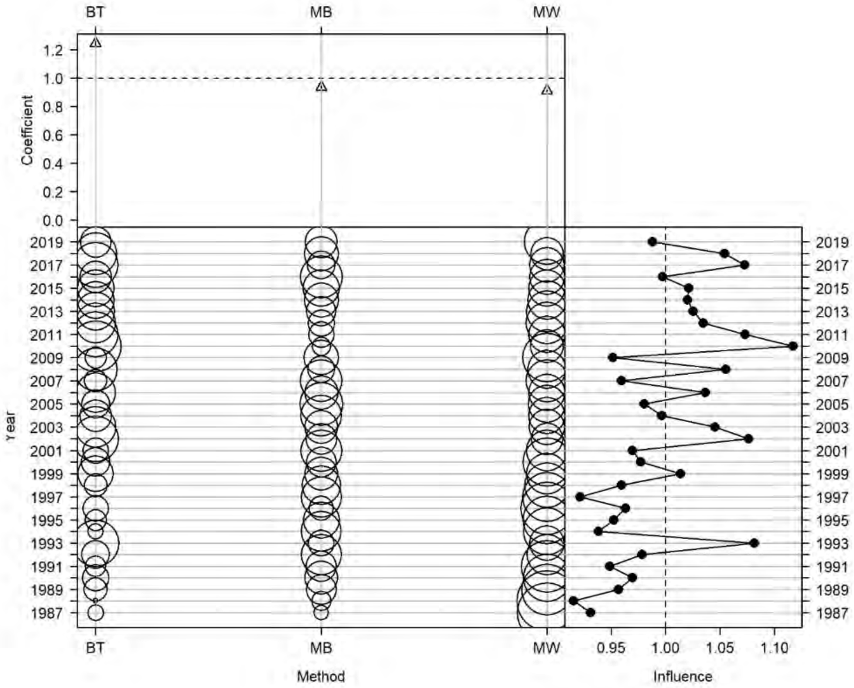

Figure 52: Gear method influence plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates. Top panel, the coefficient estimates for each gear method; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

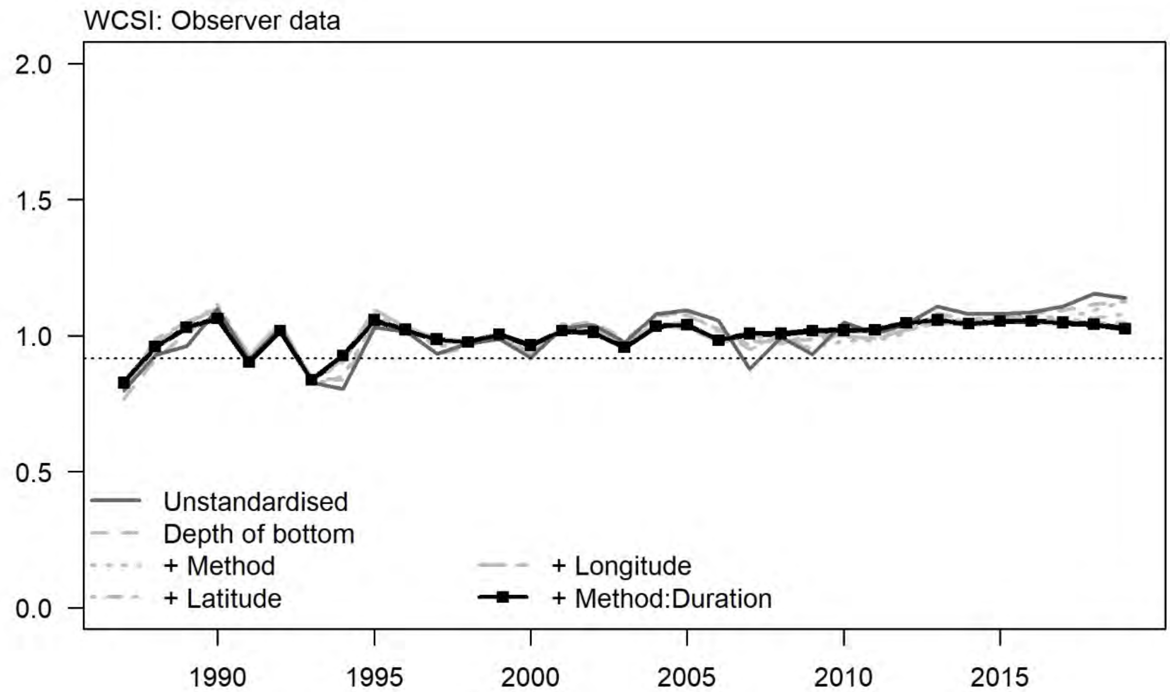

Figure 53: Step plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates. Plot shows the year effect for the unstandardised model, and after successive model predictors are added.

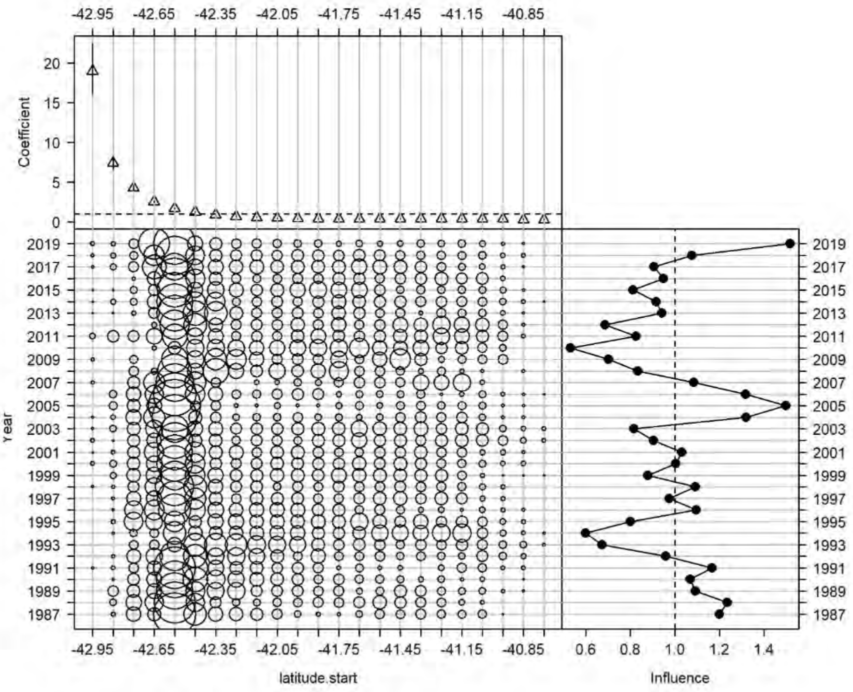

Figure 54: Latitude influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates. Top panel, the coefficient estimates for latitude; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

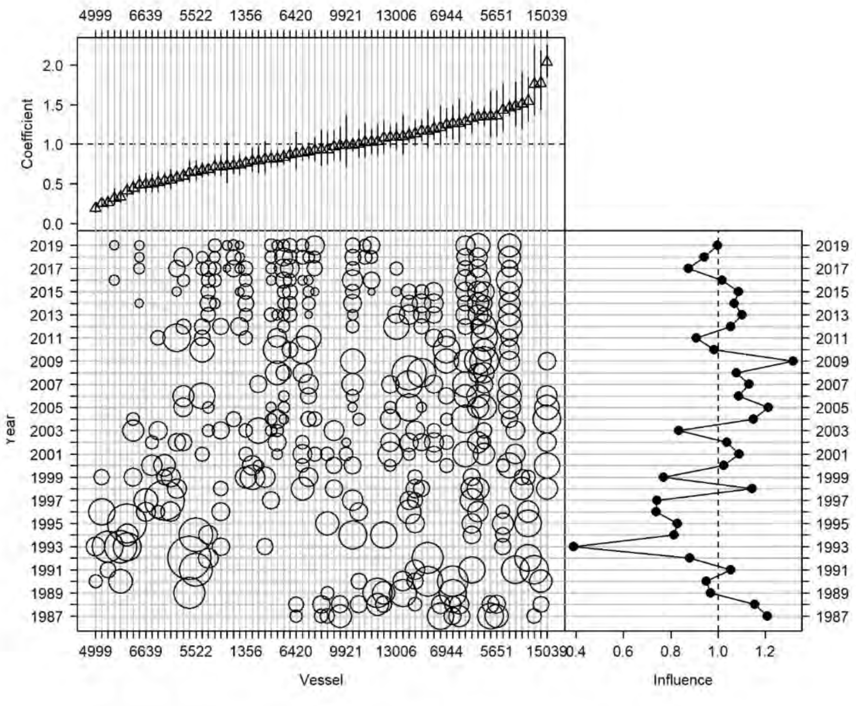

Figure 55: Vessel influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

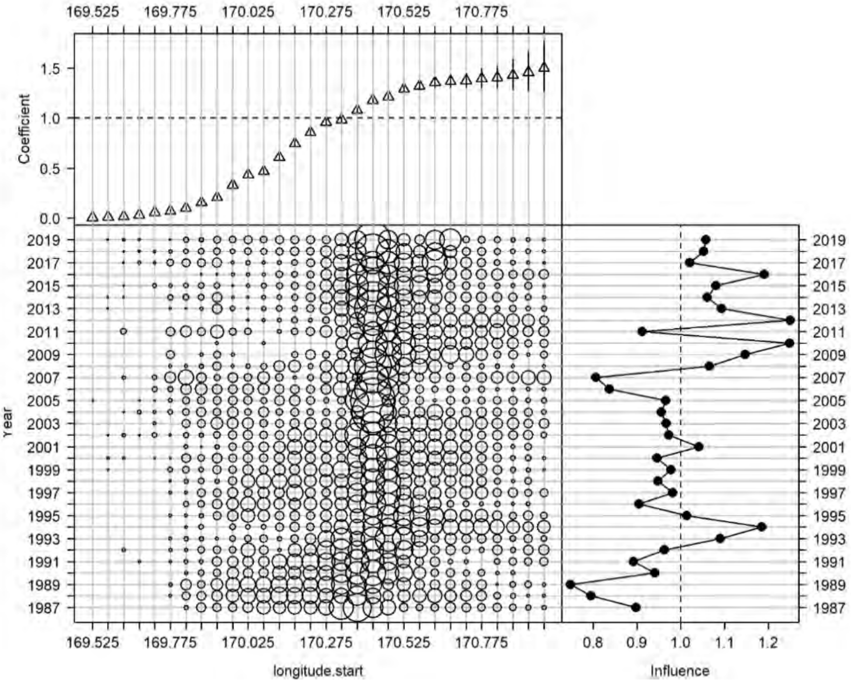

Figure 56: Longitude influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates. Top panel, the coefficient estimates for longitude; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

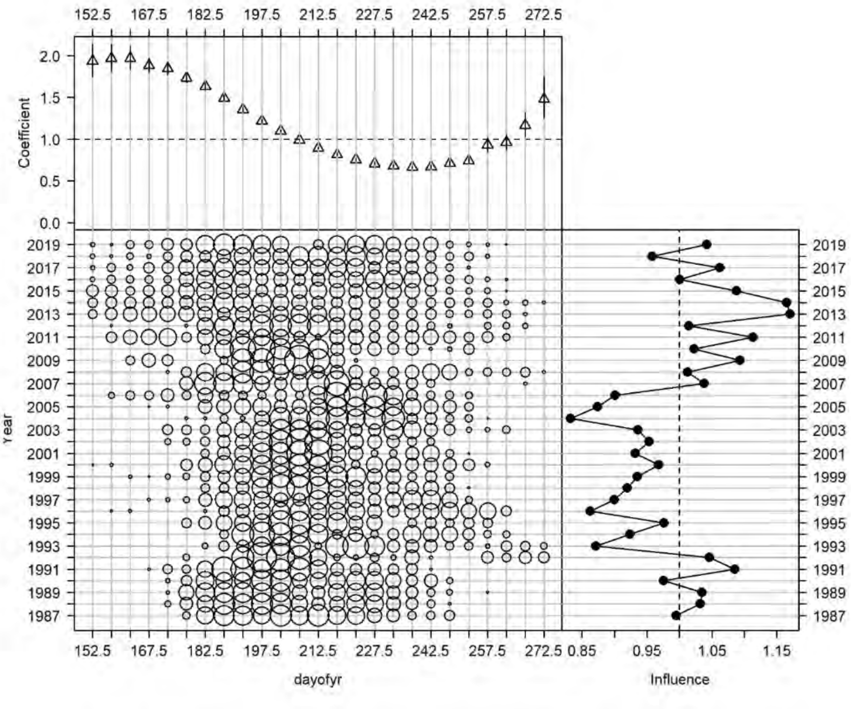

Figure 57: Day of year influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates. Top panel, the coefficient estimates for day of the year; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

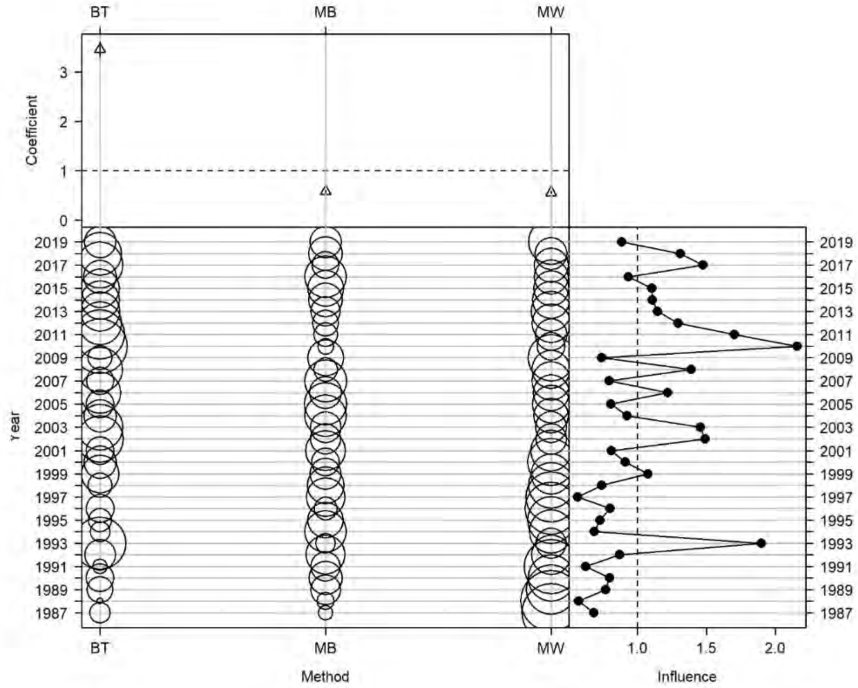

Figure 58: Gear method influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates. Top panel, the coefficient estimates for each gear method; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

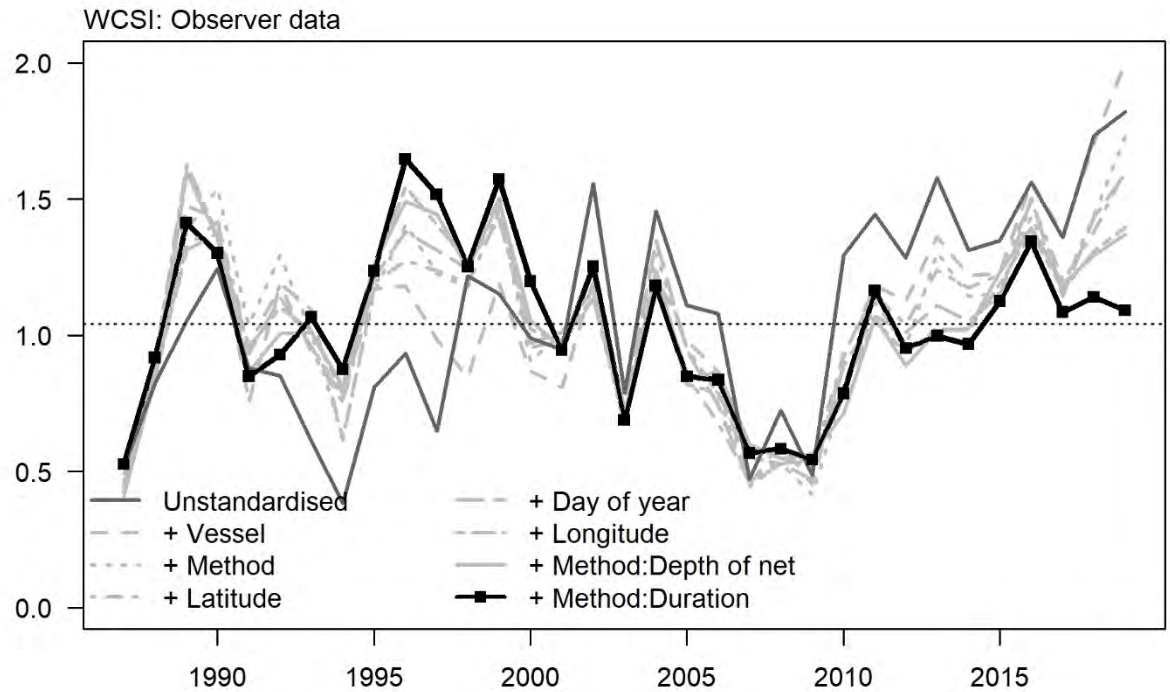

Figure 59: Step plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates. Plot shows the year effect for the unstandardised model, and after successive model predictors are added.

Table 20: CPUE standardised year indices and estimated coefficient of variation (CV) for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates. Fishing year labelled as year-ending.

	Lognormal		Binomial		Combined	
Fishing year	Index	CV	Index	CV	Index	CV
1987	0.53	0.07	0.55	0.0012	0.3	0.07
1988	0.92	0.06	0.77	0.0006	0.73	0.06
1989	1.41	0.07	0.91	0.0004	1.33	0.07
1990	1.03	0.06	0.98	0.0002	1.3	0.06
1991	0.85	0.07	0.76	0.0007	0.67	0.07
1992	0.93	0.08	0.84	0.0007	0.8	0.08
1993	1.07	0.08	0.90	0.0004	0.98	0.08
1994	0.87	0.06	0.91	0.0003	0.81	0.06
1995	1.24	0.07	0.98	0.0002	1.25	0.07
1996	1.65	0.05	0.94	0.0002	1.59	0.05
1997	1.52	0.06	0.92	0.0003	1.44	0.06
1998	1.25	0.05	0.93	0.0003	1.19	0.05
1999	1.57	0.04	0.93	0.0003	1.5	0.04
2000	1.20	0.04	0.91	0.0003	1.12	0.04
2001	0.94	0.04	0.95	0.0002	0.92	0.04
2002	1.25	0.04	0.96	0.0002	1.23	0.04
2003	0.69	0.05	0.90	0.0003	0.64	0.05
2004	1.18	0.04	0.96	0.0002	1.17	0.04
2005	0.85	0.04	0.96	0.0002	0.84	0.04
2006	0.84	0.04	0.92	0.0003	0.8	0.04
2007	0.57	0.06	0.96	0.0002	0.56	0.06
2008	0.58	0.06	0.93	0.0003	0.56	0.06
2009	0.54	0.06	0.94	0.0002	0.52	0.06
2010	0.79	0.06	0.97	0.0002	0.79	0.06
2011	1.16	0.05	0.96	0.0002	1.14	0.05
2012	0.95	0.04	0.98	0.0002	0.96	0.04
2013	1.00	0.03	0.99	0.0001	1.01	0.03
2014	0.97	0.03	0.97	0.0002	0.97	0.03
2015	1.12	0.03	0.98	0.0001	1.13	0.03
2016	1.34	0.03	0.99	0.0001	1.36	0.03
2107	1.09	0.03	0.98	0.0002	1.1	0.03
2018	1.14	0.03	1.00	0.0001	1.17	0.03
2019	1.09	0.03	0.98	0.0002	1.1	0.03

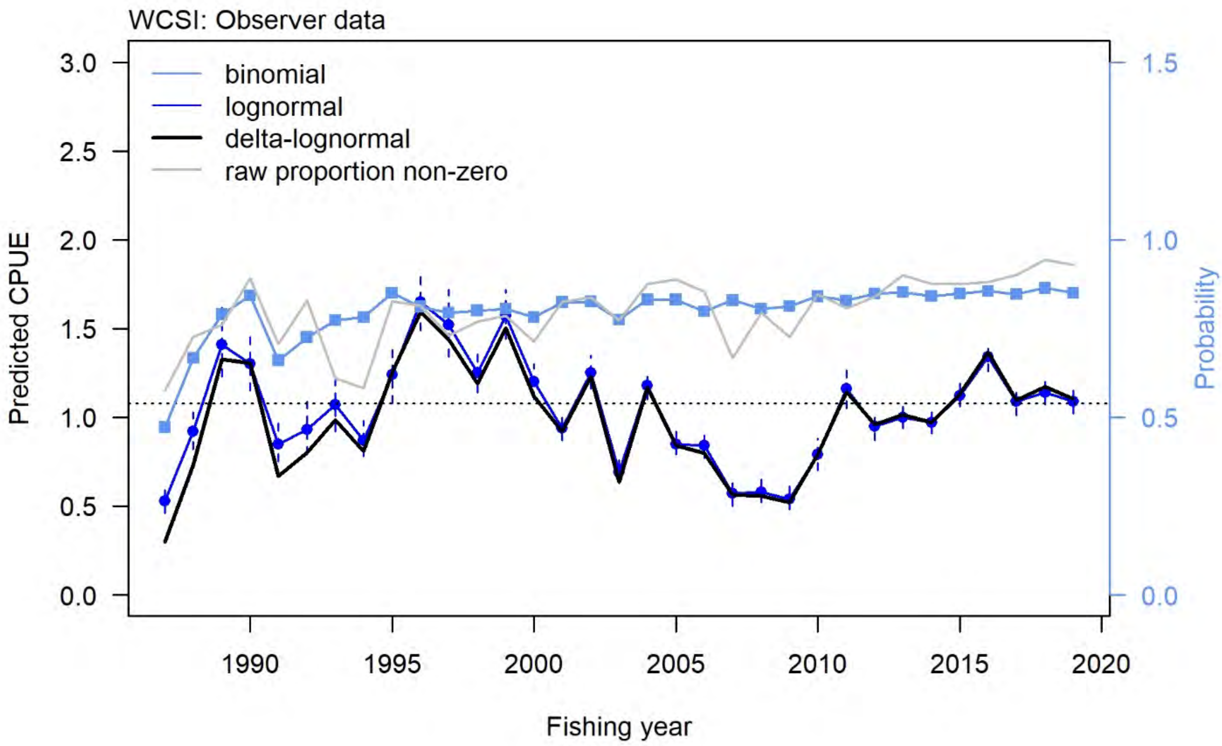

Figure 60: Comparison of the binomial, lognormal and combined CPUE indices for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates and the raw proportion of non-zero tows. Bars indicate 95% confidence intervals.

