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Fishery characterisation and set net catch-per-unit-effort indices for flatfish in FLA 1, 1989–90 to 2010–11

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T.H. Kendrick
N. Bentley

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EXECUTIVE SUMMARY

Kendrick, T.H.; Bentley, N. (2012). Fishery characterisation and setnet catch-per-unit-effort indices for flatfish in FLA 1, 1989–90 to 2010–11.

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This study was contracted as MFish project INS2011-01 with the specific objectives:

1. To characterise the GMU 1 and FLA 1 fisheries.
2. To update the standardised CPUE index for grey mullet (GMU1) and flatfish (FLA1), with the inclusion of data up to the end of the 2009/2010 fishing year.

This report describes the flatfish fisheries only; the grey mullet fisheries are described in a separate report. Data were available up to the end of the 2010–11 fishing year, and the indices updated accordingly. FLA 1 is monitored using standardised CPUE for a core fleet of inshore vessels targeting flatfish species using the setnet method. Most catch is taken in harbours and it is thought that there is little likelihood of mixing of populations. Seven substock areas are defined but most flatfish are landed from the three harbours of Manukau, Kaipara and the Firth of Thames. The series were last updated to 2008–09 (MFish project FLA2008–01). This study updates the characterisation of the fishery and confirms that there have been no major changes to the way in which this fishery has operated in the three subsequent years. Most of the catch of FLA 1 continues to be taken in targeted setnet and reported on the daily Catch Effort Landing Return (CELR).

The standardised CPUE is based on estimated catch rather than landed catch: this was necessary because of the lack of species information for landed catch (i.e., almost all recorded as FLA) and also because a significant and increasing proportion of landings are coded to destination Q, meaning that they are retained ashore in a holding receptacle, which effectively breaks the link between landings and effort. Additional grooming of the data included correcting a considerable proportion of the records from the mid 1990s erroneously reporting zero catches due to a misunderstanding of the form

Recoding the statistical area according to the reported point of landing was done in the previous study to address concerns that statistical area boundaries had not been well understood or recorded by these fishers, but it had negligible effect on the year effects and was not repeated this time.

Substock areas and species assumptions defined in FLA2008–01 were not changed. The assumption has been made that most catch from west coast harbours consists of yellow-belly flounder (YBF), and estimated catches coded as either YBF or FLA have been combined and assumed to be YBF. That assumption is not valid for the northeast coast, and there were insufficient data to perform species specific analyses. The estimated catch was combined for all flatfish species and described as TOT. Separate analyses were able to be done for yellow-belly flounder and for sand flounder (SFL) in the Hauraki Gulf (catch that was coded as FLA was excluded from the analyses).

Improvements made to the analyses for this study include a suite of graphical diagnostics that give a clearer understanding of the influence of each explanatory variable on catches, a consideration of alternative error distributions which have led to improved residual diagnostics, and residual implied coefficient plots to investigate potentially confounding interaction effects not included in the model; for example, area by year interactions. The important fisheries comprise a single statistical area, but outside of the Kaipara and Manakau Harbours, adjacent areas have been combined due to paucity of data. In each case, the fishery has either been dominated by one of the areas, or areas demonstrate differences in year effects that suggest that combining them may not be advisable.

The previous study described tentative indications of recovery in most areas, but those increases have not been sustained. All fisheries, with the exception of Lower Waikato (which increases) and east

Northland (which is flat) show long-term declines, and standardised CPUE indices in both the Kaipara and Manukau Harbours are currently at the lowest seen in the study period.

The Hauraki Gulf yellow-belly series, which had increased from a point near the series low in 2001–02 to a level currently well above the long-term mean in 2007–08 has declined now over four consecutive years and sits just below the mean for the series . The sand flounder index in the Hauraki Gulf declined from a peak in the early 1990s to a low in the early 2000s and has stabilised at a level below the long-term mean.

The north-western and East Northland fisheries are small and geographically sparse, so that they are interpreted only with caution. The north-western series declines steeply from 2002–03 and is near the lowest level of the series. The East Northland series is almost flat.

Standardisation has not markedly changed the trajectory of catch rates observed in any of these fisheries and this indicates that the fisheries have operated and reported in a consistent manner and that the declines are a common experience across the fleet despite any differences in fishing practice.

1 INTRODUCTION

For management purposes nine species of flatfish: black flounder (BFL), brill (BRI), New Zealand sole (ESO), greenback flounder (GFL), lemon sole (LSO), sand flounder (SFL), turbot (TUR), witch (WIT) and yellow-belly flounder (YBF), are combined to form a single fishery. Flatfish (FLA) ITQ provides for the landing of all nine species. Since the introduction of flatfish into the QMS, fishers have been required to use the actual species code in the estimated catch section of catch effort forms, and the degree to which they have complied has improved steadily. For FLA 1, Coburn & Beentjes (2005) first described adequate times series of catch effort data for monitoring the main flatfish species (YBF and SFL separately) using setnet CPUE in the Hauraki Gulf. For other substock areas of FLA 1, series were presented based on the generic flatfish code (FLA).

Because the exploited populations of most flatfish species generally consist of only one or two year classes (brill and turbot are notable exceptions), the size of the populations depends heavily on the strength of the recruiting year class and is therefore expected to be highly variable. Catches of flatfish from FLA 1 have varied from below 600 t to over 1100 t since 1989–90 with peaks in the early 1990s and in the mid 2000s, but the TACC of 1187 t has never been taken (Figure 1). Flatfish TACCs were deliberately set at high levels so as to provide fishers with the flexibility to take advantage of the perceived variability associated with annual flatfish abundance.

CPUE analyses presented for FLA 1 (Coburn & Beentjes 2005) revealed that inter-annual abundance of yellow-belly flounder in FLA 1 was surprisingly stable however, suggesting that some factor, e.g., size of estuarine nursery area, could be mitigating the impact of environmental effects on egg and larval survival. They described a relationship between the abundance of sand flounder and sea surface temperature (SST) at the time of spawning (two years before fish are caught). They also demonstrated marked differences in the CPUE trajectories between the two most important commercial species (yellow-belly and sand flounders) emphasising the importance of monitoring abundance for each species separately.

The series derived in that study were updated to the end of the 2008–09 fishing year (Kendrick & Bentley 2011) with minor changes to sub-stock areas including dropping the Bay of Plenty series. Catches from the two main fisheries on the west coast – i.e., the Kaipara and Manukau harbours - are comprised almost entirely of yellow-belly flounder, so catch recorded as FLA was assumed to be YBF. The main fishery on the east coast (Hauraki Gulf) catches both yellow-belly and sand flounder; and as a result species specific series were calculated, and the catch and effort data recorded using the generic FLA code were excluded.

In this study the four main FLA 1 CPUE series –Manukau (assumed YBF), Kaipara (assumed YBF), Hauraki Gulf (reported YBF), and Hauraki Gulf (reported SFL) – are updated to 2010–11. Series for smaller fisheries (northwestern, northeastern and lower Waikato areas), although less reliable, are also presented.

2 DATA SOURCES AND METHODS

Catch and effort data extracted from the research database '*warehou*' were defined by trips that landed to Fishstock FLA 1 or that estimated a catch of any of the suite of flatfish codes (including a few that are commonly used in error; BFL, BLF, BRI, ESO, FLA, FLO, GFL, LSO, SFL, SOL, TUR, WIT, YBF) or that used the setnet (SN) method in any statistical area valid for FLA 1 (QMAs 1 and 9) and targeted one of the above species. All data for the trips thus defined were obtained with no restriction on fishing method, statistical area, or target species. All landings data associated with the defined trips (from the bottom part of the CELR or from CLR forms) were also obtained.

FLA 1 is a well reported Fishstock with more than 80% of landings being estimated (as required for the top five species in the catch) (Table 1). Most FLA 1 catch is reported on the daily Catch Effort Landing Return (CELR), and all setnet catch up to 2006–07 was reported on CELR forms. Even though a new setnet catch effort form (NCELR) was introduced in 2006–07, most of the vessels participating in this fishery are small enough to be exempt from using the new form, with the result that catch and effort data for setnet activity targeted at flatfish continues to be almost entirely reported on CELRs. The small quantity of NCE format data (3.4% in 2006–07, decreasing to 0.5% in 2010–11) which records activity for every individual set rather than for a day's fishing, did not warrant amalgamating to trip-stratum resolution to make it compatible with CELR format data as most daily records in this fishery represent one set regardless of the form used. Data were therefore analysed at the resolution in which they were recorded.

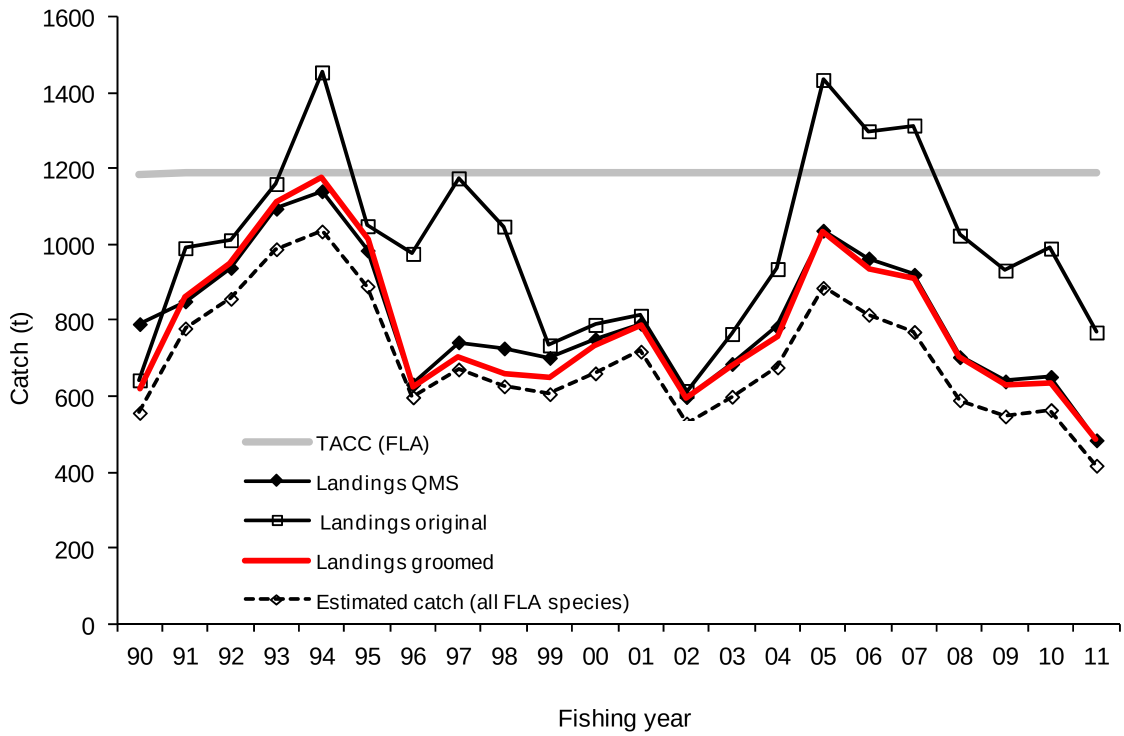

Figure 1: Landings of FLA 1 and TACC (tonnes) from 1989–90 to 2010–11 reported to the QMS (from Ministry of Fisheries 2010), compared to the landings (before and after grooming) and annual estimated catches of all flatfish species, in the analysis dataset. Year is fishing year (e.g. 99 = 1 Oct 1998 to 30 Sep 1999).

Table 1: Landings and TACC for FLA 1 (t), percent of landings estimated, estimated catch by species in tonnes and as a percent of total estimated catch for all flatfish species codes by fishing year. Estimated catch of FLA has been corrected for false zero catches[1].

Fishstock		FLA 1	Estimated								
FMA (s)	QMS	1 & 9	catch as	Estimated catch (t)				Estimated catch (%)			
	Landings (t)	TACC (t)	% of landings	FLA	YBF	SFL	Other	FLA	YBF	SFL	Other
89/90	791	1 184	70	557	0	0		100	0	0	
90/91	849	1 187	92	517	153	69	41	66	20	9	5
91/92	940	1 187	91	584	157	78	37	68	18	9	4
92/93	1 106	1 187	89	616	178	140	55	62	18	14	6
93/94	1 136	1 187	91	488	216	290	41	47	21	28	4
94/95	964	1 187	92	449	238	171	32	50	27	19	4
95/96	628	1 187	95	387	118	76	16	65	20	13	3
96/97	741	1 187	91	444	130	66	32	66	19	10	5
97/98	728	1 187	86	411	136	50	30	66	22	8	5
98/99	690	1 187	88	356	173	42	36	59	29	7	6
99/00	751	1 187	88	333	237	63	29	50	36	9	4
00/01	792	1 187	91	373	278	46	21	52	39	6	3
01/02	596	1 187	89	294	196	27	12	56	37	5	2
02/03	686	1 187	87	323	234	22	21	54	39	4	4
03/04	784	1 187	86	372	253	33	18	55	37	5	3
04/05	1 038	1 187	85	441	340	77	28	50	38	9	3
05/06	964	1 187	85	418	265	88	45	51	32	11	6
06/07	920	1 187	84	491	203	41	36	64	26	5	5
07/08	705	1 187	84	369	174	19	21	63	30	3	4
08/09	640	1 187	86	331	179	21	18	60	33	4	3
09/10	652	1 187	87	348	186	18	13	62	33	3	2
10/11	485	1 187	86	256	144	10	8	61	34	3	2

1 Due to a misunderstanding of the CELR form, estimated catch by species was left blank by some fishers when the catch consisted entirely of the target species (See section 1.1.2).

2.1 Methods used for grooming and collation of catch and effort data

Landings, estimated catch, and associated effort were all groomed separately. Outlier values in the landings data were identified by finding the trips with very high landings for flatfish based on verified maximum values supplied by the Ministry of Fisheries data unit. The effort data for these trips were then used to calculate the trip CPUE and the associated estimated catch was also examined. Trips which had a ratio of landed to estimated catch which exceeded 4 and a CPUE which exceeded two times the 95th percentile of the trip CPUE distribution for the entire dataset were excluded from the analysis.

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

For the CPUE standardisation part of this study, records for which any field had been corrected or replaced during grooming were dropped.

2.1.1 Landed greenweight versus estimated catch

The utility of the Starr (2007) methodology, which allocates landed catch to effort data, was evaluated by examining the landings data and comparing them on a trip by trip basis with the estimated catch. The Starr methodology is the preferred approach for collating catch effort data in New Zealand inshore fisheries because it uses verified greenweight reported by the permit holder against quota, and provides an elegant method for combining data across form types. For this study, however, the decision was made to characterise and standardise the estimated catches rather than the landed catches.

The evaluation involved a consideration of the reporting rate for the species (the proportion of landings that are estimated) and any trends in that statistic, but also the species information available and an examination of the linkage between landings (available only at the end of the trip) and catch effort records. Landed greenweight was mostly (69%) recorded using the generalised flatfish Fishstock code FLA 1. Very few records reported YBF 1 or SFL 1 (1% each). Further, there was a disproportionate amount of landed GFL 1 (29%) which is the code for green flounder (Table 2). This was almost certainly an error as that species is described only rarely in the estimated catch. Examination of the use of this code attributed it almost entirely to one fisher operating in Statistical Area 007. Estimated catch was more informative with respect to species (27% YBF and 9% SFL by weight) but even so, the majority of catch (60%) was estimated using the generalised FLA code (Table 3).

A greater problem with the landings data was the large and increasing proportion (up to 35% in recent years) of FLA 1 landed to destination code “Q” (Table 4). The use of this code signals that fish are held in a receptacle ashore (for example a freezer) and ‘landed’ to a Licensed Fish Receiver (LFR) at a later date. This effectively breaks the link between catch effort and landings information because when the fish are subsequently ‘landed’ to a LFR (destination code “L”) they are not identified as having been caught on a previous trip. Apart from the obvious potential for double counting (see the landings before grooming in Figure 1), this practice means that no landed catch can be associated with any particular fishing trip with confidence, and the Starr methodology, which drops landings coded to destination “Q” is not appropriate. Examination of the distribution of this code showed the practice to be widespread across operators and areas. For these reasons, and because only data in one form type (CELR) are relevant to the study, the analyses were done on estimated catch rather than by allocating landed catch.

Table 2: Species information (Fishstock code) in the ungroomed landings data, % by weight.

Species code	Landed catch (t)	Number records	% (wgt)
FLA	21 983	316 344	69
GFL	9 274	1 193	29
YBF	283	5 642	1
SFL	270	7 141	1
ESO	68	2 844	0
BRI	17	1 956	0
LSO	7	563	0
SOL	6	395	0
TUR	3	284	0
BFL	0	66	0
FLO	0	74	0

Table 3: Estimated catch by species

Species code	Estimated catch (t)	Number records	% (wgt)
FLA	9 159	171 866	60
YBF	4 187	92 254	27
SFL	1 450	50 373	9
GFL	243	4 292	2
ESO	203	5 561	1
LSO	80	2 726	1
BFL	39	802	0
BRI	21	2 148	0
TUR	5	261	0
SOL	3	174	0
FLO	1	20	0
WIT	0	10	0
SDF	0	1	0

Table 4: Percentage of landed FLA 1 in the unedited file by destination code and fishing year. L, landed to an LFRR; W, wharf sale; Q, Held in a receptacle onshore.

Fishing	Destination code			
year	L	W	Q	Other
89/90	96	4	-	0
90/91	94	4	-	2
91/92	96	3	-	0
92/93	97	3	0	0
93/94	80	20	-	0
94/95	97	2	-	1
95/96	96	2	-	2
96/97	90	9	-	1
97/98	100	0	-	0
98/99	92	7	-	1
99/00	97	2	-	1
00/01	96	3	0	1
01/02	95	3	2	0
02/03	88	2	9	0
03/04	80	2	17	1
04/05	72	1	26	1
05/06	72	2	26	0
06/07	69	2	29	0
07/08	69	2	29	0
08/09	66	2	32	0
09/10	63	2	35	0
10/11	63	2	35	0

2.1.2 Grooming of estimated catch for false zero (estimated) catches

A target fishery would normally record few zero catches , but the data recorded for the setnet method in the mid 1990s include an anomalous peak of zero catches (about 10% of records) that were identified as false zeros during an analysis of grey mullet catch effort data (involving many of the same vessels) by McKenzie & Vaughan (2008). In these records, there were no estimated catches recorded in the columns for the top five species caught, yet there was a positive value reported in the ‘total catch’ field. It appears that when the entire catch consisted of the target species, fishers felt that duplicating that value (in estimated catch of individual species) was unnecessary.

The estimated catch of FLA was corrected to equal the total catch where the method was setnet, the target species was among the suite of flatfish species codes, and the estimated catches for all flatfish species were zero, but the total catch was not zero. This scaled up the total estimated catch (TOT) of all flatfish species combined, and was also assigned to the generalised FLA code, but could not be allocated to individual species.

This correction turned out to be important in most areas, although not always for the core fleet selected for CPUE analysis. The effect of grooming was to increase the data available in the mid-1990s, with various but slight effects on the CPUE indices. The effect on the dataset for Hauraki Gulf was not great, and the additional data could not be included in the species-specific CPUE standardisations for that substock.

2.1.3 Grooming of estimated catch for poor statistical area reporting

McKenzie & Vaughan (2008) also found considerable misunderstanding among small vessel operators in the grey mullet setnet fishery regarding statistical area boundaries. They corrected the field using port of landing information. The port of landing field includes multiple spellings, local place names and other errors, and grooming the field involves considerable work. It is also somewhat subjective. In many cases, especially for the northwestern areas, Auckland was listed as the port of landing and probably meant that the catch was uplifted by truck and transported to LFRRs in Auckland. McKenzie & Vaughan used discretion in correcting statistical area on the basis of port of landing, but they could not say how much effect it had. Kendrick & Bentley (2011) re-allocated the data to substock on the basis of the port of landing without any discretionary exceptions to assess the extreme possible effect of this grooming procedure. The procedure effected little change to the datasets, or to the annual indices, and the NINSWG agreed that it probably did not warrant being repeated.

2.1.4 Definition of substock areas

Previous work defined seven substock areas that are largely based on harbours but otherwise combine several adjacent statistical areas. Changes to the substock definitions made in FLA2008–01 included dropping the Bay of Plenty due to paucity of data, and combining Statistical Areas 005, 006, and 007 into one zone (Hauraki Gulf). These were used this study without further change (Table 5). The estimated catches and number of vessel-days in each substock area are given in Appendix A.

Table 5: Definition of FLA 1 substock areas used in the characterisation and CPUE analysis.

Substock area	Description	Statistical Areas
NW	Northwest coast	045 – 047
KH	Kaipara Harbour	044
MH	Manukau Harbour	043
LW	Lower Waikato	041 and 042
HG	Hauraki Gulf	005 – 007
EN	East Northland	002 and 003

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

2.2.1 Species definitions

The catch from the west coast harbours that is reported using species codes is almost entirely YBF, and this is considered likely to represent reality as it is supported by anecdotal information and the fact that most of the substrate in west coast harbours is mud, which favours yellowbelly flounder and not sand flounder. Estimated catches from Northwest, Kaipara, Manukau, and lower Waikato substocks that were coded FLA or YBF were therefore combined and assumed to be YBF.

No such assumption could be made for the east coast, and all estimated flatfish species codes for northeast were combined and described as TOT.

In the Hauraki Gulf, there was a greater use of species codes YBF and SFL to describe the estimated catch, and, because of the relative importance of the SFL fishery in that region, separate analyses were done for YBF and for SFL. The considerable amount of catch coded as FLA was excluded.

2.2.2 Definition of fisheries

The fisheries defined for standardised CPUE analysis comprised set-net events that targeted any of the flatfish species in the substock areas described in Section 2.1.4. The fisheries and the resultant CPUE series are described by the species code and the substock code. Where the species is assumed rather than reported it is bracketed. For example, (YBF) KH means positive estimated catches of either FLA or YBF (assumed to be YBF) from the setnet fishery in Kaipara Harbour (Statistical Area 044).

YBF–HG means positive reported estimated catches of yellow-belly flounder from the setnet fishery in the Hauraki Gulf (Statistical Areas 005–007).

2.2.3 Core fleet definitions

The data sets used for the standardised CPUE analyses were further restricted to those vessels that participated with some consistency in the defined fishery. Core vessels were selected by specifying two variables: the number of trips that determined a qualifying year, and the number of qualifying years that each vessel participated in the fishery. The effect of these two variables on the amount of landed flatfish retained in the dataset, and on the number of core vessels, was plotted and examined visually (Appendix B).

The core fleet was selected by choosing values of the two variables that resulted in the fewest vessels while maintaining the largest catch of flatfish. This selection process generally reduced the number of vessels in the dataset by about 70% while reducing the amount of landed flatfish catch by about 20%. Note that the vessels thus selected are not necessarily the top vessels with respect to catching flatfish. Vessel participation was plotted for each fishery and examined for adequate overlap across years and consistency of coverage through the time series (Appendix B).

2.2.4 Models

It is general practice when analysing catch and effort data for New Zealand fisheries to exclude the zero catches if they represent 5% or fewer of the records available for analysis. There are few zero catch records for flatfish in the defined fisheries, and only the positive records were standardised.

The family of model was selected by fitting saturated models (for simplicity) that assumed alternative error distributions, to positive estimated catches and comparing the resultant log likelihoods and residual patterns. The most appropriate family of model was then used in the selection of significant explanatory variables.

Catches were standardised for variance in the explanatory variables using a stepwise multiple regression procedure, selecting until the improvement in model R^2 was less than 0.01. The year effects were extracted as canonical coefficients (Francis 1999) so that confidence bounds could be calculated for each year. The dependent variable for the lognormal models based on estimated landings was the log of catch per record. Records were a day or part day of fishing as reported on CELRs and were used in their original resolution. The explanatory variables offered to the model were: *fishing year* (always forced as the first variable), and *month* (of catch), *statistical area*, *mesh size*, and a unique *vessel* identifier. The logs of the total *length of net* and of *duration* were offered as alternative measures of effort to explain catch as a catch rate. Continuous effort variables were offered as third order polynomials. Environmental variables that were also offered in earlier exploratory work as third order polynomials included *moon phase*, sea surface temperature (*SST*) and *Annual SST Anomaly*. These were not accepted into preliminary models and were dropped in later runs described here.

3 RESULTS

3.1 FLA 1 fisheries

Most flatfish species in FLA 1 are caught by setnet (more than 94% in most years with the exception of three years in the early 1990s) and reported on CELRs. A small amount, less than 4% in each year, is taken in bottom trawl (BT), and generally less than 4% in each year by Danish seine (DS), with the exception of three years in the early 1990s when Danish seine accounted for 10–15% or about 100 tonnes, of FLA 1 (Table 6). The trawl and Danish seine catch is mostly a bycatch of fisheries for snapper, gurnard, rig, trevally, and John dory, but flatfish are also occasionally targeted by these methods. Methods other than setnet are not examined in any further detail.

3.1.1 Characterisation of FLA 1 setnet fisheries

The setnet effort for which estimated catches of flatfish are reported is mostly targeted at flatfish species. The generalised FLA code is most often used for the target species field (84 to 95% of estimated catch by weight), but YBF was also commonly used during the late 1990s and early 2000s when it accounted for over 10% of the setnet catch of flatfish in each year. The rig (SPO) setnet fishery reports about 1% (less than 10 t) per year, and some catch is reported as a bycatch of setnet targeted at snapper, red gurnard, and trevally; with even smaller amounts (usually less than 1 t per year) taken from the grey mullet fishery (Table 7).

The distribution of flatfish catches by statistical area is shown in Figure 2 and emphasises the relative importance of the Hauraki Gulf (Statistical Areas 005 to 007), and the two west coast harbours; Kaipara (Statistical Area 044), and Manukau (Statistical Area 043). Off-shore areas (Statistical Areas numbered 100 and above and also Statistical Area 001) are unlikely to have supported genuine setnet effort and the catch recorded for those areas is probably misreported. Fishers sometimes mistakenly enter the QMA in the statistical area field giving a false reference to Statistical Area 001.

The distribution of setnet catches is more usefully described by substock area (as defined in Section 2.1.4) and is shown in Figure 3. The cyclical nature of catches in the main fisheries is evident and the declining catch in recent years is a common feature.

The uptake of the new setnet form (NCE) was less than 4% overall in the first year (2006–07) and has declined since then. The distribution of catch by form type is shown for each substock area in Figure 4, and shows that the use of NCE is restricted to East Northland and the Kaipara Harbour.

The estimated catch for all flatfish species caught by setnet, and setnet effort targeted at flatfish species, are compared across substock areas on a common scale in Figure 5.

On the west coast, catches of flatfish outside the two main harbours are small (less than 50 t per year). The northwest areas, north of the Kaipara Harbour (Statistical Areas 045 to 048) combine catches from some small harbours and from some open coastline and support between 500 and 800 vessel-days per year. Effort and catch have generally been declining in the northwest, but patterns are inconsistent at the statistical area level; with the relative importance of Area 045 declining and that of 046 increasing over the time series.

The setnet fishery south of the Manukau Harbour (041 and 042) is similarly small but more consistent. Areas 041 and 042 are grouped together and referred to as Lower Waikato. Both catches and effort have been increasing steadily over the time series.

Table 6: Distribution of estimated catches of flatfish (all species combined) by method and fishing year, in tonnes and percent of annual landings. Catches are raised to the annual QMR catch (Table 1). 0, less than 0.5 t.; SN, setnet; DS, Danish seine; BT, setnet.

Fishing	Fishing method (t)				Fishing method (%)			
year	SN	DS	BT	Other	SN	DS	BT	Other
89/90	778	4	7	3	98	1	1	0
90/91	830	10	6	3	98	1	1	0
91/92	884	48	6	3	94	5	1	0
92/93	982	106	14	5	89	10	1	0
93/94	937	176	18	4	83	15	2	0
94/95	855	98	10	1	89	10	1	0
95/96	591	16	20	1	94	3	3	0
96/97	710	17	13	1	96	2	2	0
97/98	705	16	6	1	97	2	1	0
98/99	681	2	5	3	99	0	1	0
99/00	742	1	4	4	99	0	1	0
00/01	781	1	4	7	99	0	1	1
01/02	589	2	3	2	99	0	1	0
02/03	676	3	5	2	99	0	1	0
03/04	763	11	8	3	97	1	1	0
04/05	996	12	22	8	96	1	2	1
05/06	910	22	24	9	94	2	2	1
06/07	862	27	19	11	94	3	2	1
07/08	667	9	16	14	95	1	2	2
08/09	620	3	14	3	97	0	2	0
09/10	637	2	12	2	98	0	2	0
10/11	469	3	12	2	97	1	2	0

The Kaipara Harbour is characterised by an initial seven year period of relative stability at about 3000 vessel-days per year and an annual catch of 150 to 190 t, this is followed by a two-fold increase in effort between 1995–96 and 2000–01 to a peak of almost 6000 vessel-days that was not matched by an equivalent increase in catch (Figure 5). Effort then declined steadily from that peak and in 2007–08 was similar to the level seen in the early part of the time series. Catch declined along with effort to reach its lowest level in 2005–06 of about 100 t (Figure 3). Catches increased along with effort over three consecutive years but have declined sharply in the two most recent years.

In the Manukau Harbour, a similar pattern but of a smaller magnitude is evident, with effort increasing by about 100% to its peak of almost 3000 vessel-days in 2000–01, and then declining to current levels which are near the lowest for the series (Figure 5). Catches did not increase after about 1993–94 to the same degree that effort did, but were maintained at an albeit lower level after 2005, despite declining effort (Figure 3). In the three most recent years effort and catches were the lowest of the study period.

The pattern of activity for east Northland varies in a 6–7 year cycle with a period of low catches and effort in the late 1990s followed by a steady increase to a peak in the mid 2000s followed by a subsequent decline (Figures 3 and 5). In the Hauraki Gulf, setnet effort targeted at flatfish species peaked in the early 1990s at more than 4500 vessel-days. It then declined by more than half over three consecutive years to 1995–96 in response to low catches, and was relatively stable at that level until the early 2000s. Effort and catch peaked again in 2005 and have declined in each year since then to be currently around the mean for the series.

The Bay of Plenty fishery is much smaller, almost 1000 vessel-days (for 40 t of catch) at its peak in 1995–96, but declining since then to the current level of less than 200 vessel-days for 14 tonnes of catch.

Table 7: Distribution of setnet caught flatfish (all species combined) as percent of annual catch, by target species (FLA, flatfish; YBF, yellow-belly flounder; SPO, rig; SNA, snapper and other) for fishing year.

Fishing	Target species (%)				
year	FLA	YBF	SPO	SNA	Other
89/90	97	0	1	2	1
90/91	89	6	1	2	2
91/92	92	4	1	1	2
92/93	91	3	1	1	3
93/94	90	4	2	2	2
94/95	90	7	1	0	1
95/96	88	10	1	0	2
96/97	88	9	1	0	2
97/98	88	10	1	0	1
98/99	87	11	1	0	1
99/00	84	13	1	0	2
00/01	87	11	1	0	1
01/02	87	11	1	0	1
02/03	91	8	0	0	1
03/04	91	8	1	0	0
04/05	91	7	1	0	1
05/06	87	7	1	0	5
06/07	91	5	1	0	3
07/08	95	4	1	0	1
08/09	92	4	1	0	2
09/10	93	5	1	0	1
10/11	93	6	1	0	0

The catch reported by species is compared across substock areas in Figure 6**.** As fishers reporting by species may theoretically fish differently to those using the generic code FLA to record estimated catch, the species proportions may not be representative of the landings in each area. They nevertheless do provide some indication of species diversity, and support anecdotal information that most catch from west coast harbours is likely to be yellow-belly flounder. For west coast areas most catch is described by the generalised FLA code, with most of the balance reported as yellow-belly flounder (YBF).

There are complete time series of catch for sand flounder (SFL) only in the Hauraki Gulf and in the Bay of Plenty, though the actual tonnage in the Bay of Plenty is very small, only 10–30 t per year in the peaks, with a period of less than 2 t per year in the early 2000s. The Hauraki Gulf catches also include small amounts of greenback flounder (GFL). The considerable amount of “other” flatfish species reported from the Bay of Plenty are mostly New Zealand sole (ESO) and lemon sole (LSO), and were reported in almost equal amounts (less than 10 t each per year) until 2003–04. Since then, there has been negligible reported catch of ESO coincident with a strong spike of LSO (up to 30 t in 2006–07). The wider range of species reported in the catch from the Bay of Plenty makes any assumptions about the composition of catch coded to FLA spurious; likewise in the Hauraki Gulf where catches coded to YBF have increased while catches coded to SFL have decreased over the time series, the FLA catch cannot be assumed to be informative on its own, nor to add to our understanding of trends in the abundance of either of the main species caught there. The east Northland fishery is widely spread across several discrete harbours and coastal areas (Mangonui, Whangaroa, Houhora, Rangaunu Harbour, Karikari Peninsula, Doubtless Bay). It also catches both YBF and SFL, although they are not reported in large enough quantities to analyse separately.

For west coast areas where very little of any species other than yellow-belly has been recorded since 1989–90, it is reasonable to assume that the catch coded to FLA is yellow-belly flounder. Missing estimated catches (false zeros, see Section 2.1.2) during the late 1990s can only be assigned to the generalised FLA code and are therefore informative only for the west coast areas. Fortunately, in the Hauraki Gulf where the correction cannot be applied to either YBF or SFL, the incidence of false zeros was small.

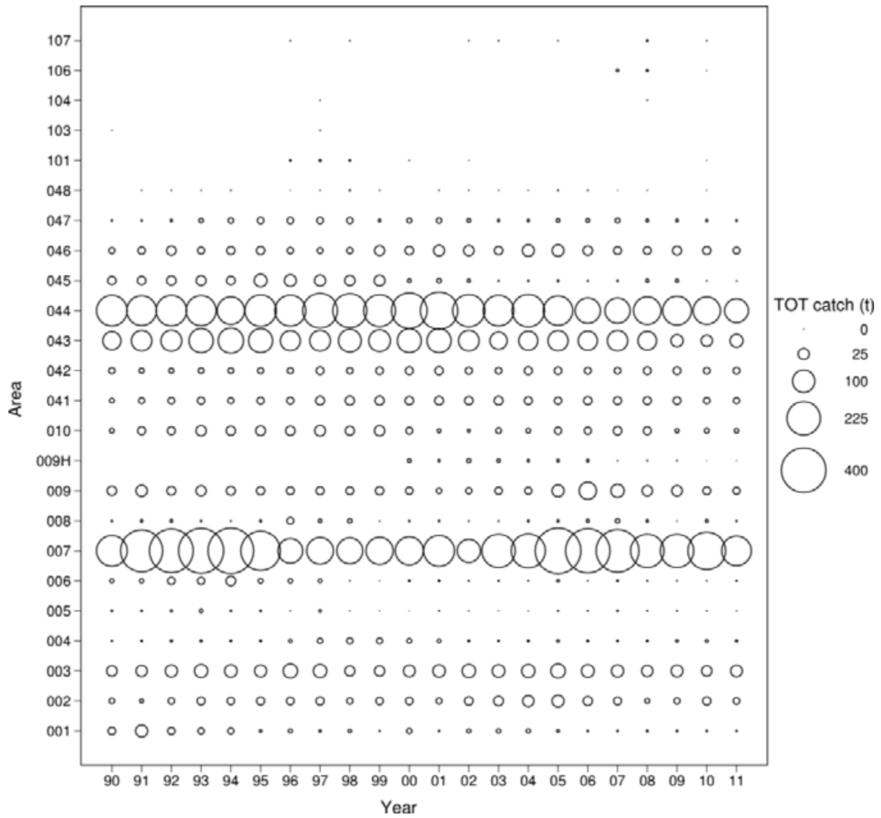

Figure 2: TOT catch (t) of all flatfish species by statistical area and fishing year for the setnet method (SN) regardless of target species.

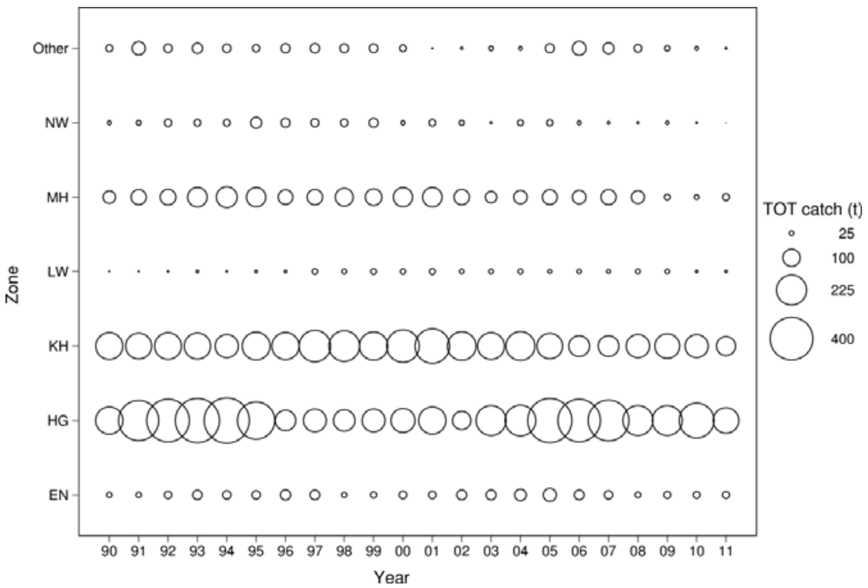

Figure 3: TOT catch (t) of all flatfish species combined, by year and substock zone for the setnet method SN (regardless of target species). Years are fishing years (e.g. 99 = 1 Oct 1998 to 30 Sep 1999).

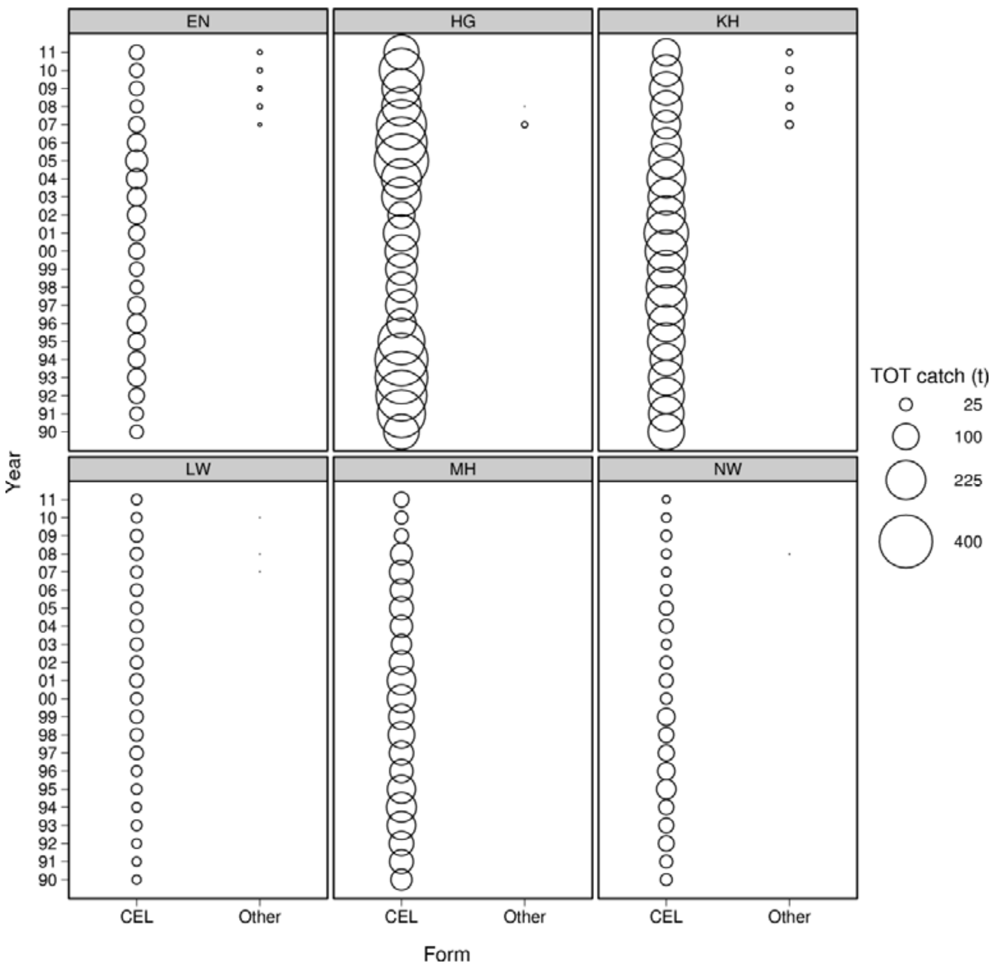

Figure 4: TOT catch (t) of all flatfish species combined, by year and form type for the setnet method SN. Other includes the new set net form (NCE). Years are fishing years (e.g. 99 = 1 Oct 1998 to 30 Sep 1999).

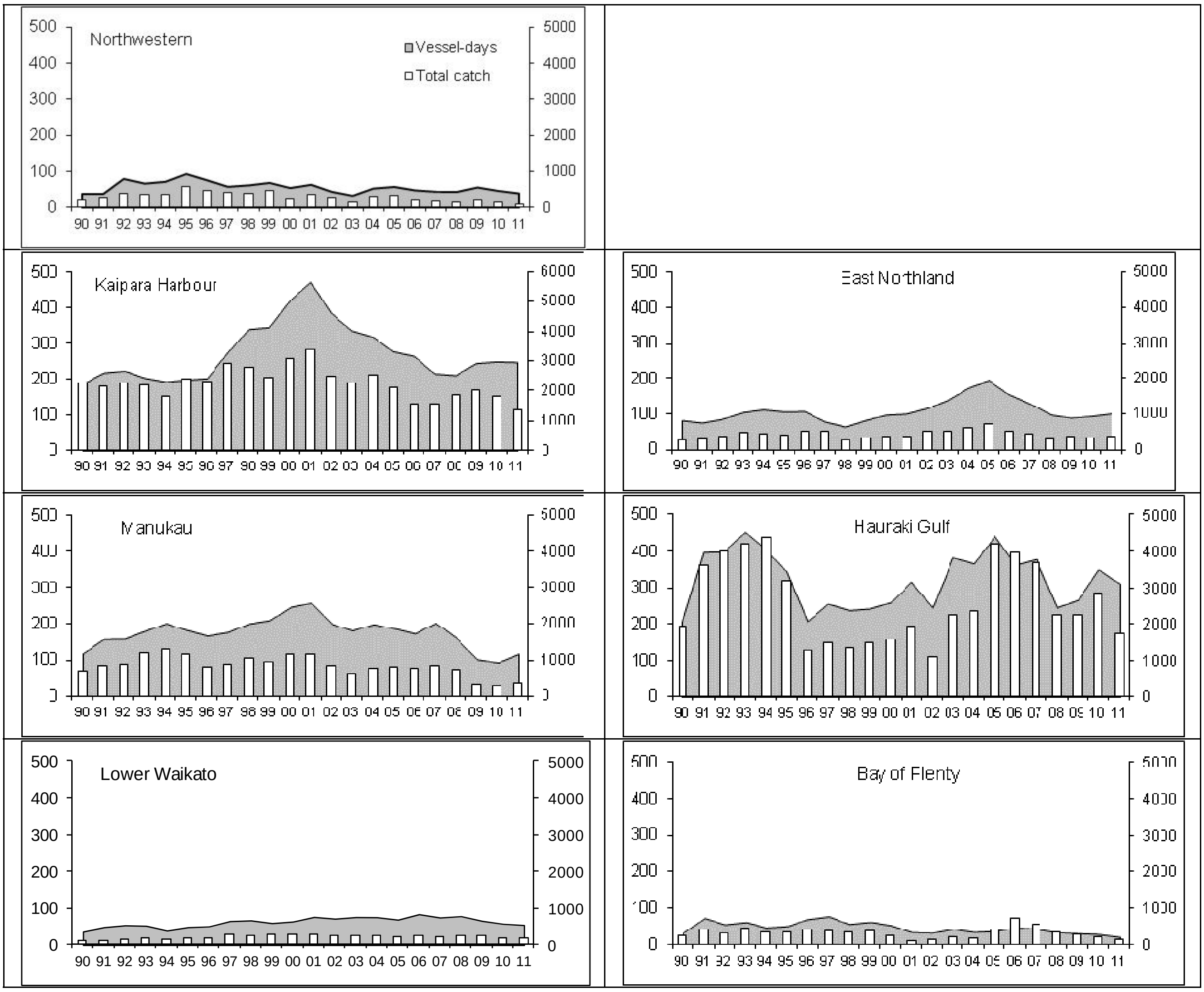

Figure 5: Effort (vessel-days, shaded area, right-hand axis) for setnet effort targeted at flatfish species, and estimated catch (tonnes, bars, left-hand axis) of all flatfish species in substock areas of FLA 1; Years are fishing years (e.g., 99 = 1 Oct 1998 to 30 Sep 1999). Data are given in Appendix A.

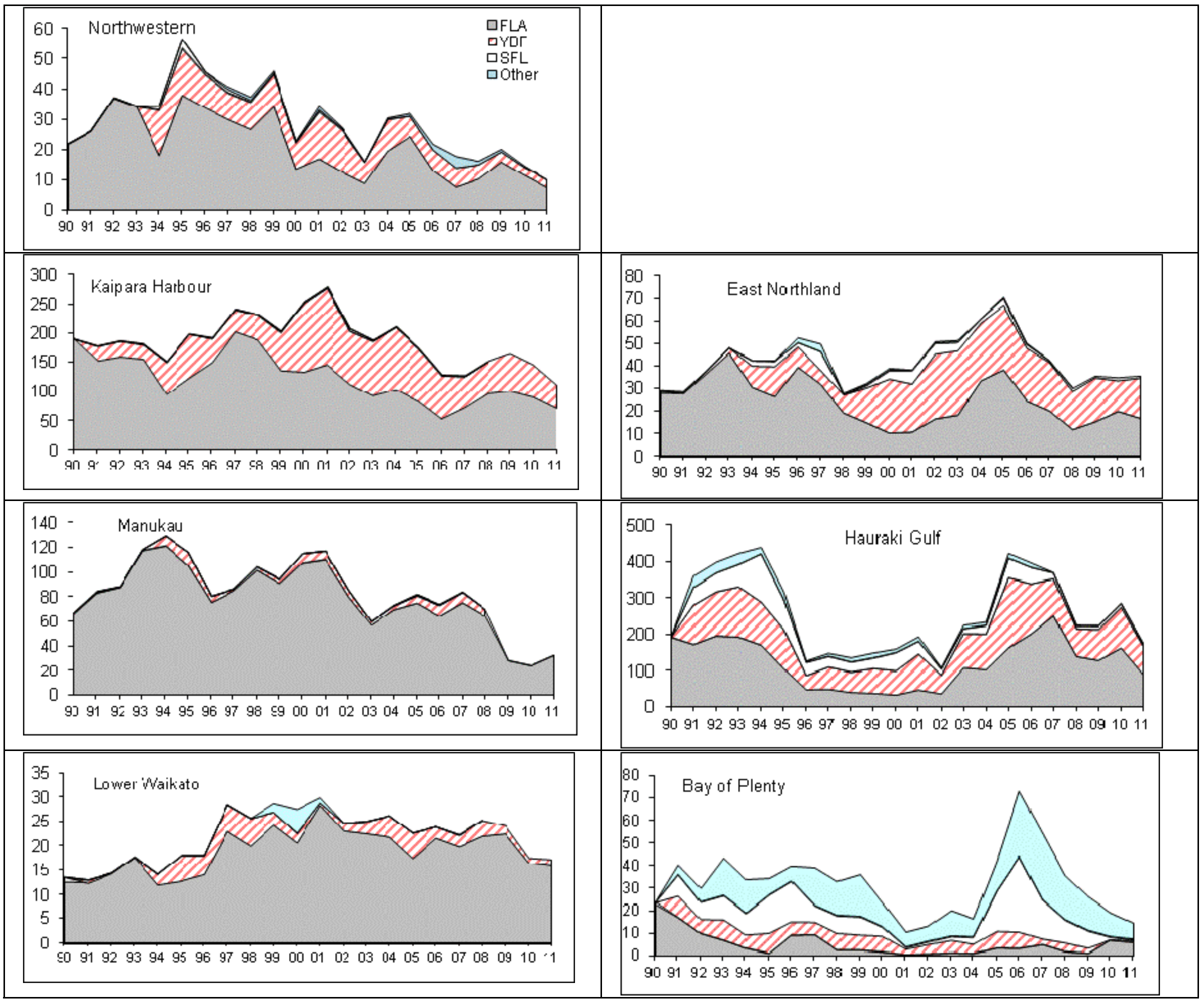

Figure 6: Reporting of estimated catch (t) by species YBF, SFL, and other, compared with the use of the generalised code FLA for setnet regardless of target species in substock areas of FLA 1; The correction to estimated catch for false zeros was assigned to FLA. Species other than FLA, YBF, and SFL accounted for less than 5% by weight in the entire dataset, in the Bay of Plenty they consist mainly of LSO and ESO. Note the different vertical scales used. Years are fishing years (e.g., 99 = 1 Oct 1998 to 30 Sep 1999). Data are given in Appendix A.

The seasonal distribution of yellow-belly flounder catches in each substock area (Figure 7), shows a focus on the first half of the fishing year in the Hauraki Gulf, from November to May, whereas in other substocks YBF is reported more consistently throughout the year. The seasonal aspect of yellow-belly catches in the Hauraki Gulf is a characteristic of the whole time series (Figure 8) except for a very few years, in which winter catches have been more important.

There is similar seasonal distribution of catch for sand flounder (Figure 9 and 10), with catches fairly evenly distributed throughout each year in the Hauraki Gulf, except for a fall-off after June. This is despite a well documented greater availability of sand flounder in winter months (McKenzie & Vaughan (2008), and see Section 3.2.2 . The seasonal pattern of catches of both species being higher during the summer months suggests the focus of the fishery is yellow-belly flounder (and has been since 1989–90), with sand flounder being largely a bycatch of that effort.

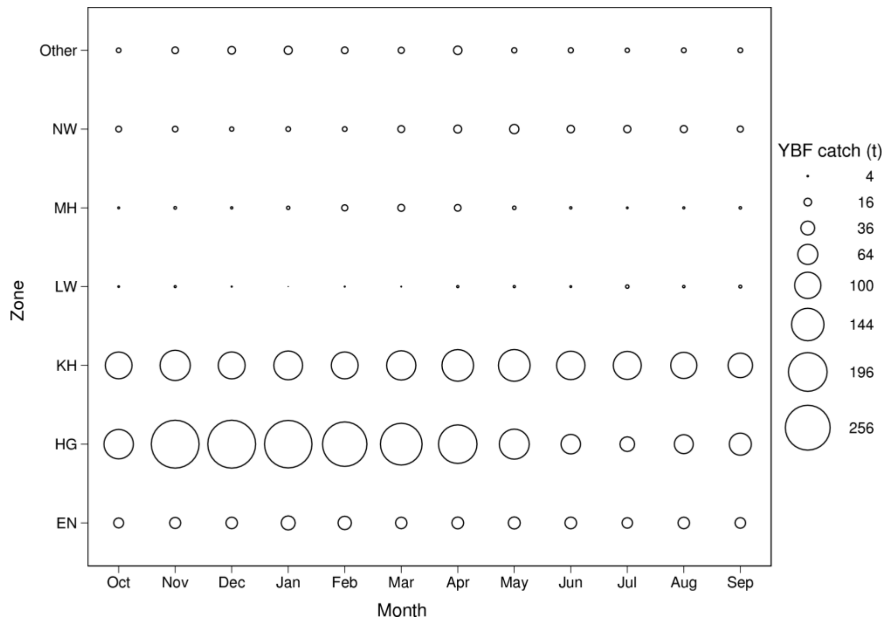

Figure 7: Estimated catch (t) of yellow-belly flounder (YBF) by zone and month for method SN regardless of target species.

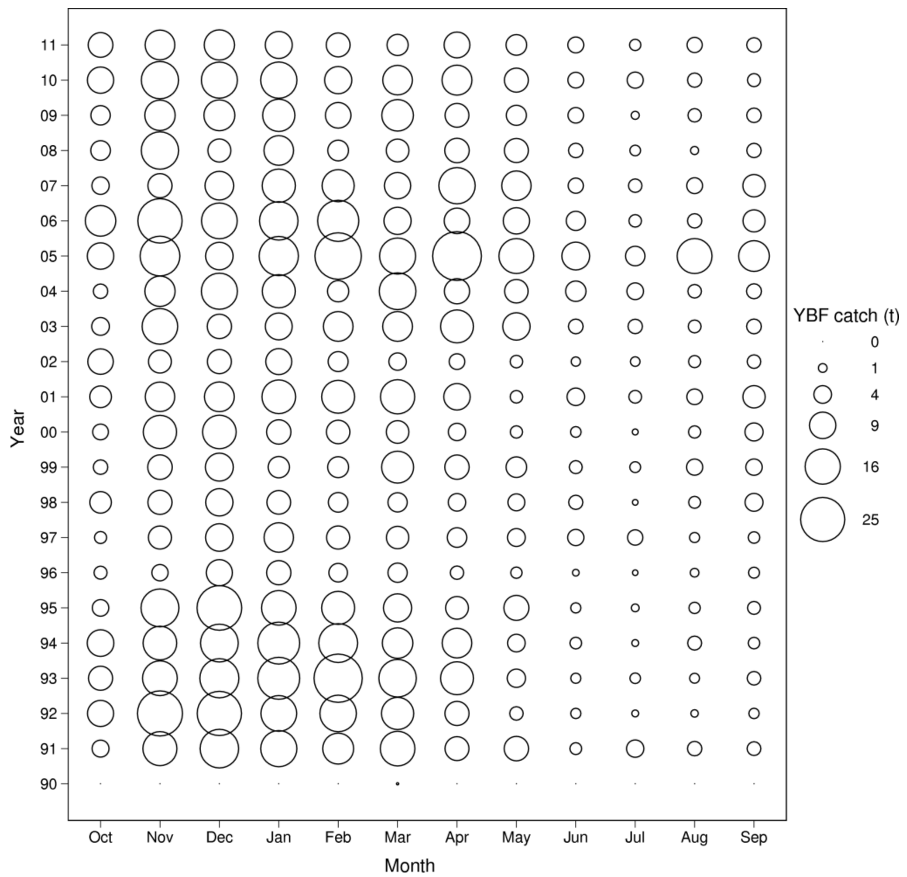

Figure 8: Estimated catch (t) of yellow-belly flounder (YBF) in Hauraki Gulf by month and year for method setnet (regardless of target species).

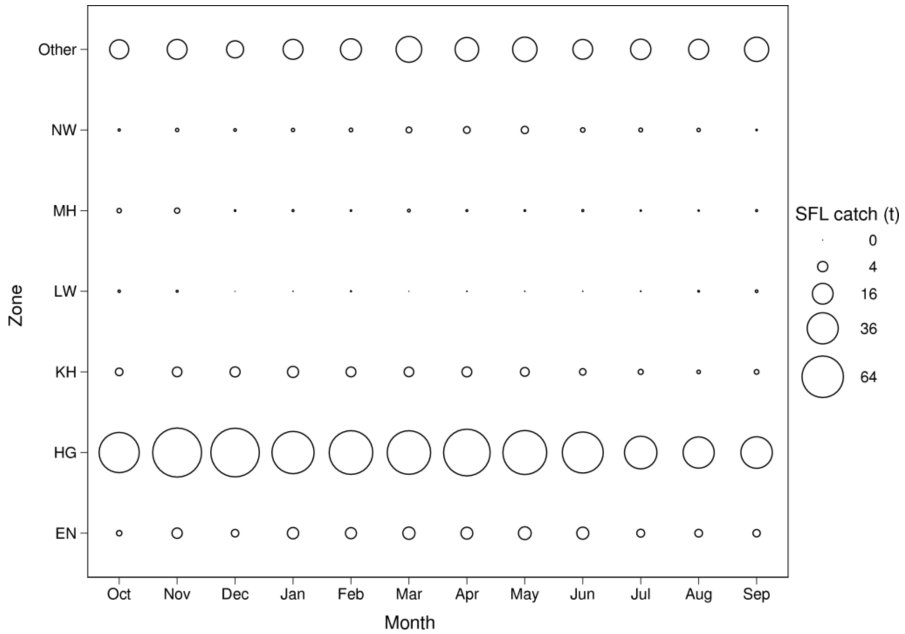

Figure 9: Estimated catch (t) of sand flounder (SFL) by zone and month for method SN regardless of target species.

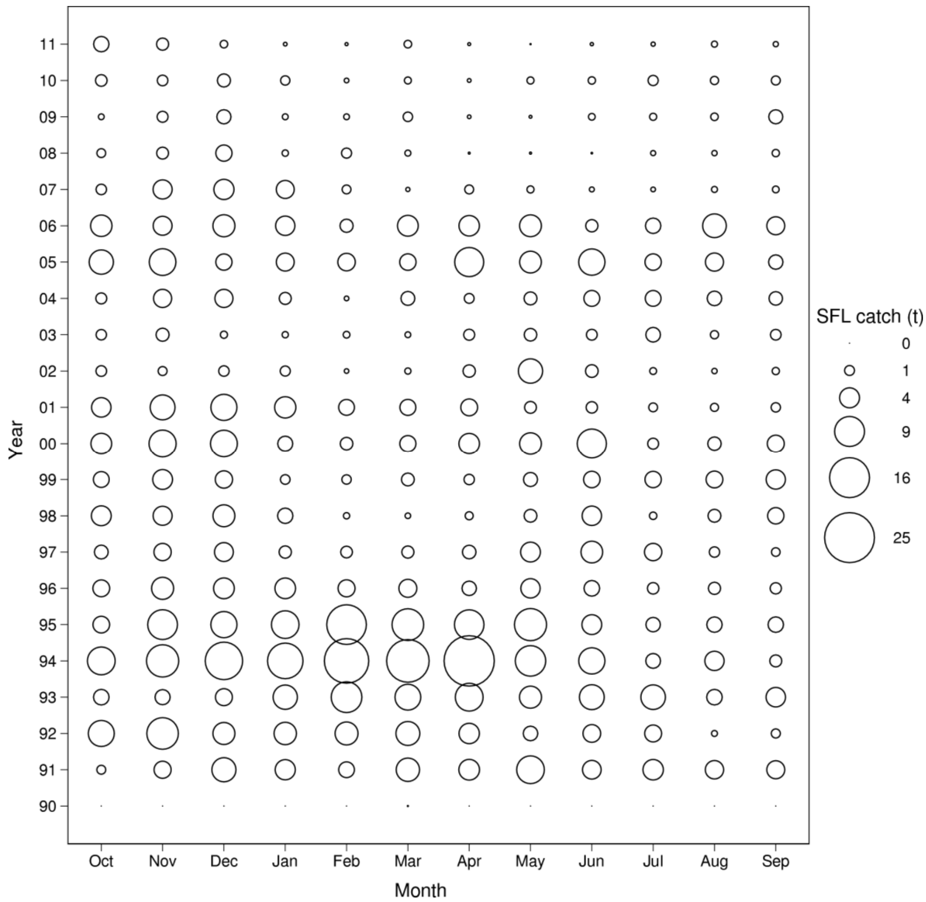

Figure 10: Estimated catch (t) of sand flounder (SFL) in Hauraki Gulf by month and year for method SN (regardless of target species).

3.2 Standardised CPUE analysis

3.2.1 Fishery definitions

Seven separate series are defined for CPUE analysis and are described by a combination of species codes –YBF, SFL, TOT or (YBF), where the brackets denote that the species YBF has been assumed, rather than reported (i.e., consists of FLA as well as YBF) – and substock area (Table 8). In all cases the method is setnet, the target is any flatfish species, and the catch is the estimated catch in statistical areas valid for the substock area (See Table 5). Only positive catches were retained for analysis and the small proportion of zero catch records was excluded.

Table 8: Summary of fisheries defined and models applied in this study.

Fishery Label	Description	Lognormal
YBF_HG	Hauraki Gulf YBF	Y
SFL_HG	Hauraki Gulf SFL	Y
(YBF) NW	Northwest FLA+ YBF	Y
(YBF) KH	Kaipara Hb FLA+YBF	Y
(YBF) MH	Manukau Hb FLA+YBF	Y
(YBF) LW	Lower Waikato FLA+YBF	Y
TOT_EN	East northland All species	Y

These fisheries typically consist of a large number of small vessels and the selection of core fleets from each fishery is described in Appendix A. In each fishery there has been consistent participation by many vessels across time and an influx of new entrants in the early 2000s. An adequate overlap of vessels across years is demonstrated in most fisheries (northwest being the exception).

3.2.2 Model selection, diagnostics, and trends in year effects

The choice of most appropriate error distribution was made by fitting saturated models to positive catches assuming alternative error distributions of the exponential dispersion family, including log-logistic, gamma, weibull, and inverse Gaussian. The resultant log likelihoods and residual distribution plots were compared, and a stepwise selection of explanatory variables was then done using the best error distribution and an appropriate model family. For the flatfish fisheries defined in this study the best fit was generally obtained by assuming a log logistic error distribution and was fitted using a 'survival' model. The diagnostics plots for alternative distributions are shown in Appendix C.

The final models selected for each fishery are described in Tables 9 to 15. These tables include those explanatory variables that met the AIC criteria and are not necessarily a complete list of the variables that were offered. The variables that met the acceptance criteria based on a 1% improvement in R^2 are indicated with asterisks in the table, along with the amount of deviance they explained. Coefficient-Distribution-Influence (CDI) plots (Bentley et al. (2011), which describe the influence of each selected variable on observed catches, are given in Appendix D.

Diagnostic plots of the residuals from each final model fit are given in Appendix E and show reasonable fits through the range in which most of the data occur. Potentially confounding interactions between fishing year and statistical area (for those fisheries that included more than one statistical area) were investigated by plotting residual implied coefficients for each area in each year and are given in Appendix F.

The models generally explained 30 to 40% of the variance in catch and included vessel ID as the factor with greatest explanatory power followed by a measure of effort; variously net length or duration (soak time), or in many cases, both. Month was also accepted into most models. In no case did target species, mesh size, or statistical area have significant explanatory power.

Following each model summary table are step-influence plots that demonstrate the progressive effect on the annual indices as each explanatory variable enters the model, and compare the influence of each variable on observed catch (which the model adjusts for), in adjacent panels. This plot highlights the observation made by Bentley et al. (2011) that the variables that explain the most deviance are not necessarily the ones responsible for most of the difference between standardised and nominal series of CPUE. The influence of an explanatory variable is a combination of its GLM coefficients and its distributional changes over years, and can be examined in more detail in the Coefficient-Distribution-Influence (CDI) plots (Bentley et al. (2011), that are given in Appendix D for each explanatory variable accepted into each model.

The time series of year effects from the models are then plotted, along with the unstandardised arithmetic CPUE (before and after selection of core vessels) and the annual geometric mean CPUE (both based on kg per kilometre of net) for the core fleets. Also overlaid are comparable series of standardised CPUE from the previous project (Kendrick & Bentley 2011). All series are rescaled relative to the years they have in common. There was good agreement for each fishery with previous series from similar models over the years in common.

For most fisheries, annual CPUE indices are well determined, with small confidence intervals around each point and changes in direction that are sustained over several consecutive years rather than manifesting as inter-annual variance. The exception is east Northland which has fluctuated relatively tightly around its mean for the whole study period without an overall trend up or down.

The similarity between unstandardised series for all vessels and for selected core vessels indicates that the core fleets are representative of the wider fisheries, and overall it is apparent that, where there have been significant differences in catch rates between years, it has been the common experience across the entire fleet despite and not due to any changes in fishing practice. Although changes in the core fleet, and in the length of net, or in duration, were significant; and although a high proportion of deviance was explained by the models adjusting for those changes, the effect of standardisation was not great, and this indicates the limited degree to which fishers are controlling or manipulating catch rates by changing their behaviour (at least within the utility of the CELR to describe it). The exceptions were in East Northland and Lower Waikato fisheries where systematic changes in the core fleet towards better performing vessels and increases in net length were corrected for by the models, lowering indices in recent years.

The unstandardised and standardised CPUE indices with 95% confidence intervals are given in Appendix I.

3.2.2.1 North western yellow-belly flounder (YBF) NW

Log logistic error distribution produced the best model fit. Fishing year was forced as the first variable in the model of positive catches and explained more than 9% of the annual variance in catch. Net-length entered the model next explaining a further 48% and altering the annual indices noticeably. Vessel was also accepted by the model as a significant variable, explaining a further 13% of variance and effecting further changes to the trajectory of the annual indices. The final model explained 70% of the variance in log of catch (Table 9, Figure 11).

Length of net has increased over time and its influence on observed/nominal CPUE has been positive overall, with a marked increase since the mid 2000s towards more net set. (Figure D1). The influence on observed CPUE of changes in the core fleet also trended positive over the period, and falls into two distinct periods that bracket a period when there was a high turnover of vessels in the fleet. The first half of the time series is dominated by poorer performing vessels, but in the most recent 5–7 years the core fleet stabilises at just a few higher performing vessels (Figure D2). Area was not accepted into the model even though characterisation shows there has been a shift over time away from area 045 and into 046. It is probable that vessel acts as a proxy for area in this analysis, and that may be why the model does not differentiate between areas

The yellow-belly flounder index in north-western Northland is characterised by a low year in 1999–2000 that was followed by the departure of many of the vessels of the core fleet, and by a decline from 2003–04 sustained over seven years (Figure 12) to the lowest year of the series in 2010–11. The decline seems to be well determined in that there are relatively small error bars around each index, and continues the decline noted in the previous study, but it is based on very few vessels (six, declining to three) and should therefore be interpreted with caution.

It is also clear that there was a shift away from area 045 towards area 046 about half way through the period (coincident with the change in the fleet and in the length of net) and that the recent declining trajectory is dominated by records from area 046. There was little similarity in the implied annual coefficients for each area in the first half of the period (Figure F1), and perhaps little justification for combining them into one fishery

Table 9: Summary of final log-logistic model for the (YBF) NW fishery based on the vessel selection criteria of at least 10 trips per year in at least four fishing years. Independent variables are listed in the order of acceptance to the model. AIC: Akaike Information Criterion, R^2: Proportion of deviance explained, Final: Whether or not variable was included in final model. Fishing year was forced as the first variable.

Term	DF	Log likelihood	AIC	R^2 (%)	Final
fyear	23	-36 729	73 504	9.12	*
poly(log(netlength), 3)	26	-34 092	68 235	57.04	*
vessel	172	-32 829	66 001	69.99	*
month	183	-32 782	65 929	70.39	
poly(log(duration), 3)	186	-32 749	65 870	70.66	

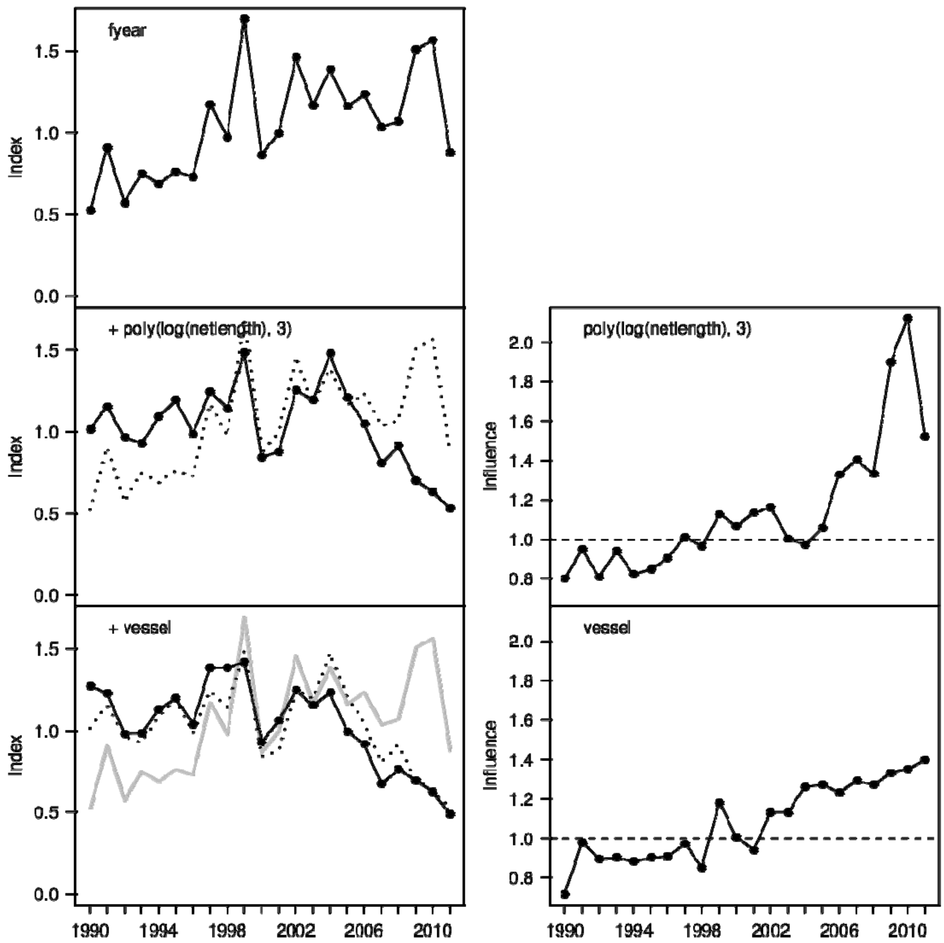

Figure 11: Step and annual influence plot for (YBF) NW. (a) CPUE index at each step in the selection of variables. The index obtained in the previous step (if any) is shown by a dotted line and for steps before that by grey lines. (b) Annual influence on observed catches arising from a combination of its coefficients and its distributional changes over years, for each explanatory variable in the final model.

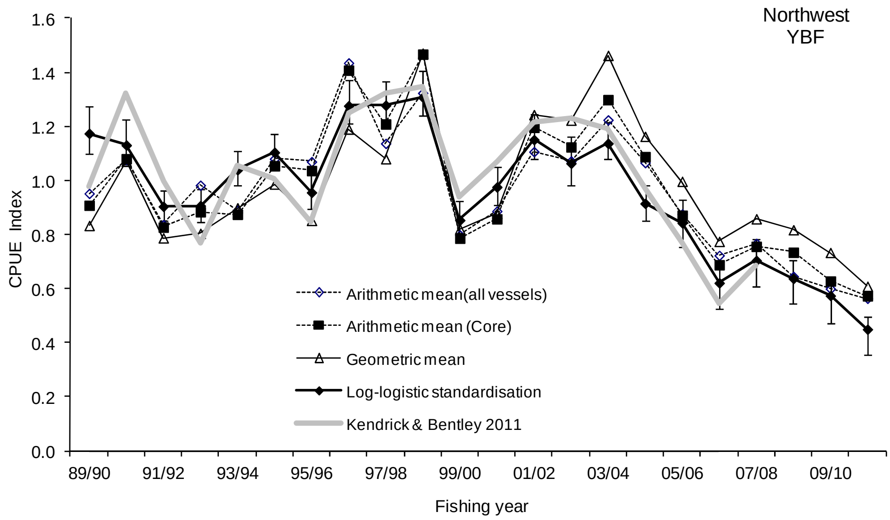

Figure 12: The effect of core vessel selection, and standardisation of indices on the raw CPUE of yellowbelly flounder in the (YBF) NW fishery. The year effects from the log-logistic model are shown ± 2 SE. Unstandardised (arithmetic) kg/km of net and a comparable series from the previous study are overlaid for comparison.