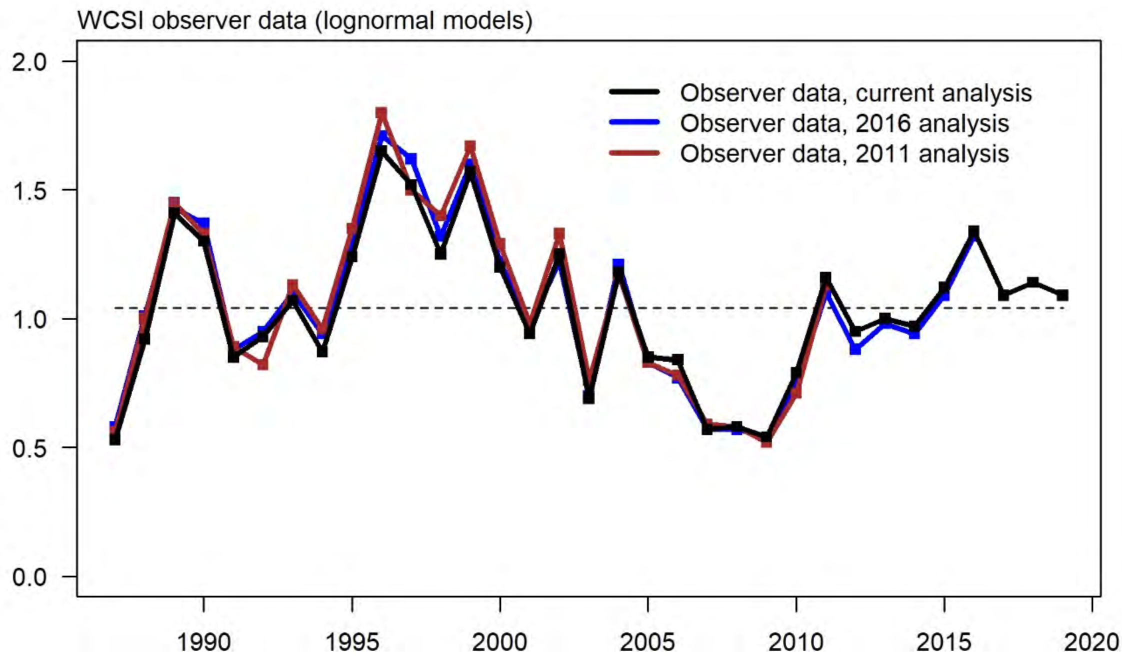

Figure 61: Comparison of the lognormal CPUE index for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates and the CPUE indices produced in 2016 (Dunn & Ballara 2019) and 2011 (Ballara & Horn 2015).

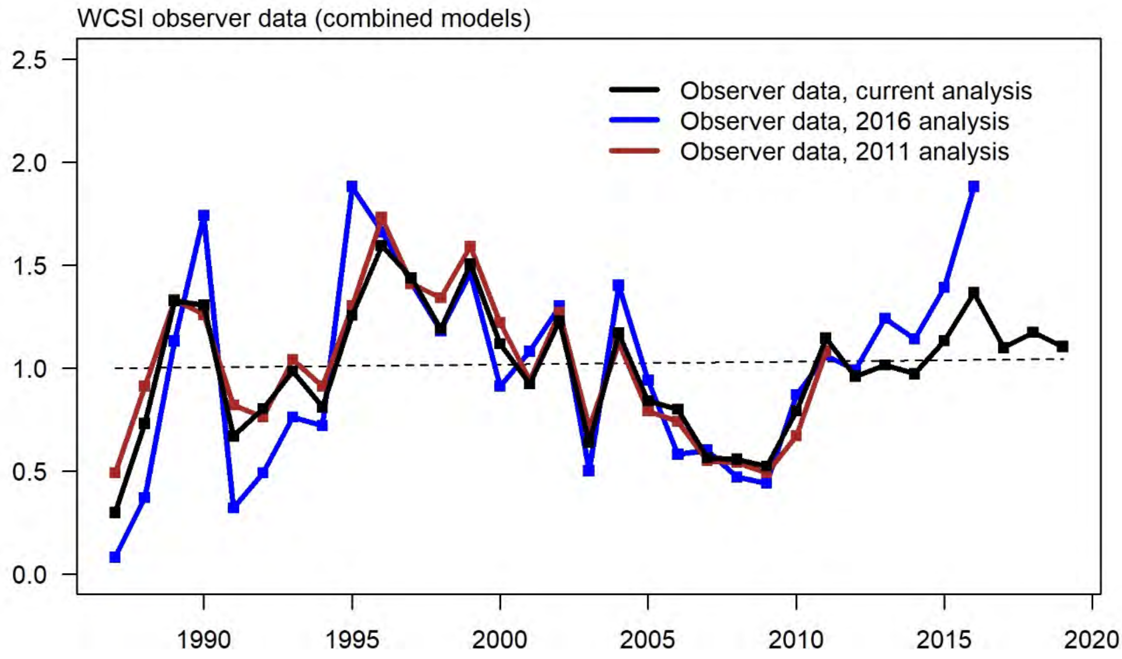

Figure 62: Comparison of the combined CPUE index for the 1987–2019 CPUE for observed tow-by-tow data with latitude and longitude offered as spatial covariates and the CPUE indices produced in 2016 (Dunn & Ballara 2019) and 2011 (Ballara & Horn 2015).

Model C: 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate

Table 21: Predictor and percentage of deviance explained for the final binomial model fit for 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate. Df, degrees of freedom; R^2, R squared.

Step	Df	R^2
Year	32	6.39
Bottom depth	3	11.63
Vessel	72	14.79
Method	2	18.05
Day of year	3	19.32
Method:Duration	12	20.96

Table 22: Predictor and percentage of deviance explained for the final lognormal model fit for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate. Df, degrees of freedom; R^2, R squared.

Step	Df	R^2
Year	32	5.72
Vessel	72	10.96
Method	2	17.82
Bottom depth	3	21.42
Day of year	3	24.99
Statarea	1	26.24
Method:Duration	12	27.90

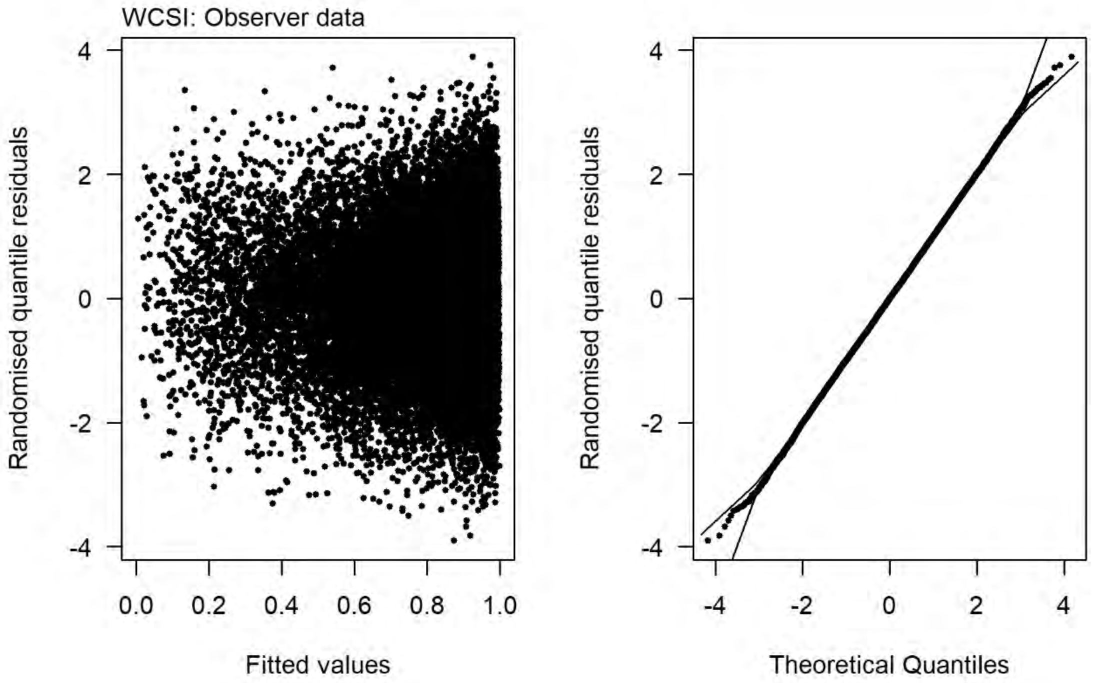

Figure 63: Residuals (left panel) and normal quantile plot (right panel) for the binomial model fit for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate.

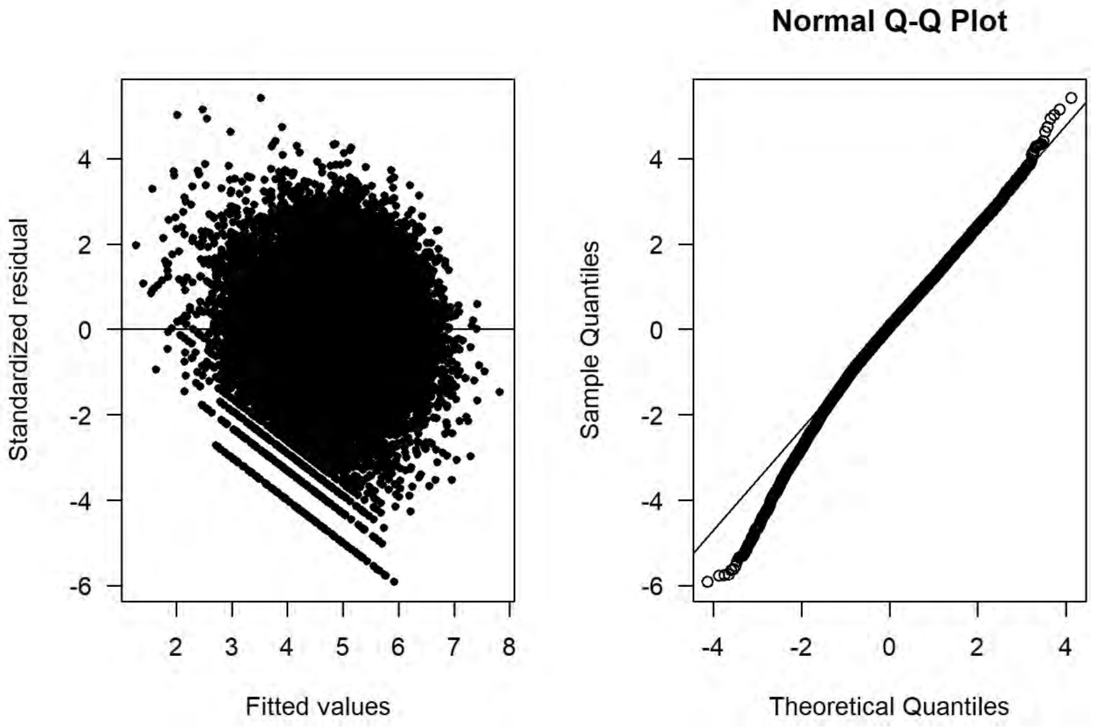

Figure 64: Residuals (left panel) and normal quantile plot (right panel) for the lognormal model fit for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate.

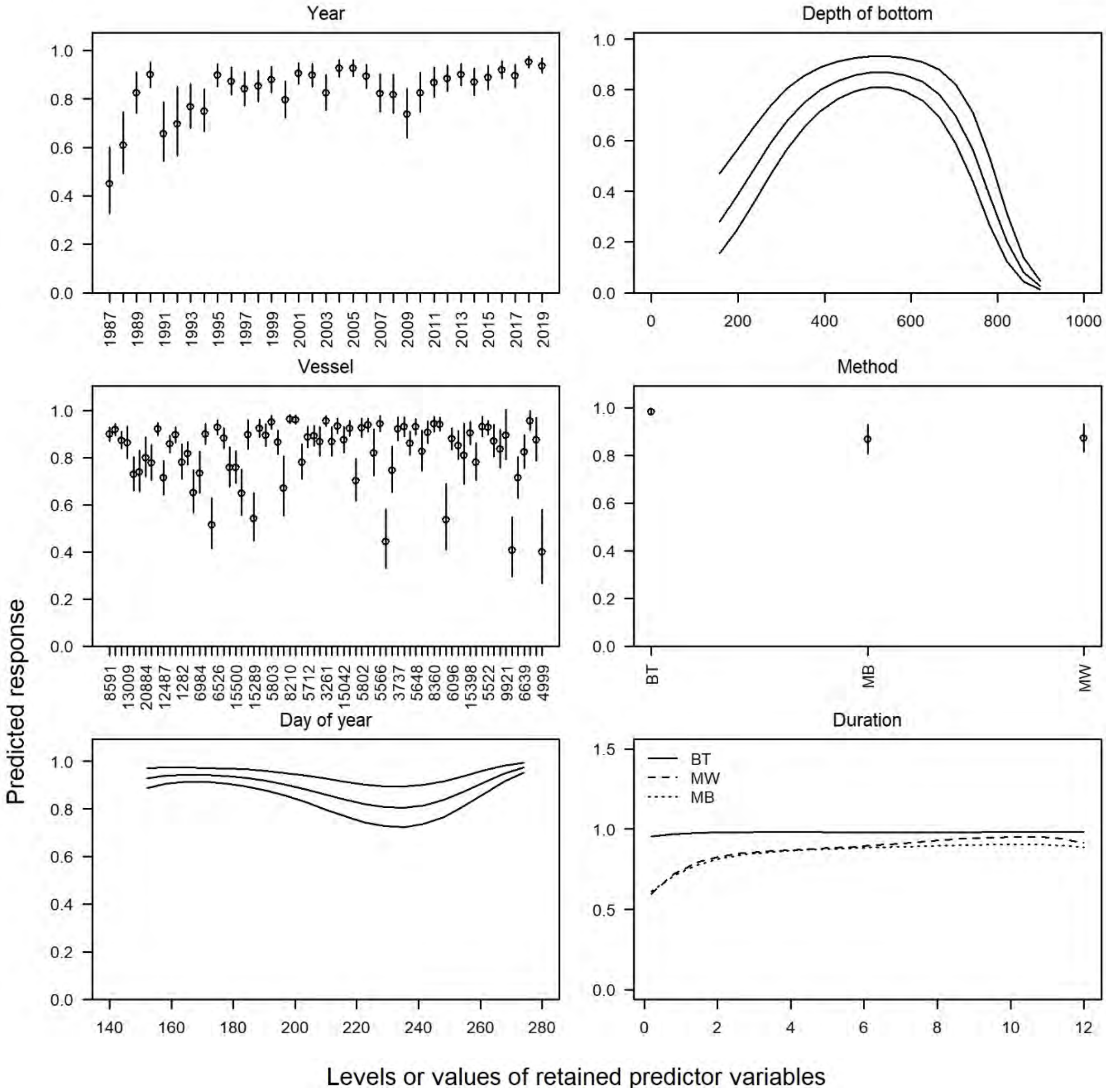

Figure 65: Model predictions for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate, by fishing year (labelled as year ending, i.e., 1991 means 1990–91) vessel, month, and fishing depth, for the binomial model made with all other predictors set to the median (fixed) values. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

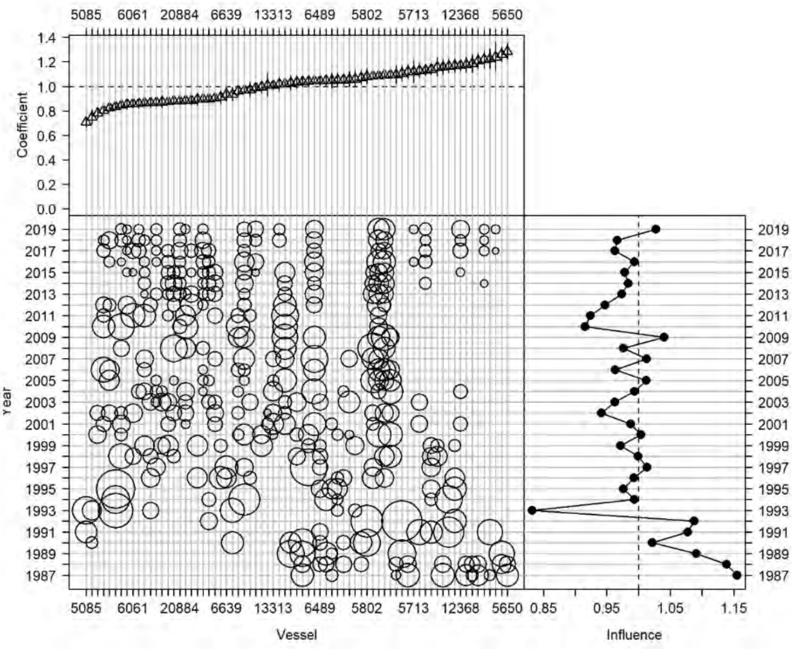

Figure 66: Vessel influence plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

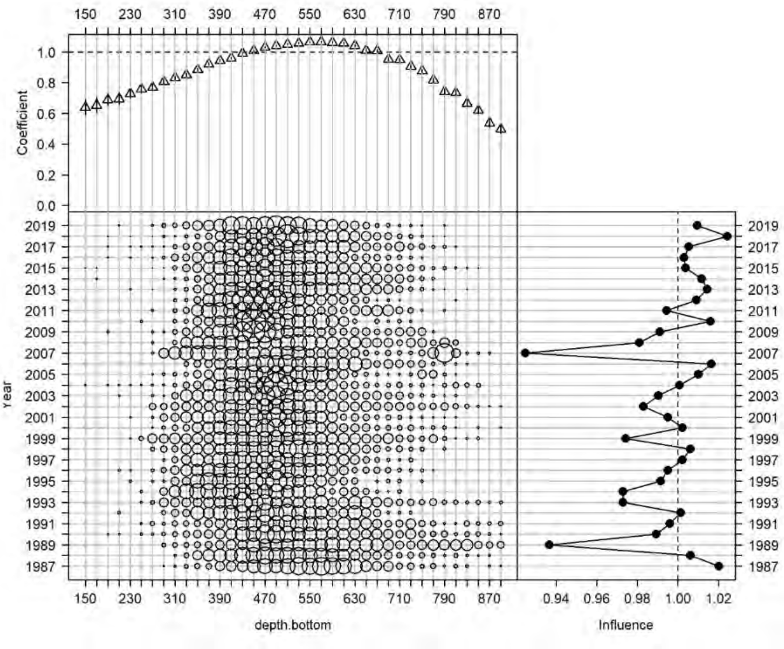

Figure 67: Bottom depth influence plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate. Top panel, the coefficient estimates for bottom depth; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

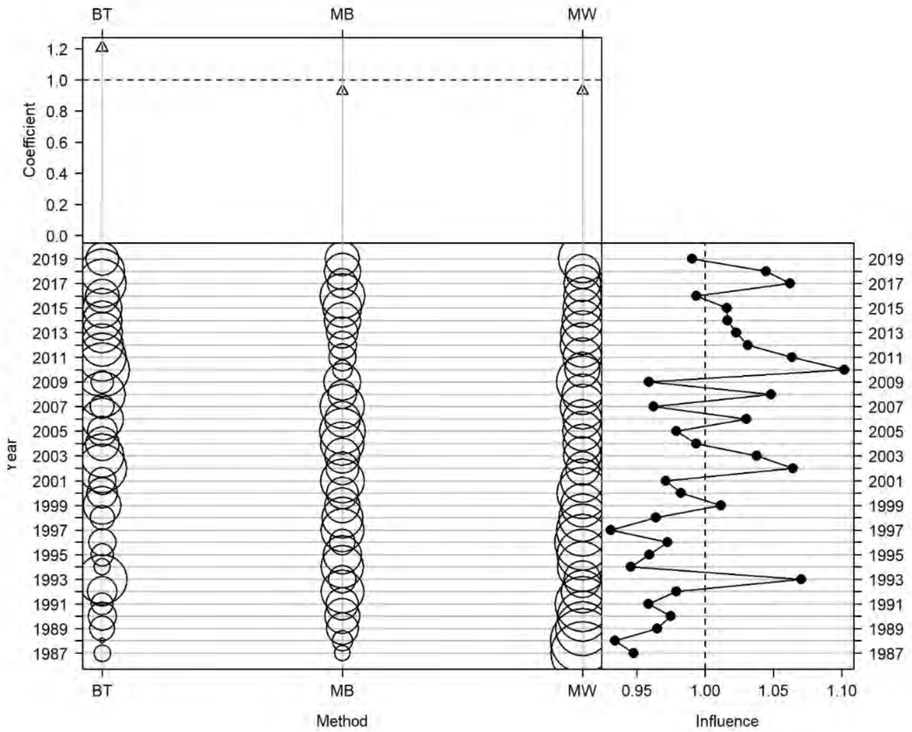

Figure 68: Gear method influence plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate. Top panel, the coefficient estimates for each gear method; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

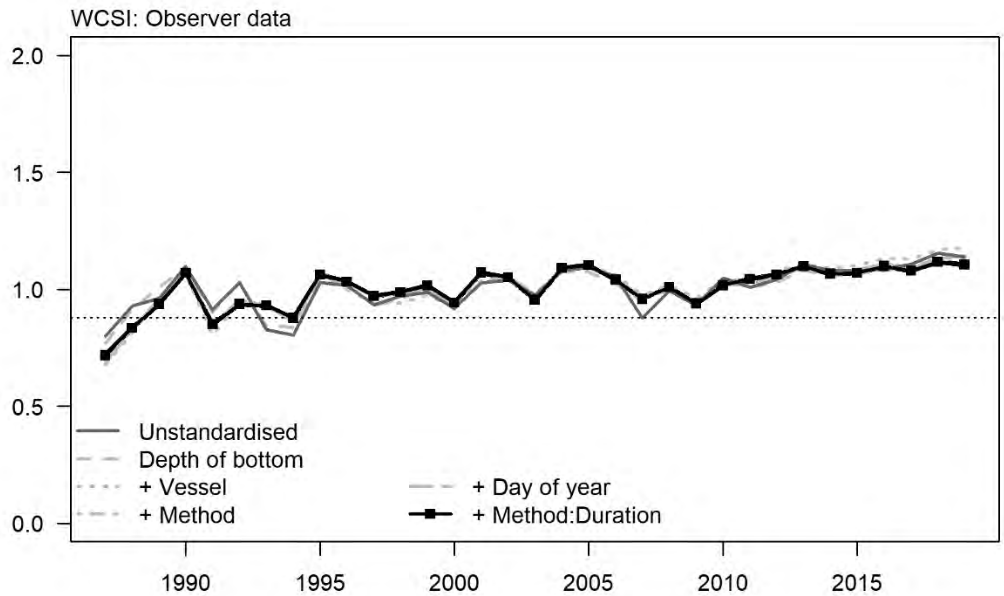

Figure 69: Step plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate. Plot shows the year effect for the unstandardised model, and after successive model predictors are added.

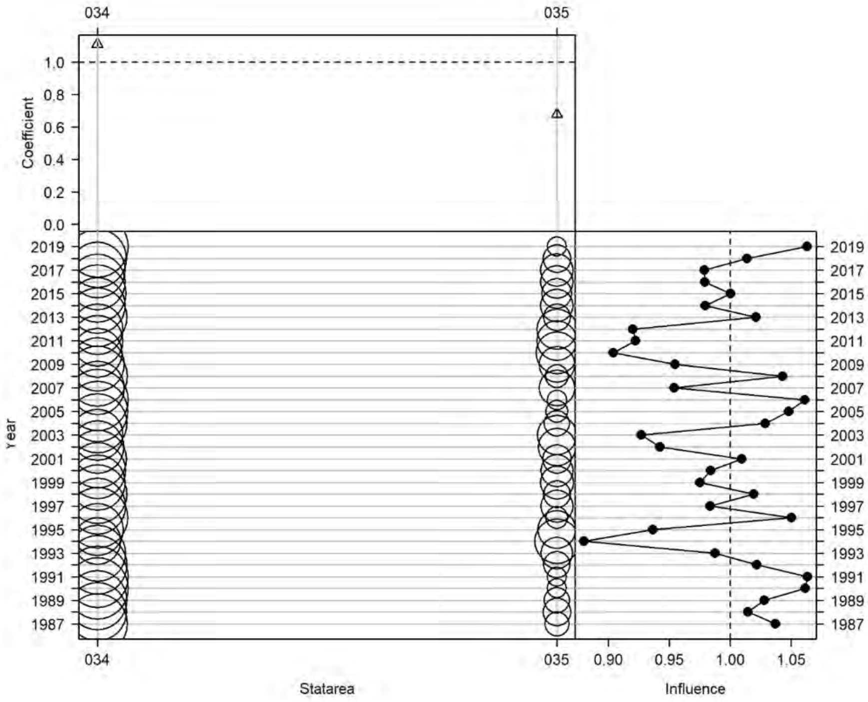

Figure 70: Statistical area influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate. Top panel, the coefficient estimates for statistical area; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

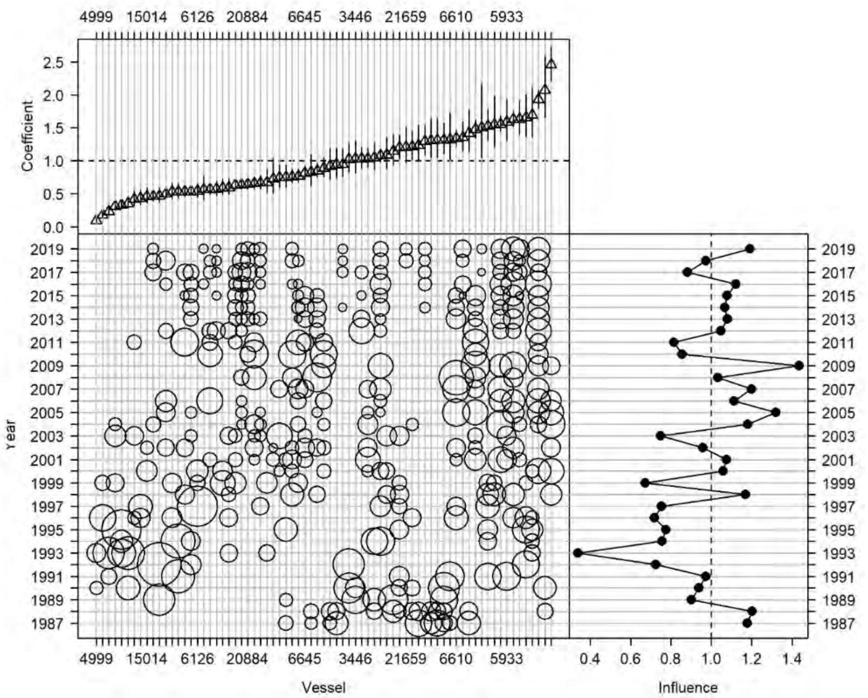

Figure 71: Vessel influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

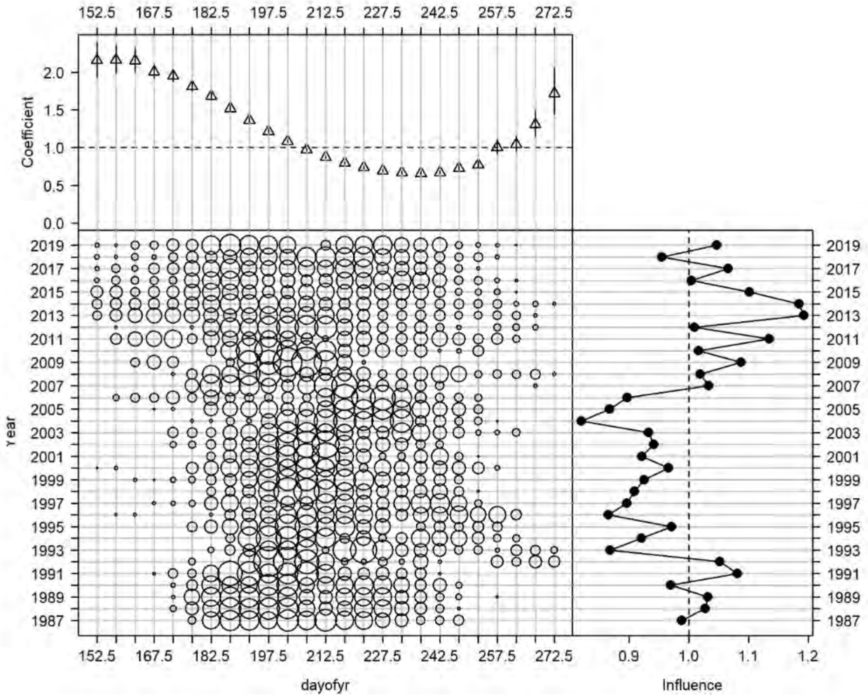

Figure 72: Day of year influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate. Top panel, the coefficient estimates for day of year; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

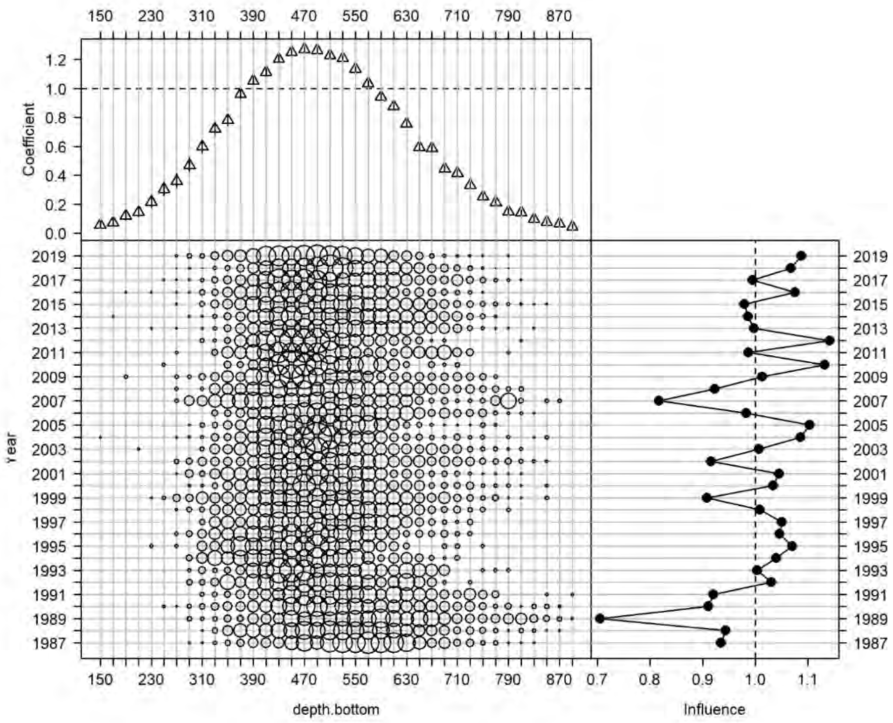

Figure 73: Bottom depth influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate. Top panel, the coefficient estimates for bottom depth; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

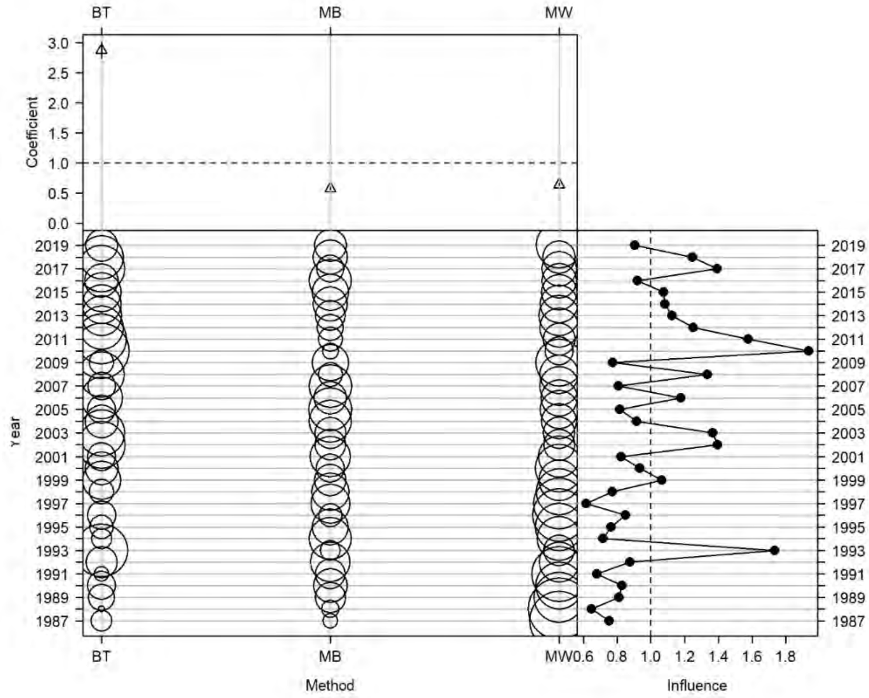

Figure 74: Gear method influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate. Top panel, the coefficient estimates for each gear method; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

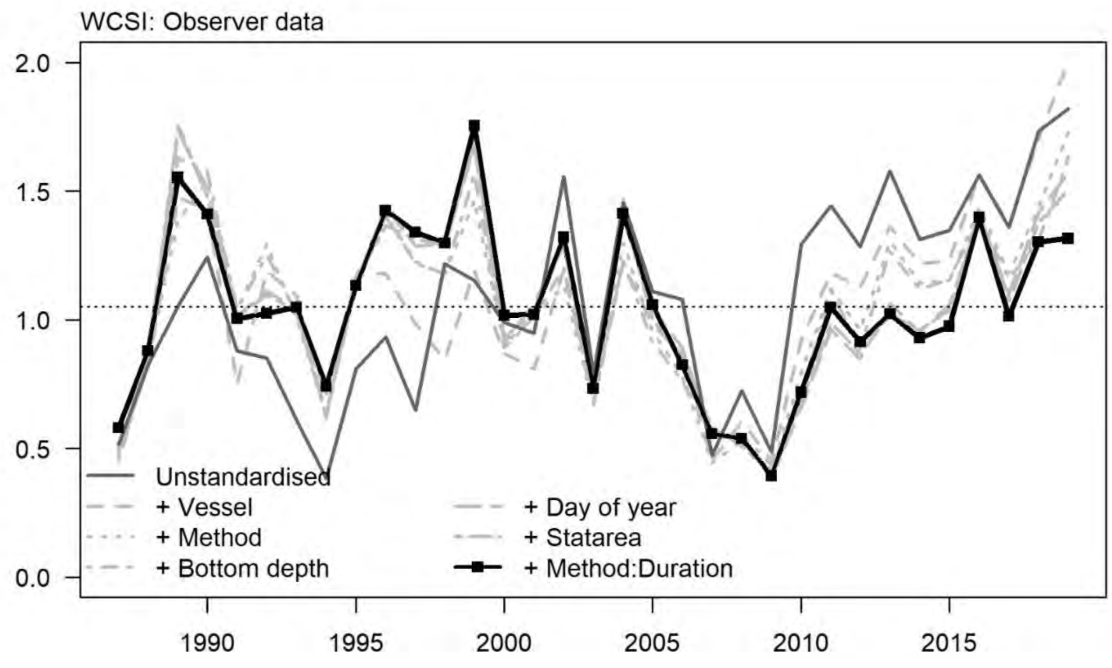

Figure 75: Step plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate. Plot shows the year effect for the unstandardised model, and after successive model predictors are added.

Table 23: CPUE standardised year indices and estimated coefficient of variation (CV) for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate. Fishing year labelled as year-ending.

		Lognormal		Binomial		Combined
Fishing year	Index	CV	Index	CV	Index	CV
1987	0.58	0.07	0.45	0	0.28	0.07
1988	0.88	0.06	0.62	0	0.59	0.06
1989	1.55	0.07	0.85	0	1.43	0.07
1990	1.41	0.06	0.94	0	1.43	0.06
1991	1.01	0.07	0.67	0	0.73	0.07
1992	1.03	0.08	0.71	0	0.79	0.08
1993	1.05	0.08	0.79	0	0.9	0.08
1994	0.74	0.06	0.77	0	0.62	0.06
1995	1.13	0.07	0.94	0	1.14	0.07
1996	1.42	0.05	0.91	0	1.39	0.05
1997	1.34	0.06	0.87	0	1.26	0.06
1998	1.3	0.05	0.89	0	1.24	0.05
1999	1.75	0.04	0.92	0	1.73	0.04
2000	1.02	0.04	0.82	0	0.91	0.04
2001	1.02	0.04	0.95	0	1.04	0.04
2002	1.32	0.04	0.94	0	1.33	0.04
2003	0.73	0.05	0.86	0	0.67	0.05
2004	1.41	0.04	0.97	0	1.47	0.04
2005	1.06	0.04	0.97	0	1.11	0.04
2006	0.83	0.04	0.93	0	0.83	0.04
2007	0.56	0.06	0.85	0	0.51	0.06
2008	0.54	0.06	0.85	0	0.49	0.06
2009	0.39	0.06	0.76	0	0.32	0.06
2010	0.72	0.06	0.86	0	0.66	0.06
2011	1.05	0.05	0.9	0	1.02	0.05
2012	0.91	0.04	0.92	0	0.9	0.04
2013	1.02	0.03	0.94	0	1.03	0.03
2014	0.93	0.03	0.91	0	0.91	0.03
2015	0.97	0.03	0.93	0	0.97	0.03
2016	1.4	0.03	0.96	0	1.45	0.03
2107	1.01	0.03	0.93	0	1.02	0.03
2018	1.3	0.03	1	0	1.4	0.03
2019	1.32	0.03	0.98	0	1.4	0.03

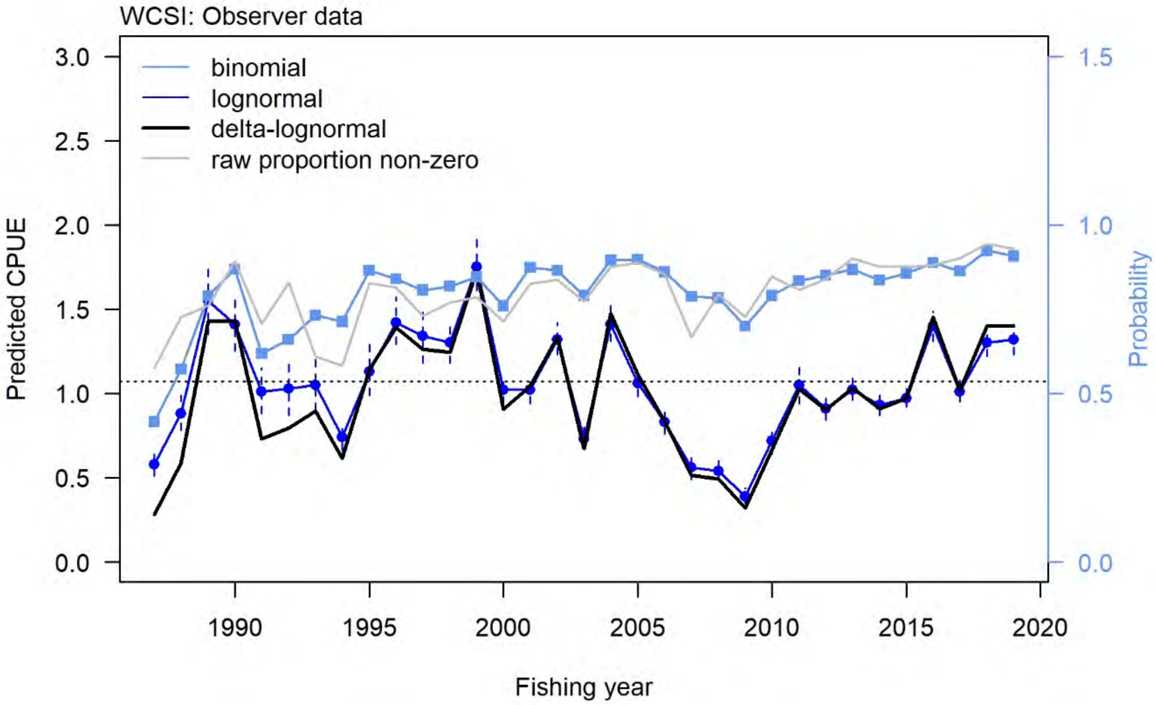

Figure 76: Comparison of the binomial, lognormal and combined CPUE indices for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate and the raw proportion of non-zero tows. Bars indicate 95% confidence intervals.

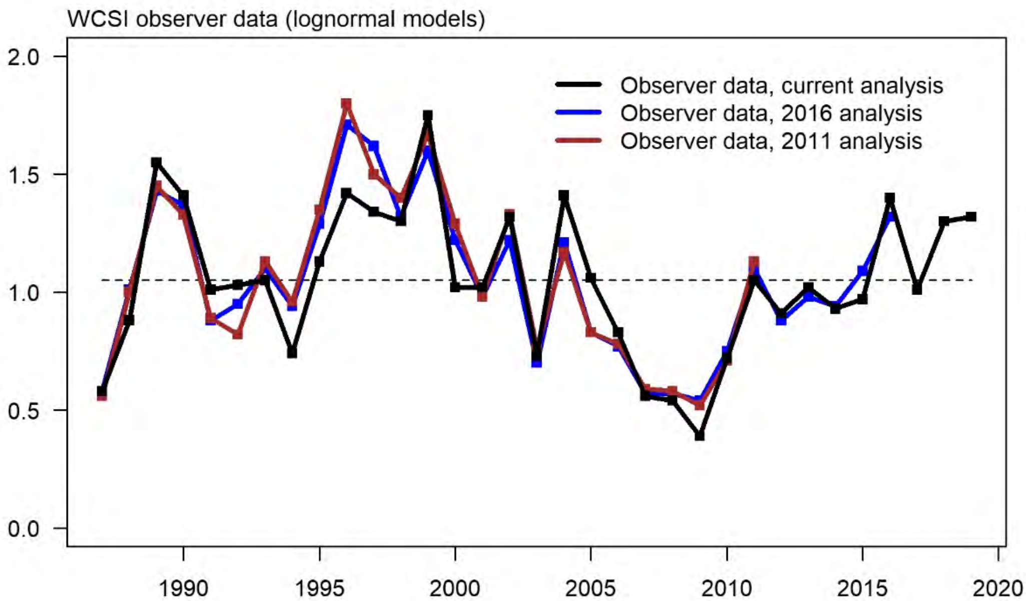

Figure 77: Comparison of the lognormal CPUE index for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate and the CPUE indices produced in 2016 (Dunn & Ballara 2019) and 2011 (Ballara & Horn 2015).

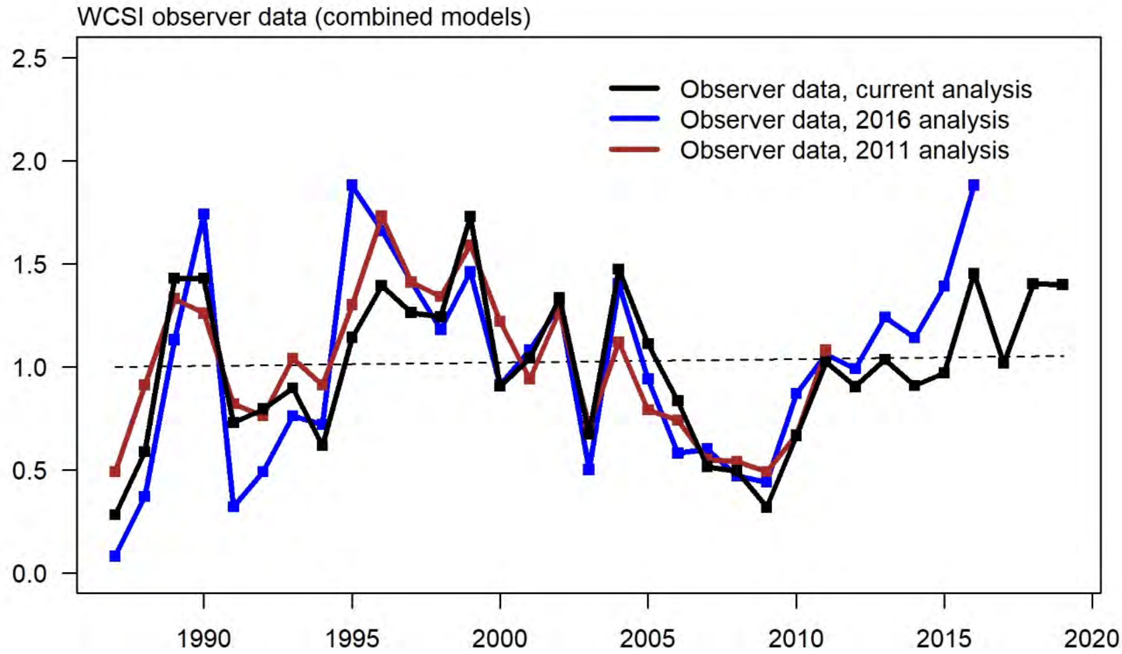

Figure 78: Comparison of the combined CPUE index for the 1987–2019 CPUE for observed tow-by-tow data with statistical area offered as spatial covariate and the CPUE indices produced in 2016 (Dunn & Ballara 2019) and 2011 (Ballara & Horn 2015).

Model D: 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate

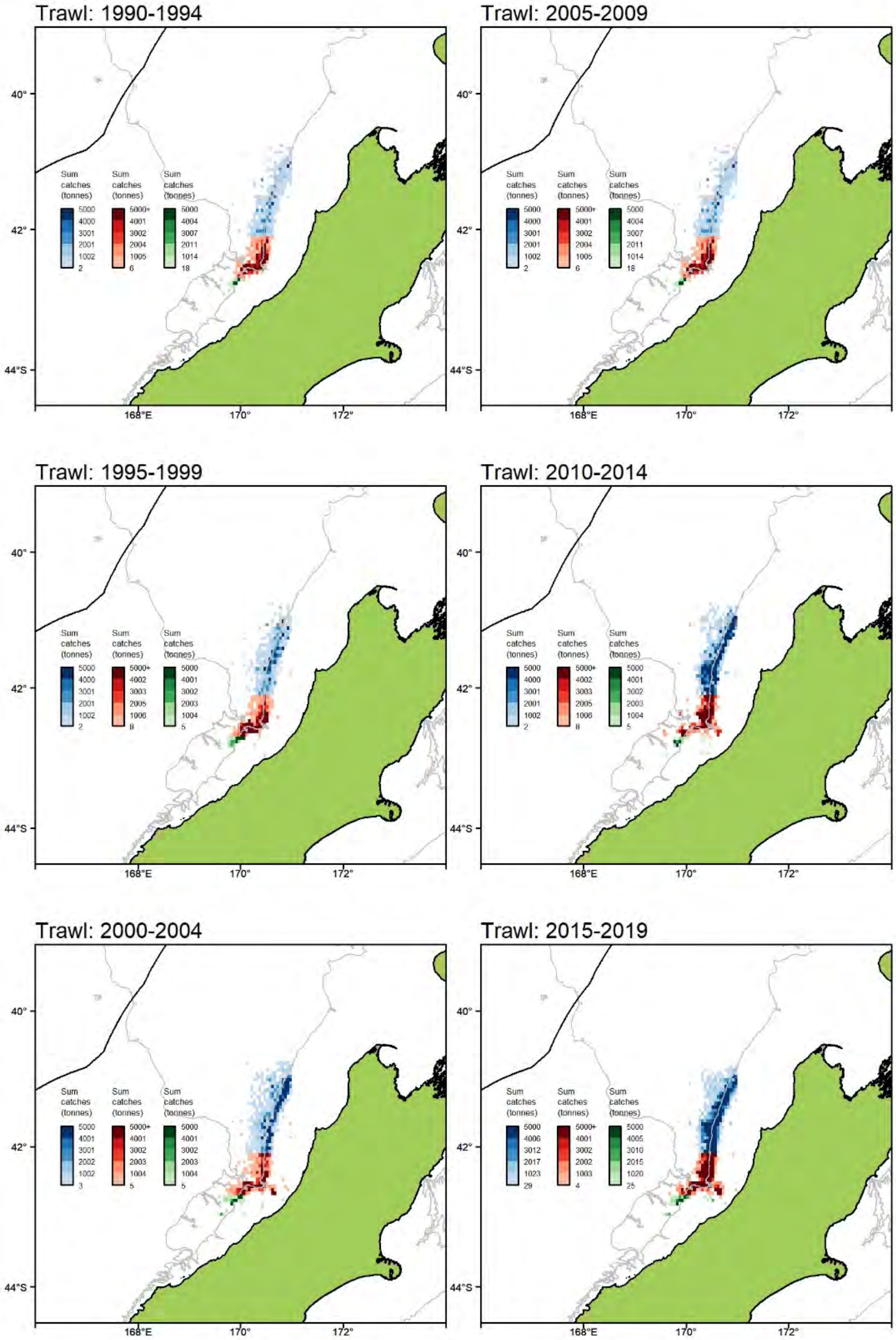

Figure 79: Spatial distribution of observed tow-by-tow trawl catch data in subareas North (blue), South (green), and Canyon (red), where Canyon was defined as being between latitudes -42.1 and -42.7, and between 169.1 and 171 degrees longitude.