3.2.2.2 Kaipara Harbour yellow-belly flounder (YBF) KH

Log logistic error distribution produced the best model fit. The model of positive catches (FLA+YBF) in the Kaipara harbour explained 48% of the deviance in catch and accepted all potential explanatory variables offered except for mesh size. Year was forced as the first variable and explained 12% of deviance and that was followed by vessel which explained a further 24% and by net-length, duration, and month; though they each had little additional explanatory power (Table 10). The influence of changes in the core fleet falls into two periods that trend negatively during the first half of the time series and positively over the second half. There are large and well defined differences in performance among vessels and many of both the poorer and the better performing vessels have participated in this fishery throughout the entire study period (Figure D3).

Length of net has tended to decrease with a negative overall influence on observed CPUE that reverses after 2007–08 (Figure D4), and that is mirrored by a similar trend in duration (Figure D6). Very small shifts in seasonal distribution of fishing were adjusted for from year to year but with neutral overall influence (Figure D5).

Despite the high explanatory power of the selected explanatory variables and the strong trends in their influence, the standardised series is almost unchanged at each step in the selection process (Figure 13) and the annual indices from the final model are almost indiscernible from the unstandardised series, except that the initial high points are dropped slightly. The series describes an overall declining trajectory that has oscillated around 80% of the series mean since 1996–97 and is currently at the lowest for the series; the additional three years having reversed the indications of recovery that were noted in the previous study (Figure 14).

Table 10: Summary of final log-logistic model for the (YBF) KH fishery based on the vessel selection criteria of at least 10 trips per year in at least six fishing years. Independent variables are listed in the order of acceptance to the model. AIC: Akaike Information Criterion, R^2: Proportion of deviance explained, Final: Whether or not variable was included in final model. Fishing year was forced as the first variable.

Term	DF	Log likelihood	AIC	R^2 (%)	Final
fyear	23	-207 190	414 427	11.38	*
vessel	253	-200 286	401 077	36.83	*
poly(log(netlength), 3)	256	-197 799	396 110	44.08	*
poly(log(duration), 3)	259	-197 152	394 822	45.82	*
month	270	-196 360	393 260	47.89	*
mesh	271	-196 355	393 252	47.90	

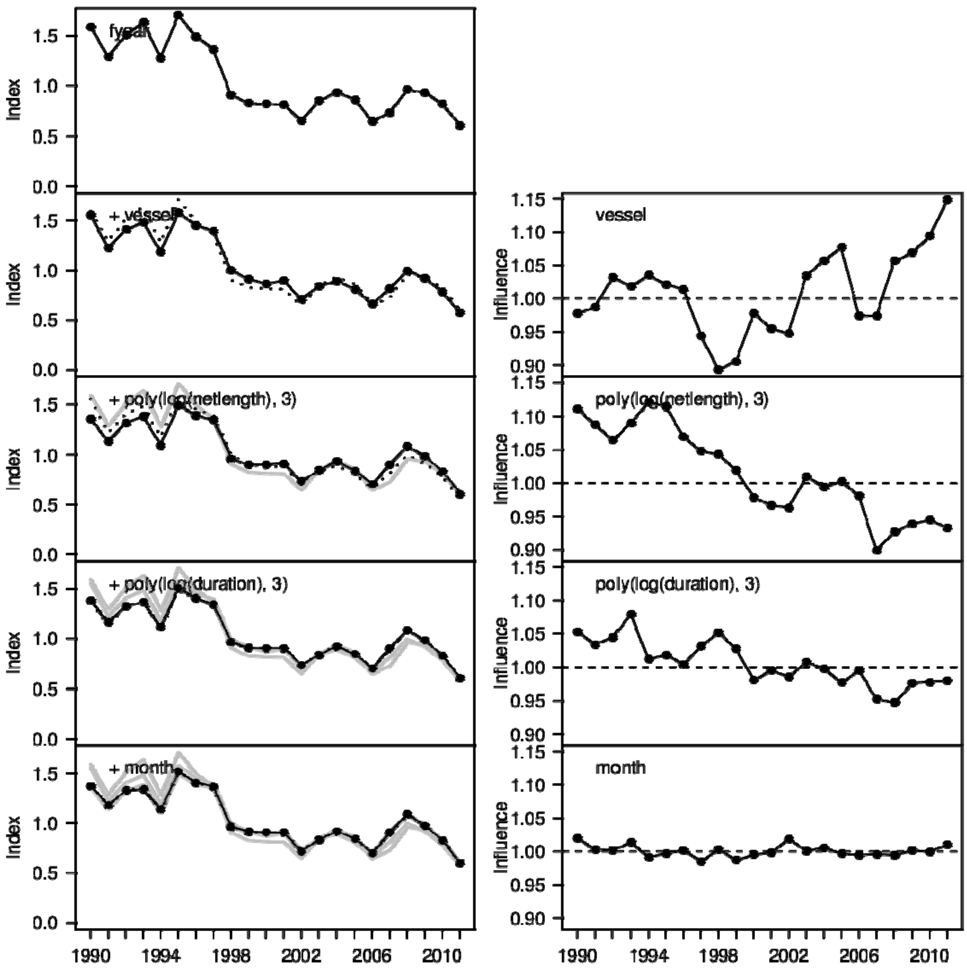

Figure 13: Step and annual influence plot for (YBF) KH. (a) CPUE index at each step in the selection of variables. The index obtained in the previous step (if any) is shown by a dotted line and for steps before that by grey lines. (b) Annual influence values for each explanatory variable in the final model.

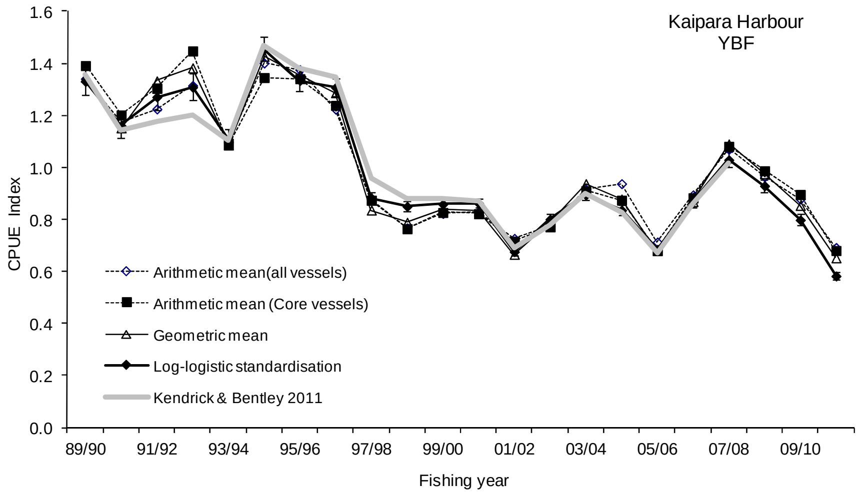

Figure 14: The effect of core vessel selection, and standardisation on the raw CPUE of yellowbelly flounder in the (YBF) KH fishery. The year effects from the log-logistic model are shown ± 2 SE. Unstandardised (arithmetic) kg/km of net and a comparable series from the previous study are overlaid for comparison.

3.2.2.3 Manukau Harbour yellow-belly flounder (YBF) MH

Log logistic error distribution produced the best model fit. The model of positive catches (assumed to be yellow-belly flounder) in the Manukau harbour explained 39% of the deviance in catch and accepted all potential explanatory variables offered except for mesh size. Year was forced as the first variable and explained 5% of the deviance, and was followed by vessel (which explained a further 23%), net-length, month and duration; each with little additional explanatory power (Table 11). The influence of changes in the core fleet was neutral overall, with less difference in performance between vessels than was seen in the Kaipara Harbour fishery. (Figure D7).

The length of net tended to increase in length during the first half of the time series with a predicted positive influence on observed catches, but was more stable, and neutral, over the most recent seven years (Figure D8). There is more evidence of seasonal changes in abundance of yellow-belly flounder in Manakau Harbour than in Kaipara Harbour, and also a suggestion that there is less fishing effort during the winter months. As in Kaipara Harbour, the pattern in fishing effort is consistent among years and the model adjusted for very small shifts in the seasonal distribution of fishing from year to year that had no overall trend up or down (Figure D9). A shift towards longer soak times (duration) in the early 2000s is predicted to have increased observed catches, but the effect is very small (Figure D10)

Despite the high explanatory power of the selected explanatory variables and the trends in their influence, the standardised series changed very little at each step in the selection process (Figure 15) and the annual indices from the final model are almost identical to the unstandardised series, except that a hump in the late 1990s is flattened somewhat. The series describes an overall declining trajectory that has oscillated around 80% of the series mean since 1998–99 and is currently (in 2010–11) the lowest for the series; the most recent three points reversing the indications of recovery that were noted in the previous study (Figure 16).

Table 11: Summary of final log-logistic model for the (YBF) MH fishery based on the vessel selection criteria of at least 10 trips per year in at least six fishing years. Independent variables are listed in the order of acceptance to the model. DF: Degrees of frredon, AIC: Akaike Information Criterion, R^2: Proportion of deviance explained, Final: Whether or not variable was included in final model. Fishing year was forced as the first variable.

Term	DF	Log likelihood	AIC	R^2 (%)	Final
fyear	23	-135 247	270 540	5.07	*
vessel	221	-131 224	262 890	28.84	*
poly(log(netlength), 3)	224	-129 479	259 406	37.20	*
month	235	-129 074	258 618	38.99	*
poly(log(duration), 3)	238	-128 812	258 099	40.13	*
mesh size	239	-128 808	258 094	40.14	

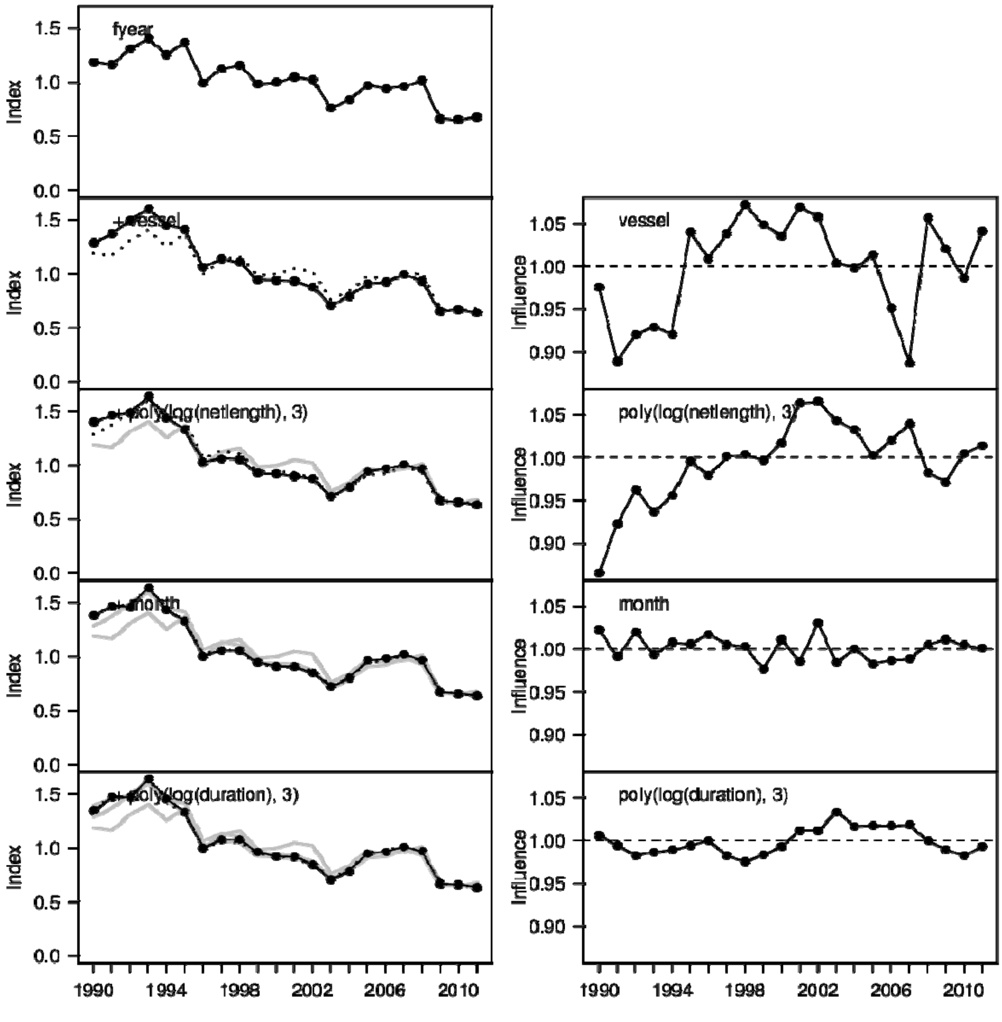

Figure 15: Step and annual influence plot for (YBF) MH. (a) CPUE index at each step in the selection of variables. The index obtained in the previous step (if any) is shown by a dotted line and for steps before that by grey lines. (b) Annual influence values for each explanatory variable in the final model.

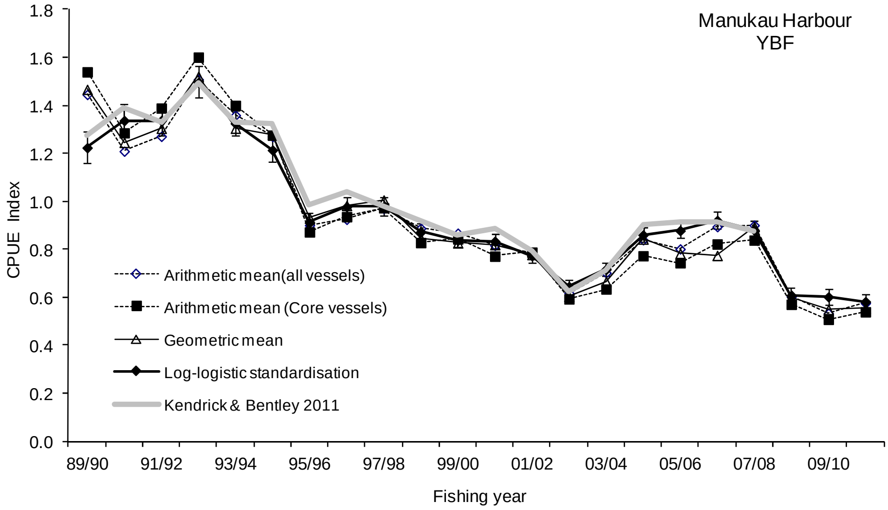

Figure 16: The effect of core vessel selection, and standardisation of indices on the raw CPUE of yellow-belly flounder in the (YBF) MH fishery. The year effects from the lognormal model are shown ± 2 SE. Unstandardised (arithmetic) kg/km of net and a comparable series from the previous study are overlaid for comparison.

3.2.2.4 Lower Waikato yellow-belly flounder (YBF) LW

A log logistic error distribution produced the best model fit.The final model explains 33% of the deviance in catch (assumed to be yellow-belly flounder) and includes vessel, net length and duration as having significant explanatory power. Fishing year was forced as the first variable and explained 5% of deviance in catch. Vessel is the first other variable selected into the model explaining a further 16%, and net length explains a further 10%. Duration also entered the model but with little additional explanatory power (Table 12).

The influence of vessel on observed CPUE is strongly positive over the whole time series (Figure D11) and its inclusion in the model lifts earlier points and drops more recent points, changing a trajectory that appears to increase steadily for most of the time series to one that is flatter (Figure 17). The influence of the two effort measures contradict each other, with net-length tending to increase and predicted to have positively influenced observed catches (Figure D12) while the duration fished tended to decrease with a predicted negative influence on catches (Figure D13). The influence of changes in each effort variable on catches was small and the net effect of their inclusion into the model on the annual indices was minimal (Figure 17). The effect of standardisation; which largely adjusts for changes in the core fleet pivots the series around a midpoint so that the recent increase is not quite so steep in the standardised series as in the unstandardised, but it remains the main feature of the trajectory, continuing and confirming the recovery that was indicated in the previous study (Figure 18).

The standardised series varies around unity during the 1990s and then declines steadily over six consecutive years to a new level by 2004–05 that was about 80% of the mean. Since then it has increased steadily over six consecutive years and the 2010–11 point is the highest in the series at just under 1.4 times the mean.

Implied annual coefficients for the constituent statistical areas confirm the recent increase in both areas, but suggest that it may have begun a year or two earlier in area 042 than in area 041, and may have begun to decline again in 042 (Figure F2).

Table 12: Summary of final lognormal model for the (YBF) LW fishery based on the vessel selection criteria of at least 10 trips per year in at least four fishing years. Independent variables are listed in the order of acceptance to the model. AIC: Akaike Information Criterion, R^2: Proportion of deviance explained, Final: Whether or not variable was included in final model. Fishing year was forced as the first variable.

Term	DF	Log likelihood	AIC	R2 (%)	Final
fyear	23	-31 327	62 700	4.92	*
vessel	166	-30 588	61 508	23.06	*
poly(log(netlength) 3)	169	-30 133	60 604	32.46	*
poly(log(duration) 3)	172	-30 001	60 347	34.96	*
month	183	-29 965	60 296	35.63	
mesh	184	-29 955	60 279	35.81	

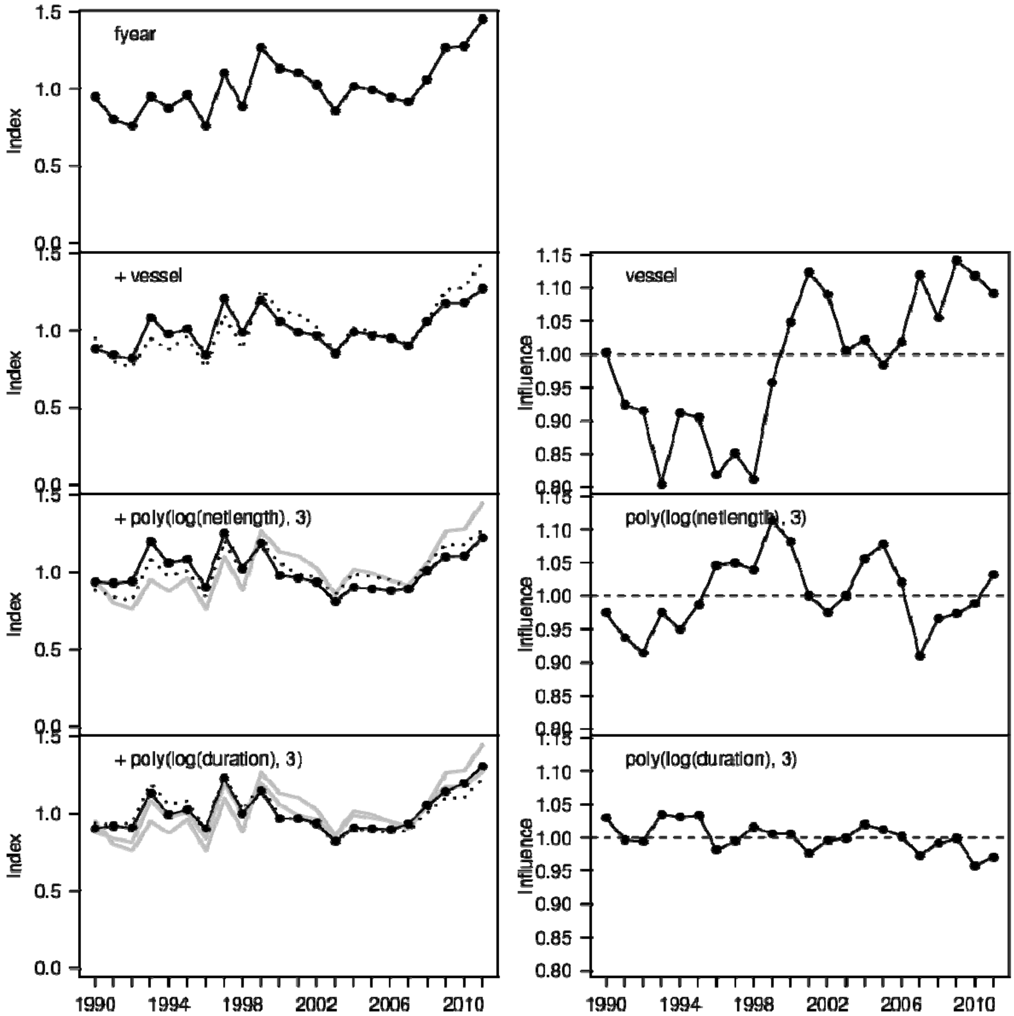

Figure 17: Step and annual influence plot for (YBF) LW. (a) CPUE index at each step in the selection of variables. The index obtained in the previous step (if any) is shown by a dotted line and for steps before that by grey lines. (b) Annual influence values for each explanatory variable in the final model.

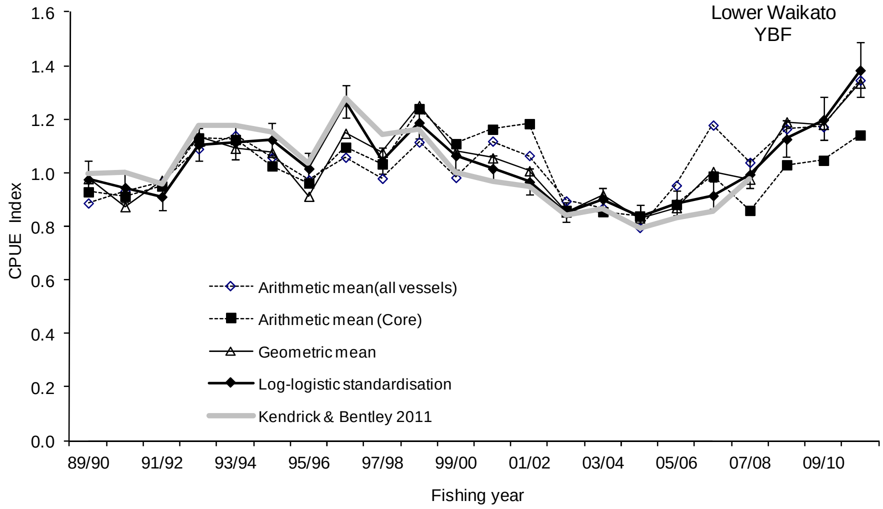

Figure 18: The effect of core vessel selection, standardisation, and combining of indices on the raw CPUE of yellow-belly flounder in the (YBF) LW fishery. The year effects from the lognormal model are shown ± 2 SE. Unstandardised (arithmetic) kg/km of net are overlaid for comparison.

3.2.2.5 East Northland total flatfish TOT_EN

A log logistic error distribution produced the best model fit. The final model explains 36% of the deviance in catch (of undefined species of flatfish) and includes vessel, net length and month as having significant explanatory power. Fishing year was forced as the first variable but explained less than 4% of the deviance in catch. Vessel was the next variable selected into the model explaining an additional 19%, and net length explained a further 12 % of deviance. Month also entered the model, although with little additional explanatory power (Table 13).

The influence of vessel on observed CPUE is positive overall mainly due to some changes to the core fleet around the middle of the time series (Figure D14) so that its inclusion in the model lifts earlier points and drops more recent points, and changes the trajectory from one that appears to increase slightly, to one that is flatter (Figure 19). The influence of changes in net-length also falls into two parts concurrent with the changes to the fleet; tending to increase in length in the second half of the time series and predicted to have positively influenced observed catches (Figure D15). Its inclusion in the model continues to move the standardised indices away from the unstandardised series; changing the trajectory from flat, to one that declines slightly overall. Adjustments for changes in the seasonal distribution of catches were neutral overall (Figure D16), and made no discernible difference to the annual indices (Figure 20).

The standardised series has fluctuated without systematic pattern or any clear trend up or down. The final point from the previous analysis (Kendrick & Bentley 2011) was the lowest in the time series but the three subsequent years have seen some improvement and the 2010–11 point sits above the mean (Figure 20). However, implied coefficient plots suggest that the increase is mainly confined to area 002, and also suggest little connection between the two areas as the year effects have not tracked each other over time (Figure F3). Because there is virtually no information on species composition of the catch, this series cannot be considered to be monitoring any specific stock. The analysis does not, however, indicate any dramatic decline in the availability of flatfish to the East Northland set net fishery.

Table 13: Summary of final lognormal model for the TOT_ EN fishery based on the vessel selection criteria of at least 10 trips per year in at least four fishing years. Independent variables are listed in the order of acceptance to the model. DF: Degrees of freedom, AIC: Akaike Information Criterion, R^2: Proportion of deviance explained, Final: Whether or not variable was included in final model. Fishing year was forced as the first variable.

Term	DF	Log likelihood	AIC	R^2 (%)	Final
fyear	23	-73 522	147 091	4.05	*
vessel	251	-71 836	144 174	21.92	*
poly(log(netlength) 3)	254	-70 518	141 544	33.55	*
month	265	-70 224	140 979	35.89	*
mesh	266	-70 103	140 739	36.83	
poly(log(duration) 3)	269	-70 045	140 627	37.29	

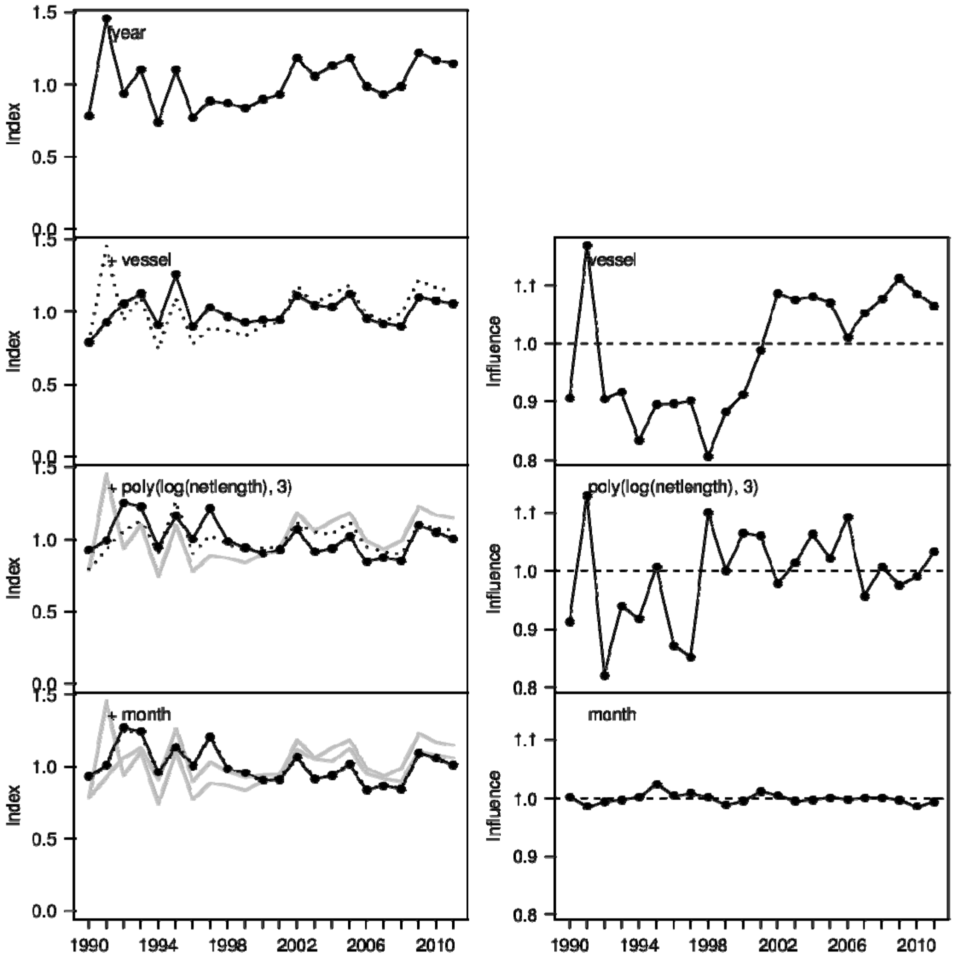

Figure 19: Step and annual influence plot for TOT_EN. (a) CPUE index at each step in the selection of variables. The index obtained in the previous step (if any) is shown by a dotted line and for steps before that by grey lines. (b) Annual influence values for each explanatory variable in the final model.

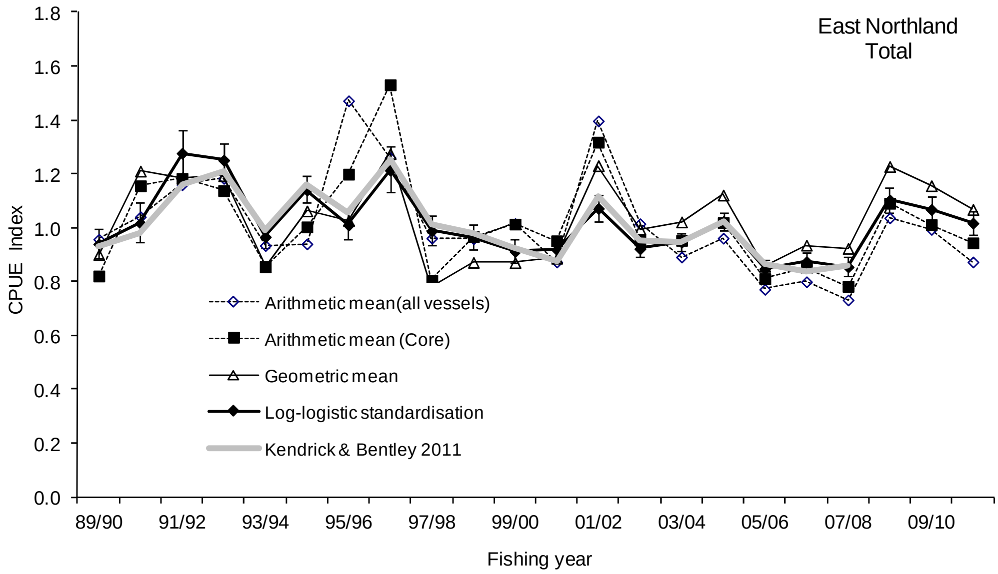

Figure 20: The effect of core vessel selection, standardisation, and combining of indices on the raw CPUE of flatfish in the TOT_EN fishery. The year effects from the lognormal model are shown ± 2 SE. Unstandardised (arithmetic) kg/km of net are overlaid for comparison.

3.2.2.6 Hauraki Gulf yellow-belly flounder YBF_HG

A gamma error distribution produced the best model fit. Fishing year was forced as the first variable in the model and explained about 8% of annual deviance in catch (reported as yellow-belly flounder). Vessel was the next explanatory variable selected, explaining a further 20% and having the greatest influence on observed catches, followed by month, duration and net-length, the final model explaining 50% of the deviance in catch (Table 14), but the influence of the explanatory variables on catch rates was neutral over most of the study period with the model adjusting for small variations that had no particular trend up or down (Figure 21). The standardised indices only move away from the unstandardised indices in recent years (after the peak in 2006–07). The influence on observed CPUE of changes in the core fleet during that time was positive due to the departure from the fishery of many of the poorer performing vessels (Figure D17), and this was countered somewhat by shifts towards more fishing in the winter months (Figure D18), and declines in fishing duration (Figure D19) as well as in the length of net set (Figure D20), although the inclusion of these variables did not further change the annual indices noticeably. The coefficients for month describe higher predicted catches of yellow-belly flounder over the spring and summer months with a pronounced low centred on July. Although effort was greatest during the months of highest abundance, fishing nevertheless continued throughout each year. Overall, there was very little effect of standardisation on the observed CPUE.

The CPUE indices for yellow-belly flounder in the Hauraki Gulf initially decline from 1990–91 to the lowest point in the series in 199596. They were relatively stable at just below the average level for the next eight years before increasing over three years to the highest point in the series in 2006–07. That recovery has since been reversed by a steady decline over four consecutive years and the 2010–11 point is just below the mean of the series. This trajectory was evident in the unstandardised catches and is not changed much by standardisation (Figure 22). The annual indices are dominated by records from area 007, with little contribution from the other areas included in the fishery definition (Figure F4).

Table 14: Summary of final gamma model for the YBF–HG fishery based on the vessel selection criteria of at least 10 trips per year in at least four fishing years. Independent variables are listed in the order of acceptance to the model. DF: Degrees of freedom, AIC: Akaike Information Criterion, R^2: Proportion of deviance explained, Final: Whether or not variable was included in final model. Fishing year was forced as the first variable.

Term	DF	Log likelihood	AIC	R^2 (%)	Final
fyear	21	-128 077	256 198	8.53	*
vessel	74	-125 076	250 302	27.99	*
poly(log(netlength) 3)	77	-122 621	245 398	40.79	*
month	88	-120 661	241 500	49.36	*
poly(log(duration) 3)	91	-120 391	240 966	50.44	*
mesh	92	-120 373	240 933	50.51	
area	93	-120 369	240 926	50.52	

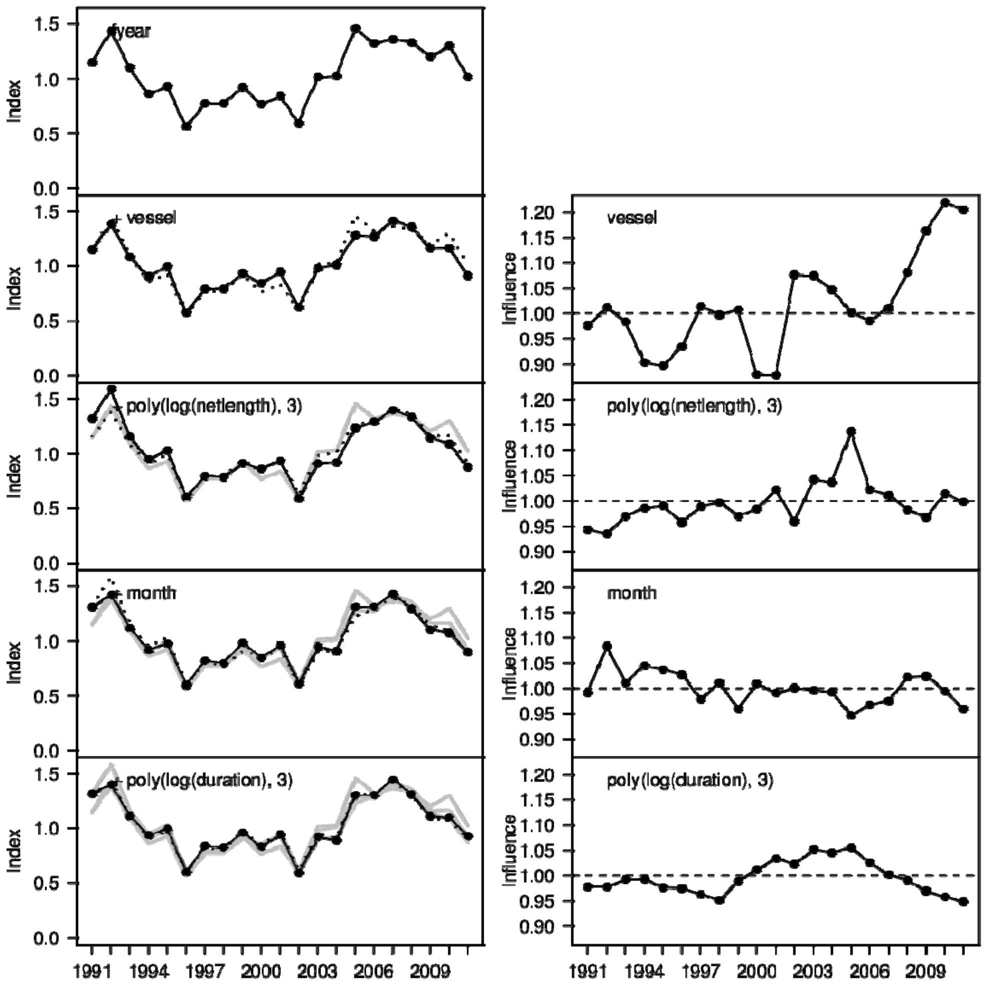

Figure 21: Step and annual influence plot for YBF_HG. (a) CPUE index at each step in the selection of variables. The index obtained in the previous step (if any) is shown by a dotted line and for steps before that by grey lines. (b) Annual influence values for each explanatory variable in the final model.