Table 24: Proportion of observed tow-by-tow trawl catch data from each subarea: North, South, and Canyon, where Canyon was defined as being between latitudes -42.1 and -42.7, and between 169.1 and 171 degrees longitude.

	Canyon	North	South		Canyon	North	South
1987	82.43	16.05	1.53	2004	68.36	28.25	3.40
1988	92.60	2.61	4.79	2005	64.46	31.72	3.83
1989	82.38	12.30	5.33	2006	69.45	20.77	9.78
1990	86.62	11.40	1.98	2007	71.66	22.90	5.44
1991	90.19	5.69	4.12	2008	68.09	30.80	1.10
1992	70.35	25.63	4.02	2009	66.16	33.08	0.76
1993	70.14	24.71	5.15	2010	31.50	68.50	-
1994	50.65	47.85	1.51	2011	35.73	56.72	7.54
1995	36.55	40.98	22.47	2012	48.91	51.09	-
1996	76.61	11.42	11.97	2013	68.53	31.03	0.43
1997	85.42	7.20	7.38	2014	60.02	36.01	3.97
1998	81.21	15.92	2.87	2015	56.19	43.10	0.71
1999	43.91	51.22	4.87	2016	67.48	32.33	0.19
2000	63.48	33.12	3.40	2017	53.54	44.66	1.79
2001	72.12	24.87	3.01	2018	65.79	31.67	2.54
2002	48.66	48.50	2.85	2019	79.33	18.56	2.10
2003	53.15	39.41	7.44				

Table 25: Predictor and percentage of deviance explained for the final binomial model fit for 1987–2019 CPUE for observed tow-by-tow data with subareas North, South and Canyon offered as spatial covariate. Df, degrees of freedom; R^2, R squared.

Step	Df	R^2
Year	32	6.39
Bottom depth	3	11.63
Method	2	14.03
Area	2	16.65
Day of year	3	17.59
Method:Duration	12	20.03

Table 26: Predictor and percentage of deviance explained for the final lognormal model fit for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South and Canyon offered as spatial covariate. Df, degrees of freedom; R^2, R squared.

Step	Df	R^2
Year	32	5.72
Vessel	72	10.96
Method	2	17.82
Bottom depth	3	21.42
Area	2	25.05
Day of year	3	28.16
Method:Duration	12	30.10

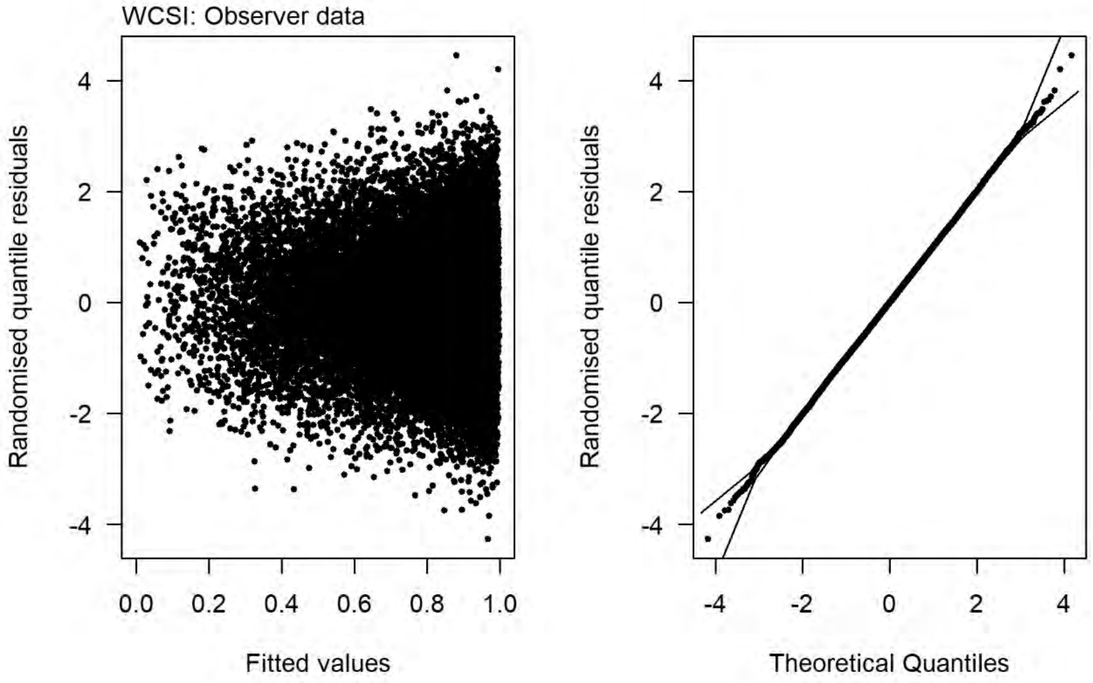

Figure 80: Residuals (left panel) and normal quantile plot (right panel) for the binomial model fit for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate.

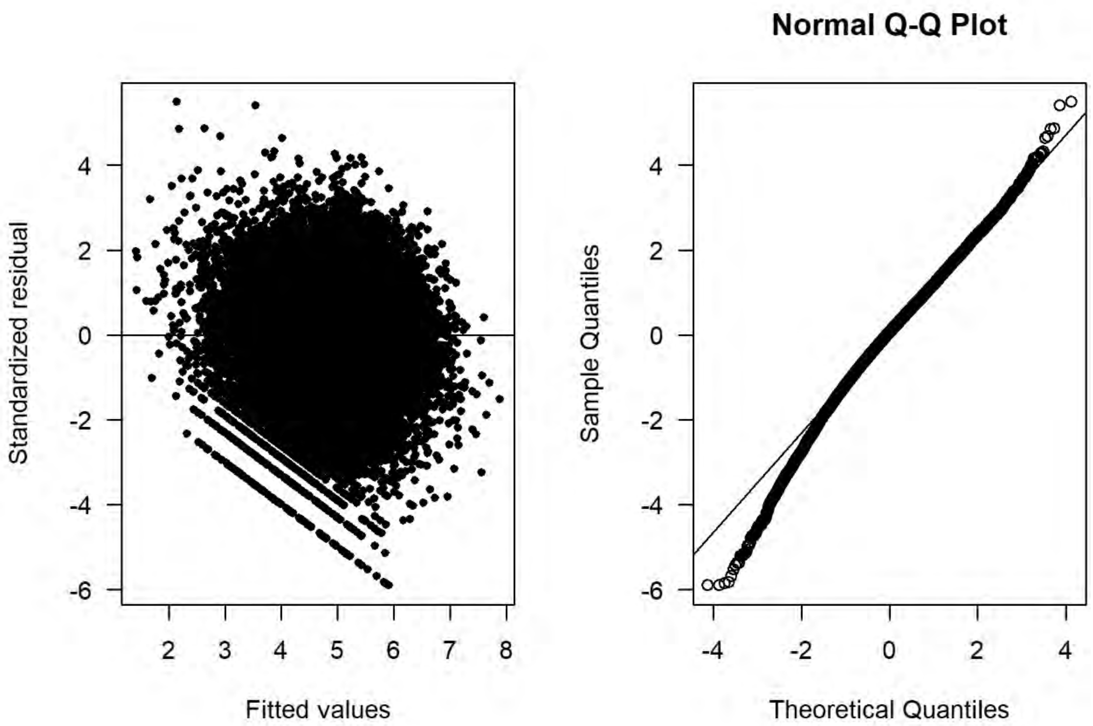

Figure 81: Residuals (left panel) and normal quantile plot (right panel) for the lognormal model fit for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South and Canyon offered as spatial covariate.

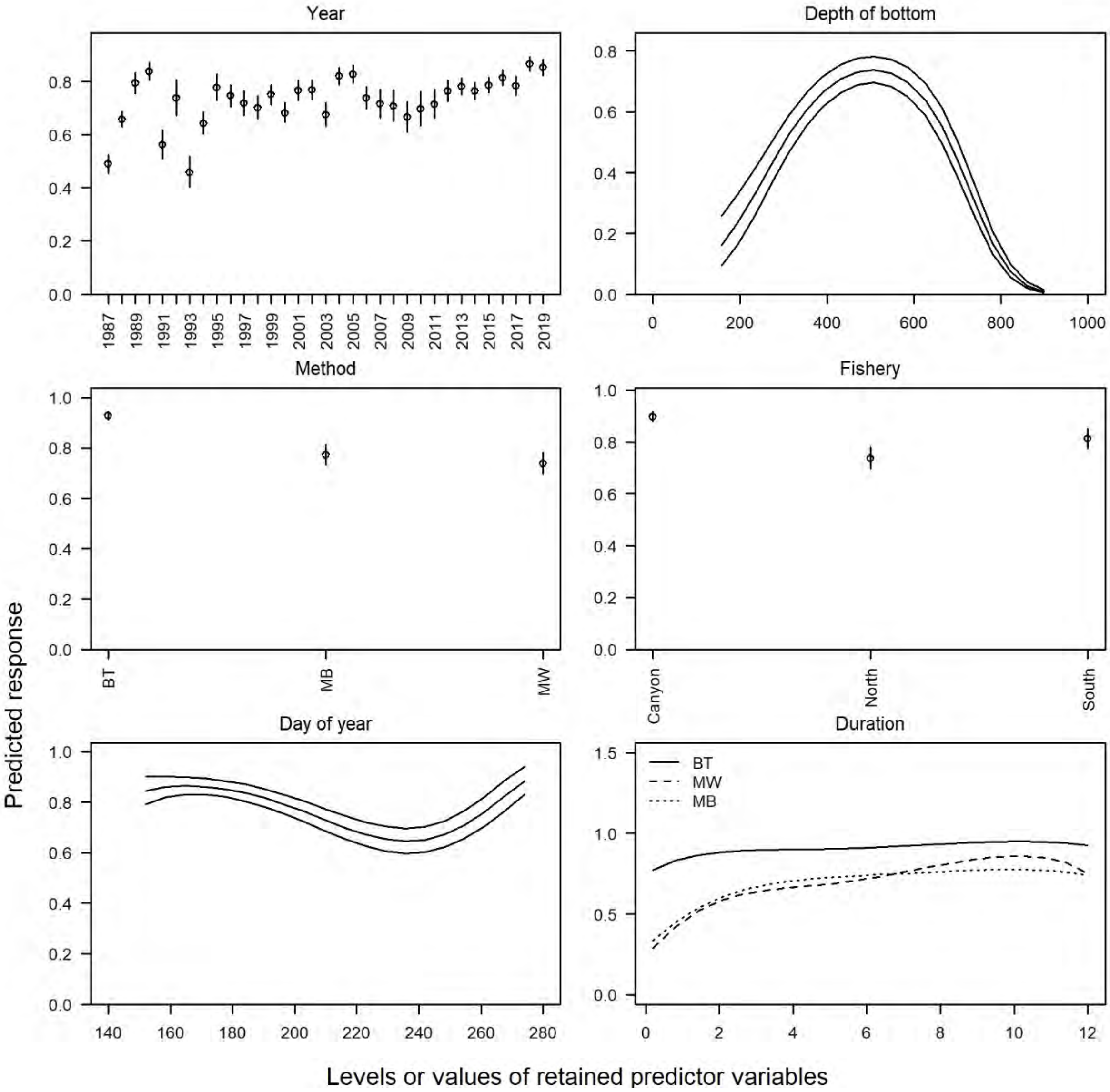

Figure 82: Model predictions for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate, by fishing year (labelled as year ending, i.e., 1991 means 1990–91) vessel, month, and fishing depth, for the binomial model made with all other predictors set to the median (fixed) values. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

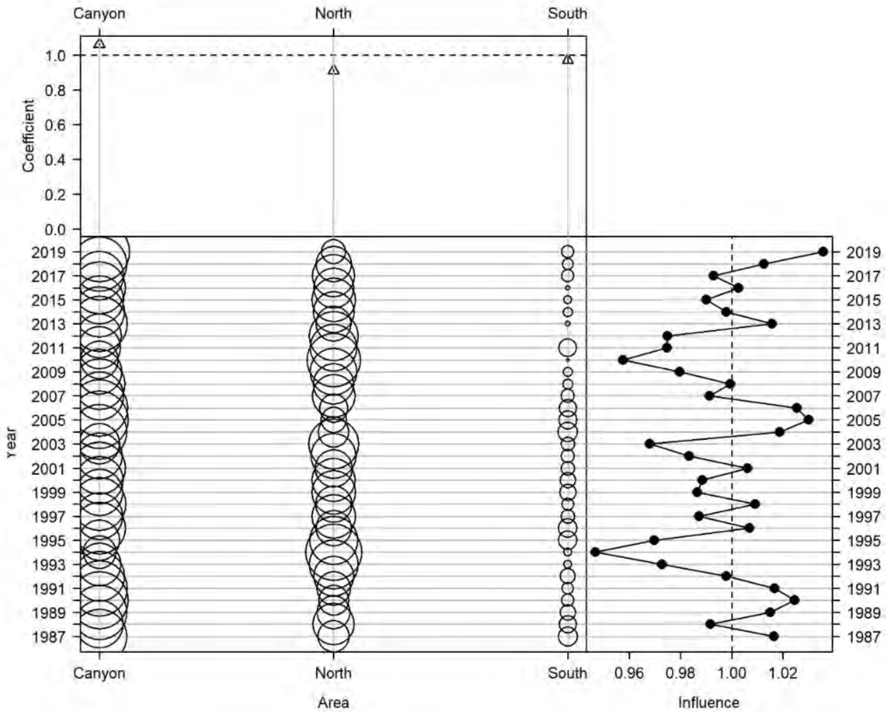

Figure 83: Area influence plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate. Top panel, the coefficient estimates for each area; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

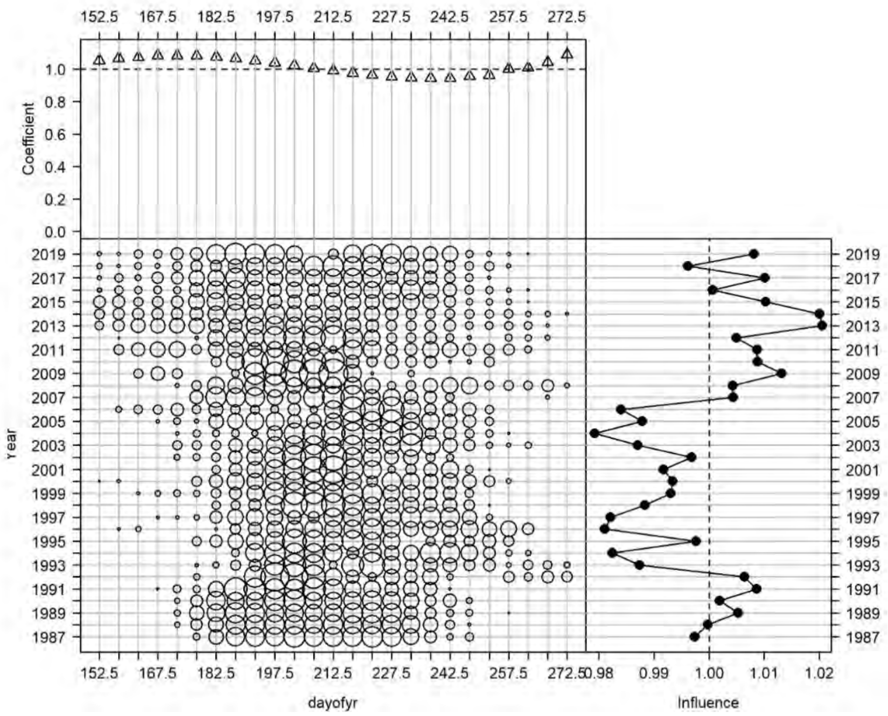

Figure 84: Day of year influence plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate. Top panel, the coefficient estimates for day of year; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

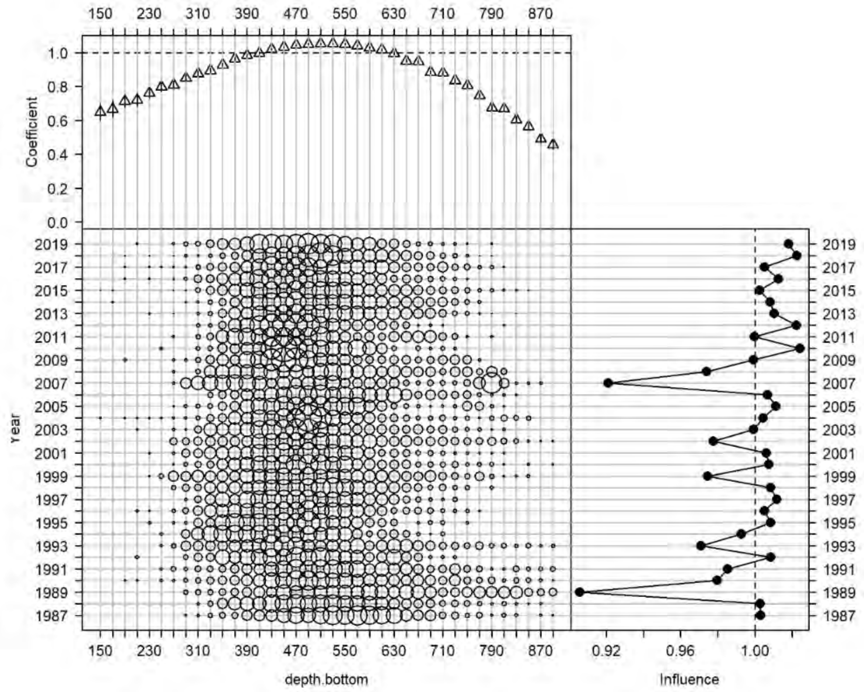

Figure 85: Bottom depth influence plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate. Top panel, the coefficient estimates for bottom depth; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

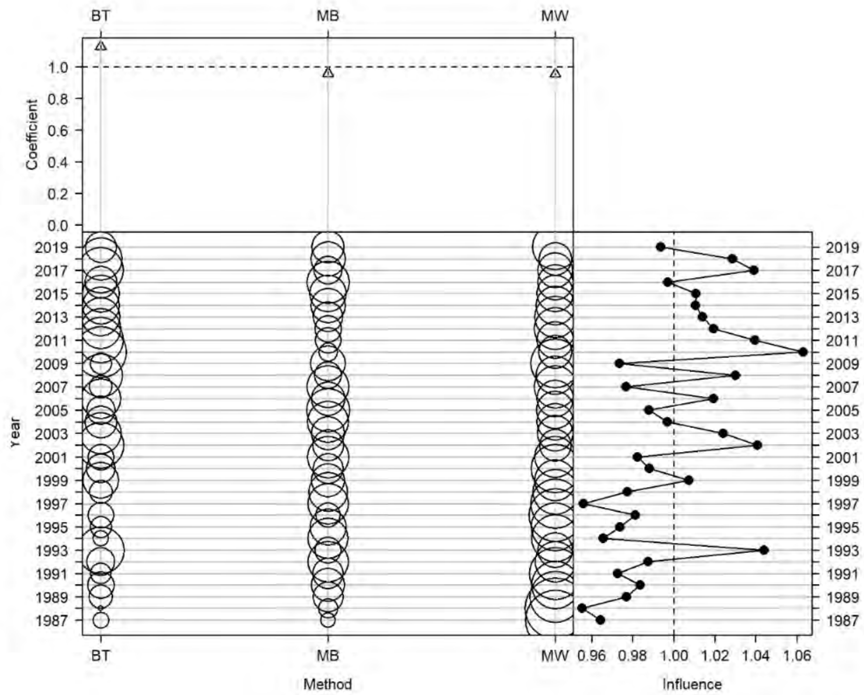

Figure 86: Gear method influence plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate. Top panel, the coefficient estimates for each gear method; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

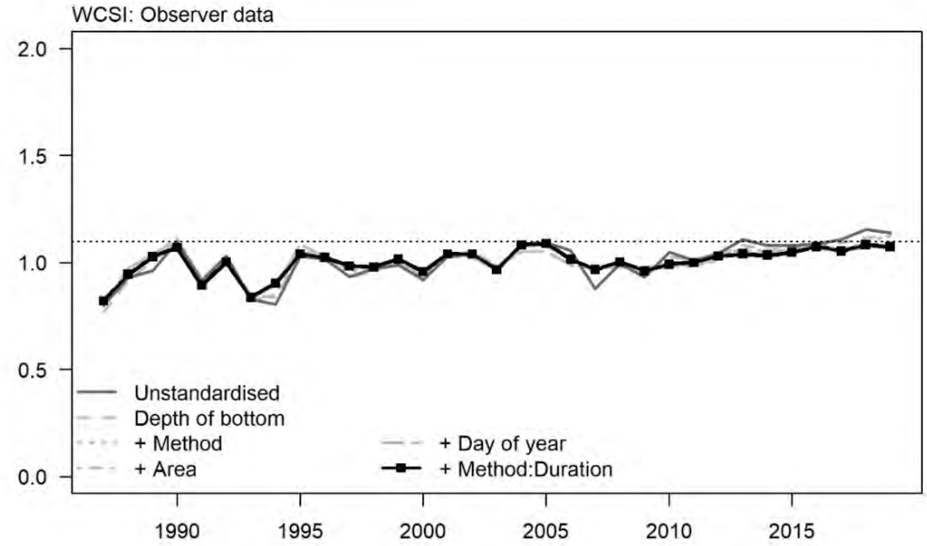

Figure 87: Step plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate. Plot shows the year effect for the unstandardised model, and after successive model predictors are added.

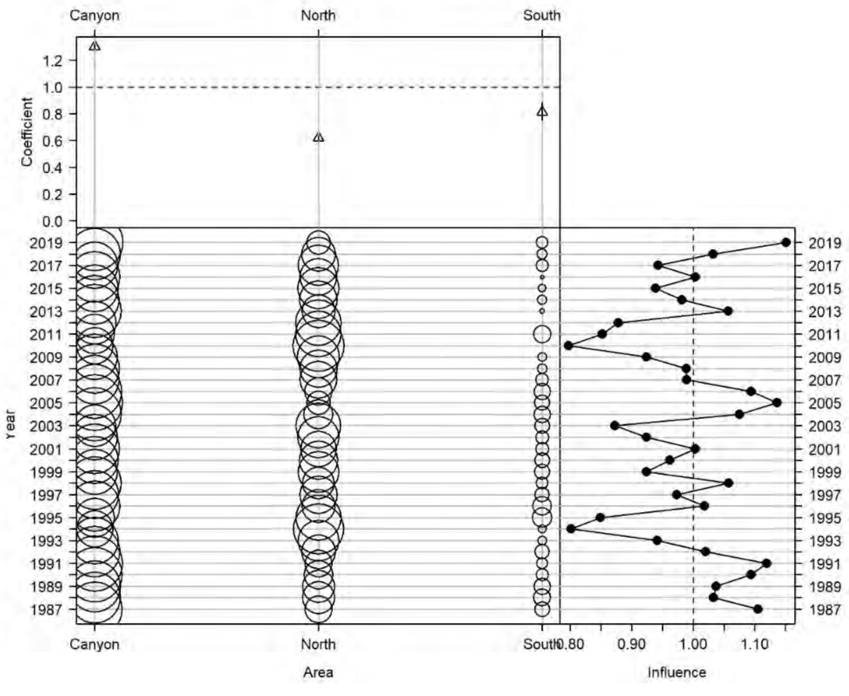

Figure 88: Area influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate. Top panel, the coefficient estimates for each area; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

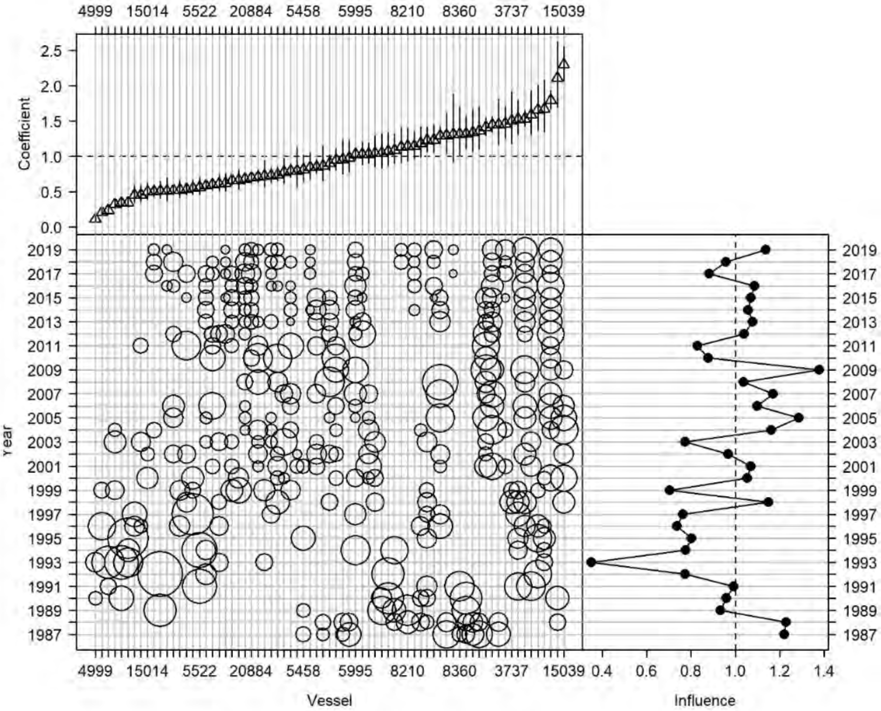

Figure 89: Vessel influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

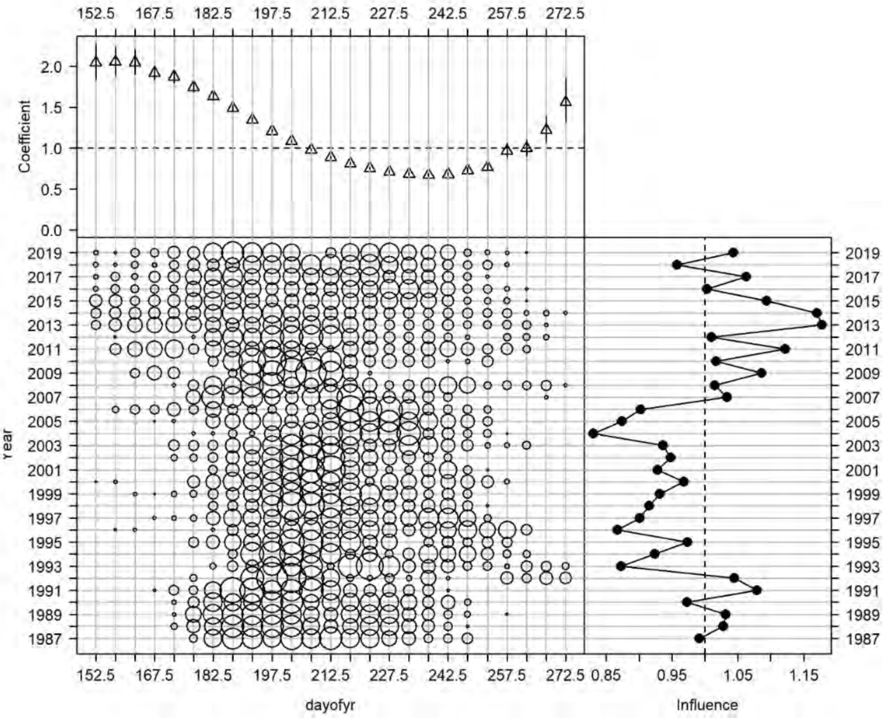

Figure 90: Day of year influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate. Top panel, the coefficient estimates for day of the year; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

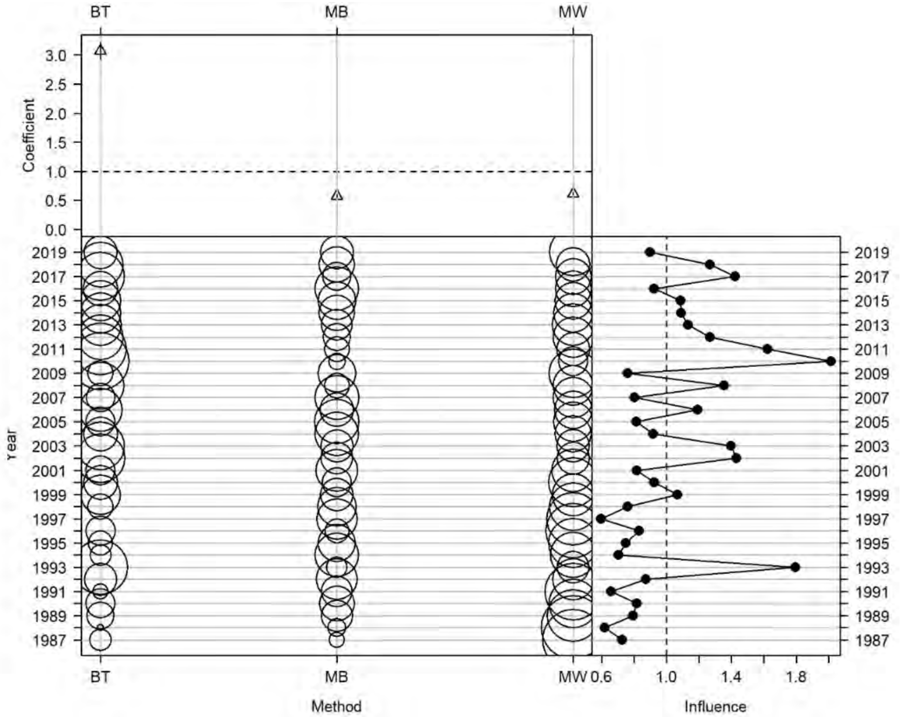

Figure 91: Gear method influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate. Top panel, the coefficient estimates for each gear method; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

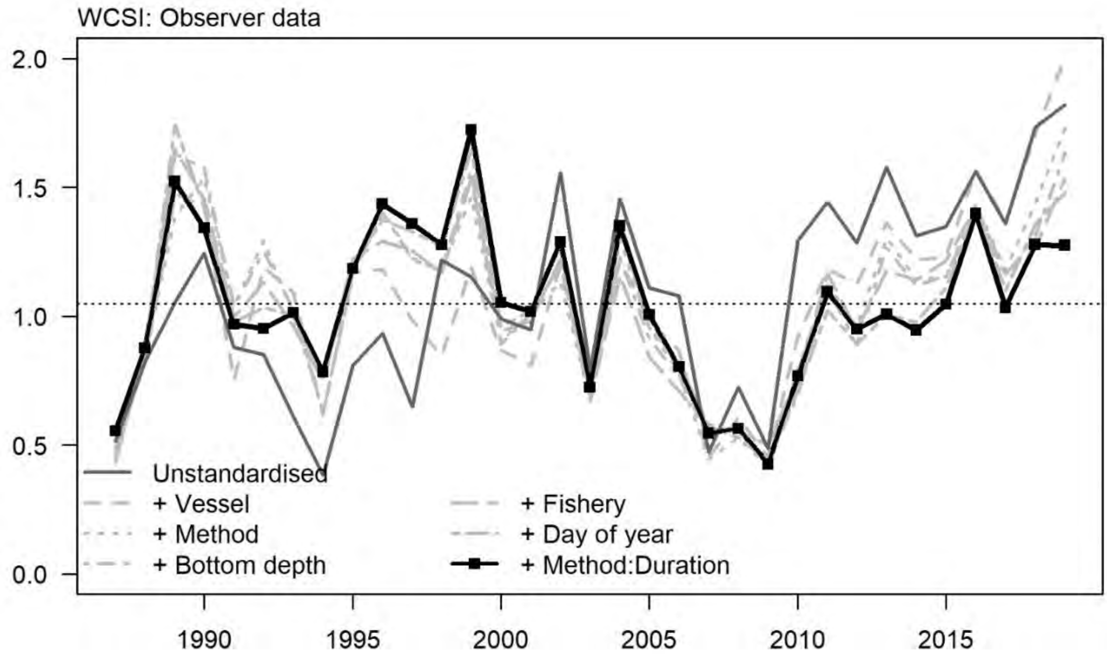

Figure 92: Step plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate. Plot shows the year effect for the unstandardised model, and after successive model predictors are added.

Table 27: CPUE standardised year indices and estimated coefficient of variation (CV) for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate. Fishing year labelled as year-ending.

	Lognormal		Binomial		Combined	
Fishing year	Index	CV	Index	CV	Index	CV
1987	0.55	0.07	0.55	0	0.34	0.07
1988	0.88	0.06	0.75	0	0.74	0.06
1989	1.52	0.07	0.91	0	1.56	0.07
1990	1.34	0.06	0.96	0	1.45	0.06
1991	0.97	0.07	0.63	0	0.69	0.07
1992	0.95	0.08	0.84	0	0.9	0.08
1993	1.01	0.08	0.51	0	0.58	0.08
1994	0.78	0.06	0.73	0	0.64	0.06
1995	1.19	0.07	0.89	0	1.19	0.07
1996	1.44	0.05	0.85	0	1.38	0.05
1997	1.36	0.06	0.82	0	1.25	0.06
1998	1.28	0.05	0.8	0	1.15	0.05
1999	1.72	0.04	0.86	0	1.66	0.04
2000	1.05	0.04	0.78	0	0.92	0.04
2001	1.02	0.04	0.88	0	1.01	0.04
2002	1.29	0.04	0.88	0	1.28	0.04
2003	0.72	0.05	0.77	0	0.62	0.05
2004	1.35	0.04	0.94	0	1.43	0.04
2005	1.01	0.04	0.95	0	1.08	0.04
2006	0.8	0.04	0.84	0	0.76	0.04
2007	0.55	0.06	0.82	0	0.5	0.06
2008	0.56	0.06	0.81	0	0.51	0.06
2009	0.43	0.06	0.76	0	0.37	0.06
2010	0.77	0.06	0.79	0	0.69	0.06
2011	1.09	0.05	0.81	0	1	0.05
2012	0.95	0.04	0.88	0	0.93	0.04
2013	1.01	0.03	0.9	0	1.02	0.03
2014	0.95	0.03	0.87	0	0.93	0.03
2015	1.05	0.03	0.9	0	1.06	0.03
2016	1.4	0.03	0.94	0	1.47	0.03
2107	1.03	0.03	0.9	0	1.04	0.03
2018	1.28	0.03	1	0	1.44	0.03
2019	1.28	0.03	0.98	0	1.41	0.03

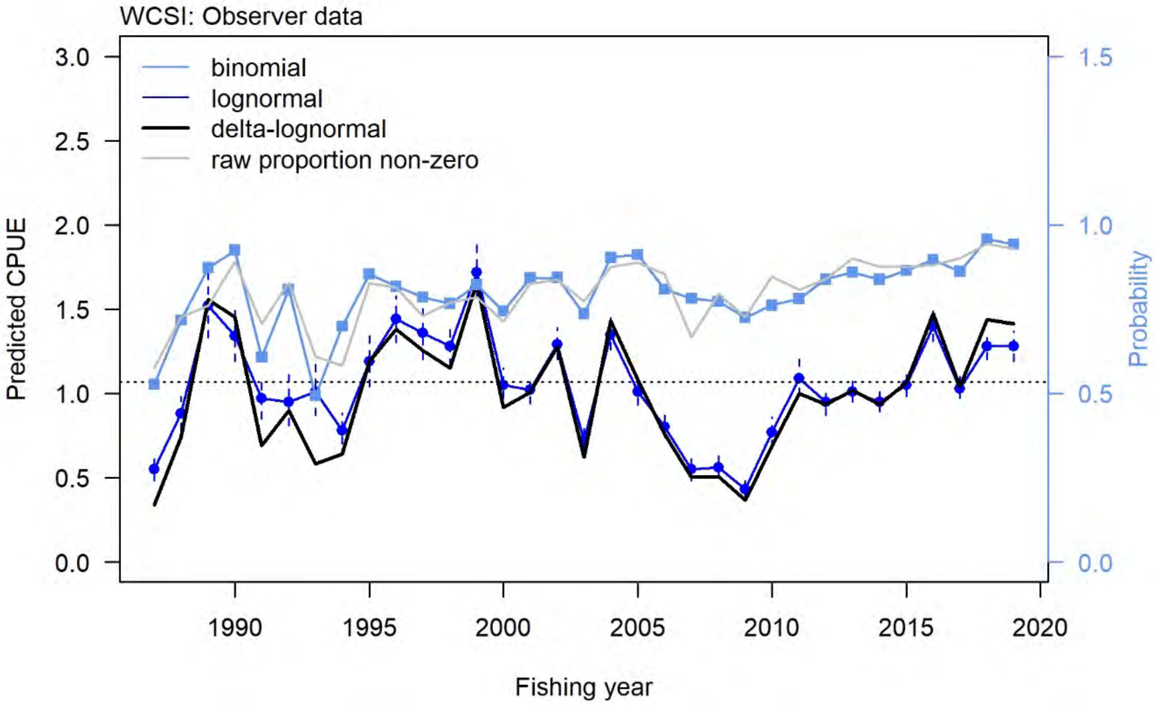

Figure 93: Comparison of the binomial, lognormal and combined CPUE indices for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate and the raw proportion of non-zero tows. Bars indicate 95% confidence intervals.

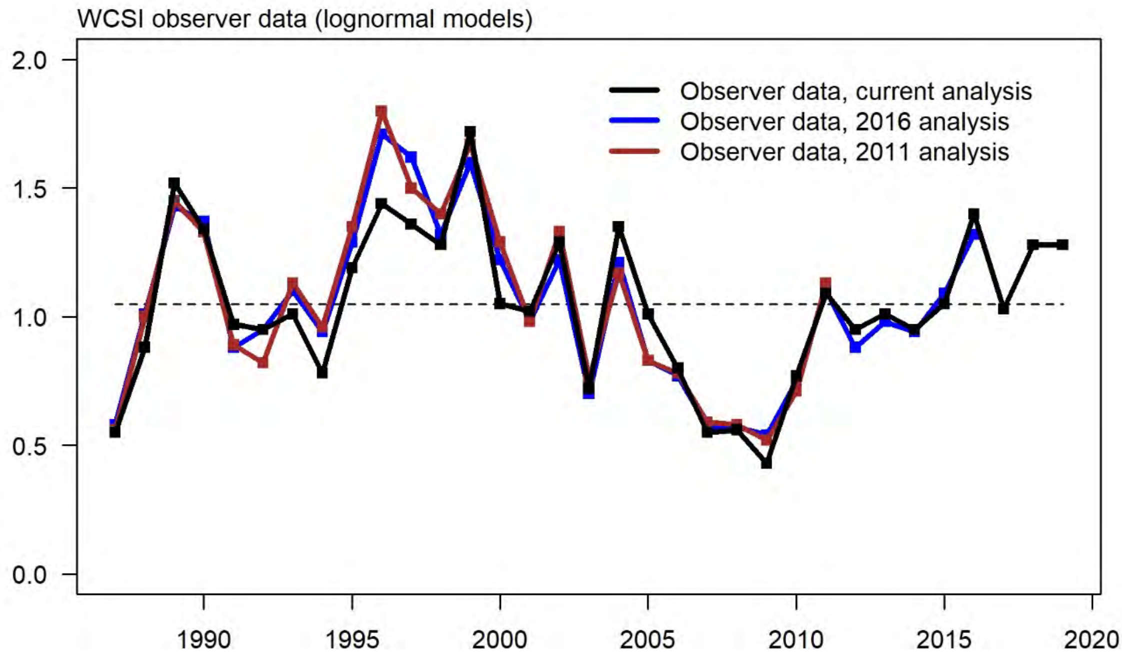

Figure 94: Comparison of the lognormal CPUE index for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate and the CPUE indices produced in 2016 (Dunn & Ballara 2019) and 2011 (Ballara & Horn 2015).

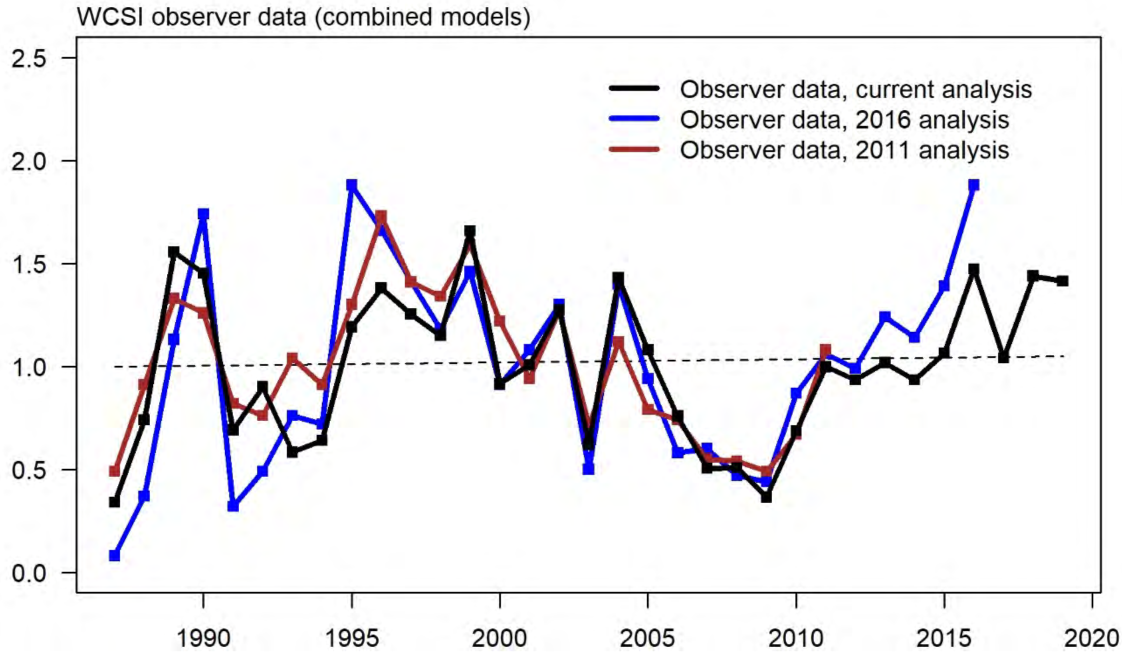

Figure 95: Comparison of the combined CPUE index for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate and the CPUE indices produced in 2016 (Dunn & Ballara 2019) and 2011 (Ballara & Horn 2015).

Model E: 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate, but no seasonal covariates offered

Table 28: Predictor and percentage of deviance explained for the final binomial model fit for 1987–2019 CPUE for observed tow-by-tow data with subareas North, South and Canyon offered as spatial covariate, but no seasonal covariates offered. Df, degrees of freedom; R^2, R squared.

Step	Df	R^2
Year	30	6.39
Bottom depth	3	11.63
Method	2	14.03
Area	2	16.65
Method:Duration	12	18.96

Table 29: Predictor and percentage of deviance explained for the final lognormal model fit for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South and Canyon offered as spatial covariate, but no seasonal covariates offered. Df, degrees of freedom; R^2, R squared.

Step	Df	R^2
Year	30	5.72
Vessel	72	10.96
Method	2	17.82
Bottom depth	3	21.42
Area	2	25.05
Target	1	26.22
Method:Duration	12	27.98

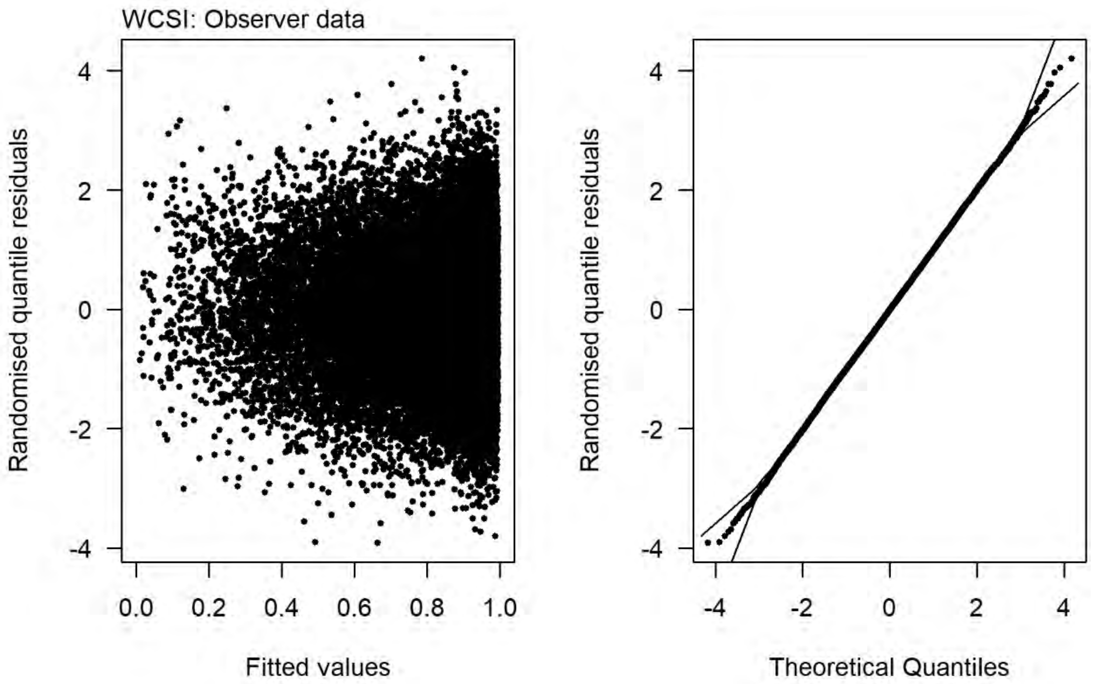

Figure 96: Residuals (left panel) and normal quantile plot (right panel) for the binomial model fit for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate, but no seasonal covariates offered.