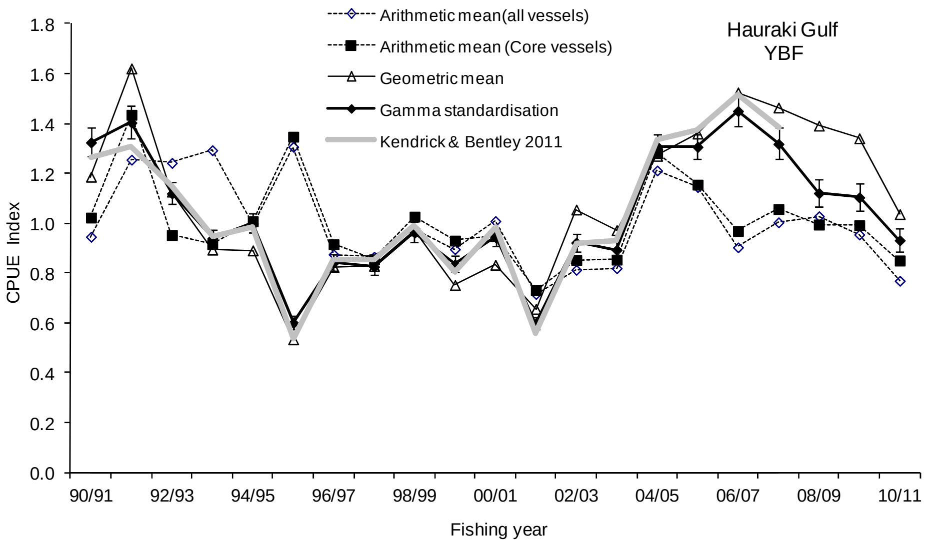

Figure 22: The effect of core vessel selection, standardisation, and combining of indices on the raw CPUE of yellow-belly flounder in the YBF–HG fishery. The year effects from the lognormal model are shown ± 2 SE. Unstandardised (arithmetic) kg/km of net and a comparable series from the previous study are overlaid for comparison.

3.2.2.7 Hauraki Gulf sand flounder SFL–HG

A lognormal error distribution produced the best model fit. Fishing year was forced as the first variable in the model and explained more than 12% of the annual deviance in the catch (reported as sand flounder). Vessel entered the model next explaining a further 15% of the deviance and steepening the overall decline of the annual indices noticeably. Duration, month and mesh size also entered the model with little additional explanatory power and without further changing the annual indices appreciably (Figure 23). The final model explained 37% of the deviance in log of catch (Table 15).

The influence on observed CPUE of changes in the core fleet trended positive over the whole period, and the entry of several high performing vessels contributed to the peak in observed catches in 2005–06. (Figure D21). Coincident with these changes in the fleet was an increase in set duration that is also predicted to have had a positive influence on catches but which has since been reversed (Figure D22). The seasonal pattern described for SFL–HG is dramatically different from that described for yellow-belly flounder in the same fishery. The lowest catches are predicted to occur in January to March, while abundance peaks in June. Effort is obviously not optimised for sand flounder as it more closely resembles the pattern of abundance of yellow-belly flounder, but small shifts towards more winter fishing in some recent years has resulted in the month of fishing having a positive influence on the observed catches of sand flounder (Figure D23). Mesh size is accepted into this model as the final variable with very little explanatory power or influence. The CDI plot does however show a clear negative linear relationship between mesh size and catch and a trend towards larger mesh sizes that is predicted to have lowered catches slightly (Figure D24).

The sand flounder index in the Hauraki Gulf declines from a peak in the early 1990s to a low in the early 2000s. A brief recovery in the mid 2000s was reduced by standardisation suggesting that it was, to some extent, an artefact of changes in fishing, and the series has been below the long-term mean for the last decade; effectively unchanged from the low level reported in the previous study (Figure 24). The year effects are dominated by data from area 007, and there is little contribution from the other two statistical areas in the definition of this fishery (Figure F5).

Table 15: Summary of final lognormal model for the SFL–HG fishery based on the vessel selection criteria of at least 10 trips per year in at least six fishing years. Independent variables are listed in the order of acceptance to the model. DF: Degrees of freedom, AIC: Akaike Information Criterion, R^2: Proportion of deviance explained, Final: Whether or not variable was included in final model. Fishing year was forced as the first variable.

Term	DF	Log likelihood	AIC	R^2 (%)	Final
fyear	22	-74 002	148 047	12.87	*
vessel	439	-72 396	145 669	27.48	*
poly(log(duration) 3)	442	-71 753	144 389	32.61	*
month	453	-71 340	143 586	35.71	*
mesh	454	-71 200	143 307	36.74	*
poly(log(netlength) 3)	457	-71 185	143 285	36.84	

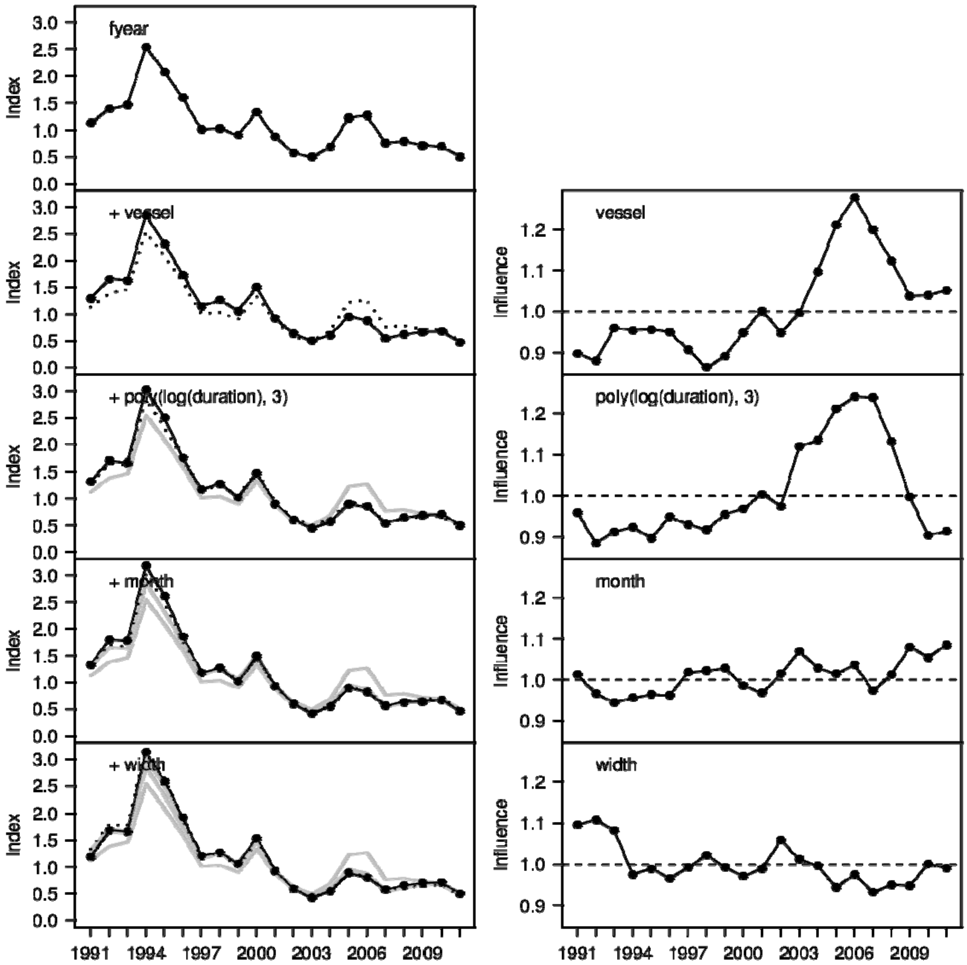

Figure 23: Step and annual influence plot for SFL_HG. (a) CPUE index at each step in the selection of variables. The index obtained in the previous step (if any) is shown by a dotted line and for steps before that by grey lines. (b) Annual influence values for each explanatory variable in the final model.

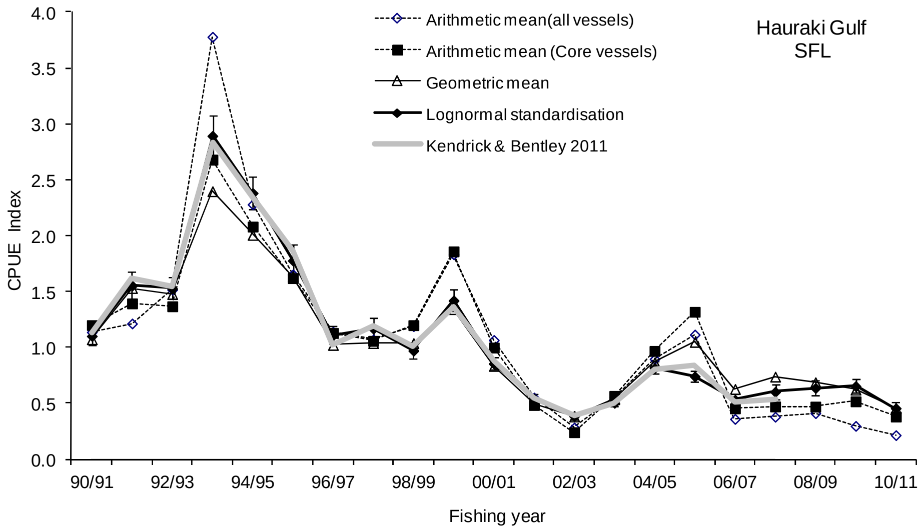

Figure 24: The effect of core vessel selection, standardisation, and combining of indices on the raw CPUE of sand flounder in the SFL_HG fishery. The year effects from the lognormal model are shown ± 2 SE. Unstandardised (arithmetic) kg/km of net and a comparable series from the previous study are overlaid for comparison.

4 CONCLUSIONS

Catches of flatfish on the west coast mostly come from the two large harbours; Kaipara and Manukau, and the analyses based on these two single statistical area fisheries are robust and well-determined. The catch coded to the generic code “FLA” can be included in the analyses because it can be assumed to be yellowbelly flounder, as there is very little reported catch of other flatfish species. The setnet fisheries have been consistently operated and reported and do not appear to be contaminated by misreporting of other net methods, which has proven to be an intractable problem for the grey mullet set net fisheries in the same areas (Kendrick & Bentley 2012, this study). The abundance of yellow-belly flounder declined to its lowest level in the early 2000s in the Kaipara and Manukau Harbours, showed some indications of recovery by 2008–09, but in the subsequent three years these increases were lost, and in 2010–11, both series were almost equal to their lowest levels.

Because flounders are short-lived and the fishery depends on only one or two year classes, cyclical fluctuations in abundance are what would be expected, however they should also be reasonably robust to fishing pressure and the declining trends are therefore a concern; and considered by the Working Group likely to be caused by factors other than fishing. Recent work by NIWA has demonstrated increased eutrophication in the Manukau Harbour which may be a consequence of heavy agricultural use in the environs, and the Working Group noted that it would be useful to extend this work to the Kaipara Harbour.

Areas north of the Kaipara Harbour have been combined into the North-western fishery which supports sparse and sporadic fishing from several distinct harbours and areas of open coast that are not identifiable at the level of detail provided on CELR forms. The standardised CPUE for the north-western fishery declined overall and particularly steeply over the last decade, but is now based on very few vessels. There are also demonstrable differences between statistical areas that mean that the indices should be interpreted with caution. South of Manukau Harbour, the Lower Waikato sub area analysis is also based on several statistical areas offering considerable potential for serial exploitation that cannot be quantified. The standardised series increases over the last decade but because there are demonstrable differences between statistical areas the indices must be interpreted with caution.

The east Northland fishery is widely spread across several discrete harbours and coastal areas (including Mangonui, Whangaroa, Houhora, Rangaunu Harbour, Karikari Peninsula, Doubtless Bay). It also catches both YBF and SFL though they are not reported in large enough quantities to analyse separately. The standardised CPUE for the east Northland substock is flat, but there is virtually no information on species or location of fishing that might allow any interpretation to be made with confidence.

On the east coast, most catch is from the Hauraki Gulf, and this is dominated by catches in Area 007. Separate analyses were able to be done for catch reported as either yellowbelly or sand flounder, but a large proportion of the data, which was described only by the generic FLA code, had to be excluded.

The relative abundance of yellow-belly flounder declined to its lowest level in the early 2000s, but showed a dramatic increase by 2008–09 to what is still the highest level for the series. Since then much of the increase has been lost and the series is on a downward part of its cycle, currently sitting just below the overall mean for the series. The sand flounder index in the Hauraki Gulf declined from a peak in the early 1990s to a low in the early 2000s and has stabilised at a level below the long-term mean.

The divergence of the indices for the two main species in the Hauraki Gulf after 2000–01 probably reflected the underlying abundance of the two species. They show inverse seasonal abundance, with yellow-belly flounder being most abundant in summer and sand flounder most abundant in winter, so that the mix of species in the annual catch could easily be manipulated, but that does not appear to have happened. The fishery is focused on yellow-belly flounder and appears to have been for the whole time series, but effort is maintained into the winter by the bycatch of sand flounder.

Vessel was the most important variable in all models, but changes to the core fleets did not explain the declining CPUE trends in the main three substocks. Similarly, the trends in effort have been toward longer nets and shorter soak times, but these shifts have not driven the main trends in observed CPUE in the main substocks.

There was very little effect of standardisation in any of these fisheries that indicates that they have been operated in a consistent manner and/or that fishers do not greatly manipulate their catch rates by making changes in fishing practices. The small error bars around annual indices suggest that the changes from year to year are a common experience across the core fleet despite any differences in fishing practices.

The working group concluded that;

- Standardized CPUE is probably tracking abundance in the two west coast harbours
- Trends in CPUE for the NW, NE and Waikato fisheries should be treated with caution.
- CPUE trends for YBF in the Kaipara and Manukau Harbours and the Firth of Thames, where the bulk of the FLA 1 catch is made, are declining and are cause for concern.

5 ACKNOWLEDGMENTS

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APPENDIX A. CATCH SUMMARY

Table A1: Estimated catch (t) of all flatfish species combined (Total), yellowbelly flounder (YBF), sand flounder (SFL), and generalised flatfish (FLA), (the balance includes small amounts of other flatfish species), and number of records (vessel-days) for setnet fishing targeted at flatfish species, by substock and fishing year from the characterisation dataset. FLA and TOT estimated catches include the correction for false zeros.

Substock	Northwestern					Kaipara Harbour				
	Estimated catch (t)				Vessel days	Estimated catch (t)				Vessel days
Year	Total	YBF	SFL	FLA		Total	YBF	SFL	FLA	
1989–90	22	0	0	22	373	190	0	0	190	2 267
1990–91	26	0	0	26	368	153	26	0	153	2 623
1991–92	37	0	0	37	792	168	27	0	160	2 693
1992–93	34	0	0	34	661	162	25	2	156	2 458
1993–94	34	15	1	18	711	128	54	1	97	2 332
1994–95	57	15	3	38	929	156	75	0	124	2 396
1995–96	46	11	1	34	755	148	41	1	151	2 446
1996–97	41	9	1	30	571	191	38	1	204	3 300
1997–98	37	9	1	27	611	185	42	1	190	4 094
1998–99	46	11	0	34	680	146	65	3	137	4 150
1999–00	23	9	0	14	536	186	119	3	135	5 068
2000–01	34	16	1	17	628	212	132	2	147	5 677
2001–02	27	14	0	13	430	164	90	4	114	4 619
2002–03	16	7	0	9	317	151	93	2	94	4 042
2003–04	31	10	0	20	521	176	106	1	105	3 839
2004–05	32	7	0	24	567	143	91	1	84	3 339
2005–06	22	7	0	13	471	100	74	1	54	3 185
2006–07	18	6	0	8	431	116	53	1	73	2 598
2007–08	16	5	0	10	425	141	54	1	98	2 544
2008–09	20	3	0	16	552	142	64	1	102	2 945
2009–10	15	3	0	12	456	143	55	4	92	2 998
2000–11	10	3	0	8	382	144	41	1	72	2977

Substock					Manukau Harbour					Lower Waikato
	Estimated catch (t)				Vessel days	Estimated catch (t)				Vessel days
Year	Total	YBF	SFL	FLA		Total	YBF	SFL	FLA	
1989–90	66	0	0	66	1 170	13	0	0	13	371
1990–91	84	1	0	83	1 568	13	1	0	12	489
1991–92	88	0	0	88	1 581	14	0	0	14	540
1992–93	119	0	0	118	1 789	18	0	0	18	528
1993–94	129	8	0	122	2 012	14	2	0	12	400
1994–95	117	11	0	106	1 819	18	5	0	13	488
1995–96	81	5	0	76	1 662	18	4	0	14	510
1996–97	86	1	0	85	1 759	29	5	0	23	655
1997–98	104	2	0	102	2 006	26	6	0	20	676
1998–99	95	4	0	91	2 094	29	3	0	24	599
1999–00	115	7	0	108	2 462	28	2	0	21	645
2000–01	118	6	0	111	2 578	30	1	0	28	770
2001–02	86	5	0	81	1 992	25	2	0	23	722
2002–03	60	3	0	57	1 806	25	3	0	23	767
2003–04	73	3	0	70	1 988	26	4	0	22	763
2004–05	82	6	1	75	1 865	23	5	0	18	695
2005–06	74	9	1	65	1 720	24	2	0	22	847
2006–07	84	8	0	76	2 021	22	2	0	20	756
2007–08	70	5	0	65	1 595	25	3	0	22	793
2008–09	31	2	0	29	1 016	25	2	0	23	663
2009–10	26	2	0	25	921	18	1	0	17	582
2000–11	35	2	0	33	1165	17	1	0	16	547

Substock					East Northland					Hauraki Gulf
	Estimated catch (t)				Vessel days	Estimated catch (t)				Vessel days
Year	Total	YBF	SFL	FLA		Total	YBF	SFL	FLA	
1989–90	28	0	0	28	827	194	0	0	194	2 076
1990–91	29	0	0	28	764	361	108	48	174	3 994
1991–92	38	1	0	37	865	399	121	51	198	4 013
1992–93	48	2	0	46	1 052	423	138	61	194	4 559
1993–94	43	10	2	31	1 125	439	118	132	172	4 079
1994–95	42	13	2	27	1 064	320	108	82	108	3 470
1995–96	53	9	2	40	1 077	127	39	35	50	2 092
1996–97	50	6	8	32	793	148	62	28	50	2 575
1997–98	28	8	0	19	657	135	57	27	42	2 396
1998–99	32	15	1	15	834	149	69	28	39	2 439
1999–00	39	24	4	10	981	159	67	49	34	2 614
2000–01	38	21	6	11	1 011	193	99	34	49	3 186
2001–02	51	29	5	17	1 165	108	52	15	38	2 470
2002–03	52	28	4	19	1 398	225	94	13	110	3 852
2003–04	61	26	2	34	1 732	234	98	23	104	3 684
2004–05	71	29	3	38	1 934	423	192	53	165	4 451
2005–06	50	23	2	25	1 543	397	137	45	203	3 647
2006–07	43	21	1	20	1 307	370	101	16	253	3 806
2007–08	30	17	1	12	990	225	76	8	141	2 468
2008–09	36	19	1	16	901	224	85	9	130	2 682
2009–10	35	14	1	20	946	286	111	10	164	3 525
2000–11	36	18	1	17	1 018	176	78	6	92	3 126

Substock					Bay of Plenty
	Estimated catch (t)				Vessel days SN (FLA)
Year	Total	YBF	SFL	FLA	
1989–90	23	0	0	23	311
1990–91	40	10	9	17	731
1991–92	30	7	8	10	544
1992–93	43	9	11	7	609
1993–94	34	6	10	3	462
1994–95	34	9	17	1	505
1995–96	40	6	18	9	697
1996–97	39	6	7	9	770
1997–98	33	8	8	3	556
1998–99	36	7	8	3	615
1999–00	24	7	4	2	526
2000–01	10	3	1	0	330
2001–02	13	4	1	1	314
2002–03	20	6	2	1	425
2003–04	16	4	3	1	338
2004–05	42	8	18	3	365
2005–06	73	8	33	3	459
2006–07	55	3	17	5	427
2007–08	36	4	10	2	327
2008–09	26	3	7	1	296
2009–10	19	0	1	7	270
2000–11	14	1	1	6	194

APPENDIX B. CORE VESSEL SELECTION

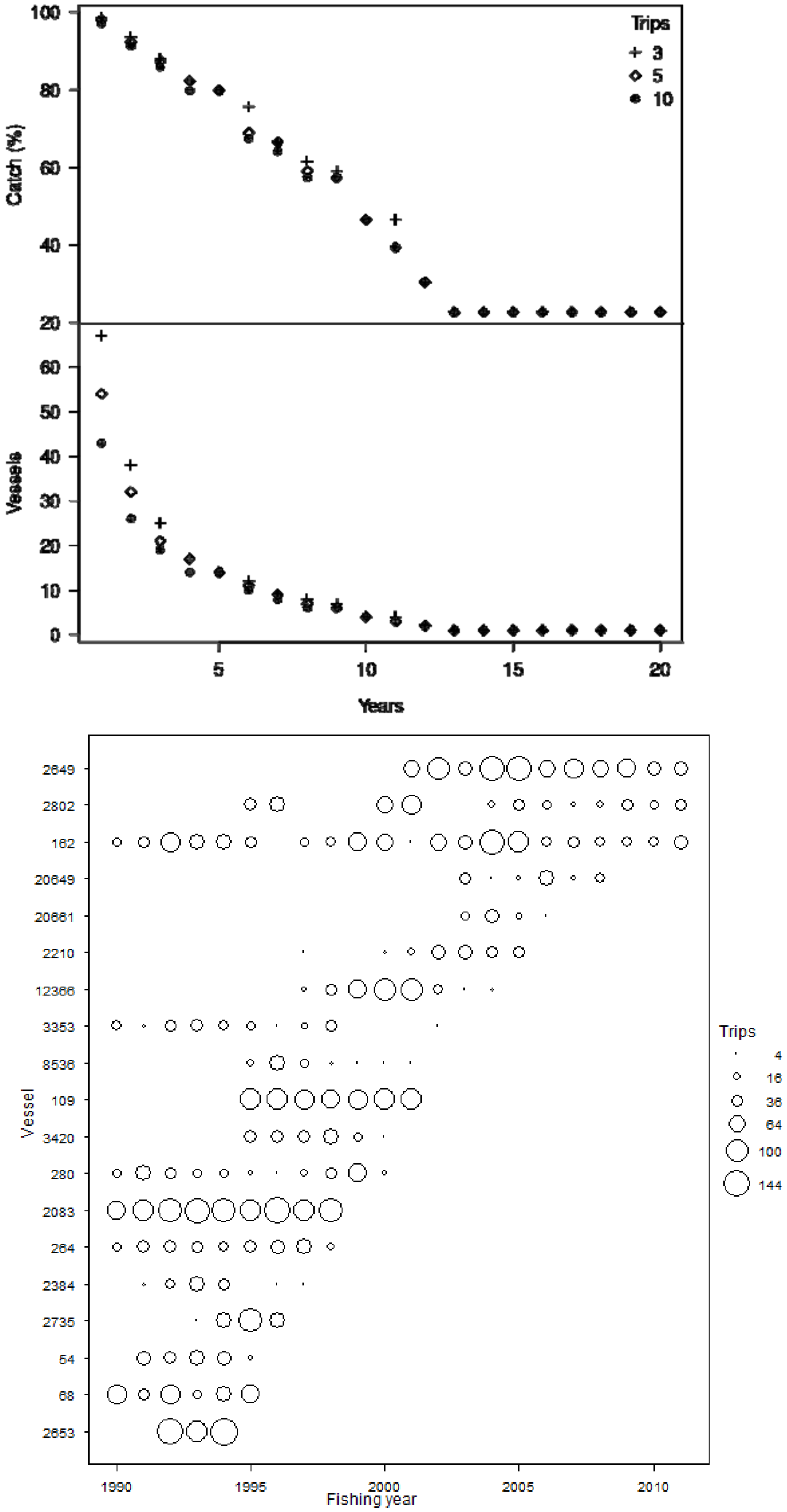


Figure B1: The total estimated flatfish catch [top] and the number of vessels [second] retained in the (YBF) NW dataset depending on the definition of qualifying year (minimum number of trips per year), and the minimum number of qualifying years used to define core vessels. The participation of selected core vessels (based on at least 10 trips per year in at least three years); number of records for each vessel in each fishing year [bottom].

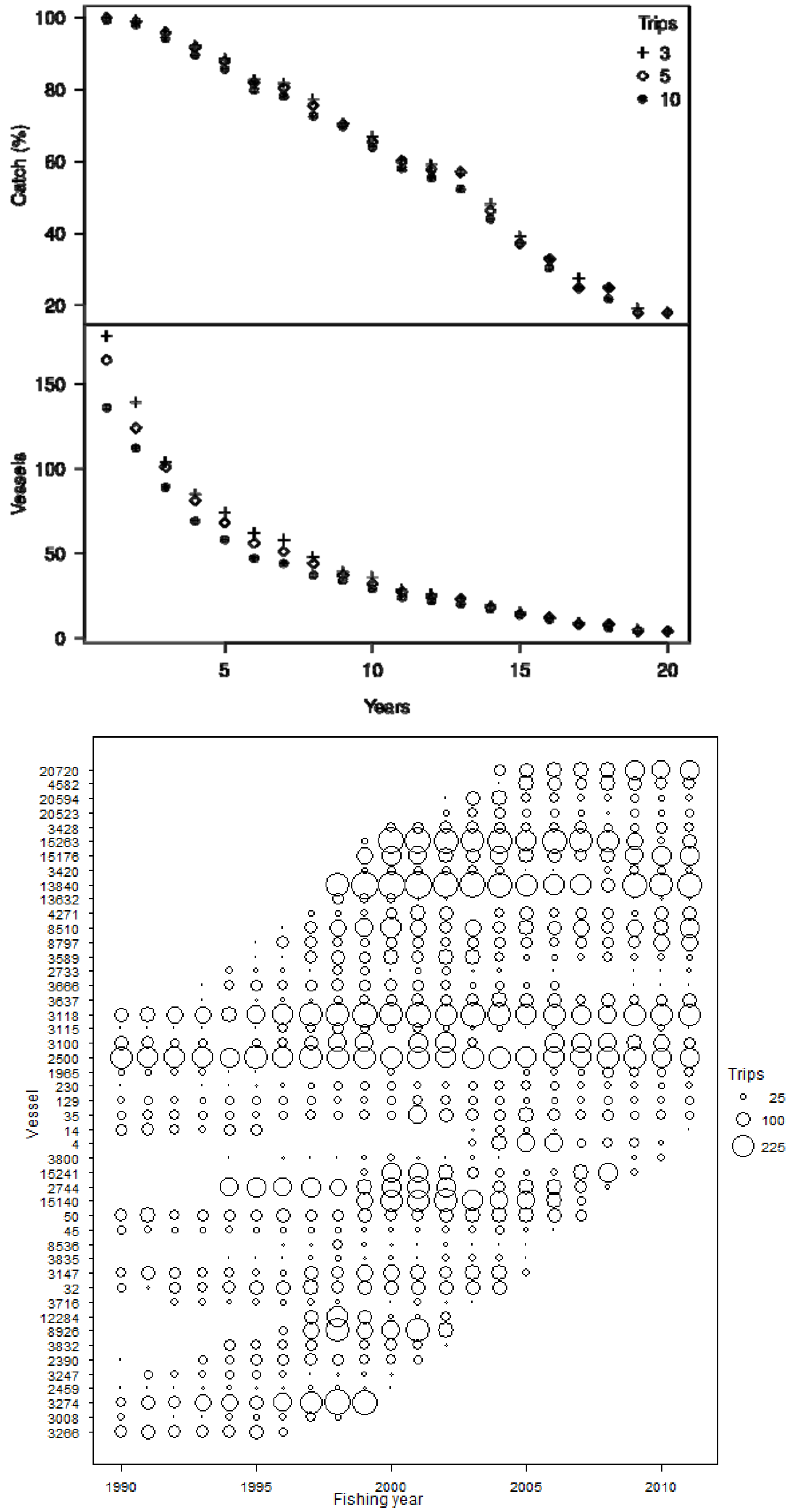
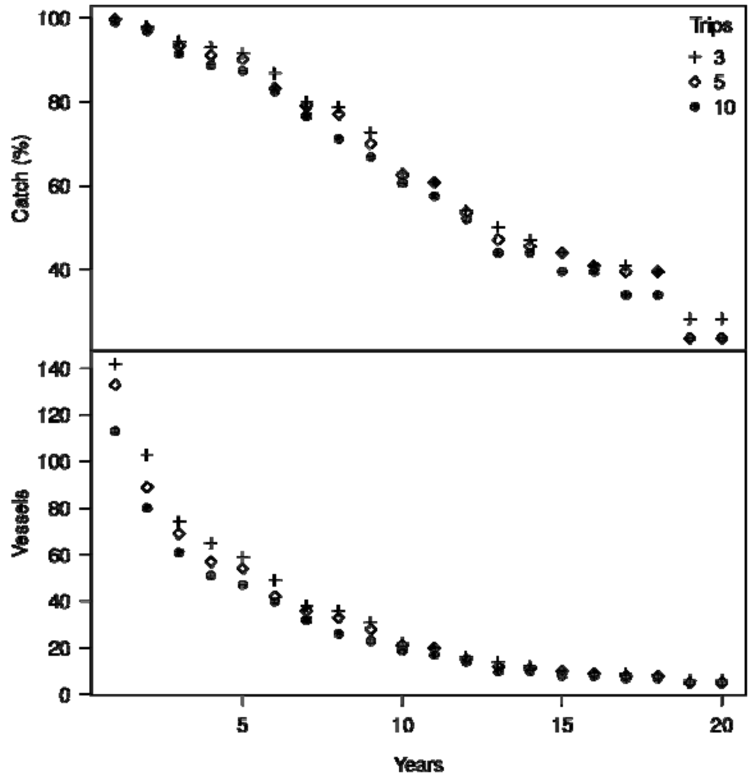


Figure B2: The total estimated flatfish catch [top] and the number of vessels [second] retained in the (YBF) KH dataset depending on the definition of qualifying year (minimum number of trips per year), and the minimum number of qualifying years used to define core vessels. The participation of selected core vessels (based on at least 10 trips per year in at least four years); number of records for each vessel in each fishing year [bottom].



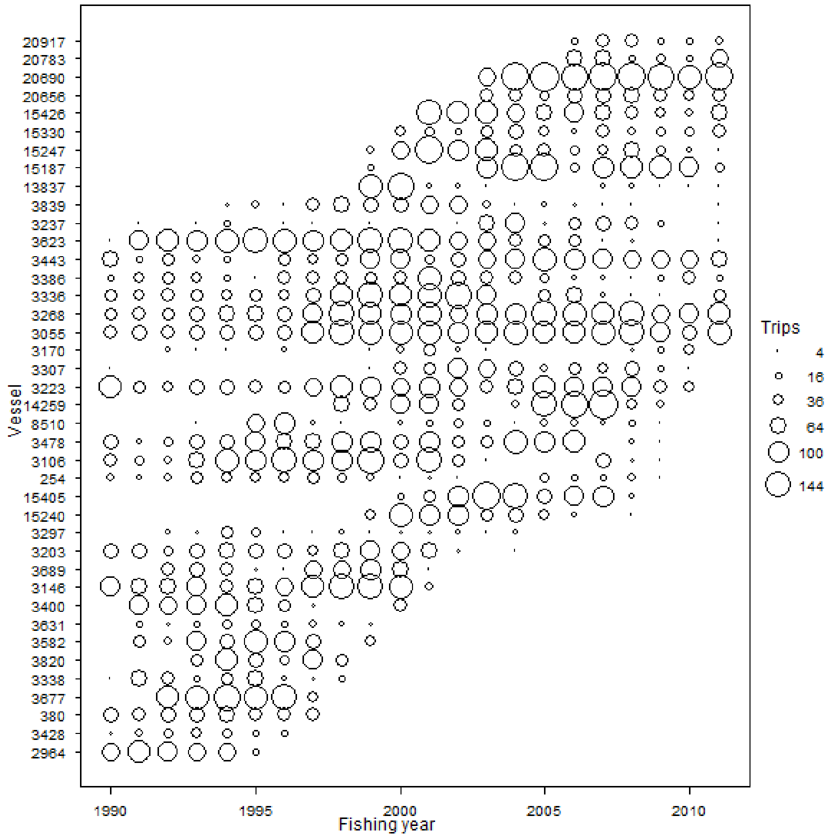


Figure B3: The total estimated flatfish catch [top] and the number of vessels [second] retained in the (YBF) MH dataset depending on the definition of qualifying year (minimum number of trips per year), and the minimum number of qualifying years used to define core vessels. The participation of selected core vessels (based on at least 10 trips per year in at least six years); number of records for each vessel in each fishing year [bottom].

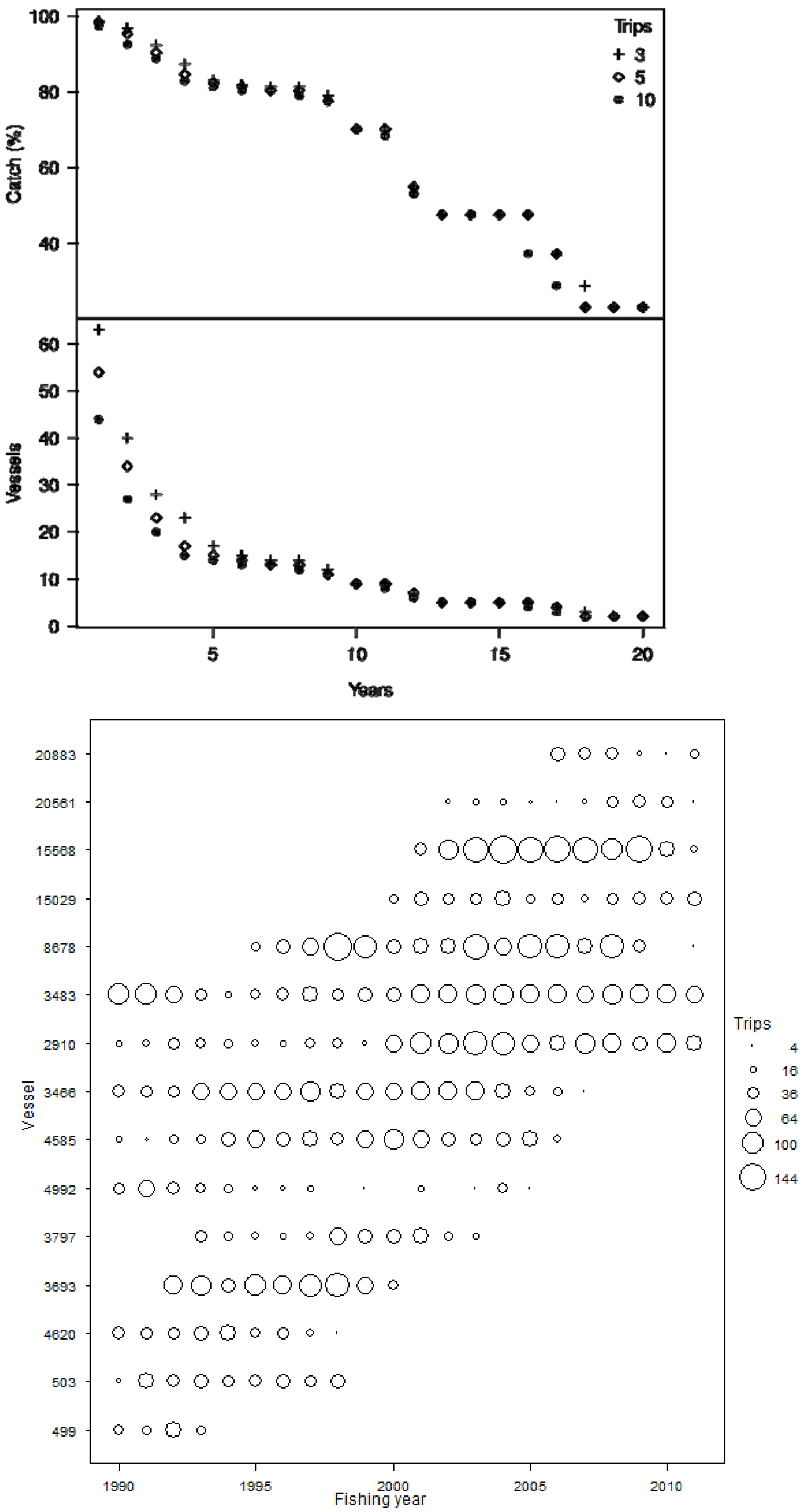


Figure B4: The total estimated flatfish catch [top] and the number of vessels [second] retained in the (YBF) LW dataset depending on the definition of qualifying year (minimum number of trips per year), and the minimum number of qualifying years used to define core vessels. The participation of selected core vessels (based on at least 10 trips per year in at least four years); number of records for each vessel in each fishing year [bottom].

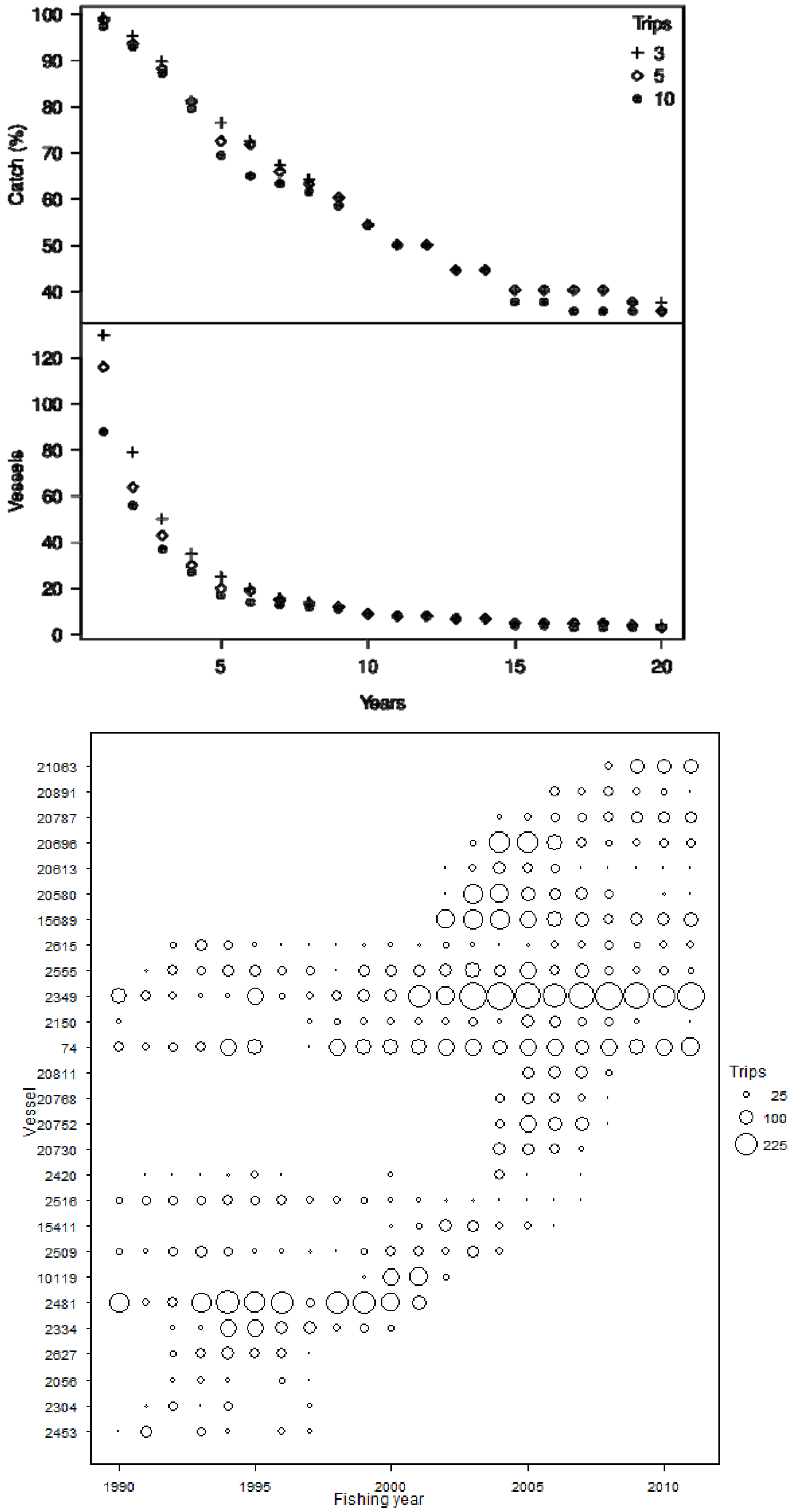


Figure B5: The total estimated flatfish catch [top] and the number of vessels [second] retained in the TOT_EN dataset depending on the definition of qualifying year (minimum number of trips per year), and the minimum number of qualifying years used to define core vessels. The participation of selected core vessels (based on at least 10 trips per year in at least four years); number of records for each vessel in each fishing year [bottom].

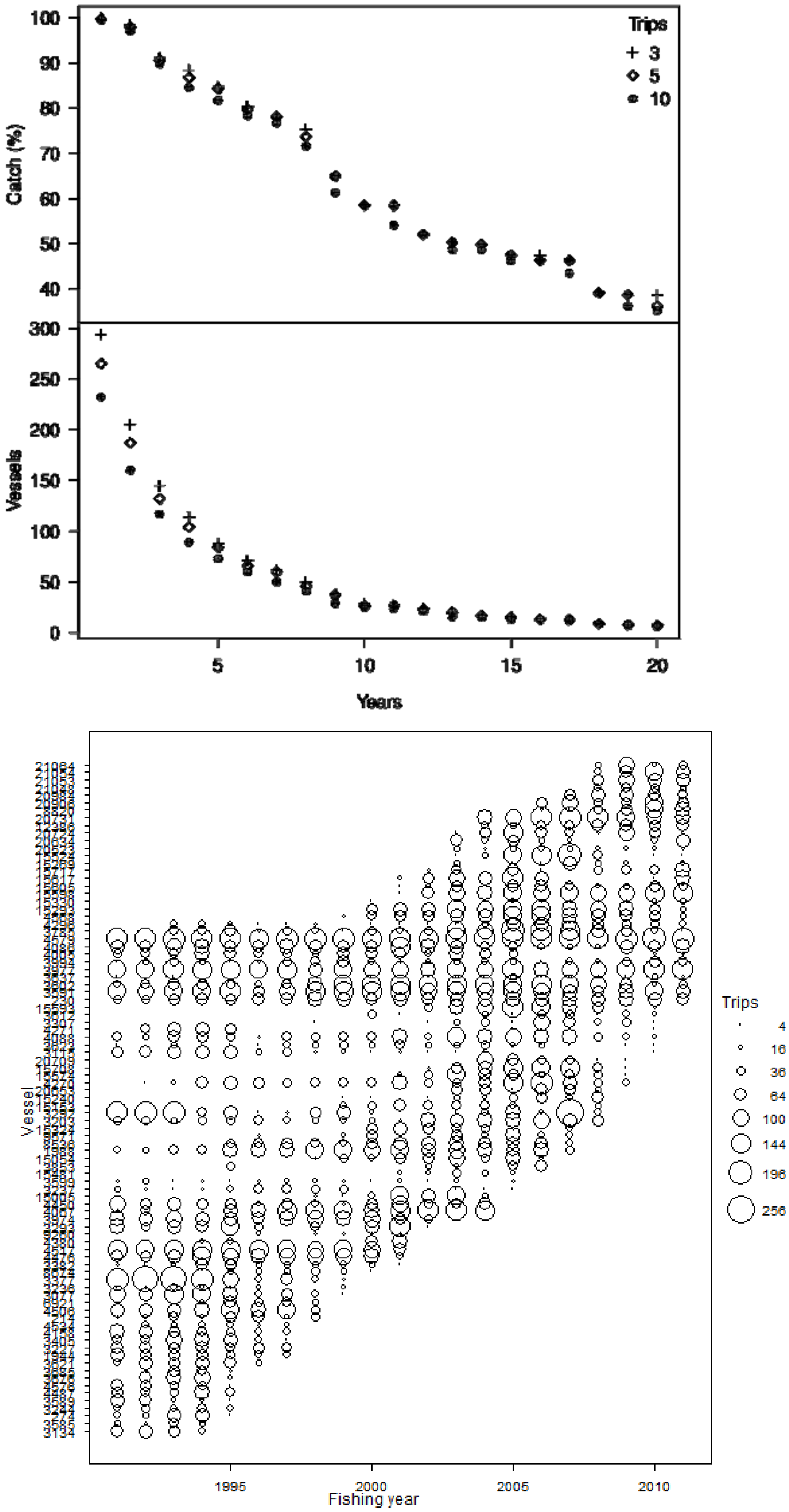
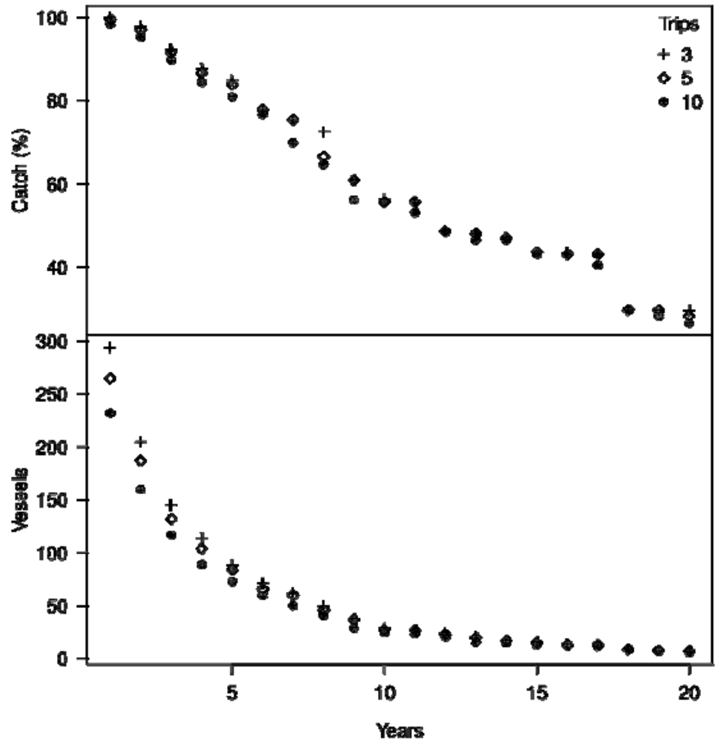


Figure B6: The total estimated flatfish catch [top] and the number of vessels [second] retained in the YBF_HG dataset depending on the definition of qualifying year (minimum number of trips per year), and the minimum number of qualifying years used to define core vessels. The participation of selected core vessels (based on at least 10 trips per year in at least four years); number of records for each vessel in each fishing year [bottom].



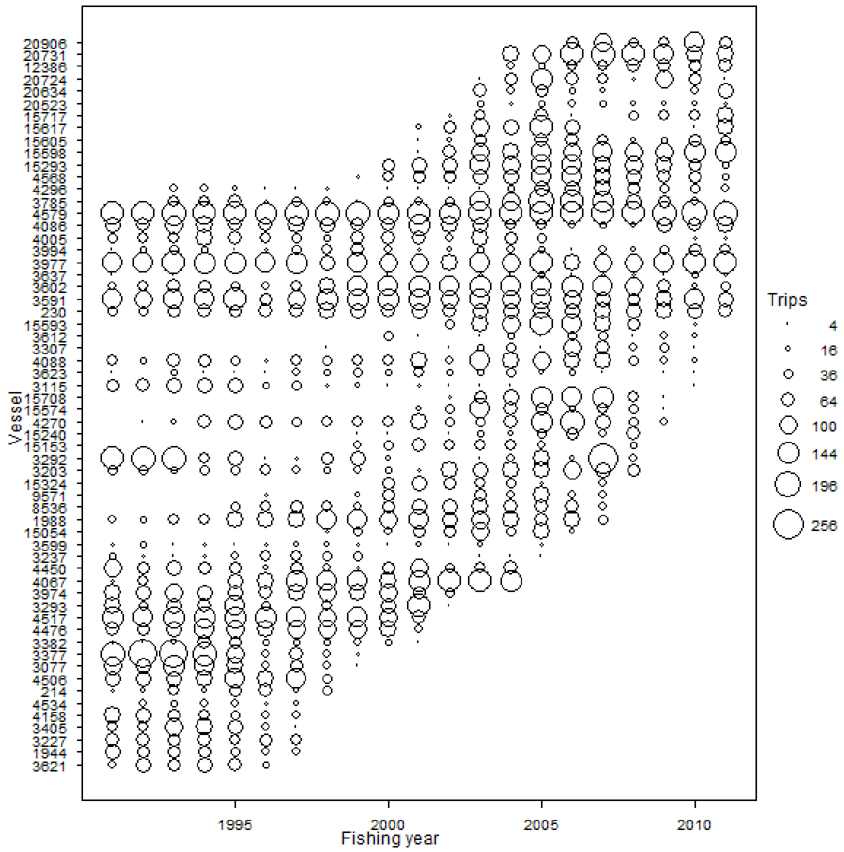


Figure B7: The total estimated flatfish catch [top] and the number of vessels [second] retained in the SFL_HG dataset depending on the definition of qualifying year (minimum number of trips per year), and the minimum number of qualifying years used to define core vessels. The participation of selected core vessels (based on at least 10 trips per year in at least six years); number of records for each vessel in each fishing year [bottom].

APPENDIX C. ATERNATIVE ERROR DISTRIBUTIONS

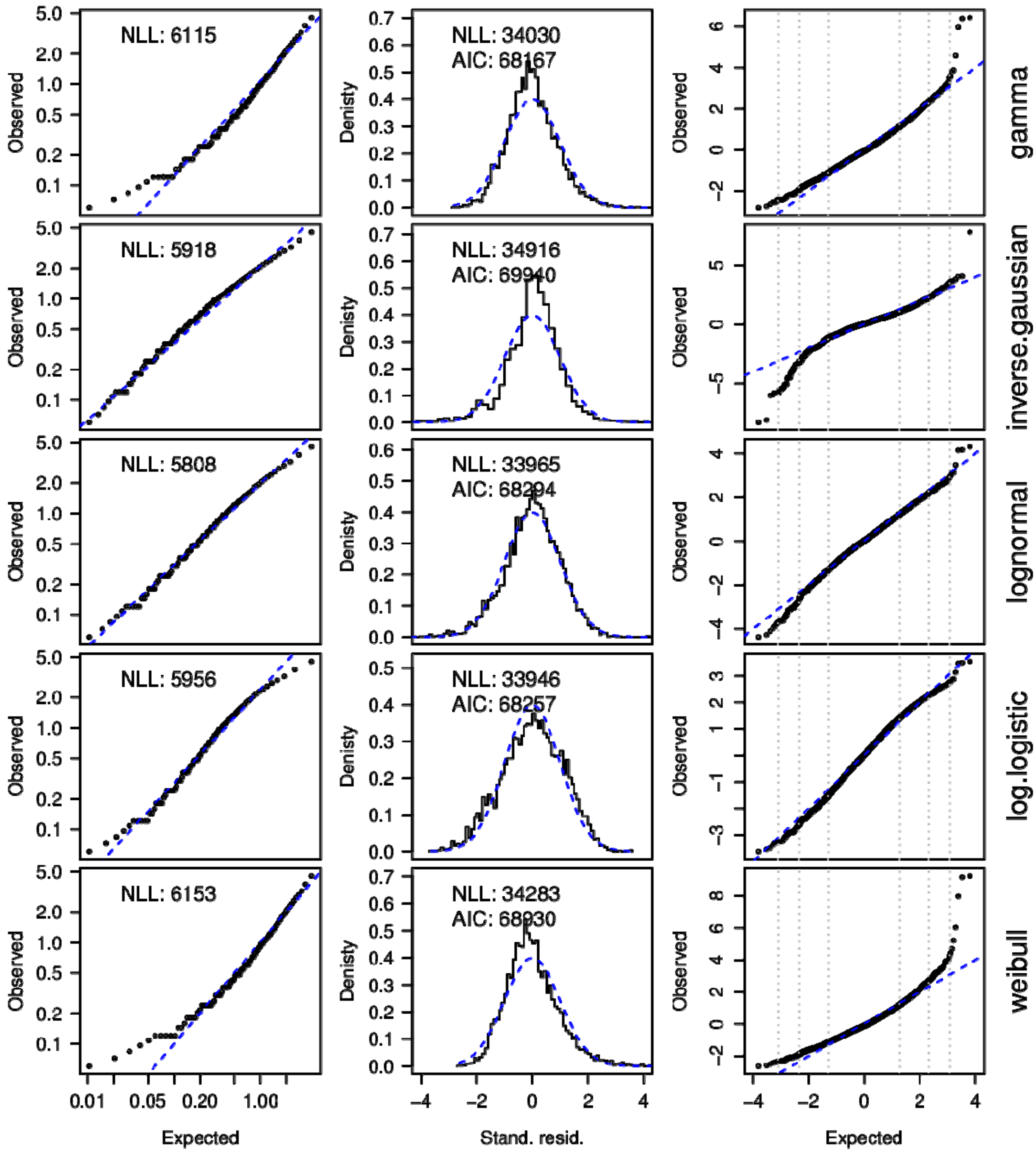


Figure C1: Diagnostics for alternative distributional assumptions for catch in (YBF) NW. Left: maximum likelihood fit (dotted) to observed catches (solid, scaled by their mean); Middle: standardised residuals from a model catch~fyear + month + vessel; Right: quantile-quantile plot of standardised residuals of model. LL = log-likelihood of fit. The best distribution was log-logistic.

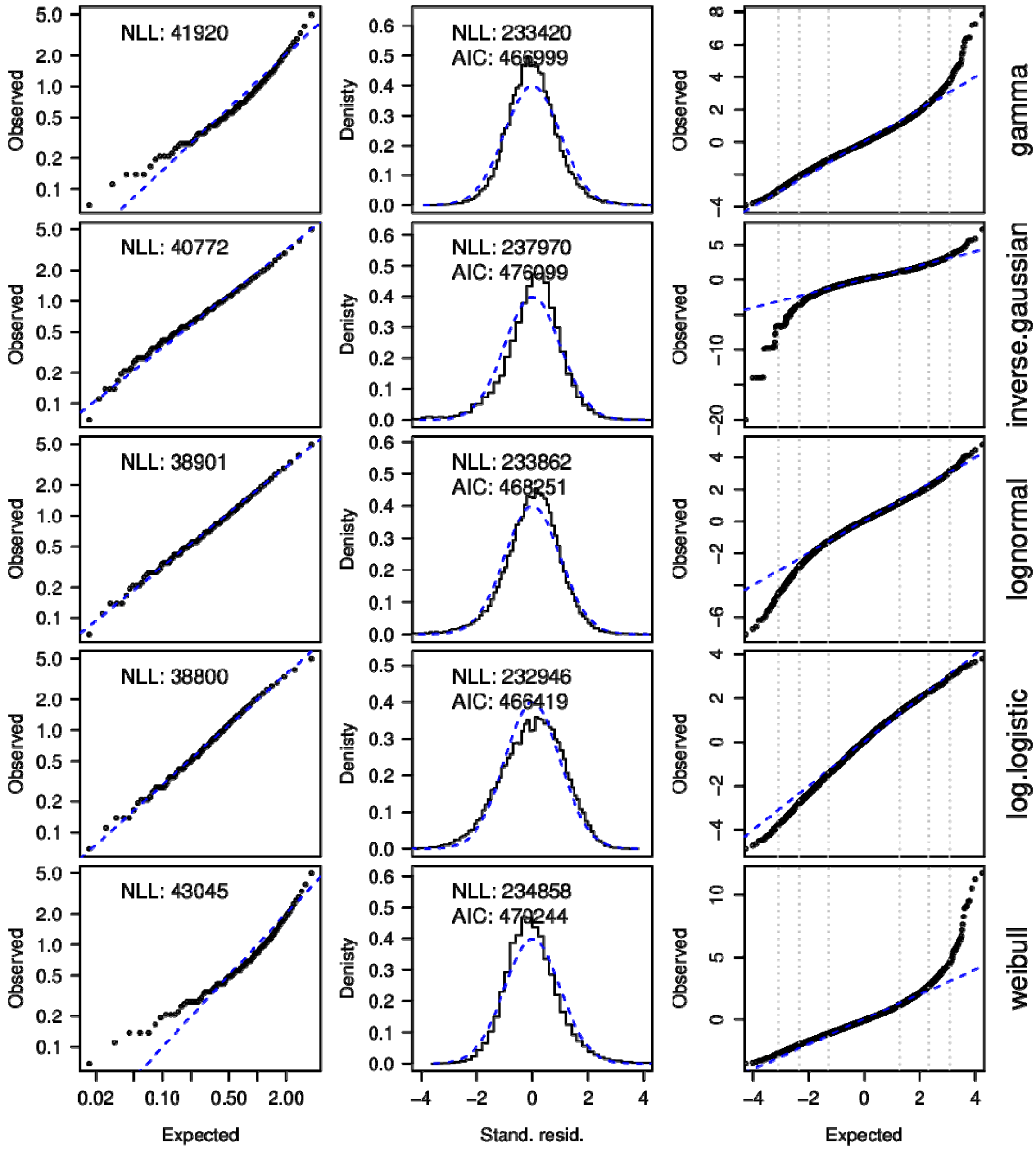


Figure C2: Diagnostics for alternative distributional assumptions for catch in (YBF) KH. Left: maximum likelihood fit (dotted) to observed catches (solid, scaled by their mean); Middle: standardised residuals from a model catch~fyear+month+vessel; Right: quantile-quantile plot of standardised residuals of model. LL = log-likelihood of fit. The best distribution was log-logistic.

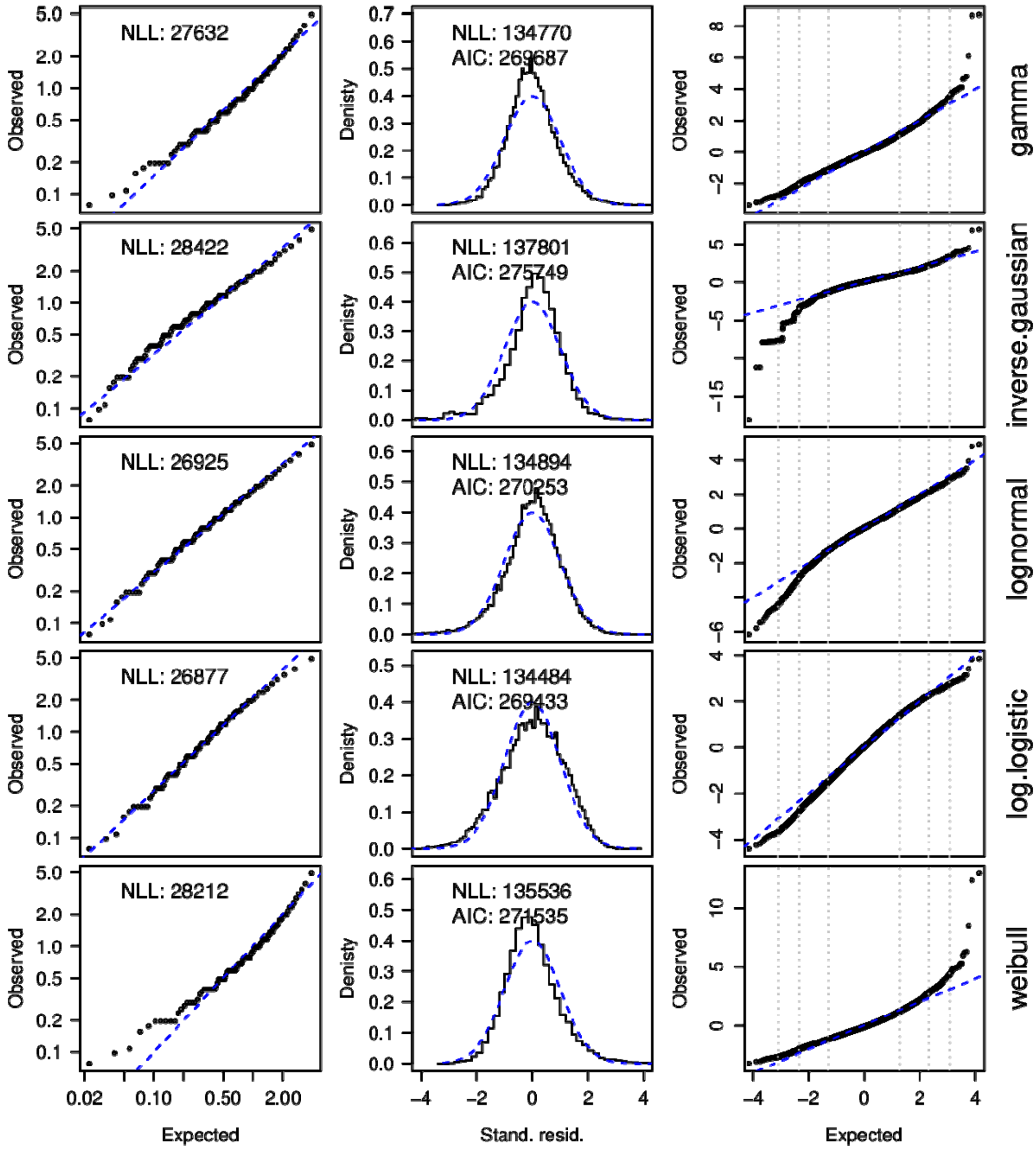


Figure C3: Diagnostics for alternative distributional assumptions for catch in (YBF) MH. Left: maximum likelihood fit (dotted) to observed catches (solid, scaled by their mean); Middle: standardised residuals from a model catch~fyear+month+vessel; Right: quantile-quantile plot of standardised residuals of model. LL = log-likelihood of fit. The best distribution was log-logistic.

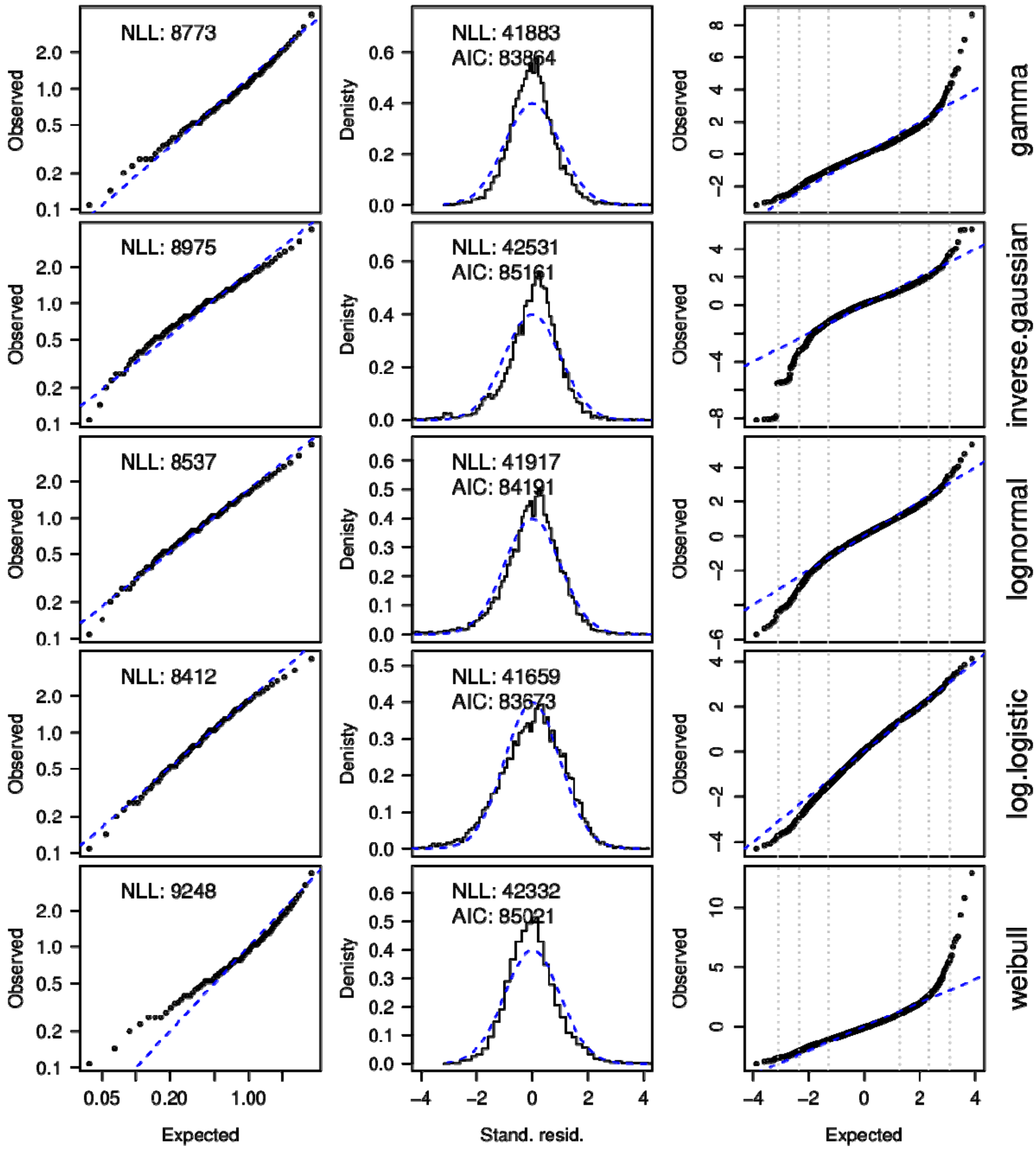


Figure C4: Diagnostics for alternative distributional assumptions for catch in (YBF) LW. Left: maximum likelihood fit (dotted) to observed catches (solid, scaled by their mean); Middle: standardised residuals from a model catch~fyear+month +vessel; Right: quantile-quantile plot of standardised residuals of model. LL = log-likelihood of fit. The best distribution was log-logistic.

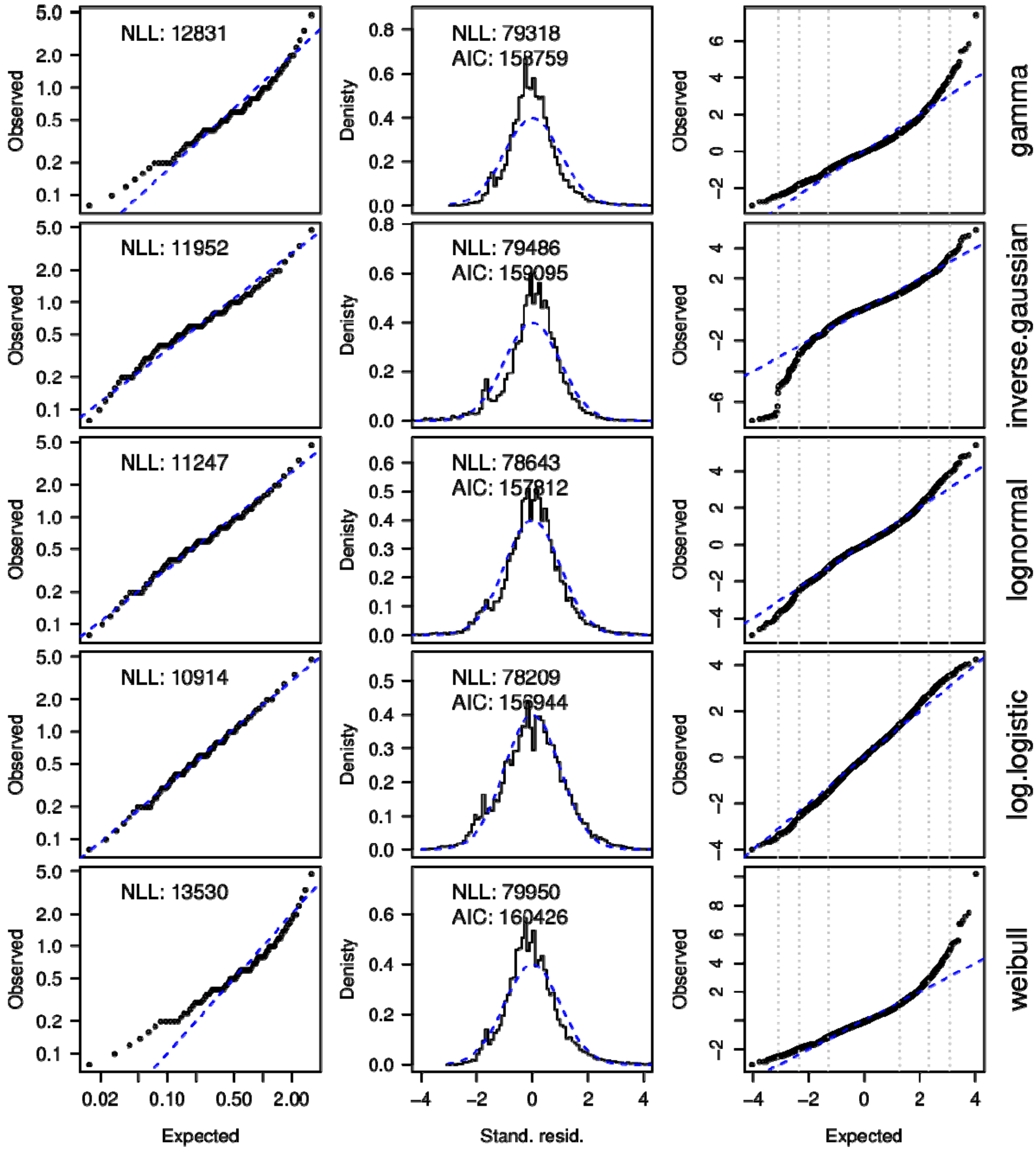


Figure C5: Diagnostics for alternative distributional assumptions for catch in TOT_EN. Left: maximum likelihood fit (dotted) to observed catches (solid, scaled by their mean); Middle: standardised residuals from a model catch~fyear+month +vessel; Right: quantile-quantile plot of standardised residuals of model. LL = log-likelihood of fit. The best distribution was log-logistic.