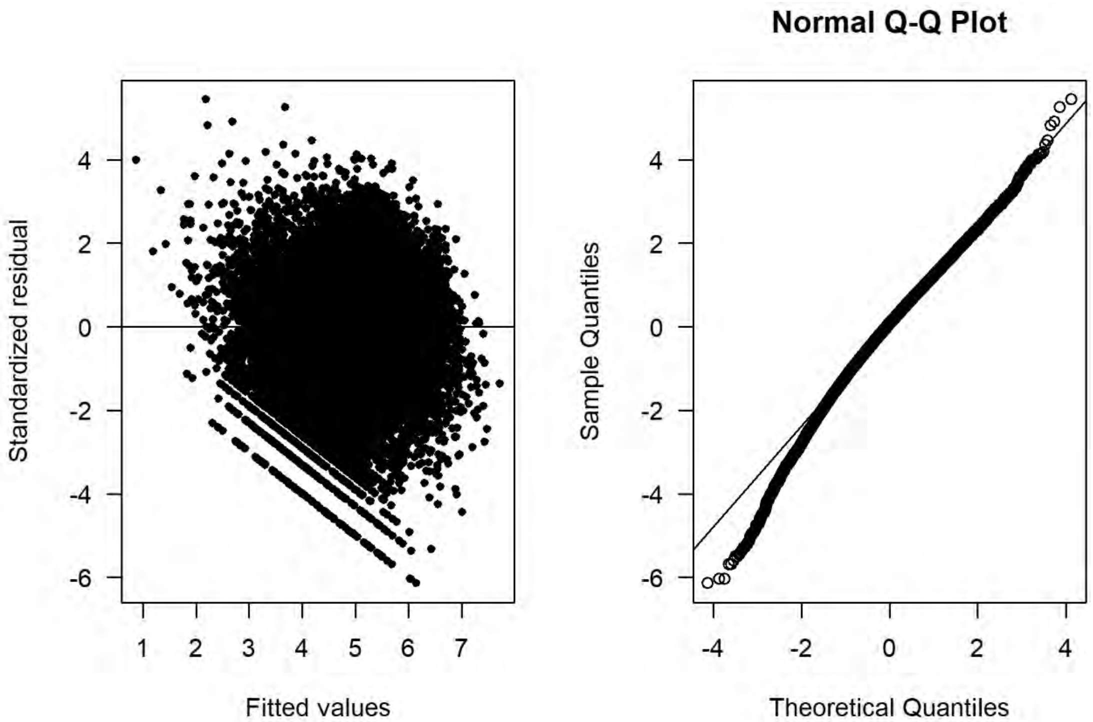

Figure 97: Residuals (left panel) and normal quantile plot (right panel) for the lognormal model fit for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate, but no seasonal covariates offered.

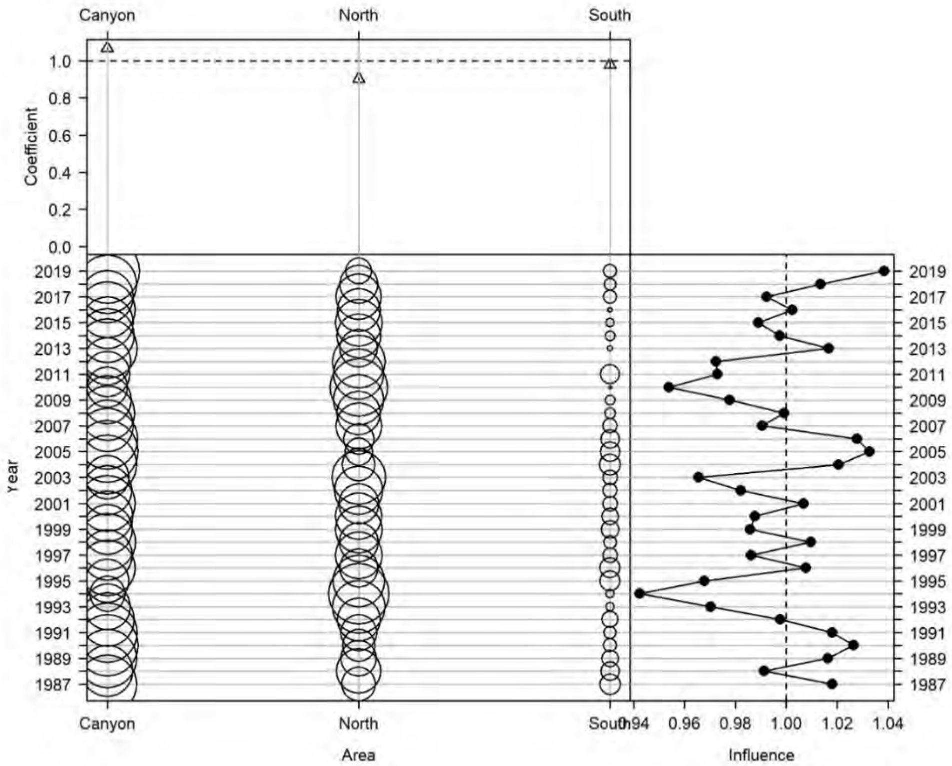

Figure 98: Area influence plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate, but no seasonal covariates offered. Top panel, the coefficient estimates for each area; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

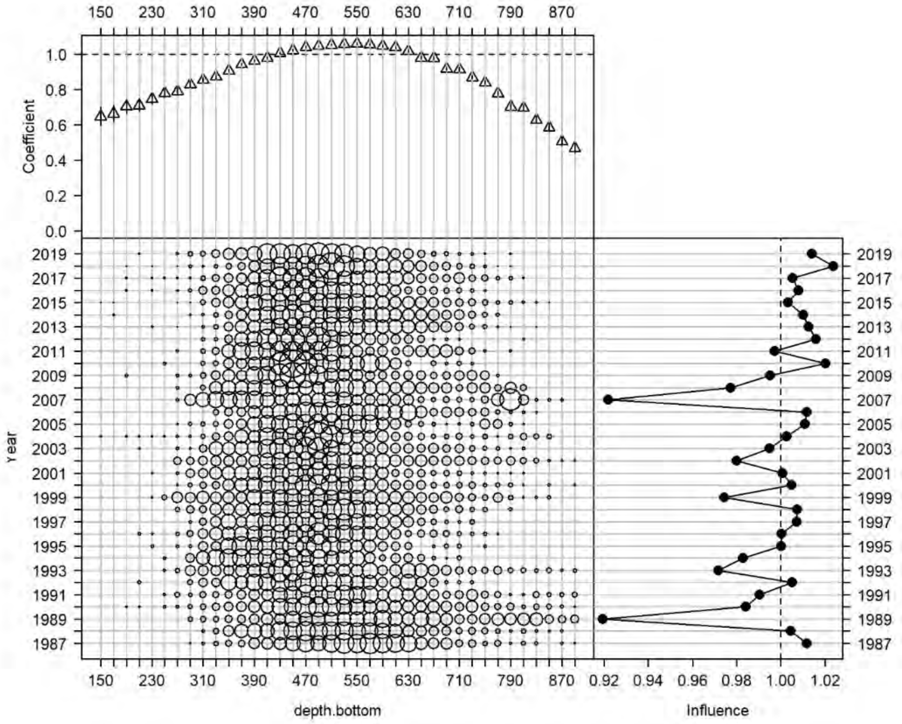

Figure 99: Bottom depth influence plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate, but no seasonal covariates offered. Top panel, the coefficient estimates for bottom depth; bottom left 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.

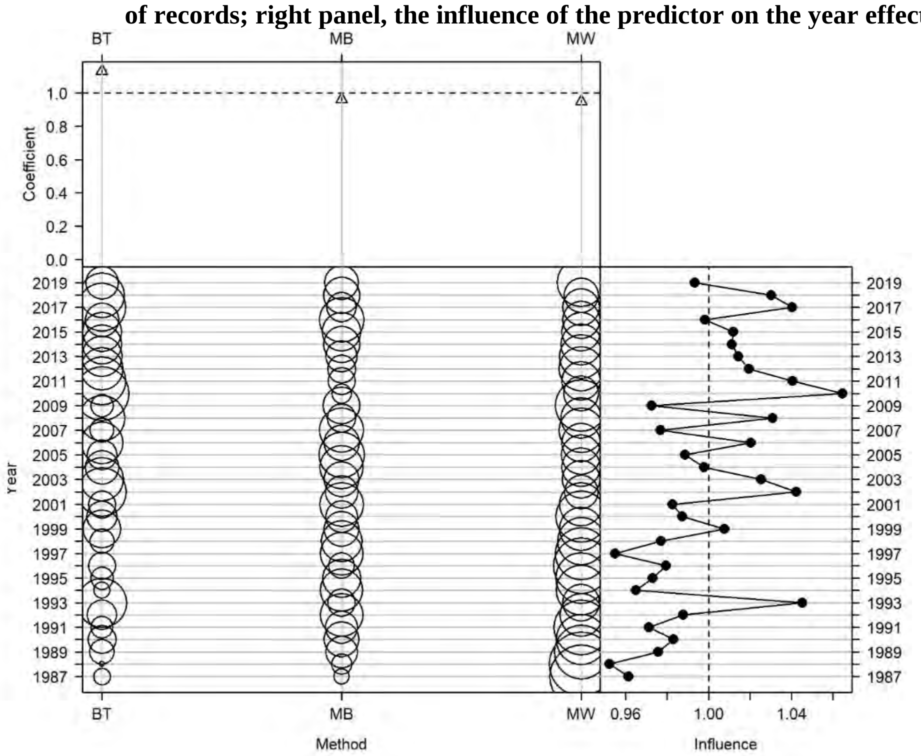

Figure 100: Gear method influence plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate, but no seasonal covariates offered. Top panel, the coefficient estimates for each gear method; bottom 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.

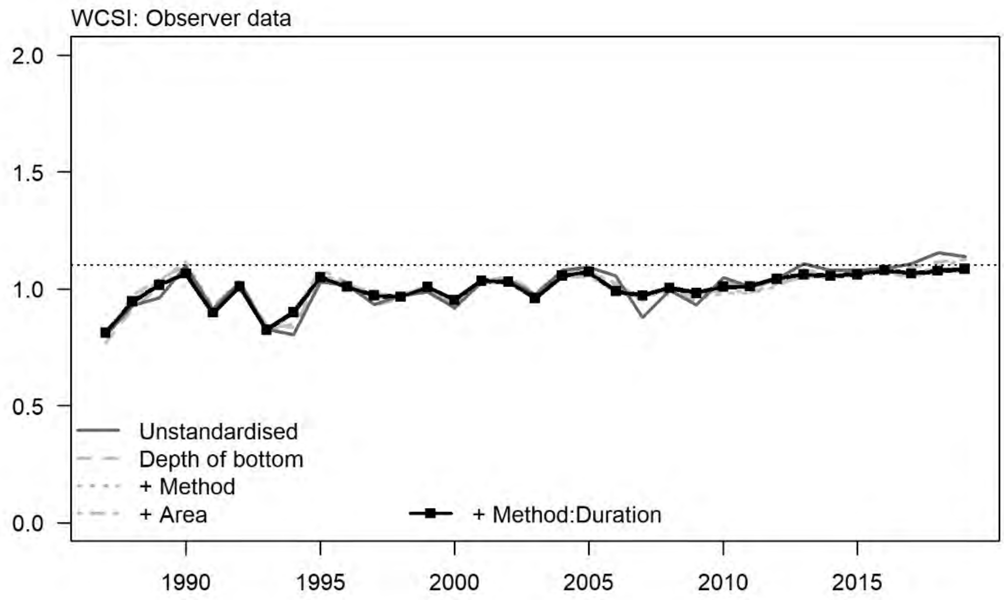

Figure 101: Step plot for the fishing success (binomial) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate, but no seasonal covariates offered. Plot shows the year effect for the unstandardised model, and after successive model predictors are added.

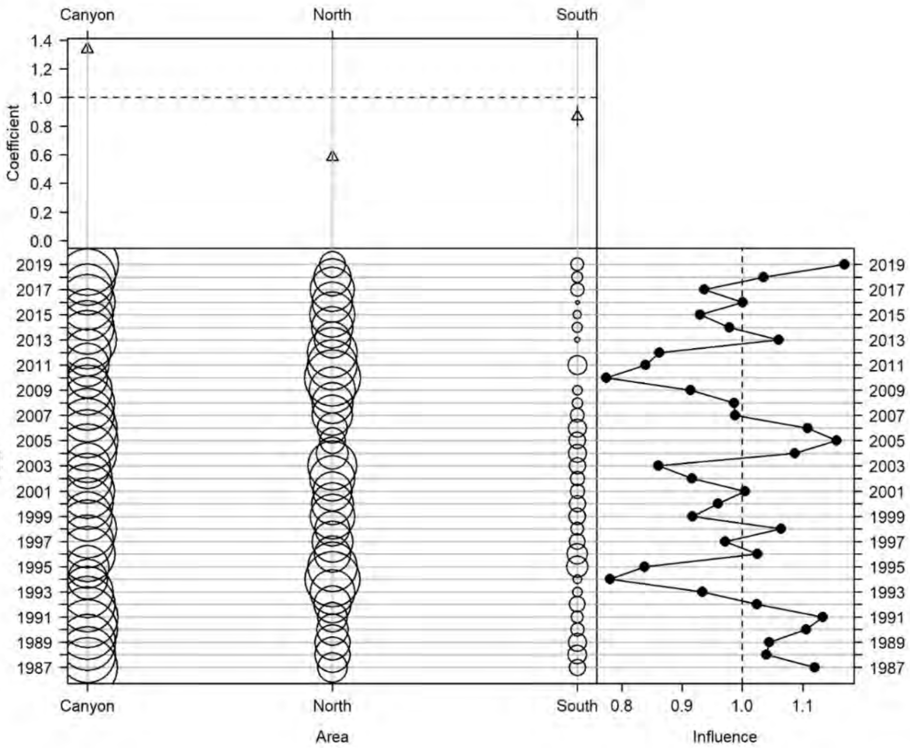

Figure 102: Area influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate, but no seasonal covariates offered. Top panel, the coefficient estimates for area; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

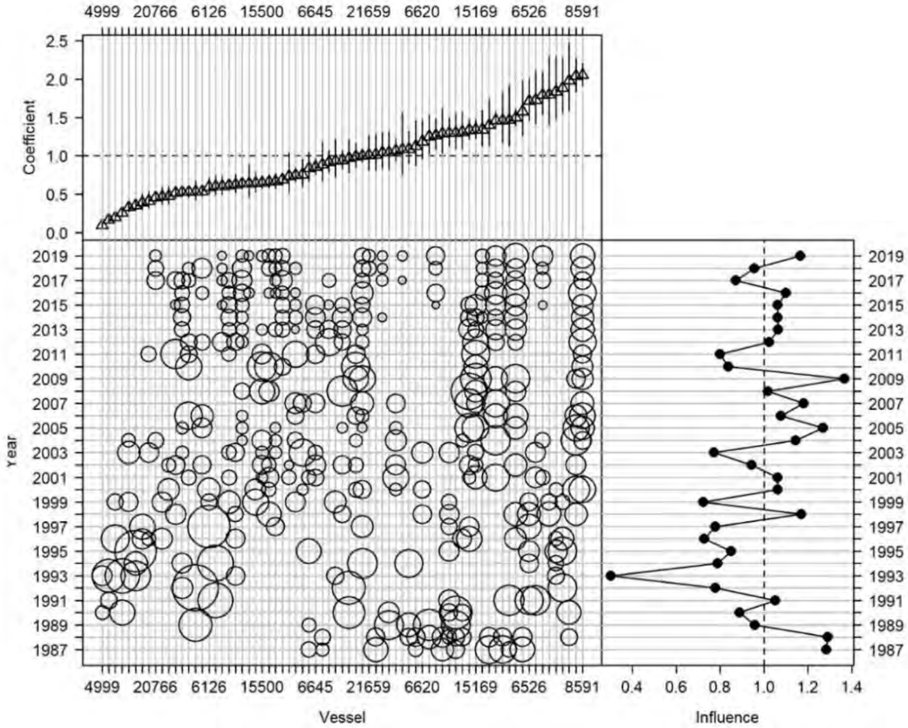

Figure 103: Vessel influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate, but no seasonal covariates offered. Top panel, the coefficient estimates for each vessel; bottom left 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.

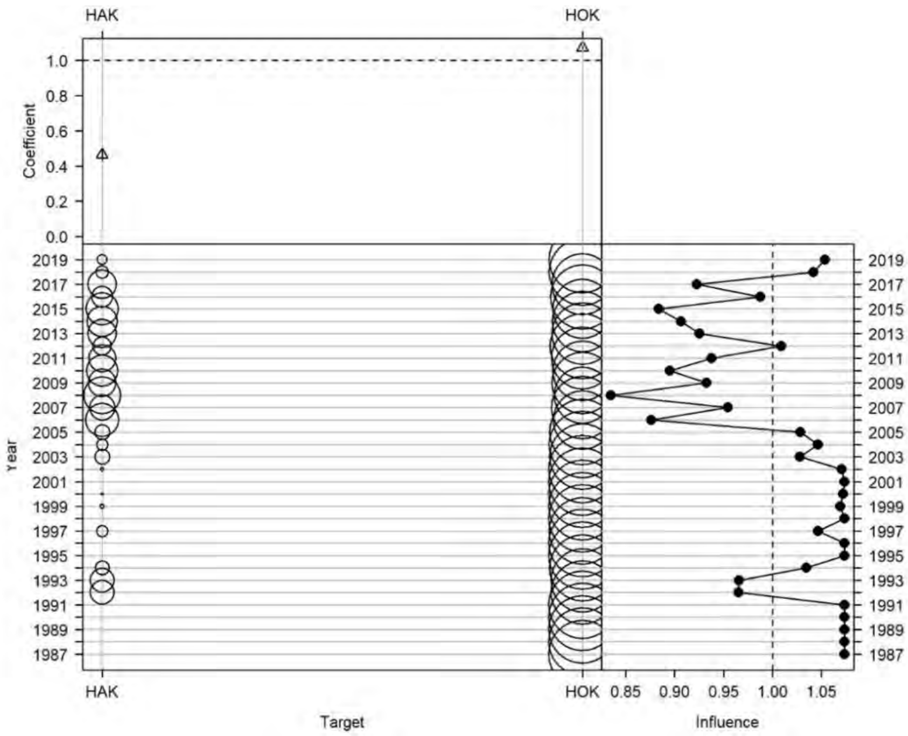

Figure 104: Target species influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate, but no seasonal covariates offered. Top panel, the coefficient estimates for each target species; 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.

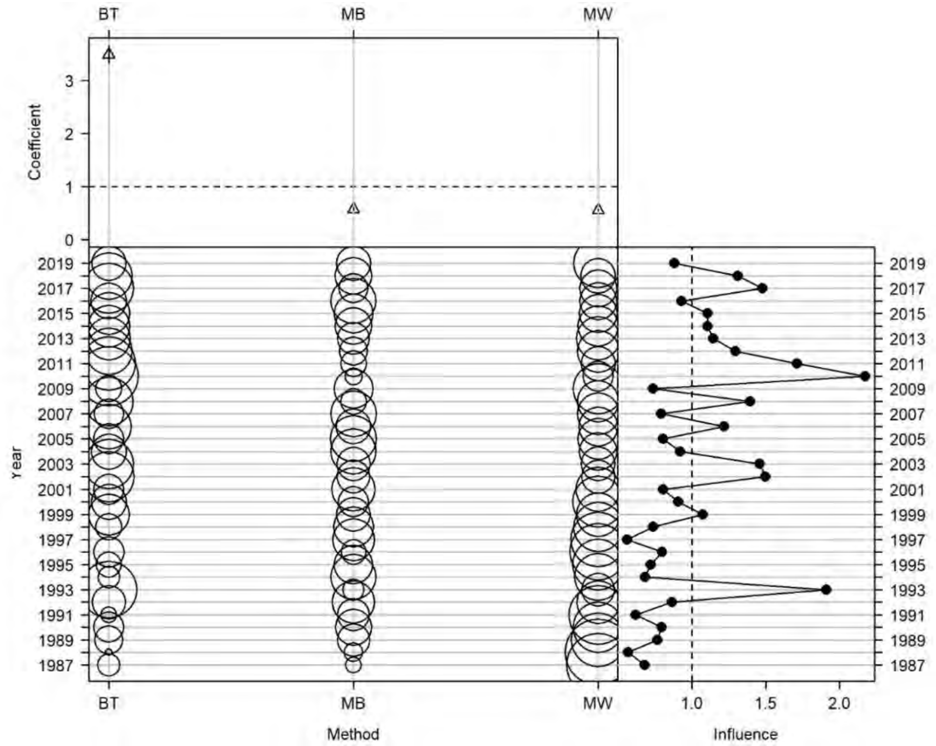

Figure 105: Gear method influence plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate, but no seasonal covariates offered. Top panel, the coefficient estimates for each gear method; 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.

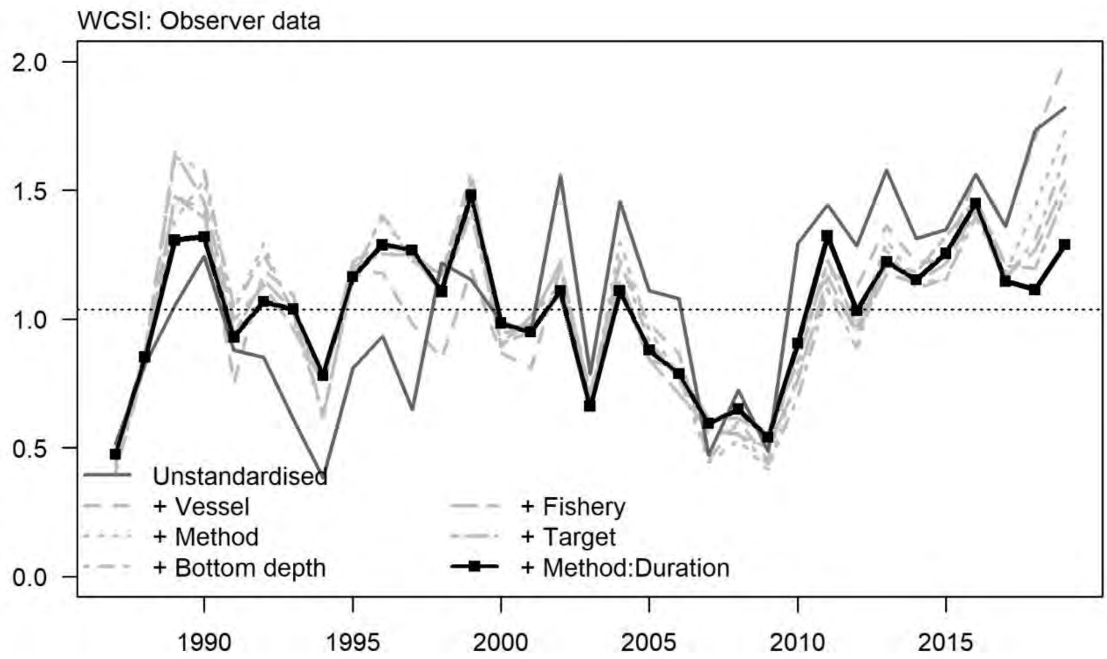

Figure 106: Step plot for the non-zero catch rate (lognormal) model for the 1987–2019 CPUE for observed tow-by-tow data with latitude subareas North, South, and Canyon as spatial covariate, but no seasonal covariates offered. Plot shows the year effect for the unstandardised model, and after successive model predictors are added.