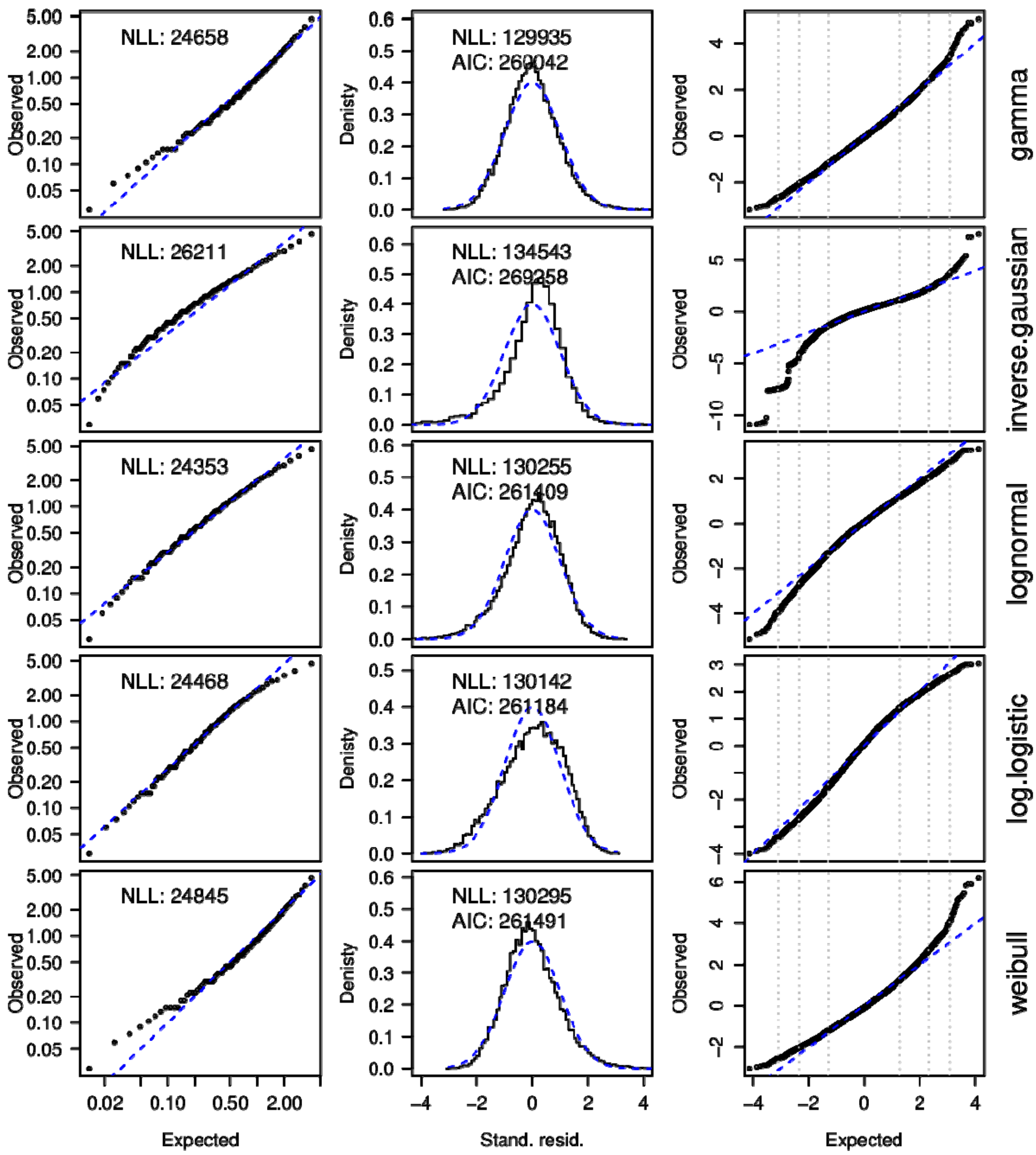


Figure C6: Diagnostics for alternative distributional assumptions for catch in YBF_HG KH. Left: maximum likelihood fit (dotted) to observed catches (solid, scaled by their mean); Middle: standardised residuals from a model catch~fyear+month+vessel; Right: quantile-quantile plot of standardised residuals of model. LL = log-likelihood of fit. The best distribution was gamma.

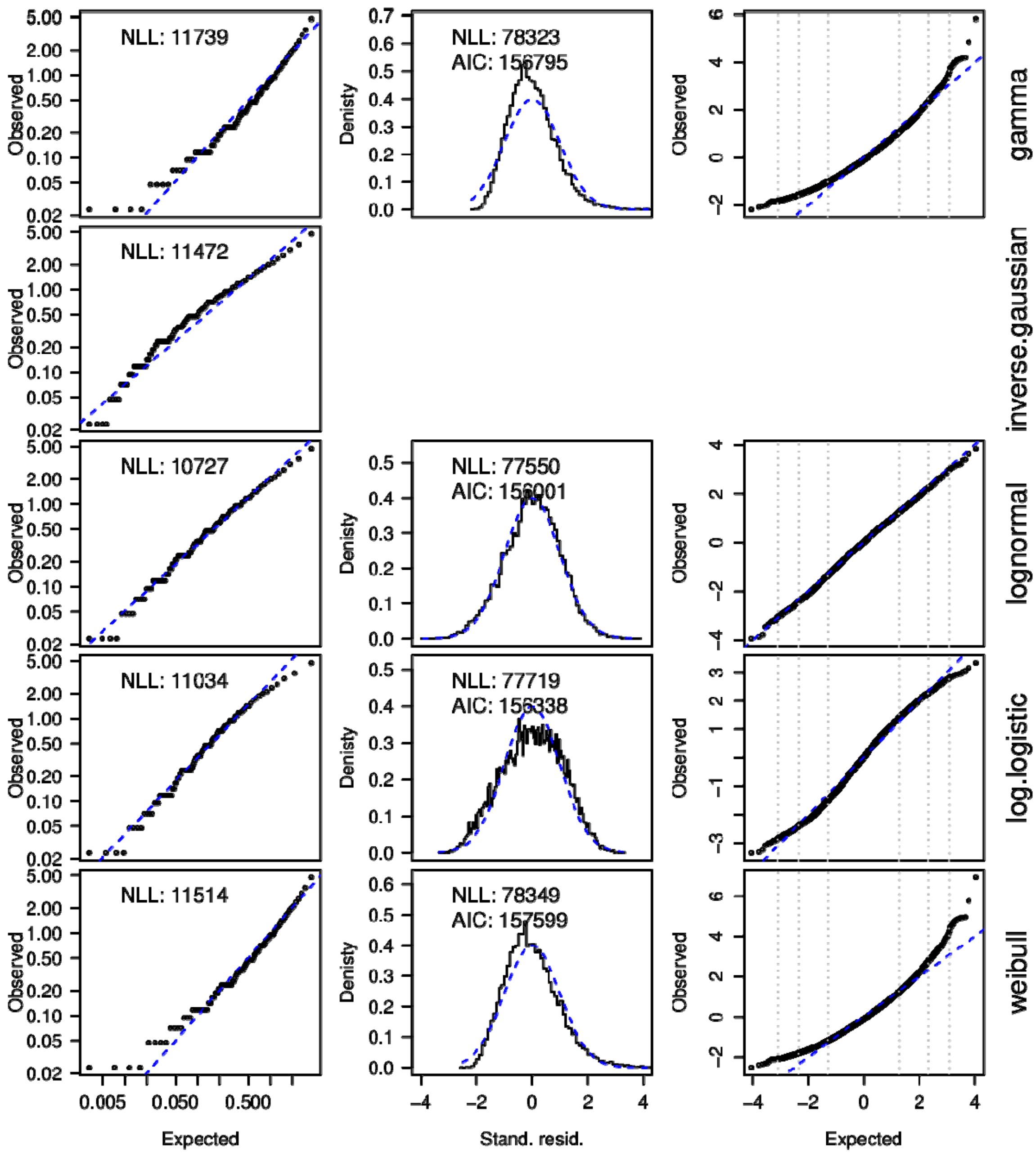


Figure C7: Diagnostics for alternative distributional assumptions for catch in SFL_HG. Left: maximum likelihood fit (dotted) to observed catches (solid, scaled by their mean); Middle: standardised residuals from a model catch~fyear+month+vessel; Right: quantile-quantile plot of standardised residuals of model. LL = log-likelihood of fit. The best distribution was lognormal. Missing plots indicate a failure of the model to converge.

APPENDIX D. INFLUENCE OF TERMS

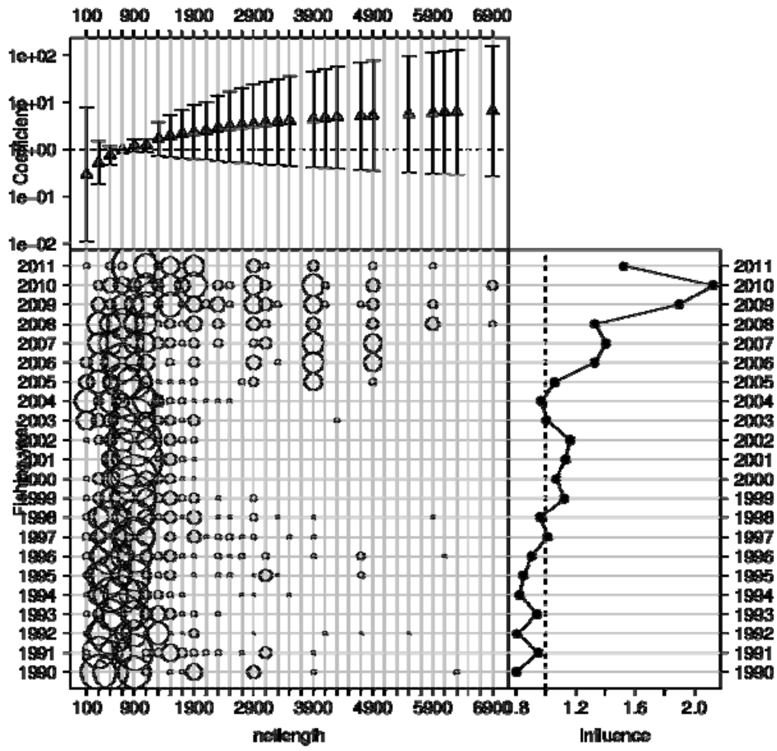


Figure D1: Effect and influence of ***log(netlength)*** **in the (YBF) NW log-logistic model. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.**

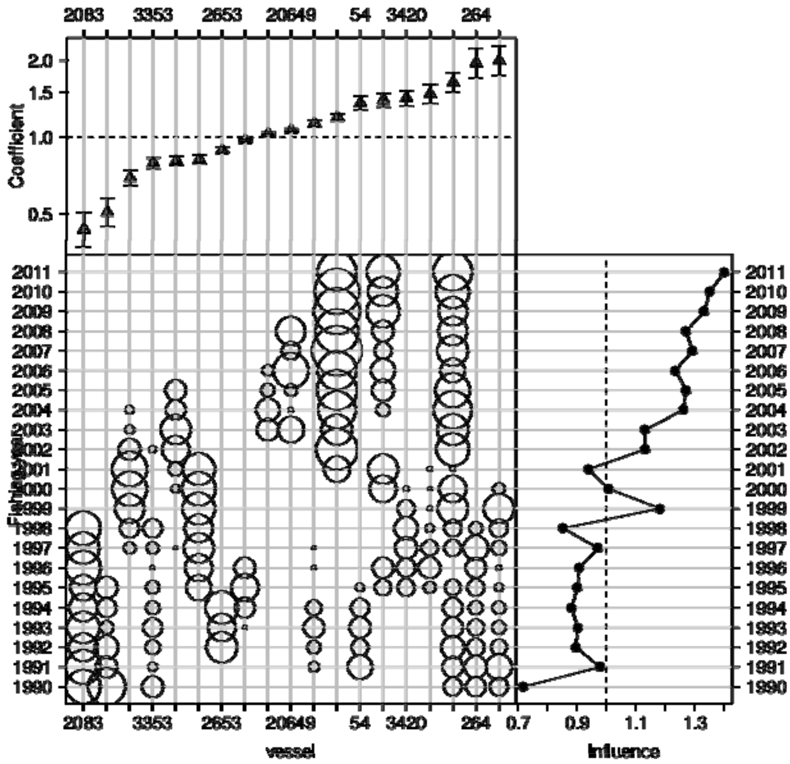


Figure D2: Effect and influence of ***vessel ID*** **in the (YBF) NW log-logistic model. See caption (D1) for details.**

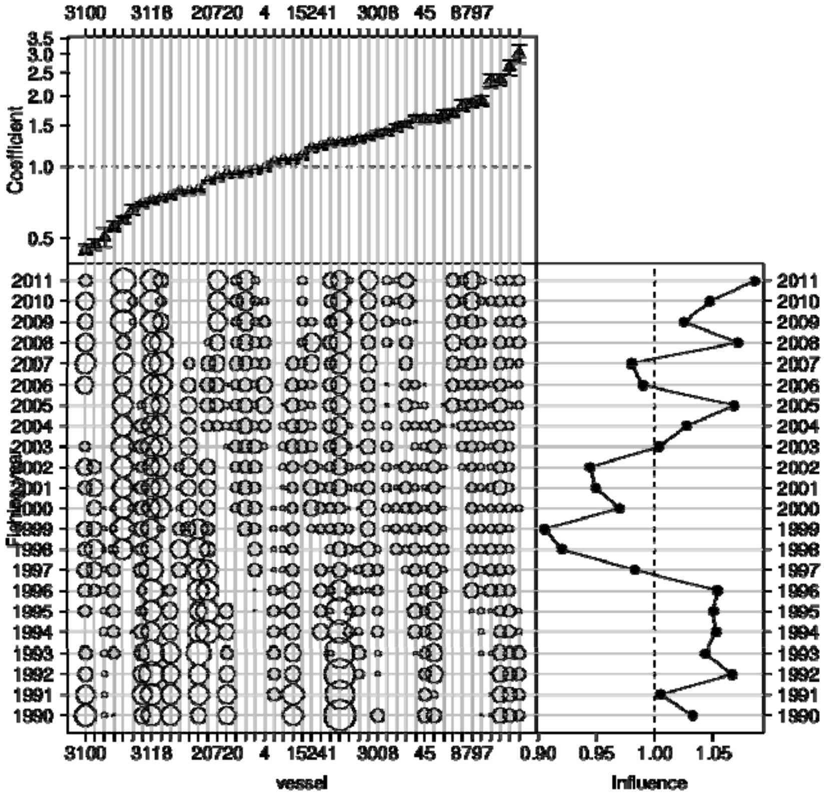


Figure D3: Effect and influence of *vessel ID* in the (YBF) KH log-logistic model. See caption (D1) for details.

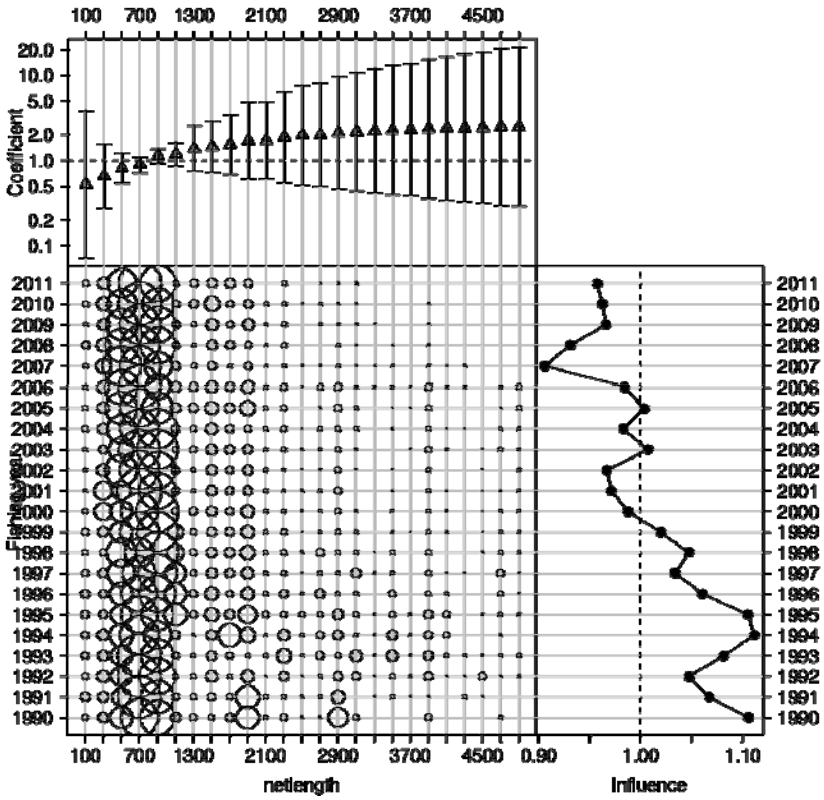


Figure D4: Effect and influence of *log(netlength)* in the (YBF) KH log-logistic model. See caption (D1) for details.

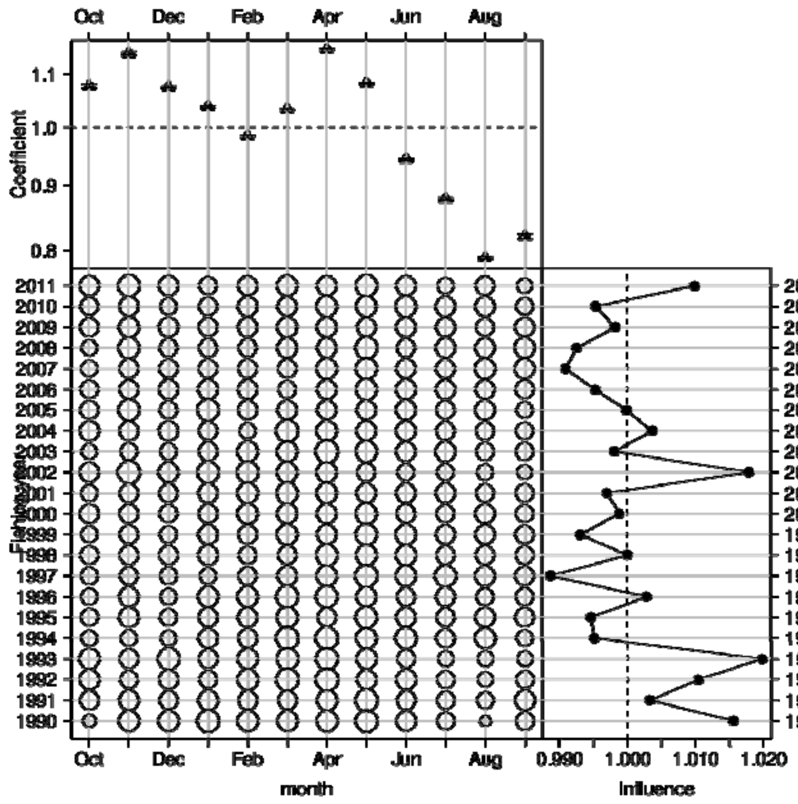


Figure D5: Effect and influence of *month* in the (YBF) KH log-logistic model. See caption (D1) for details.

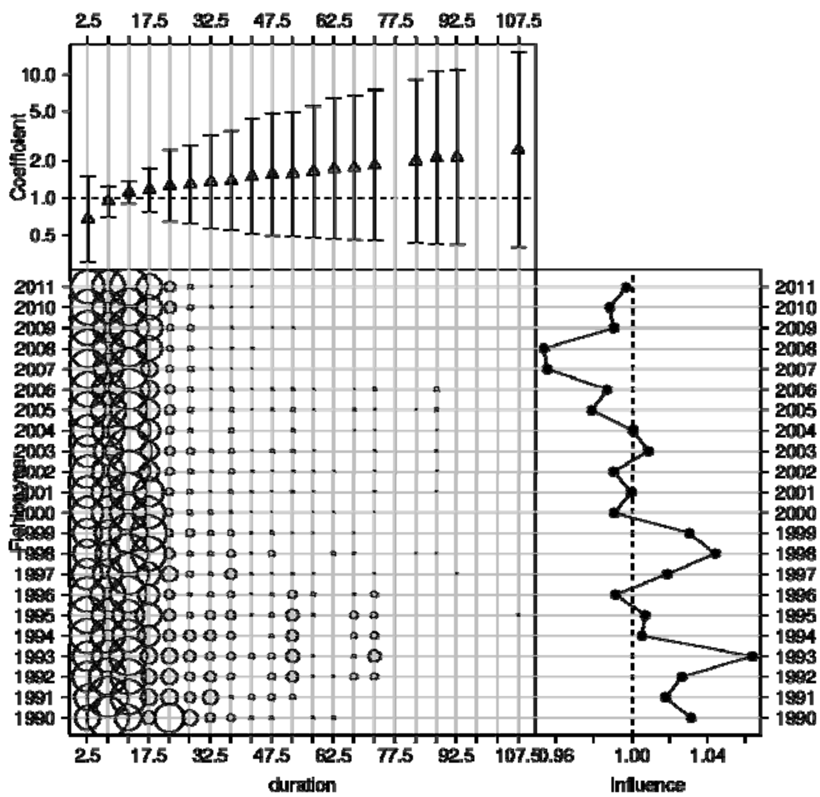


Figure D6: Effect and influence of *log(duration)* in the (YBF) KH log-logistic model. See caption (D1) for details.

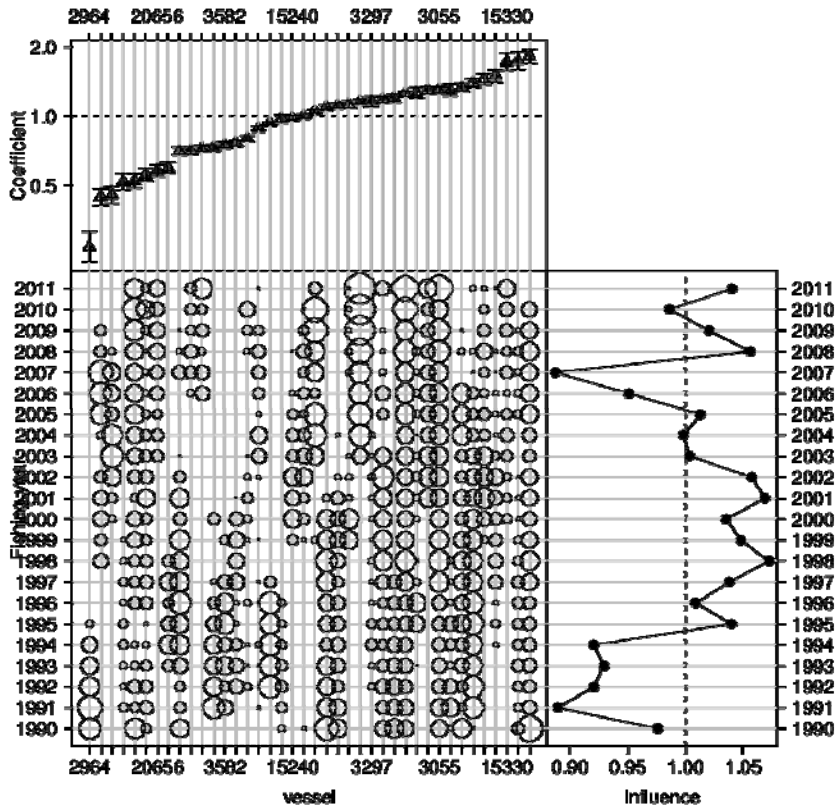


Figure D7: Effect and influence of *vessel ID* in the (YBF) MH log-logistic model. See caption (D1) for details.

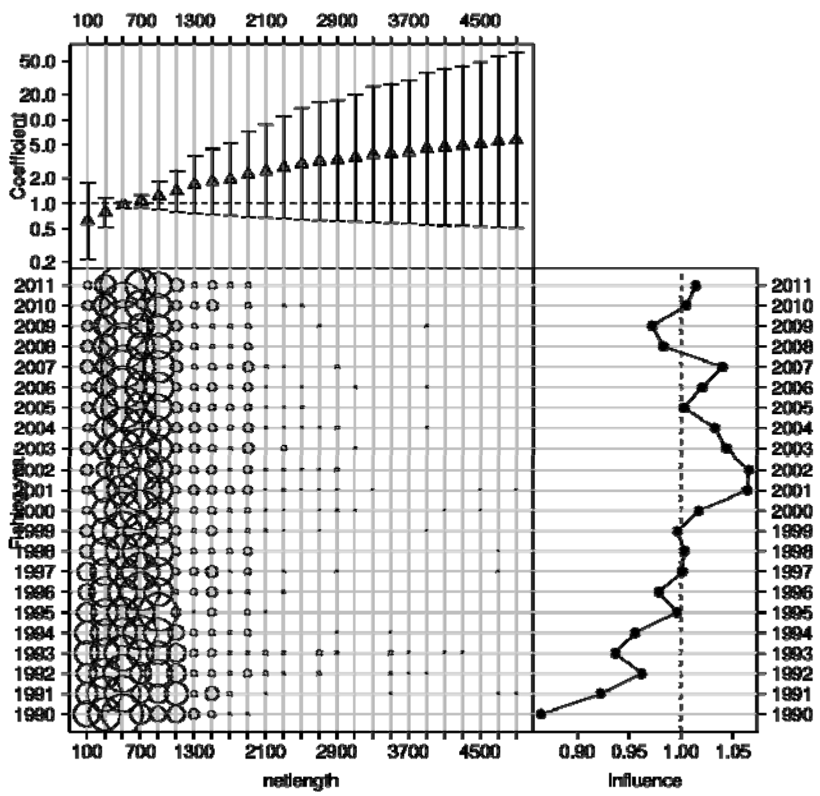


Figure D8: Effect and influence of *log(netlength)* in the (YBF) MH log-logistic model. See caption (D1) for details.

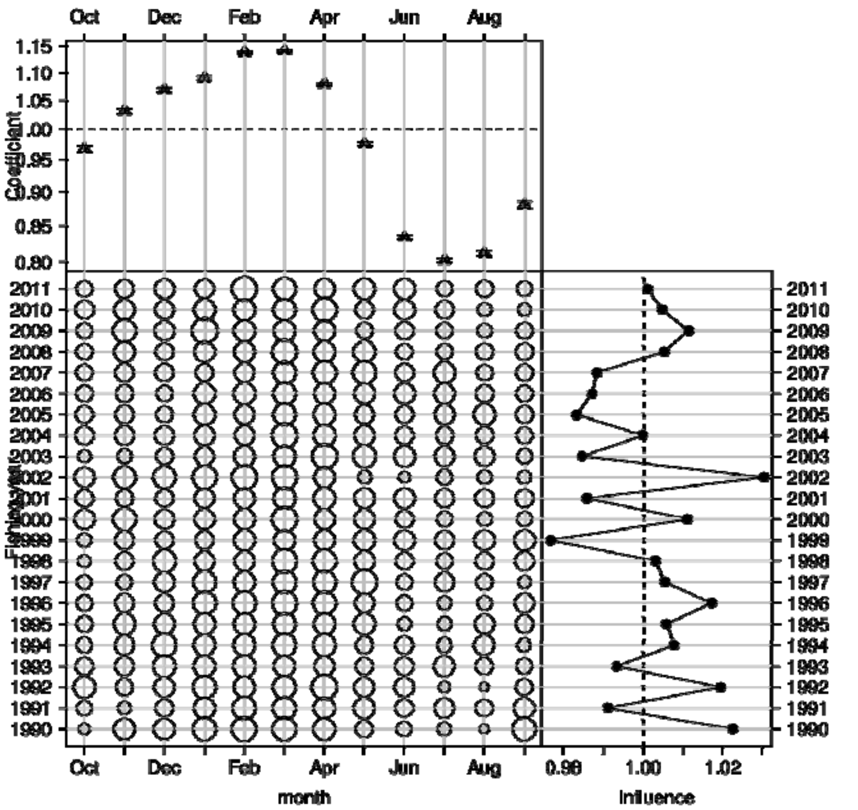


Figure D9: Effect and influence of *month* in the (YBF) MH log-logistic model. See caption (D1) for details.

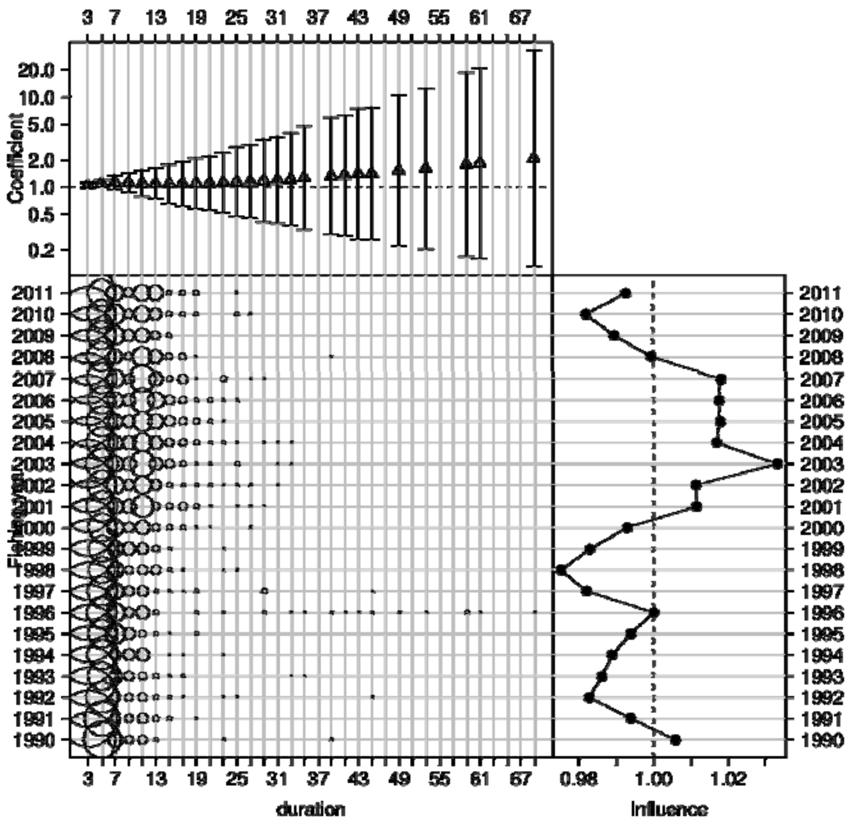


Figure D10: Effect and influence of *log(duration)* in the (YBF) MH log-logistic model. See caption (D1) for details.

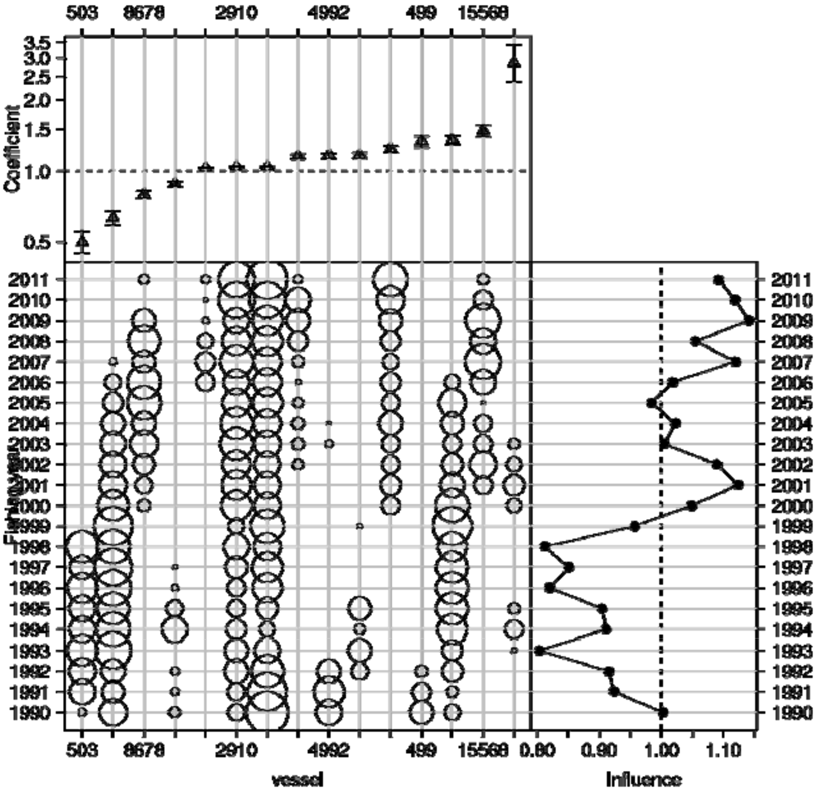


Figure D11: Effect and influence of *vessel ID* in the (YBF) LW log-logistic model. See caption (D1) for details.

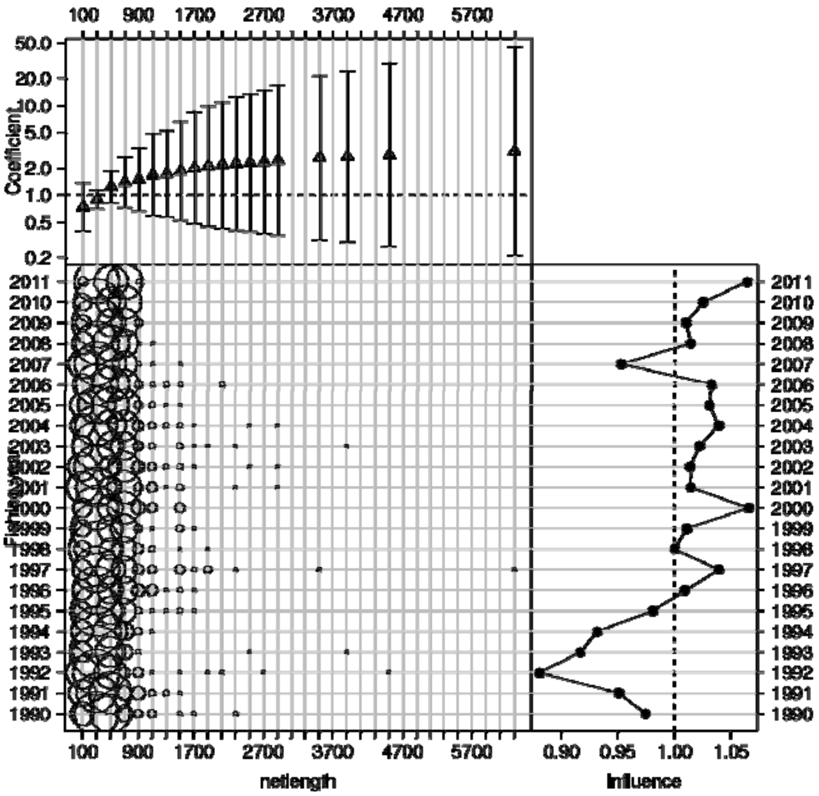


Figure D12: Effect and influence of *log(netlength)* in the (YBF) LW log-logistic model. See caption (D1) for details.

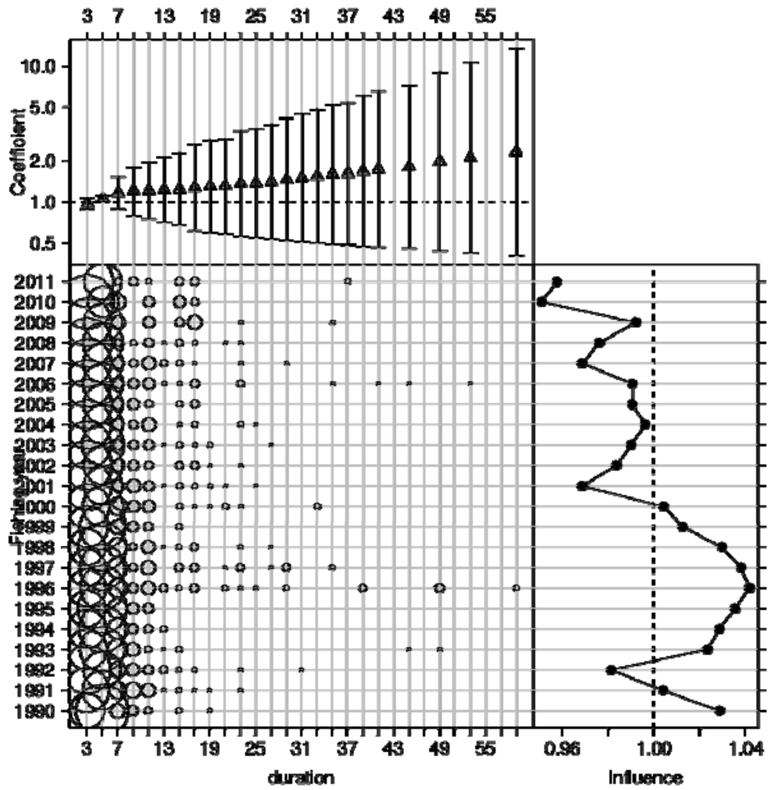


Figure D13: Effect and influence of *log(duration)* in the (YBF) LW log-logistic model. See caption (D1) for details.

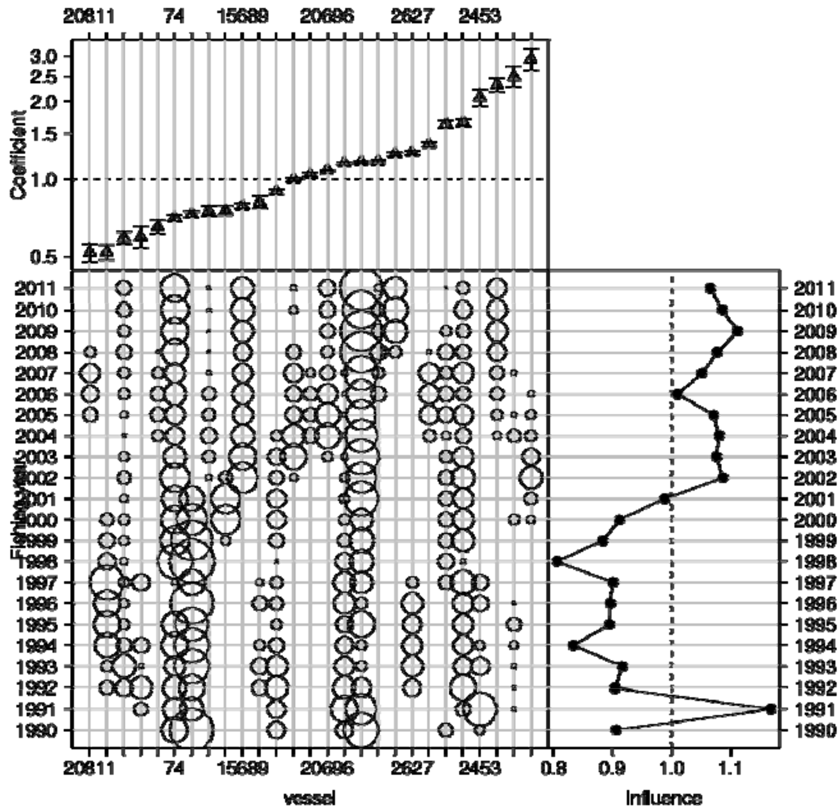


Figure D14: Effect and influence of *vessel ID* in the TOT_EN log-logistic model. See caption (D1) for details.

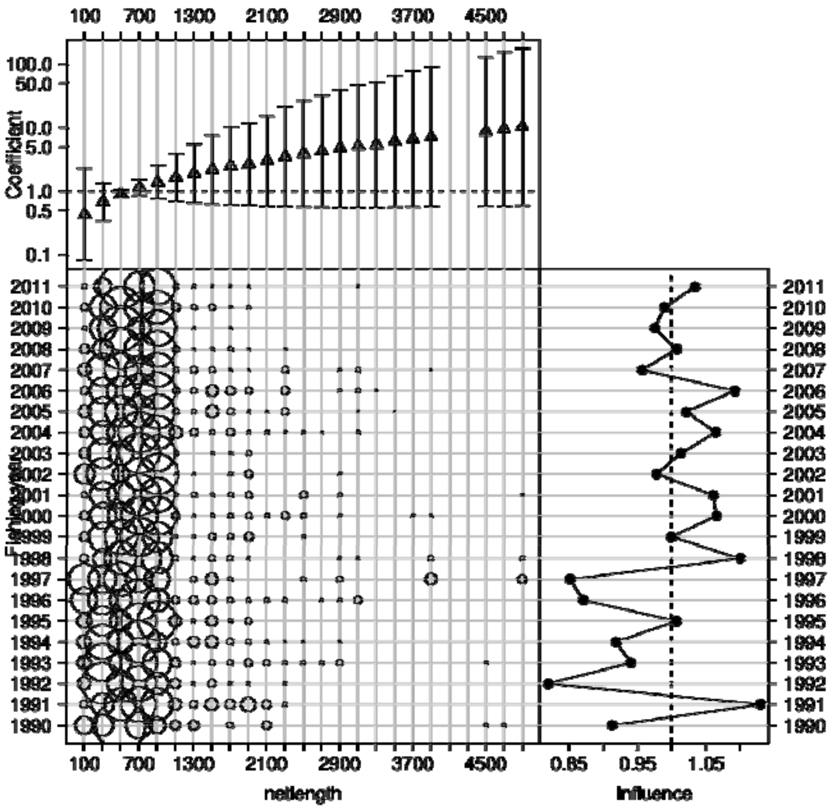


Figure D15: Effect and influence of *log(netlength)* in the TOT_EN log-logistic model. See caption (D1) for details.

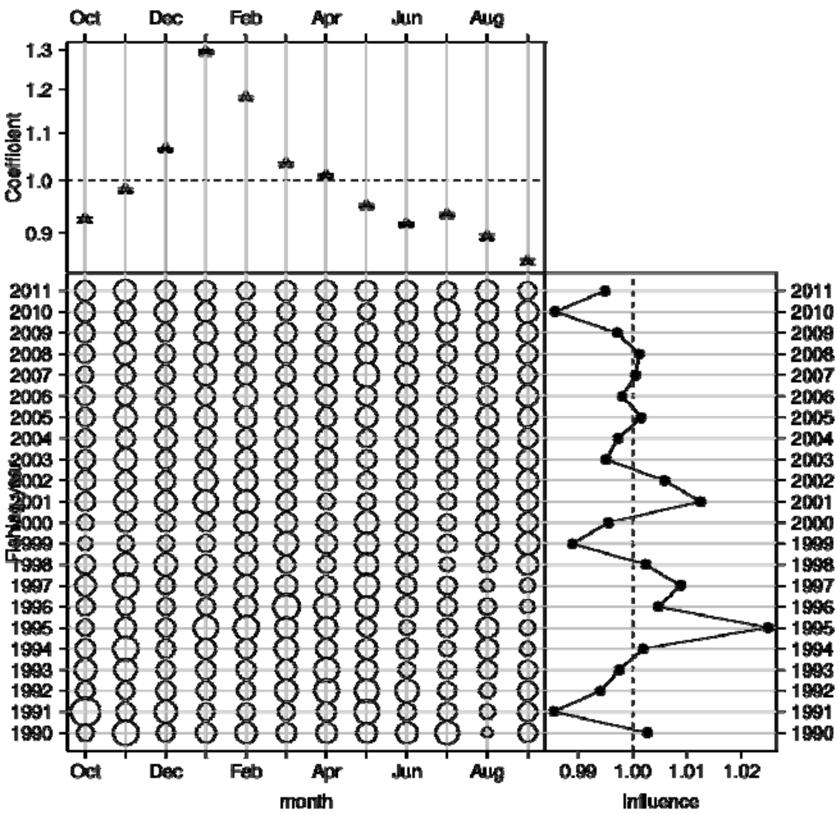


Figure D16: Effect and influence of *month* in the TOT_EN log-logistic model. See caption (D1) for details.

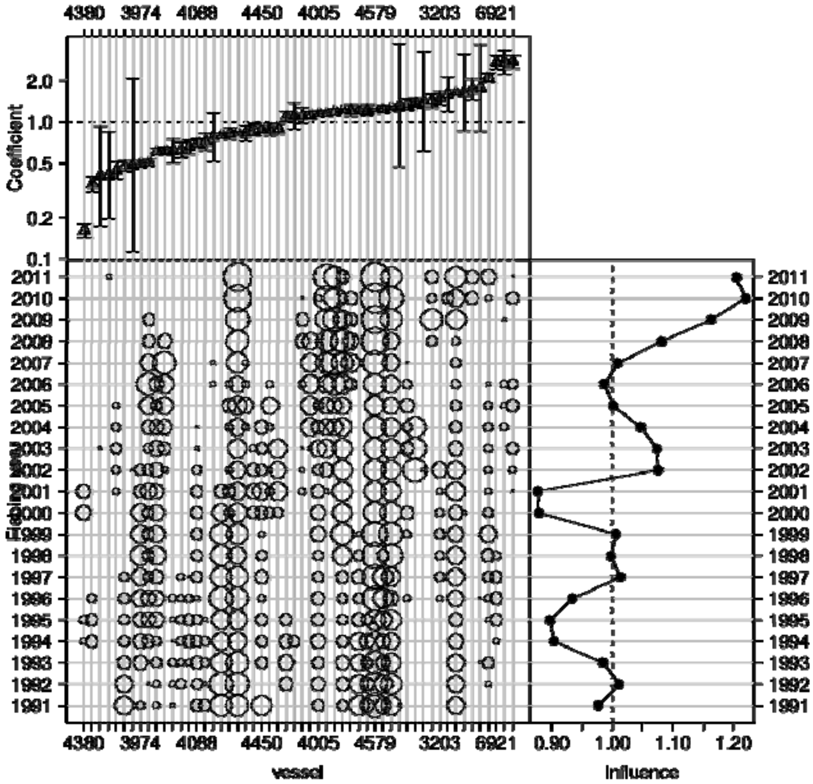


Figure D17: Effect and influence of *vessel* in the YBF_HG gamma model. See caption (D1) for details.

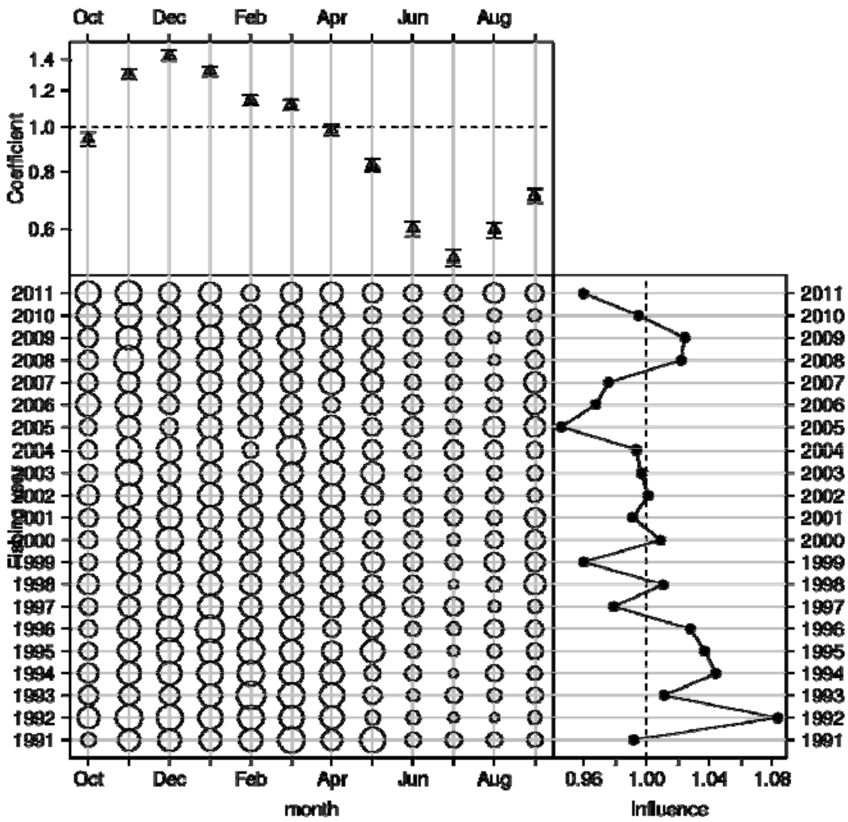


Figure D18: Effect and influence of *month* in the YBF_HG gamma model. See caption (D1) for details.

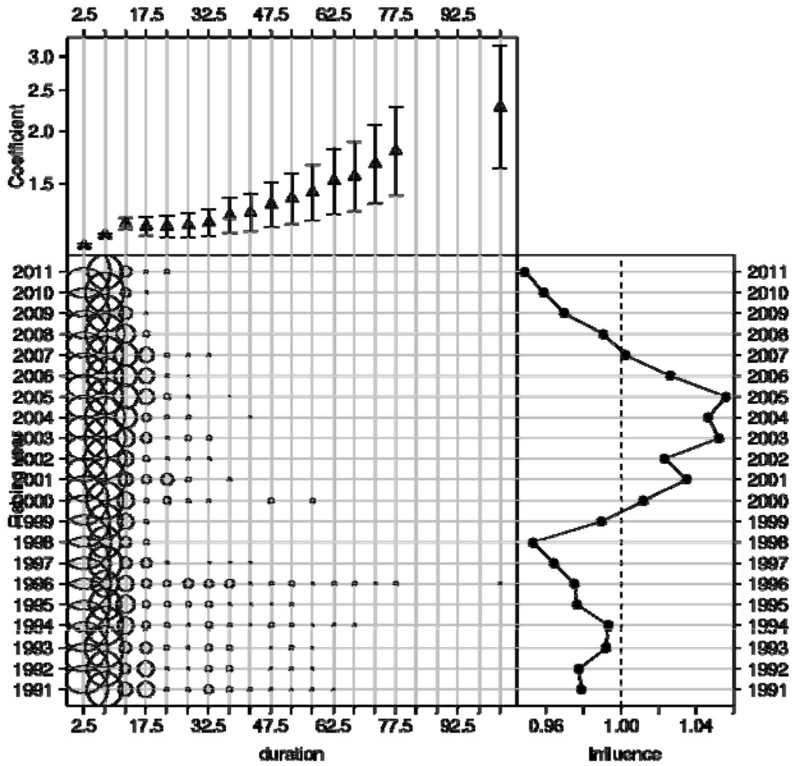


Figure D19: Effect and influence of *log duration* in the YBF_HG gamma model. See caption (D1) for details.

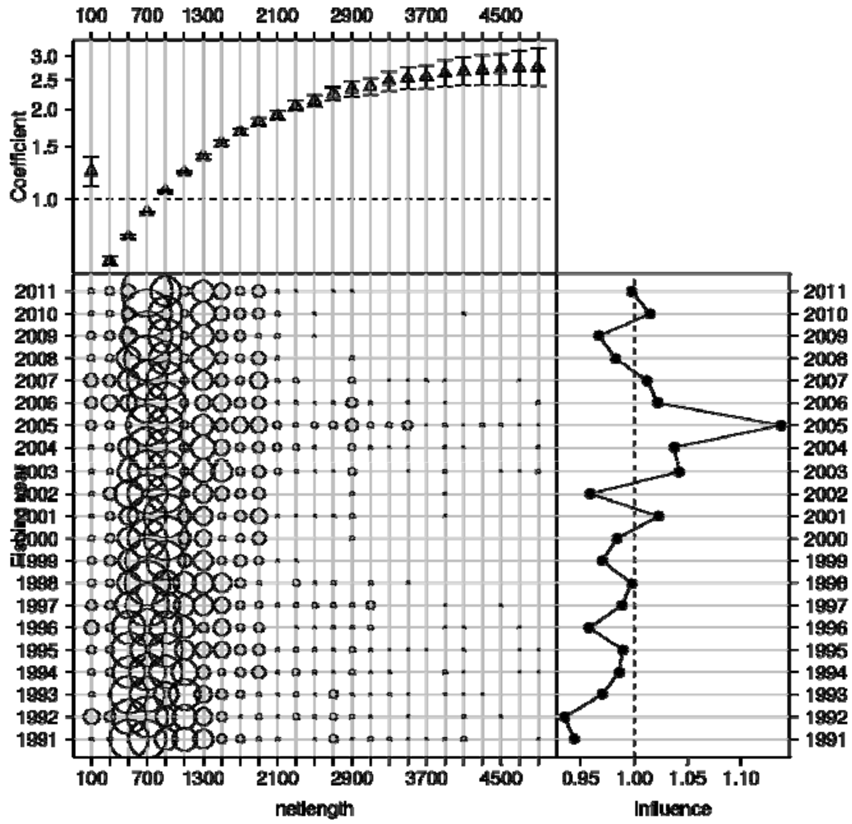


Figure D20: Effect and influence of *log netlength* in the YBF_HG gamma model. See caption (D1) for details.

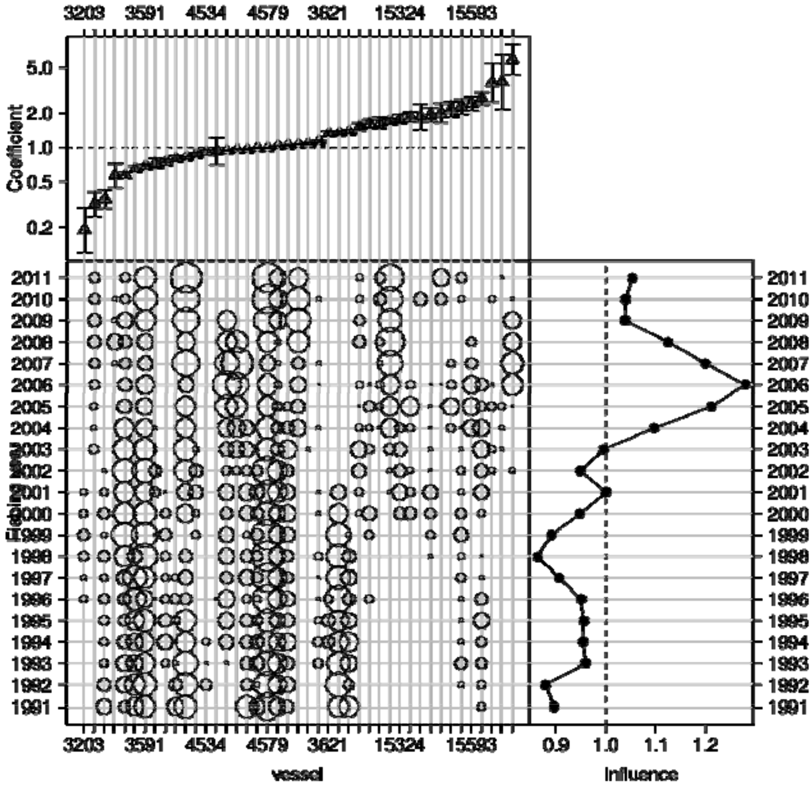


Figure D21: Effect and influence of *vessel ID* in the SFL_HG Lognormal model. See caption (D1) for details.

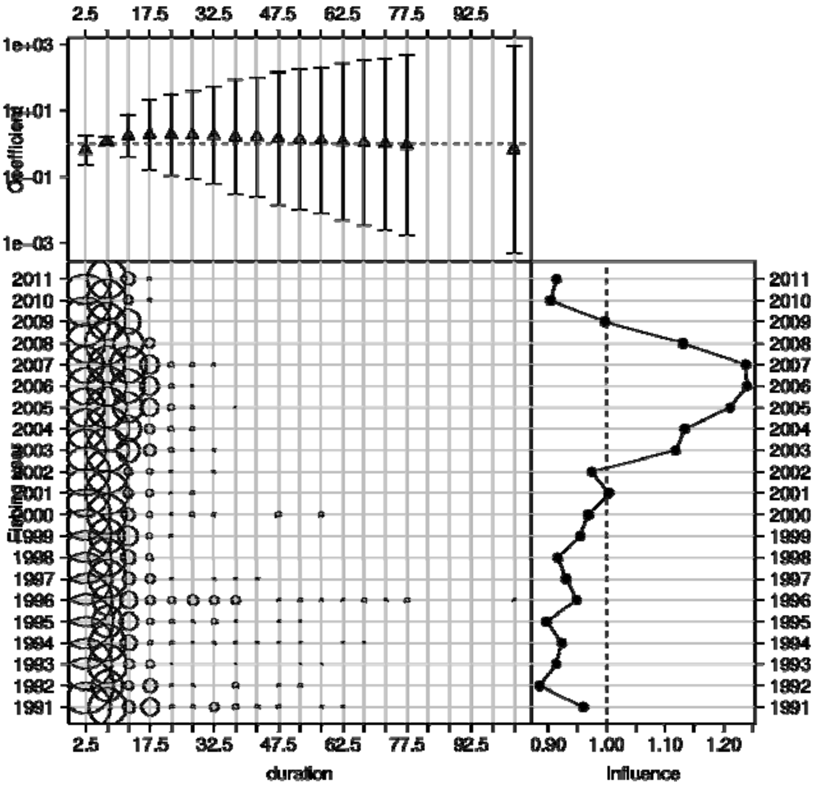


Figure D22: Effect and influence of *log duration* in the SFL_HG Lognormal model. See caption (D1) for details.

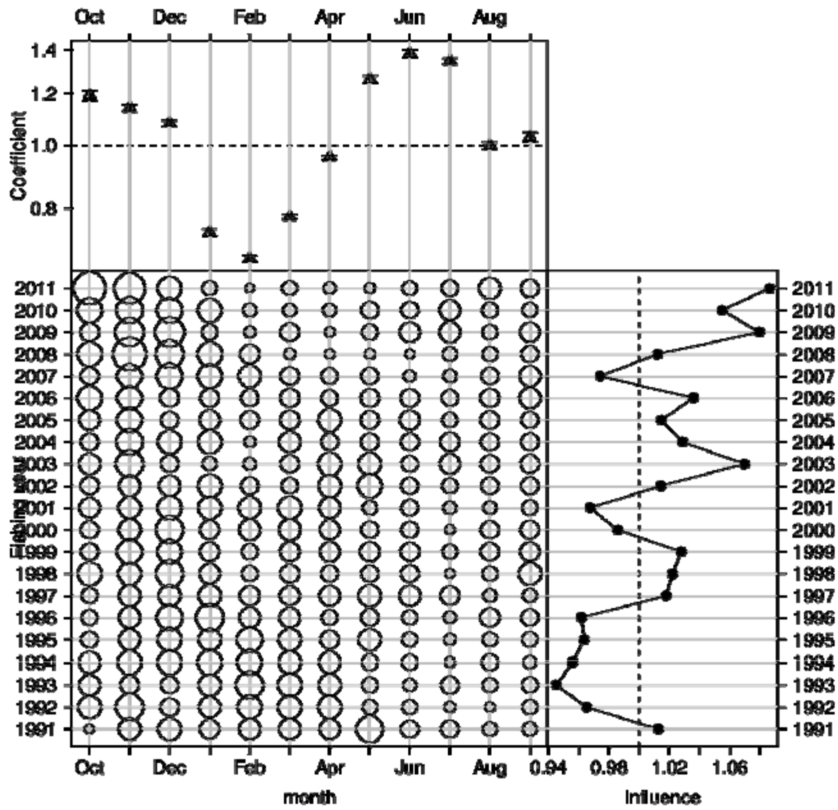


Figure D23: Effect and influence of *month* in the SFL_HG Lognormal model. See caption (D1) for details.

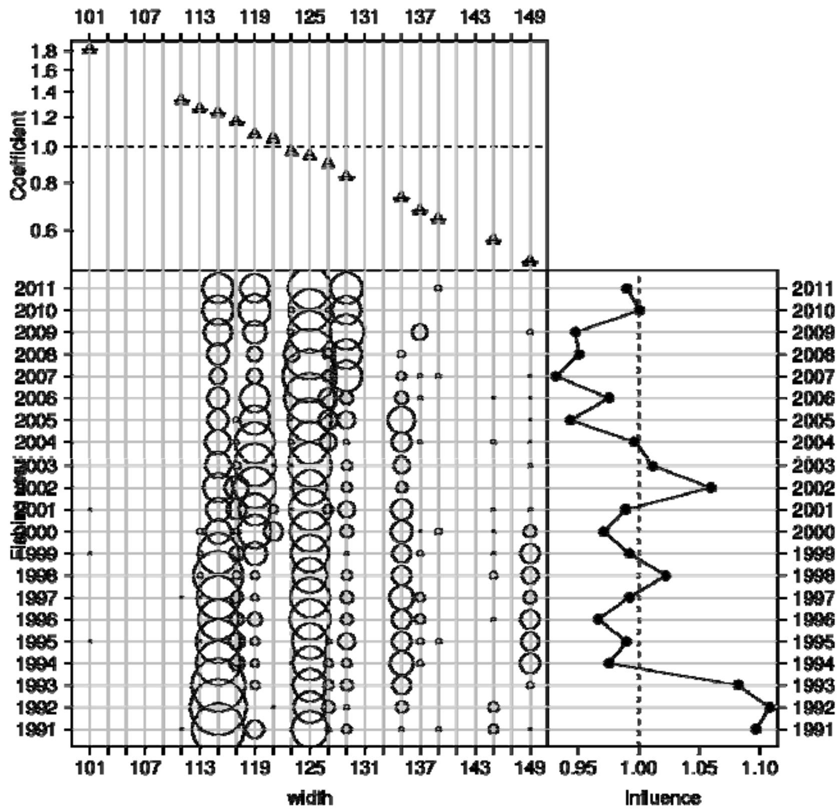


Figure D24: Effect and influence of *mesh size* in the SFL_HG Lognormal model. See caption (D1) for details.

APPENDIX E: FINAL MODEL RESIDUAL DIAGNOSTICS

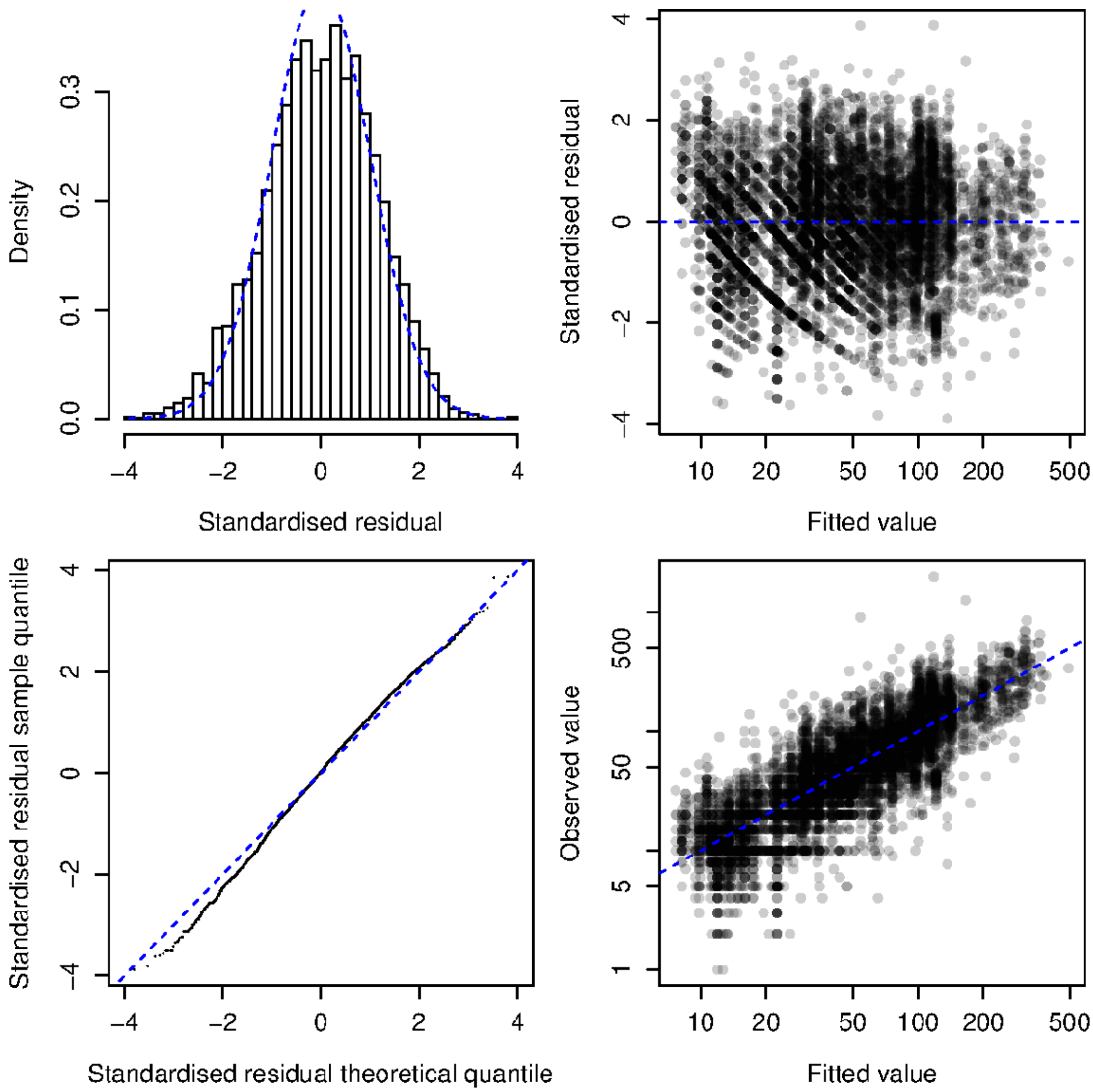


Figure E1: Plots of the fit of the final standardised CPUE model to positive catches in the (YBF) NW fishery assuming a log logistic error distribution. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: standardised residuals versus fitted values. Bottom right: observed values versus fitted values.

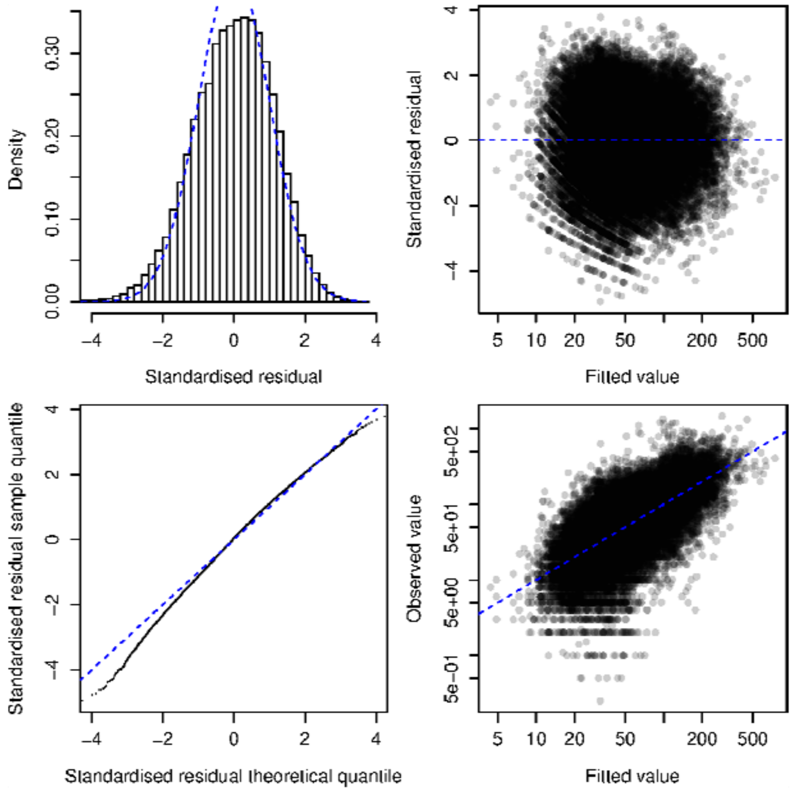


Figure E2: Plots of the fit of the final standardised CPUE model to positive catches in the (YBF) KH fishery assuming a log logistic error distribution. See caption of Figure E1 for details.

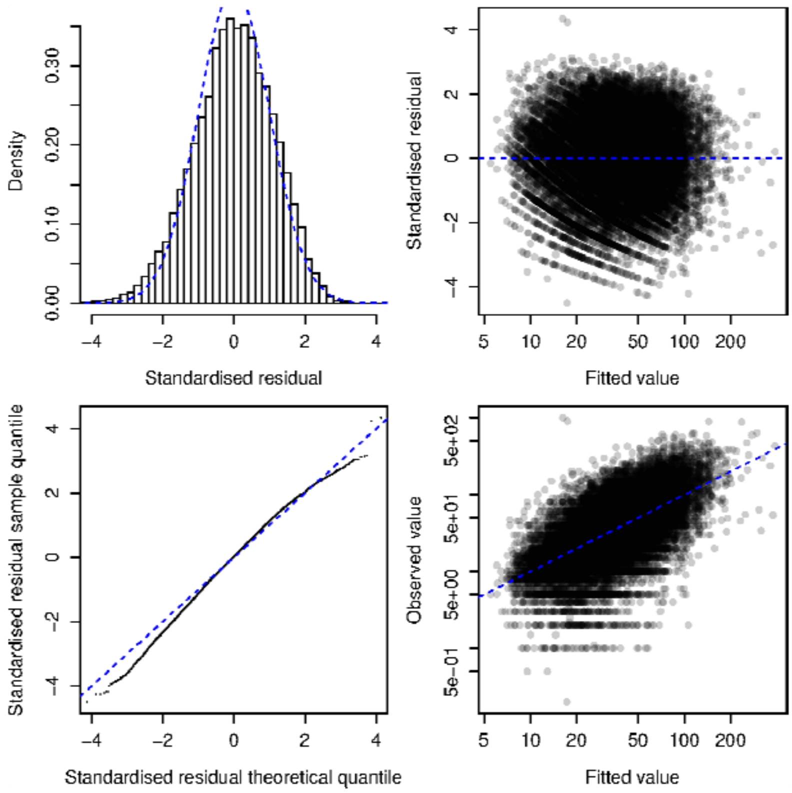


Figure E3: Plots of the fit of the standardised CPUE model to positive catches in the (YBF) MH fishery assuming a log logistic error distribution. See caption of Figure E1 for details.