Table 30: CPUE standardised year indices and estimated coefficient of variation (CV) for the 1987–2019 CPUE for observed tow-by-tow data with latitude offered as spatial covariate, but no seasonal covariates offered. Fishing year labelled as year-ending.

	Lognormal		Binomial		Combined	
Fishing year	Index	CV	Index	CV	Index	CV
1987	0.58	0.07	0.56	0.0020	0.34	0.07
1988	0.89	0.06	0.76	0.0011	0.7	0.06
1989	1.54	0.07	0.91	0.0006	1.45	0.07
1990	1.38	0.06	0.97	0.0003	1.39	0.06
1991	0.97	0.07	0.76	0.0011	0.77	0.07
1992	0.96	0.08	0.83	0.0010	0.82	0.08
1993	1.05	0.08	0.88	0.0007	0.96	0.08
1994	0.80	0.06	0.89	0.0006	0.74	0.06
1995	1.14	0.07	0.97	0.0003	1.14	0.07
1996	1.35	0.05	0.92	0.0005	1.28	0.05
1997	1.32	0.06	0.91	0.0005	1.24	0.06
1998	1.30	0.05	0.92	0.0005	1.23	0.05
1999	1.74	0.04	0.94	0.0004	1.69	0.04
2000	1.05	0.04	0.88	0.0006	0.96	0.04
2001	1.00	0.04	0.95	0.0004	0.99	0.04
2002	1.28	0.04	0.95	0.0004	1.26	0.04
2003	0.72	0.05	0.90	0.0006	0.67	0.05
2004	1.29	0.04	0.96	0.0003	1.28	0.04
2005	0.95	0.04	0.96	0.0003	0.95	0.04
2006	0.75	0.04	0.92	0.0005	0.71	0.04
2007	0.55	0.06	0.93	0.0005	0.53	0.06
2008	0.58	0.06	0.92	0.0005	0.55	0.06
2009	0.45	0.06	0.91	0.0005	0.42	0.06
2010	0.81	0.06	0.96	0.0004	0.8	0.06
2011	1.07	0.05	0.95	0.0004	1.05	0.05
2012	0.96	0.04	0.98	0.0003	0.97	0.04
2013	1.03	0.03	0.98	0.0003	1.04	0.03
2014	0.96	0.03	0.97	0.0003	0.96	0.03
2015	1.06	0.03	0.97	0.0003	1.06	0.03
2016	1.41	0.03	0.99	0.0002	1.44	0.03
2107	1.04	0.03	0.97	0.0003	1.05	0.03
2018	1.26	0.03	1.00	0.0002	1.3	0.03
2019	1.23	0.03	0.99	0.0002	1.26	0.03

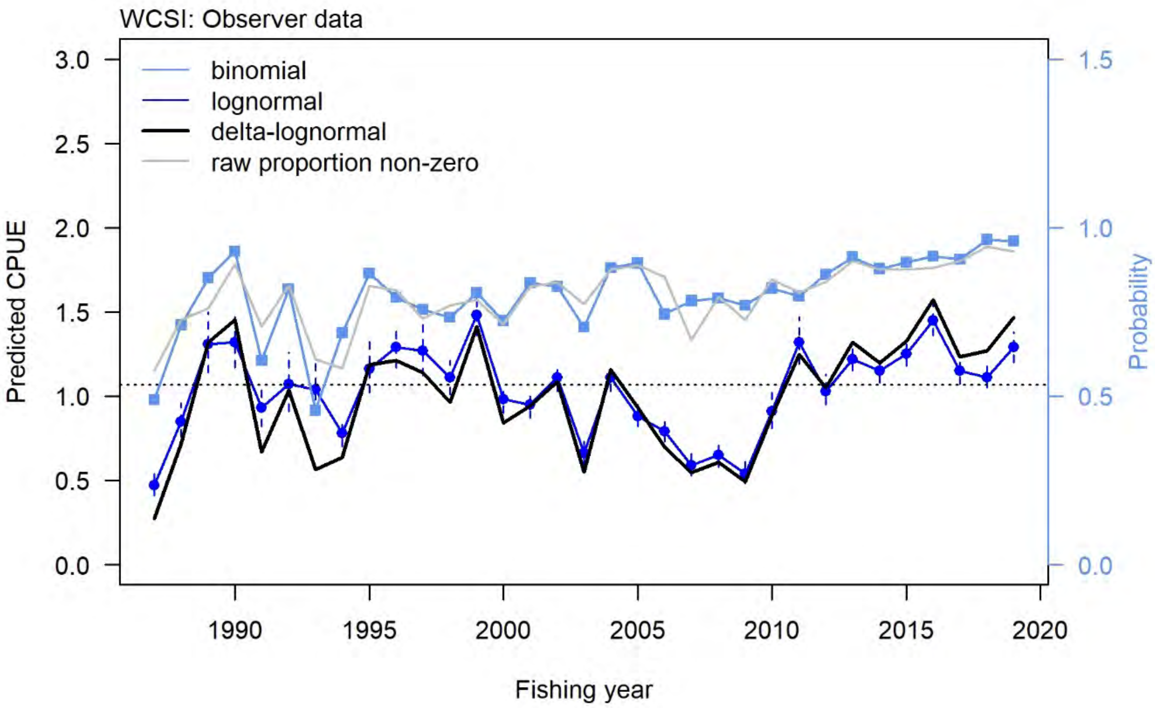

Figure 107: Comparison of the binomial, lognormal and combined CPUE indices for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate, but no seasonal covariates offered and the raw proportion of non-zero tows. Bars indicate 95% confidence intervals.

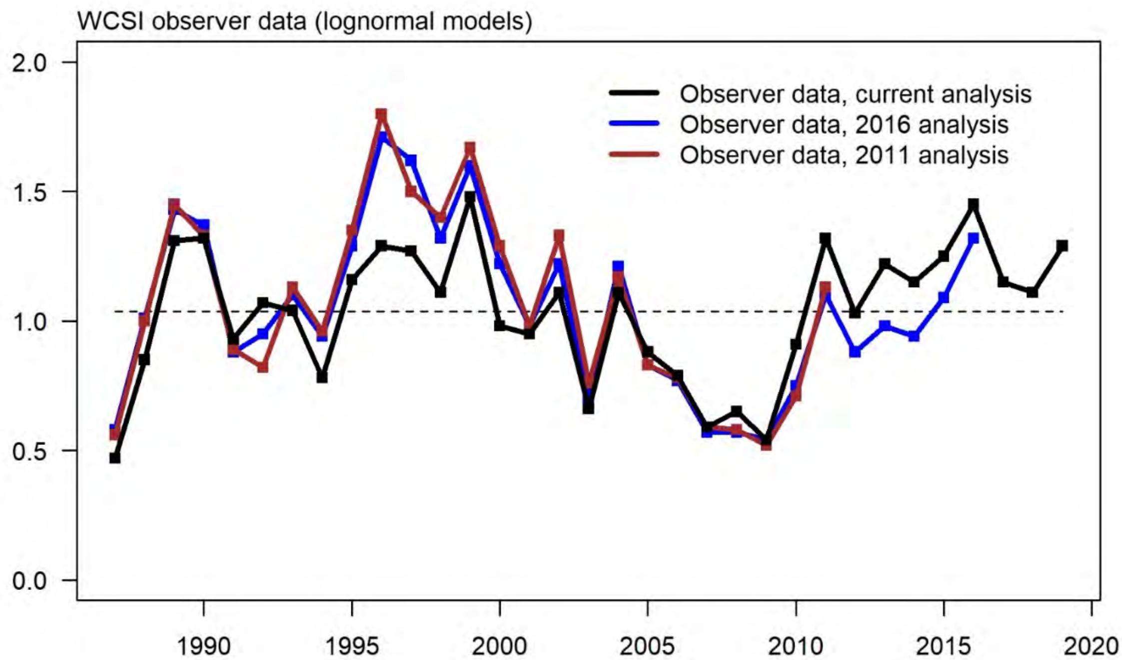

Figure 108: Comparison of the lognormal CPUE index for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate, but no seasonal covariates offered and the CPUE indices produced in 2016 (Dunn & Ballara 2019) and 2011 (Ballara & Horn 2015).

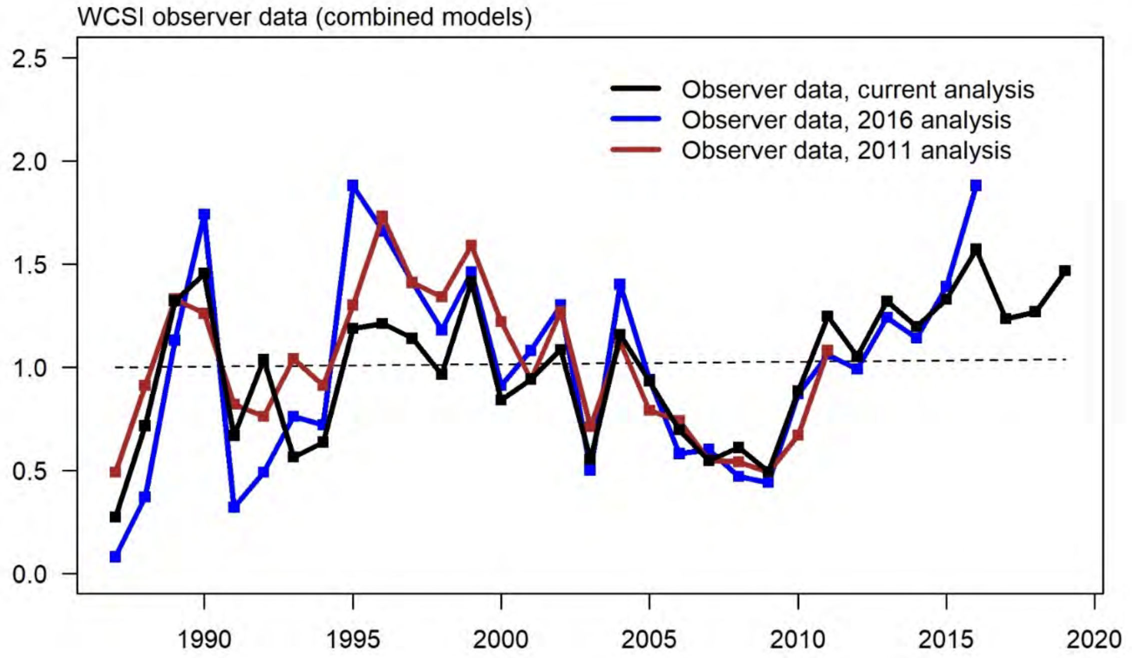

Figure 109: Comparison of the combined CPUE index for the 1987–2019 CPUE for observed tow-by-tow data with subareas North, South, and Canyon offered as spatial covariate, but no seasonal covariates offered and the CPUE indices produced in 2016 (Dunn & Ballara 2019) and 2011 (Ballara & Horn 2015).

Model F: 2009–2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate

Table 31: Predictor and percentage of deviance explained for the final binomial model fit for the 2009–2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate. Df, degrees of freedom; R^2, R squared.

Step	Df	R^2
Year	10	1.62
Bottom depth	3	6.28
Vessel	16	12.92
Day of year	3	17.13
Mid time	3	18.49
Duration	4	19.63
Start time	3	21.40

Table 32: Predictor and percentage of deviance explained for the final lognormal model fit for the 2009–2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate. Df, degrees of freedom; R^2, R squared.

Step	Df	R^2
Year	10	4.16
Bottom depth	3	18.88
Day of year	3	32.38
Start time	3	36.96
Duration	4	40.91
Vessel	16	42.95

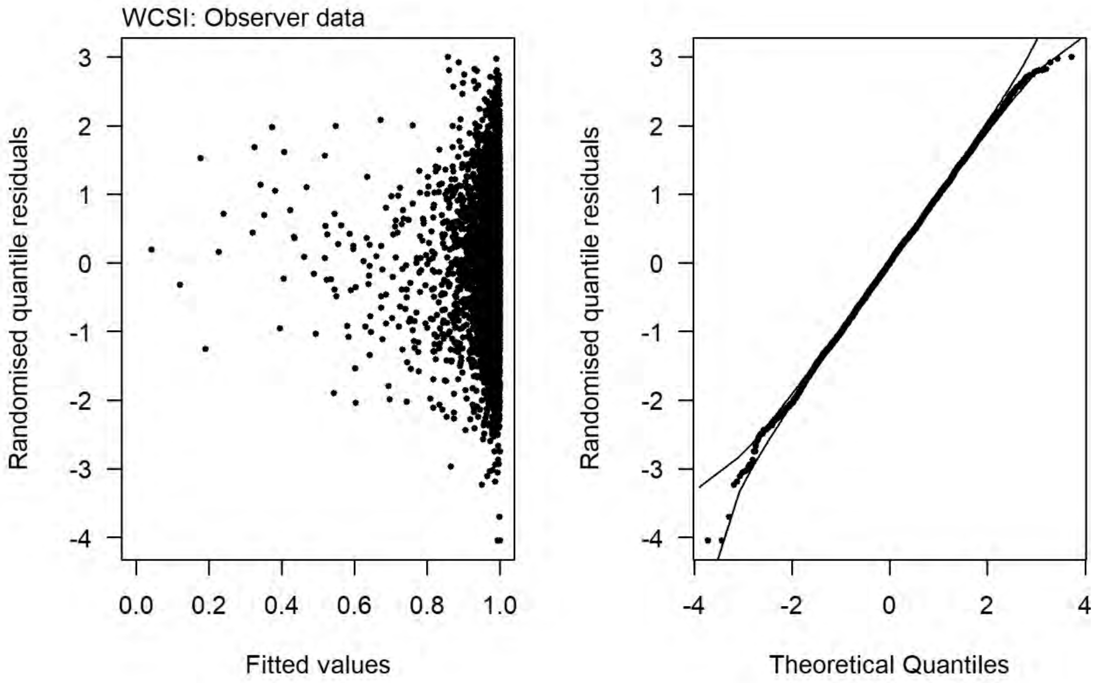

Figure 110: Residuals (left panel) and normal quantile plot (right panel) for the binomial model fit for the 2009–2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate.

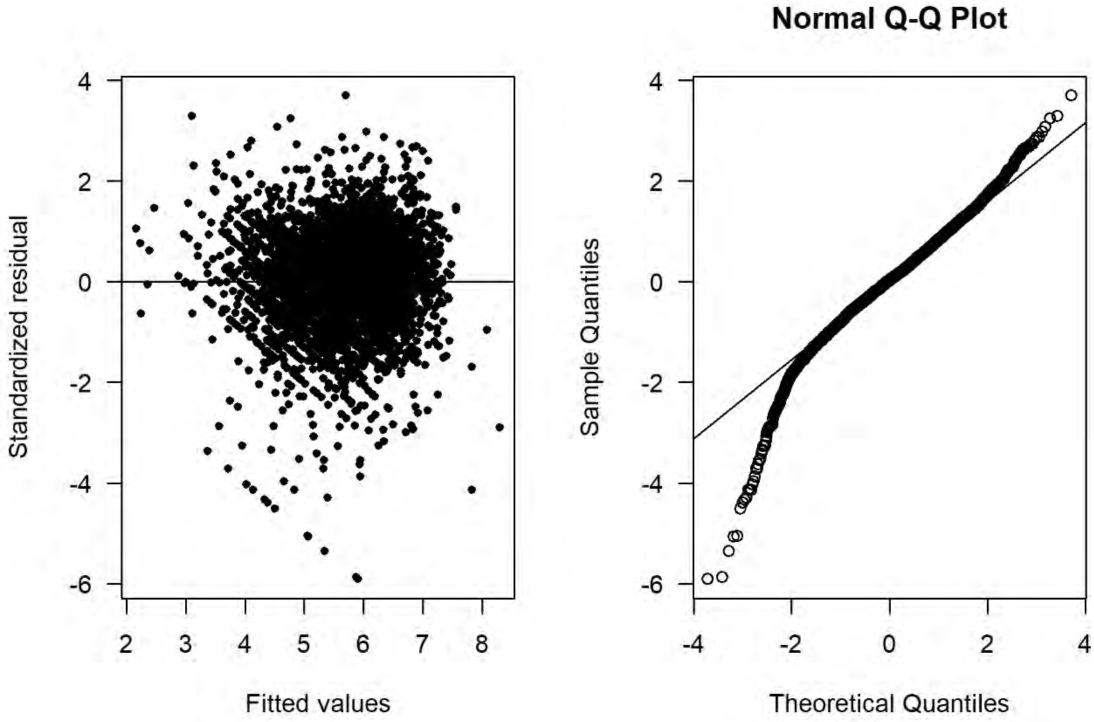

Figure 111: Residuals (left panel) and normal quantile plot (right panel) for the lognormal model fit for the 2009–2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate.

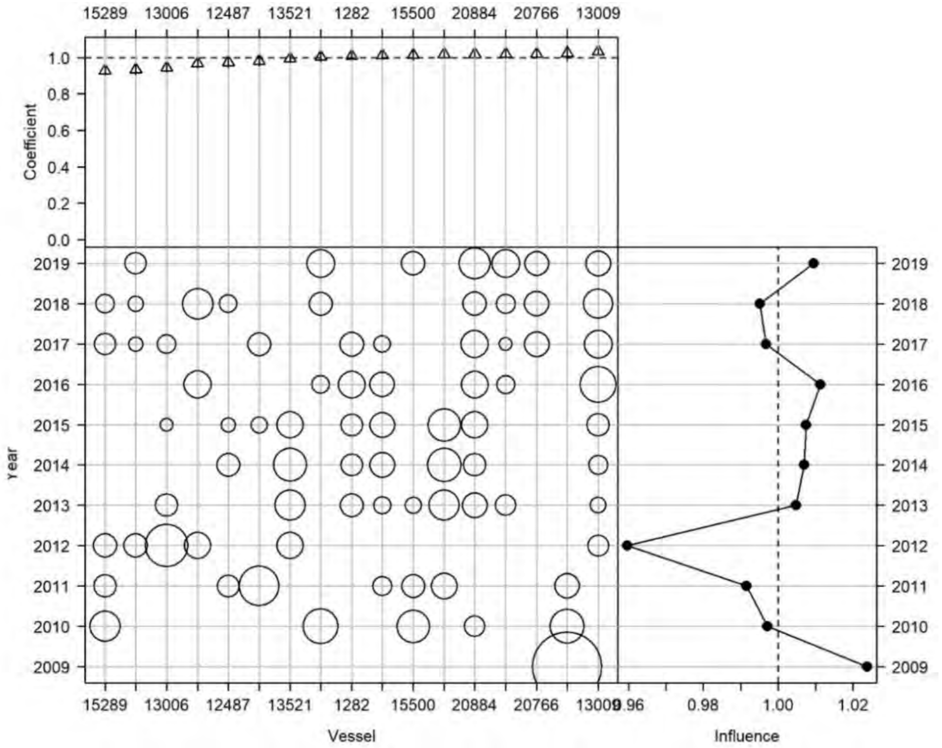

Figure 112: Vessel influence plot for the fishing success (binomial) model for the 2009–2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

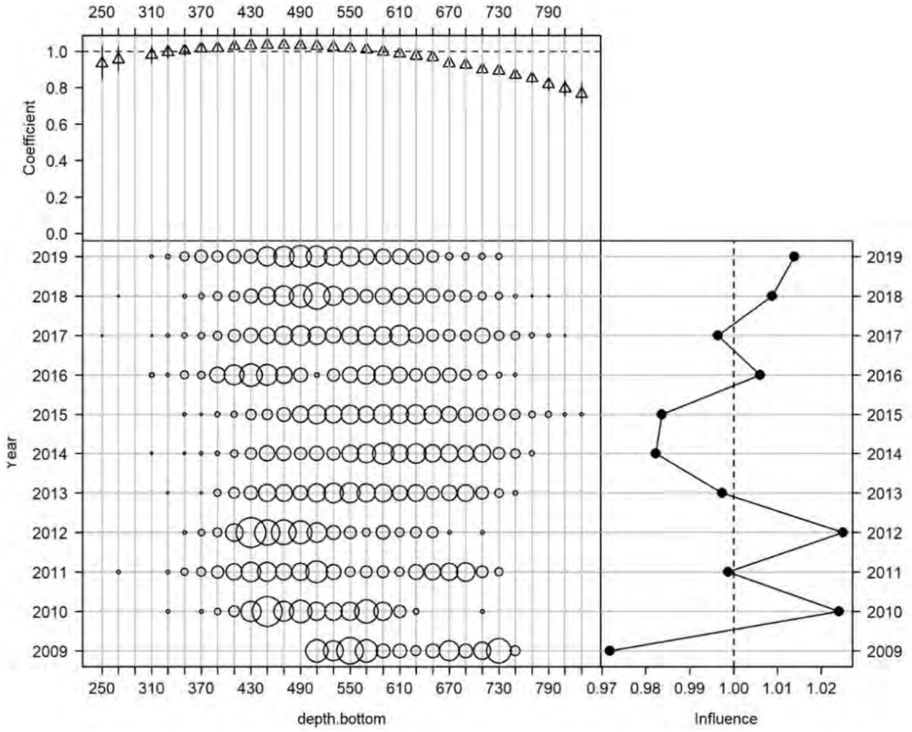

Figure 113: Bottom depth influence plot for the fishing success (binomial) model for the 2009–2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate. Top panel, the coefficient estimates for bottom depth; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

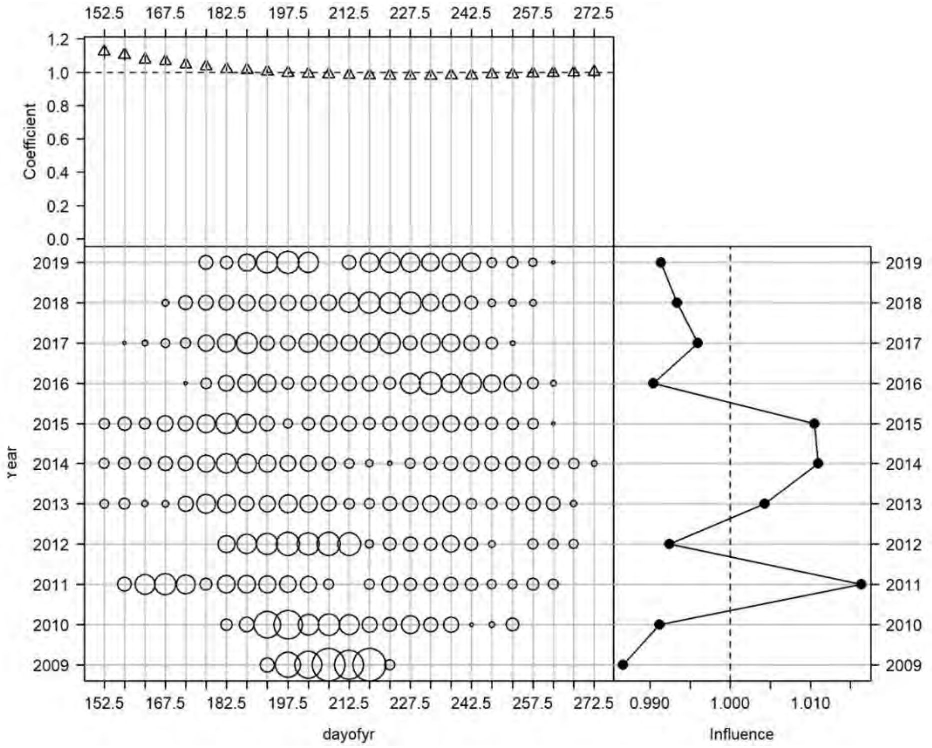

Figure 114: Day of year influence plot for the fishing success (binomial) model for the 2009–2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate. Top panel, the coefficient estimates for day of year; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

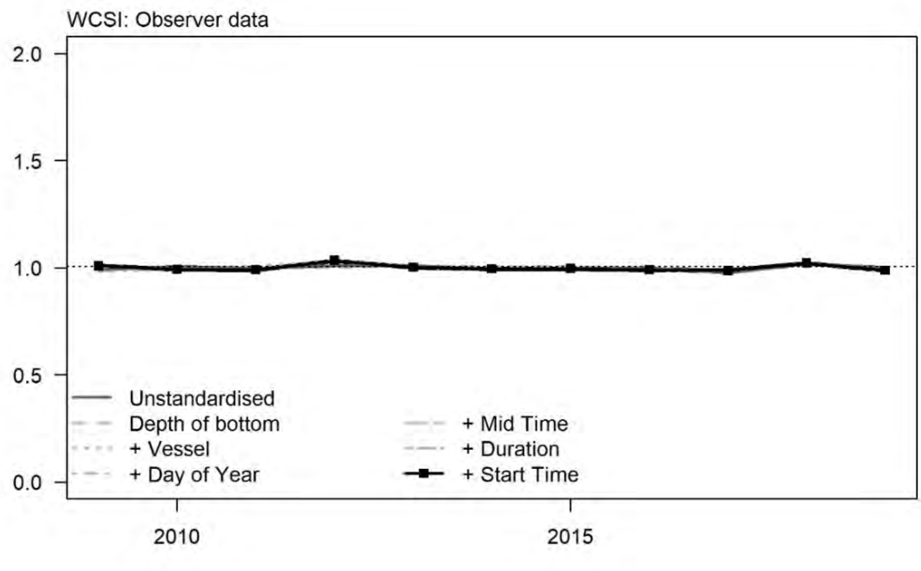

Figure 115: Step plot for the fishing success (binomial) model for the 2009–2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate. Plot shows the year effect for the unstandardised model, and after successive model predictors are added.

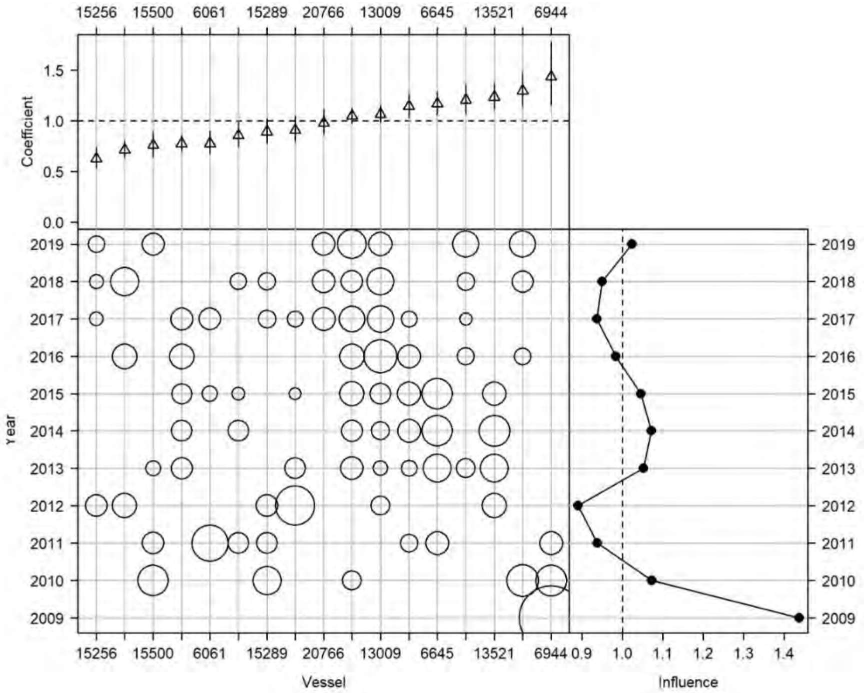

Figure 116: Vessel influence plot for the non-zero catch rate (lognormal) model for the 2009–2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate. Top panel, the coefficient estimates for each vessel; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

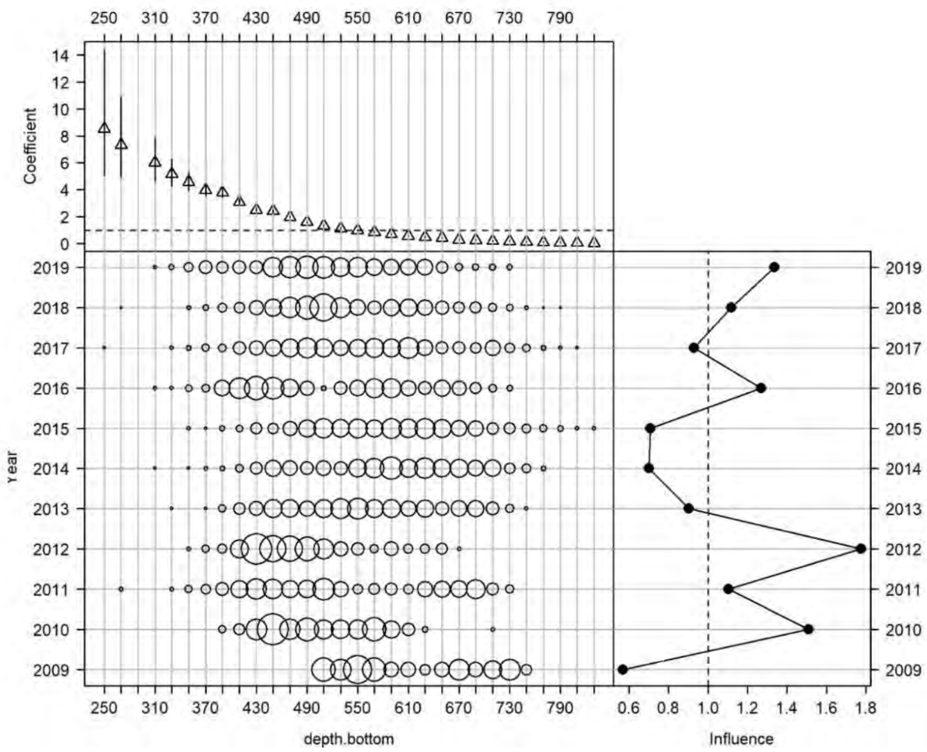

Figure 117: Bottom depth influence plot for the non-zero catch rate (lognormal) model for the 2009–2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate. Top panel, the coefficient estimates for bottom depth; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

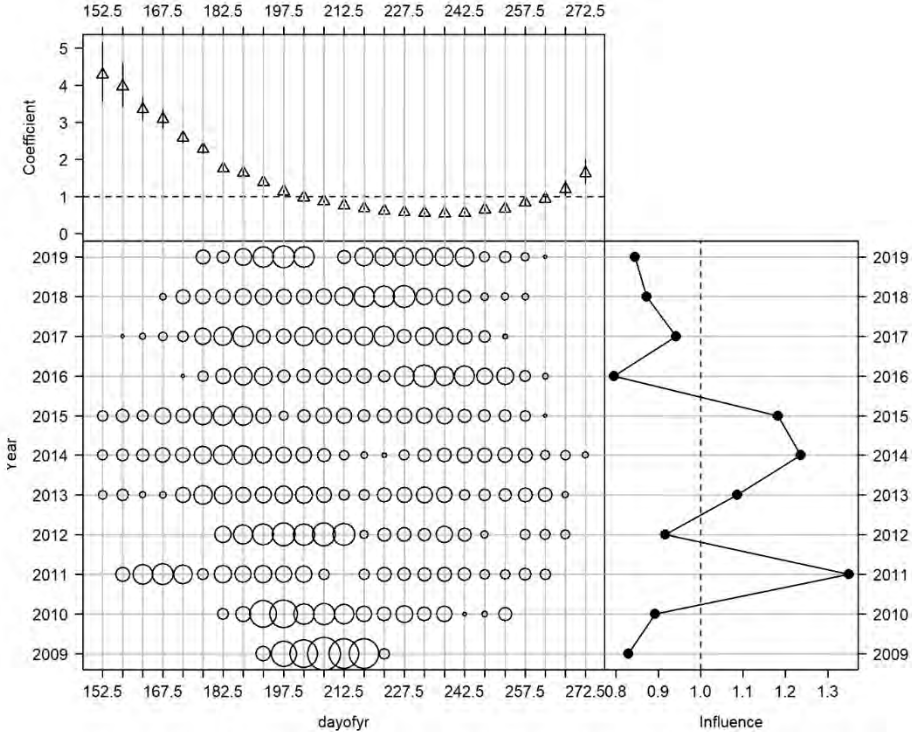

Figure 118: Day of year influence plot for the non-zero catch rate (lognormal) model for the 2009–2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate. Top panel, the coefficient estimates for day of the year; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

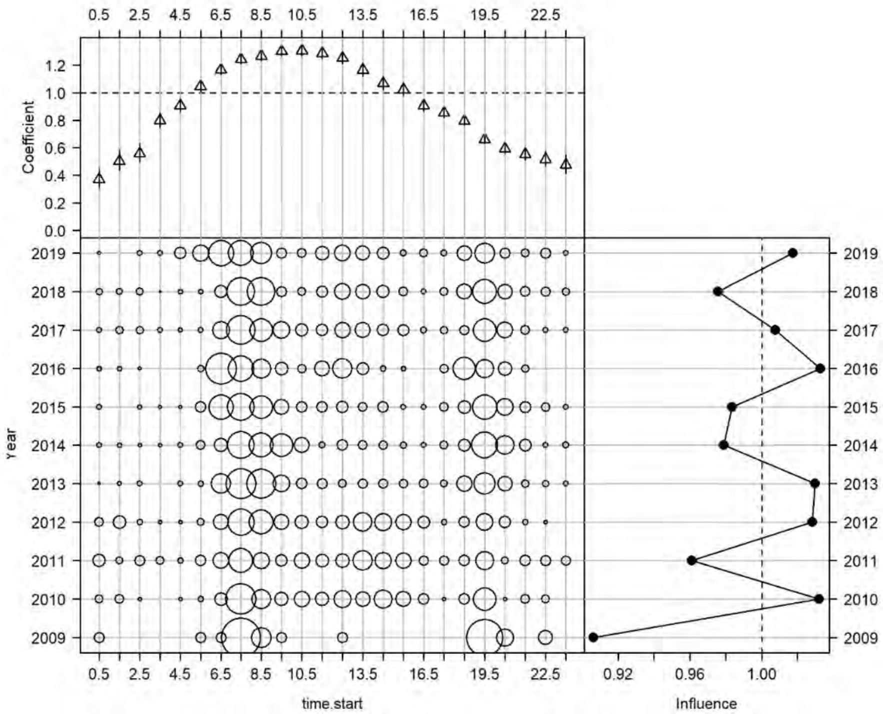

Figure 119: Start time influence plot for the non-zero catch rate (lognormal) model for the 2009–2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate. Top panel, the coefficient estimates for start time; bottom left panel, the number of records, with bubble size proportional to the number of records; right panel, the influence of the predictor on the year effect.

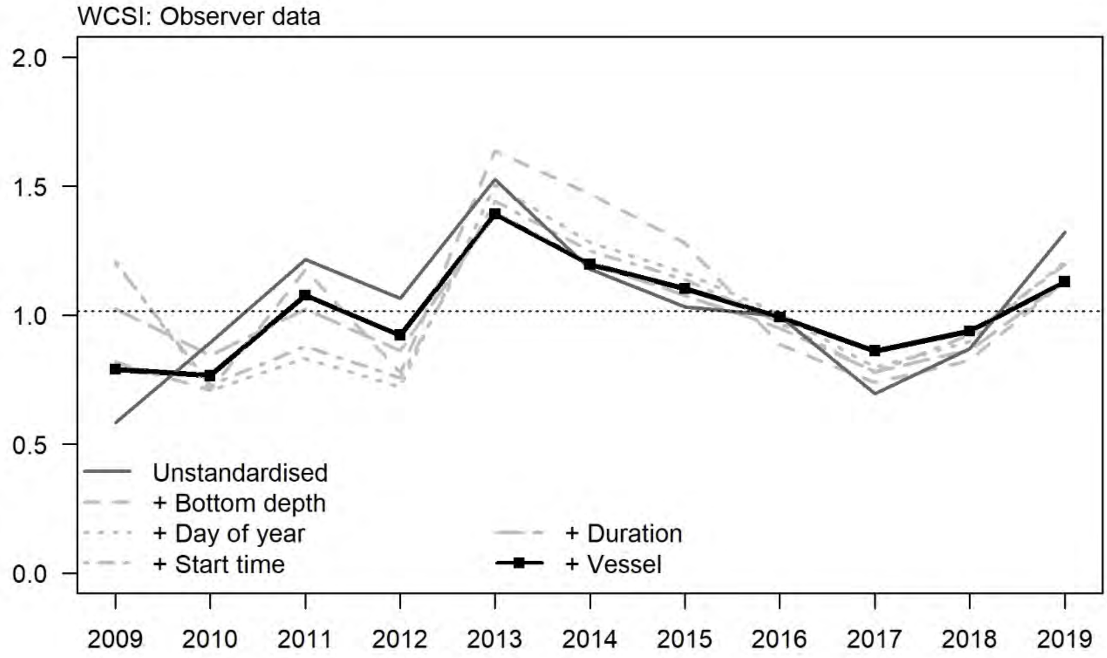

Figure 120: Step plot for the non-zero catch rate (lognormal) model for the 2009–2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate. Plot shows the year effect for the unstandardised model, and after successive model predictors are added.

Table 33: CPUE standardised year indices and estimated coefficient of variation (CV) for the 2009–2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate. Fishing year labelled as year-ending.

		Lognormal		Binomial		Combined
Fishing year	Index	CV	Index	CV	Index	CV
2009	0.79	0.18	1.00	0	0.78	0.18
2010	0.76	0.07	0.99	0	0.75	0.07
2011	1.08	0.07	0.99	0	1.06	0.07
2012	0.92	0.07	1.00	0	0.91	0.07
2013	1.39	0.05	1.00	0	1.37	0.05
2014	1.20	0.05	0.99	0	1.18	0.05
2015	1.10	0.05	0.99	0	1.09	0.05
2016	0.99	0.06	0.99	0	0.97	0.06
2107	0.86	0.05	0.99	0	0.85	0.05
2018	0.94	0.05	1.00	0	0.93	0.05
2019	1.13	0.06	0.99	0	1.11	0.06

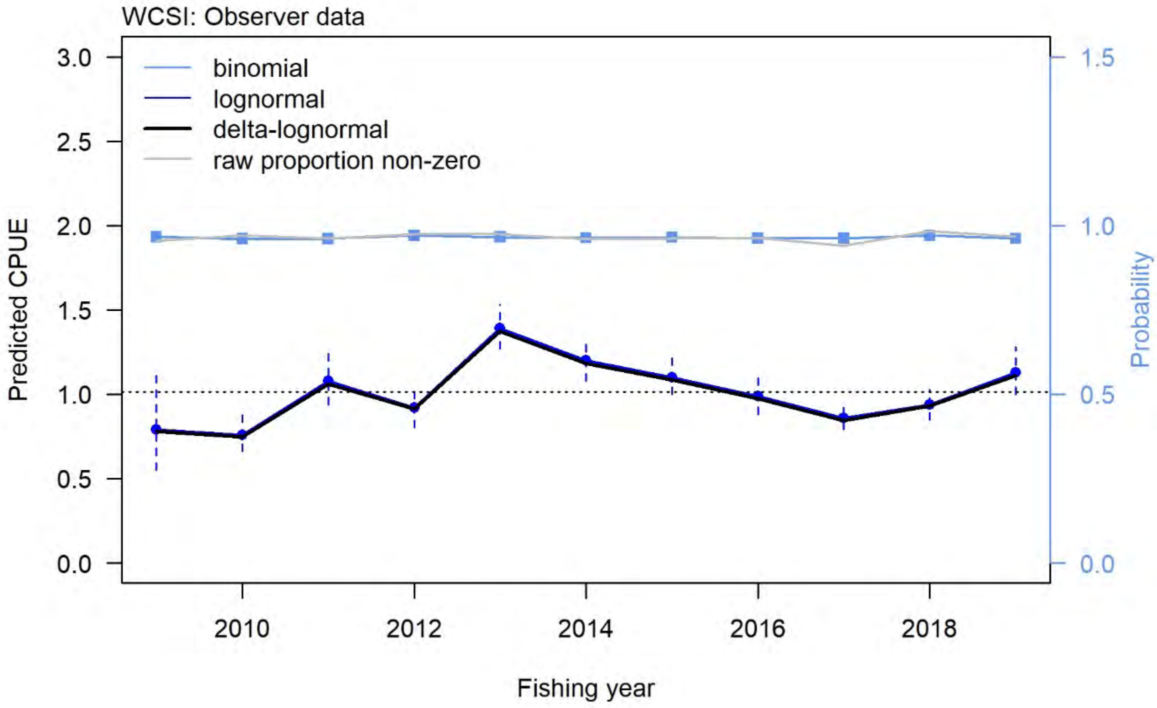

Figure 121: Comparison of the binomial, lognormal and combined CPUE indices for the 2009–2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate and the raw proportion of non-zero tows. Bars indicate 95% confidence intervals.

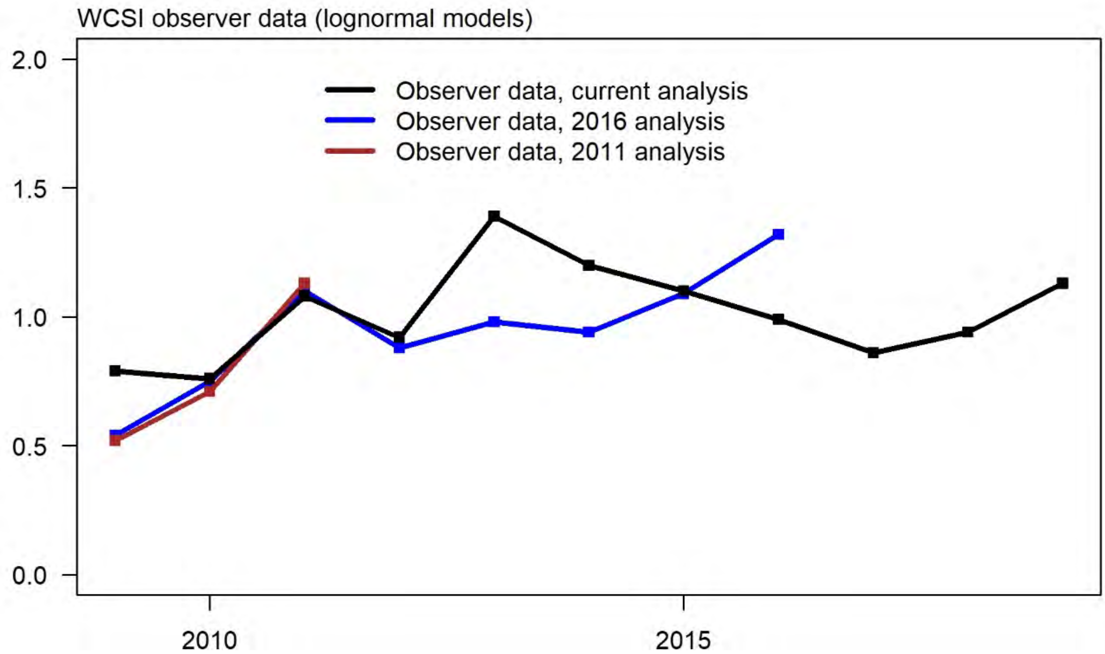

Figure 122: Comparison of the lognormal CPUE index for the 2009 – 2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate and the CPUE indices produced in 2016 (Dunn & Ballara 2019) and 2011 (Ballara & Horn 2015).

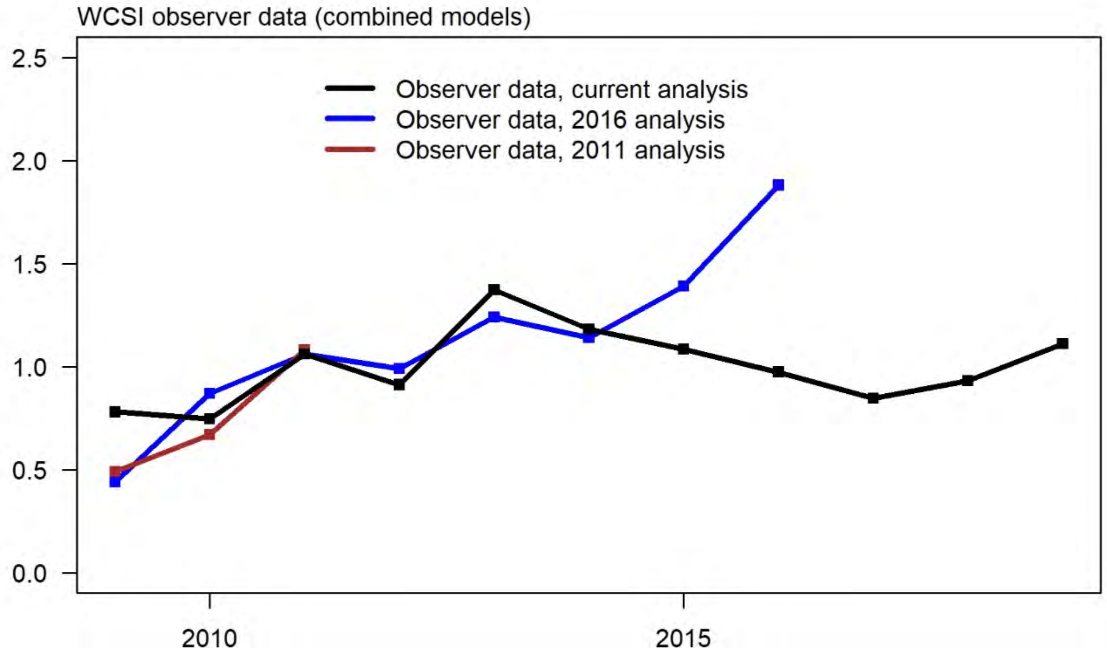

Figure 123: Comparison of the combined CPUE index for the 2009 – 2019 CPUE for observed tow-by-tow bottom trawl data with latitude offered as spatial covariate and the CPUE indices produced in 2016 (Dunn & Ballara 2019) and 2011 (Ballara & Horn 2015).