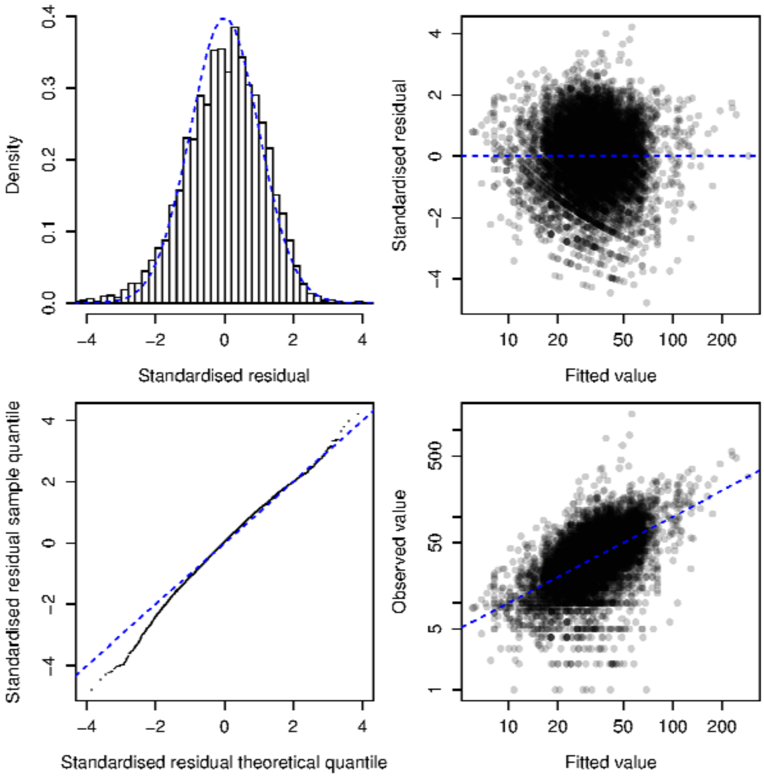


Figure E4: Plots of the fit of the standardised CPUE model to positive catches in the (YBF) LW fishery assuming a log logistic error distribution. See caption of Figure E1 for details.

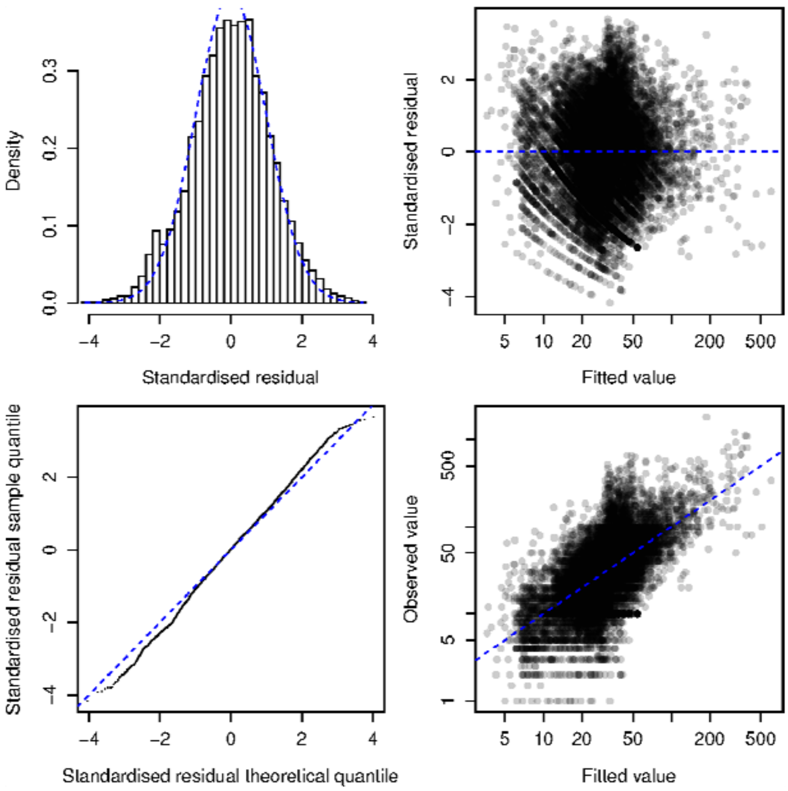


Figure E5: Plots of the fit of the final standardised CPUE model to positive catches in the TOT_EN fishery assuming a log logistic error distribution. See caption of Figure E1 for details.

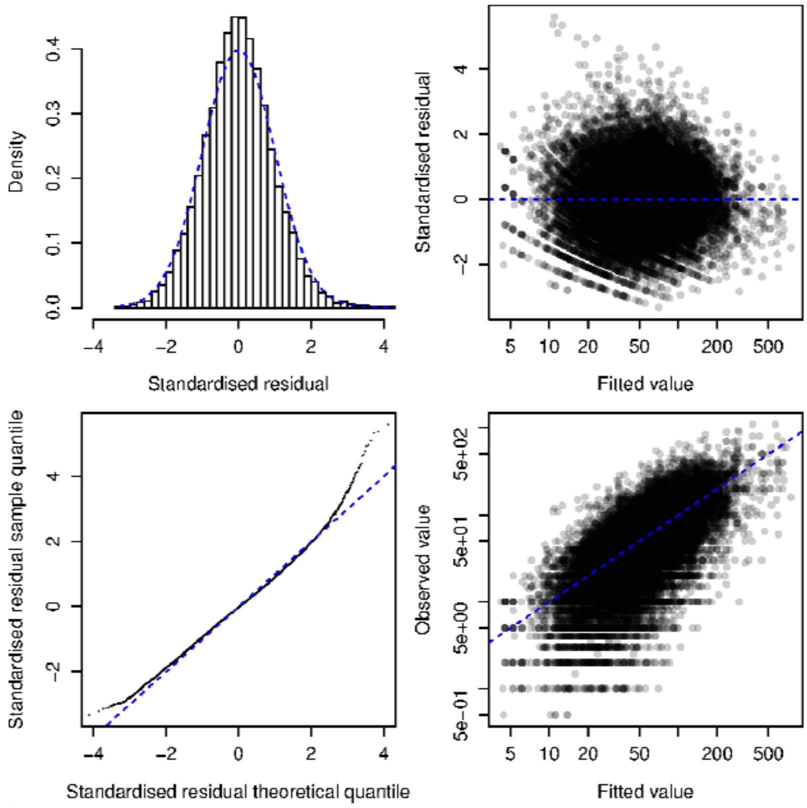


Figure E6: Plots of the fit of the standardised CPUE model to positive catches in the YBF_HG fishery assuming a gamma error distribution. See caption of Figure E1 for details.

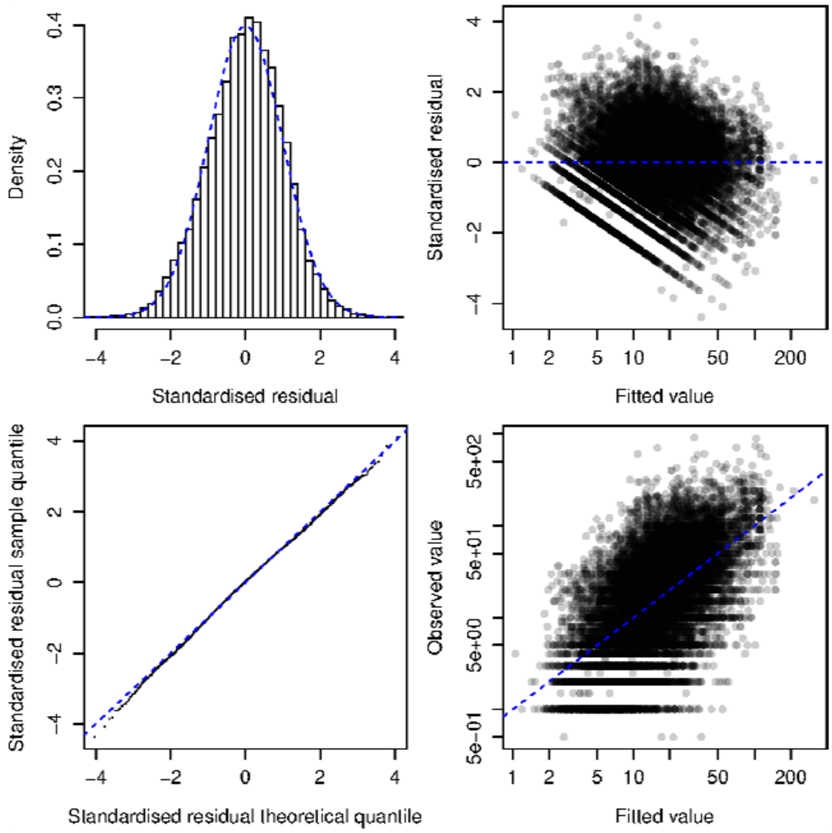


Figure E7: Plots of the fit of the final standardised CPUE model to positive catches in the SFL_HG fishery assuming a lognormal error distribution. See caption of Figure E1 for details.

APPENDIX F: POTENTIAL INTERACTION TERMS (NOT FITTED)

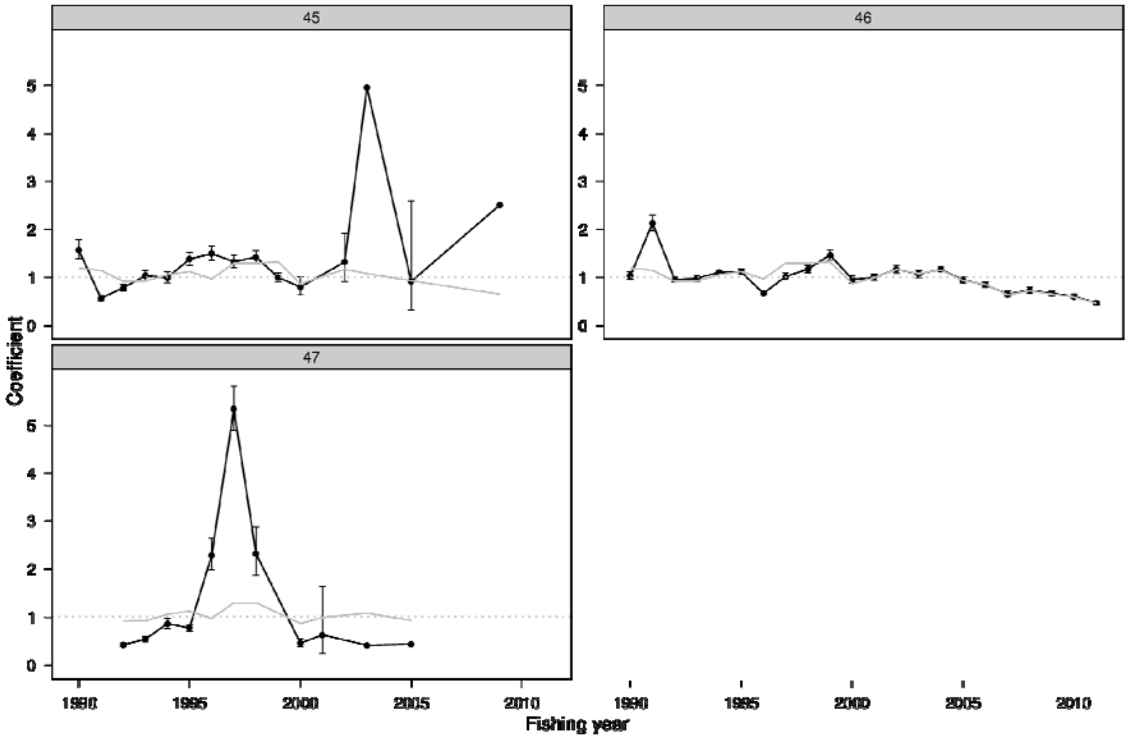


Figure F1: Residual implied coefficients for each area in each fishing year from the final log logistic model of the (YBF) NW fishery. Implied coefficients are calculated as the sum of the fishing year coefficient plus the mean of the residuals in each fishing year in each area. The error bars indicate one standard error of residuals. The grey line indicates the model's overall fishing year coefficients.

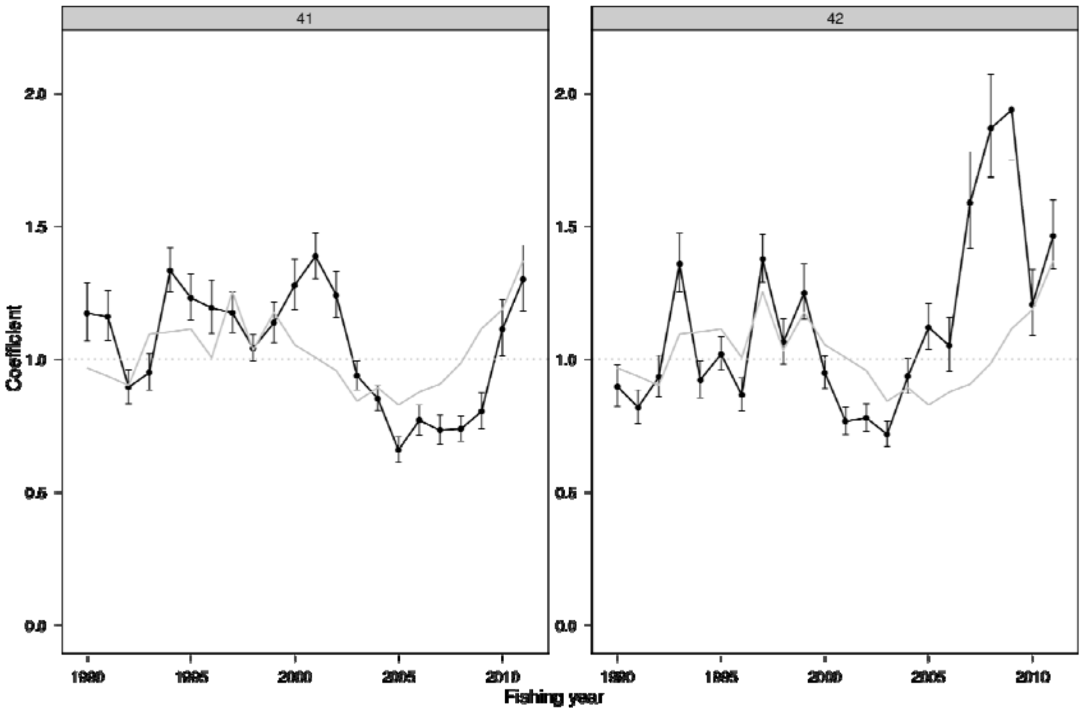


Figure F2: Residual implied coefficients for each area in each fishing year from the final log logistic model of the (YBF) LW fishery. Implied coefficients are calculated as the sum of the fishing year coefficient plus the mean of the residuals in each fishing year in each area. The error bars indicate one standard error of residuals. The grey line indicates the model's overall fishing year coefficients.

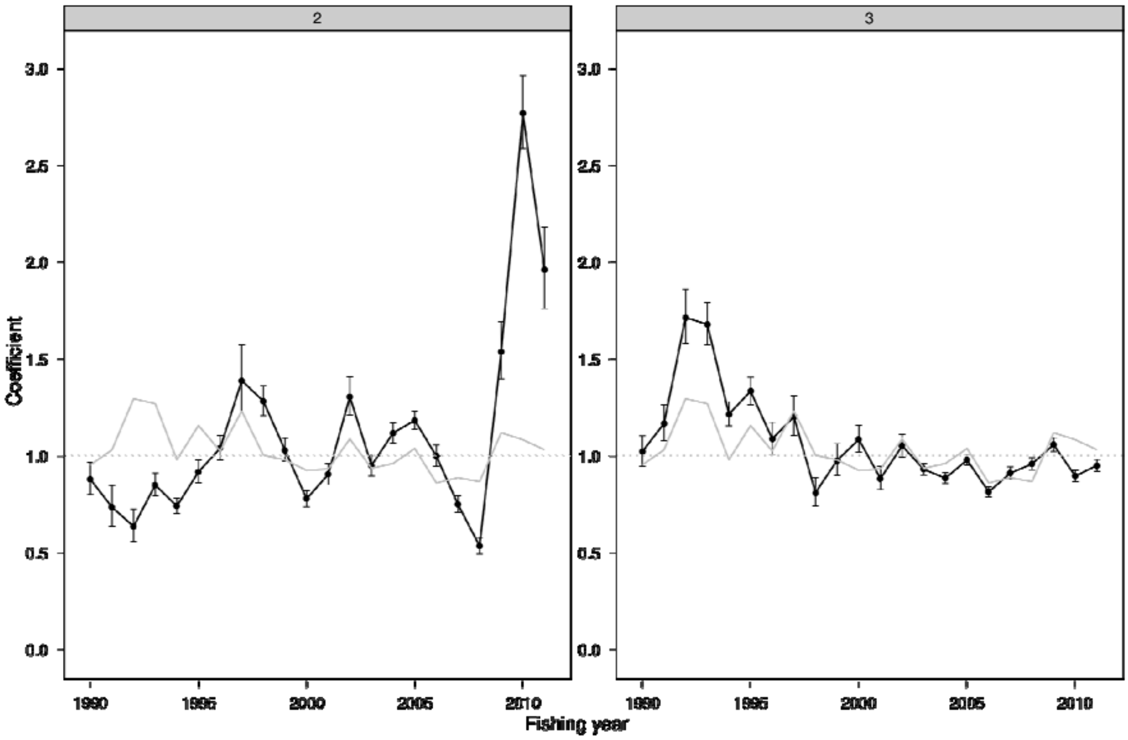


Figure F3: Residual implied coefficients for each area in each fishing year from the final log logistic model of the TOT_EN fishery. Implied coefficients are calculated as the sum of the fishing year coefficient plus the mean of the residuals in each fishing year in each area. The error bars indicate one standard error of residuals. The grey line indicates the model's overall fishing year coefficients.

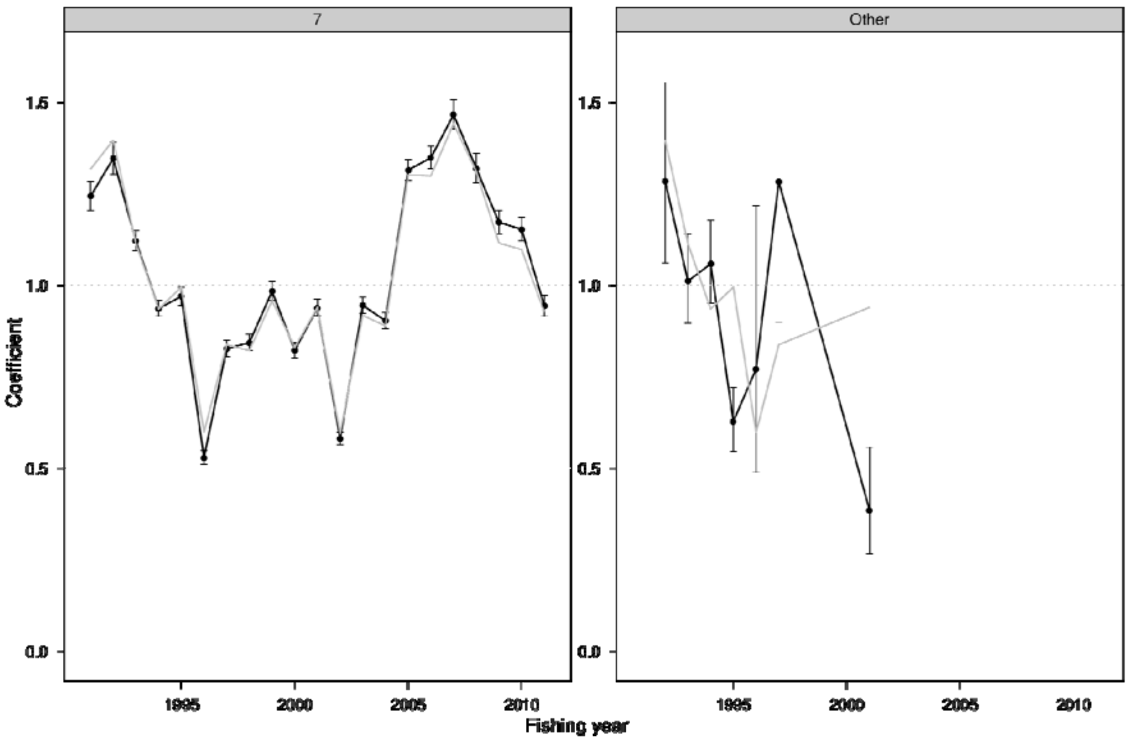


Figure F4: Residual implied coefficients for each area in each fishing year from the final gamma model of the YBF_ HG fishery. Implied coefficients are calculated as the sum of the fishing year coefficient plus the mean of the residuals in each fishing year in each area. The error bars indicate one standard error of residuals. The grey line indicates the model's overall fishing year coefficients.

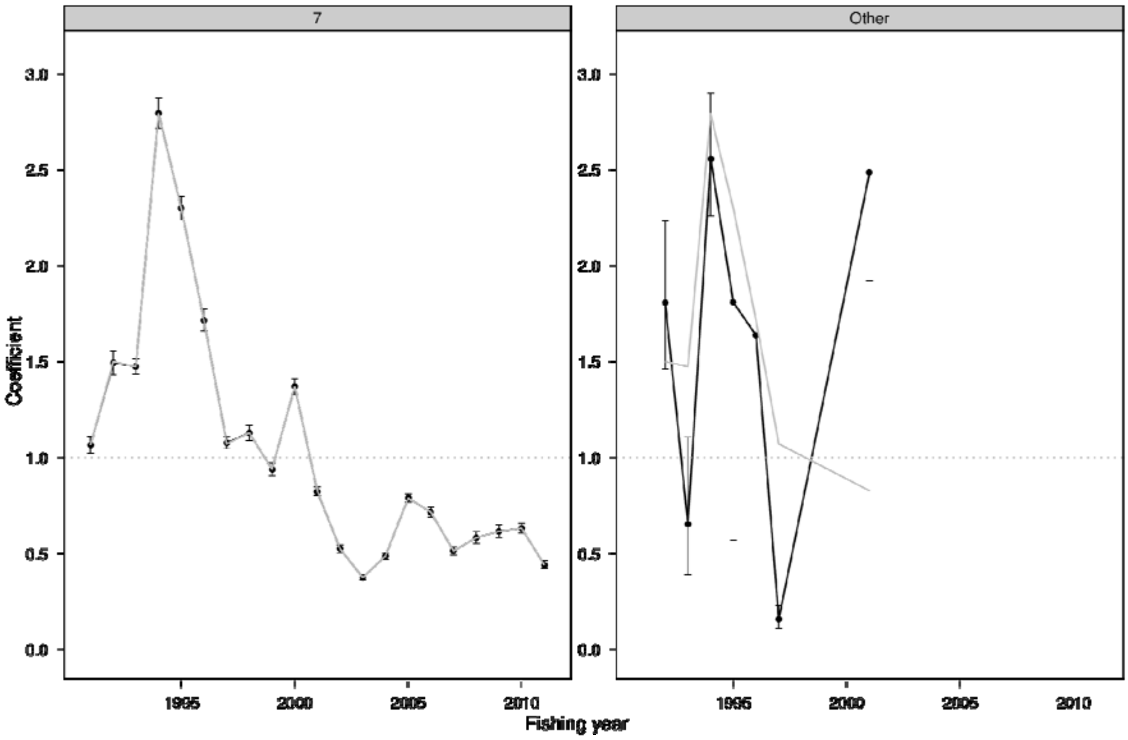


Figure F5: Residual implied coefficients for each area in each fishing year from the final lognormal model of the SFL_HG fishery. Implied coefficients are calculated as the sum of the fishing year coefficient plus the mean of the residuals in each fishing year in each area. The error bars indicate one standard error of residuals. The grey line indicates the model's overall fishing year coefficients.

APPENDIX G: COMPARISON WITH OTHER MODELS (SENSITIVITIES)

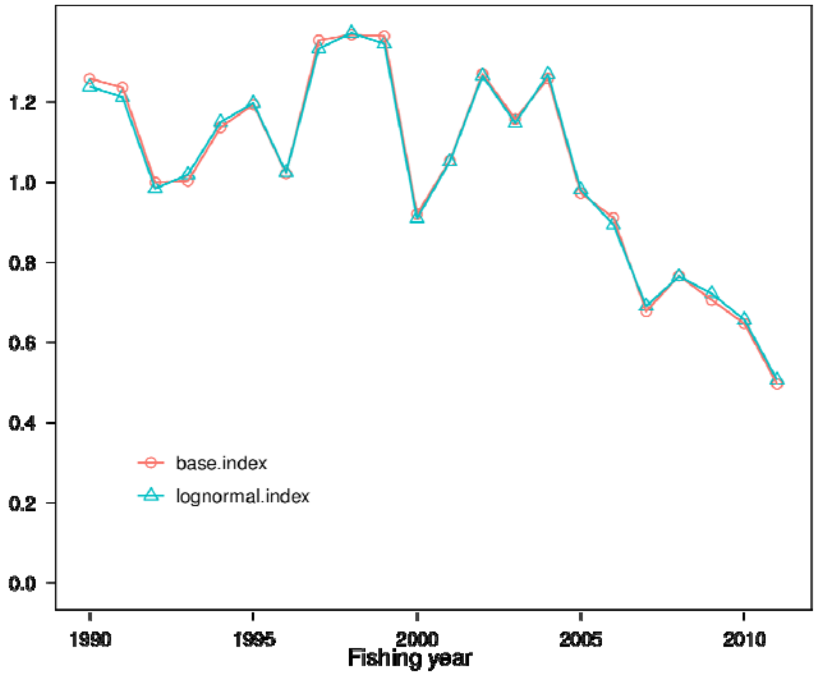


Figure G1: Comparison between the final log logistic index for (YBF) NW and an index from a similar model fit assuming lognormal errors.

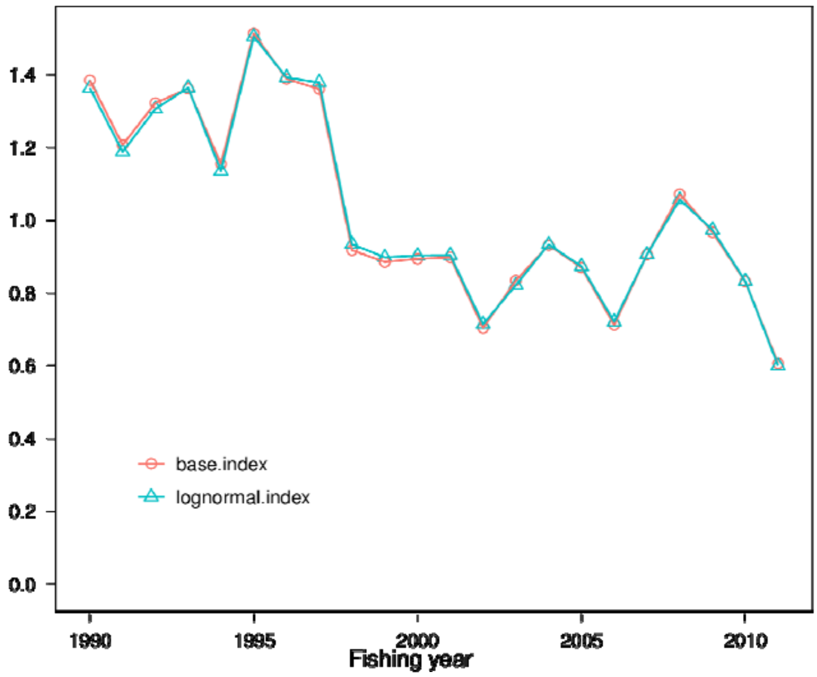


Figure G2: Comparison between the final log logistic index for (YBF) KH and an index from a similar model fit assuming lognormal errors.

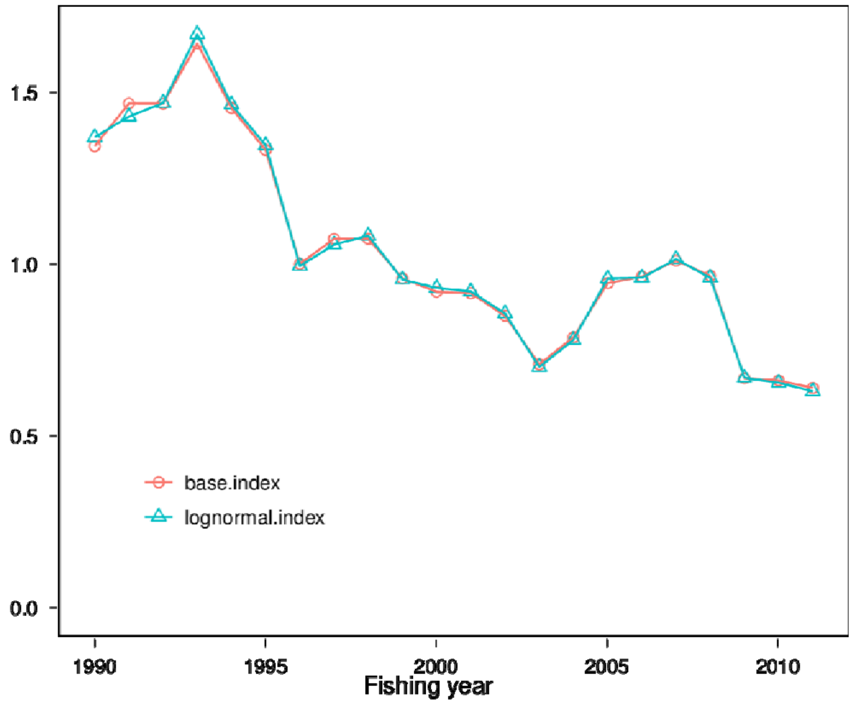


Figure G3: Comparison between the final log logistic index for (YBF) MH and an index from a similar model fit assuming lognormal errors.

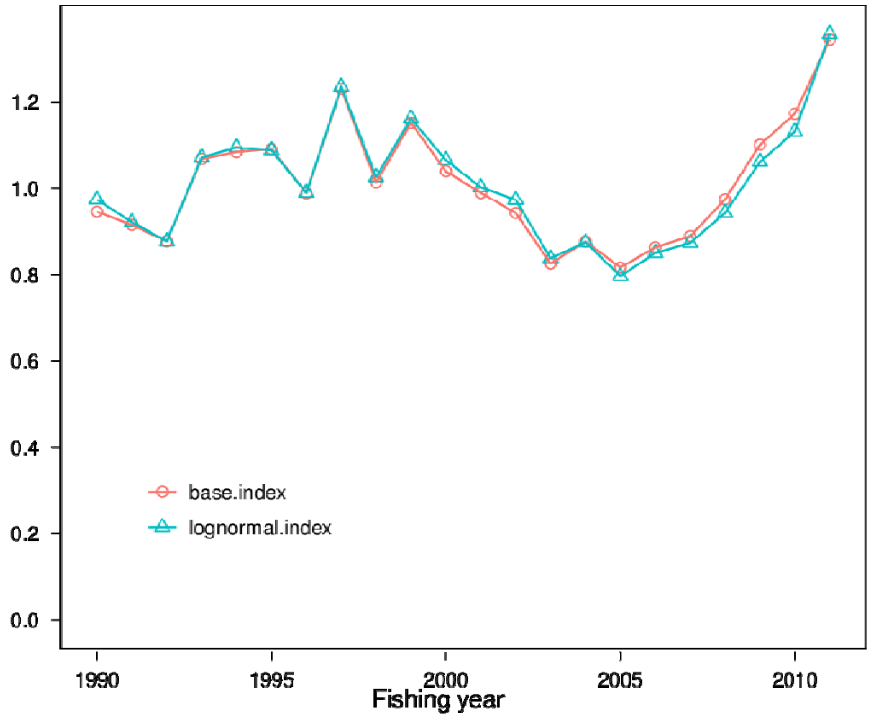


Figure G4: Comparison between the final log logistic index for (YBF) LW and an index from a similar model fit assuming lognormal errors.

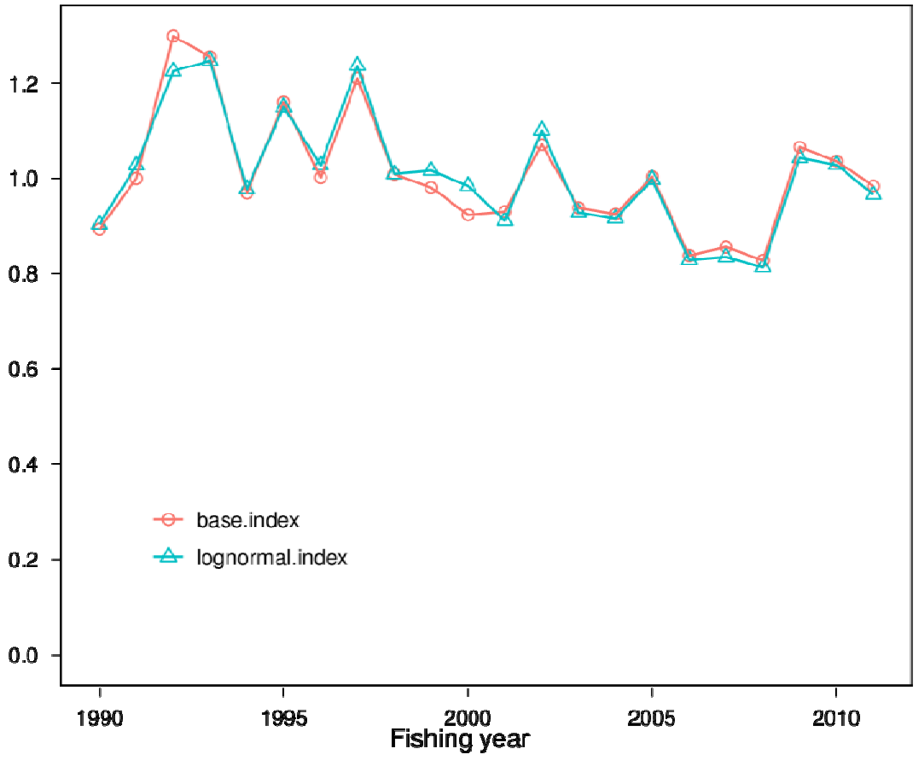


Figure G5: Comparison between the final log logistic index for TOT_EN and an index from a similar model fit assuming lognormal errors.

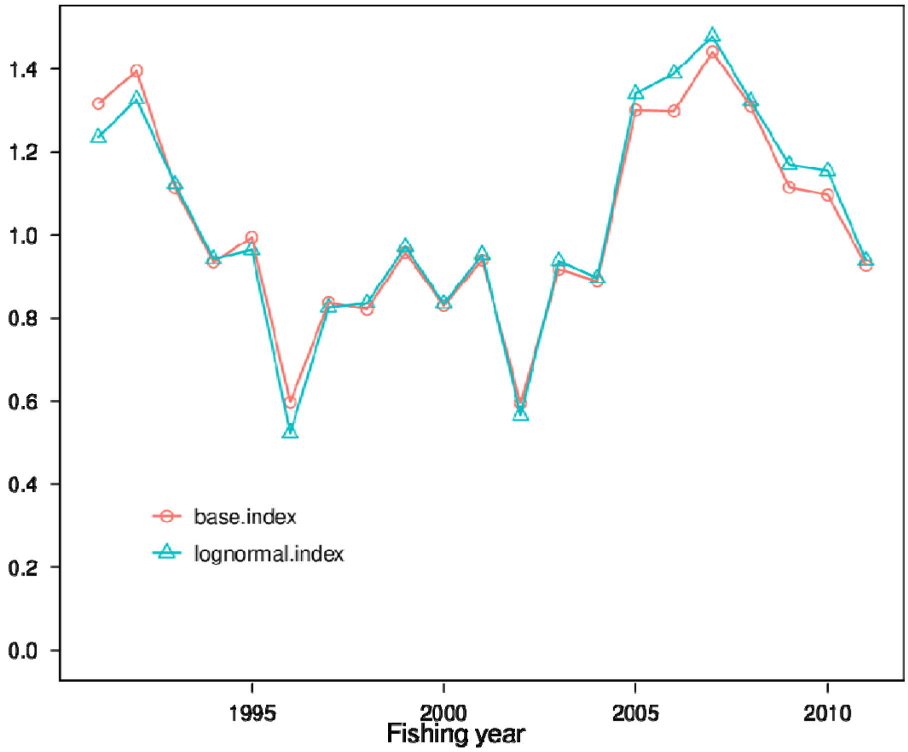


Figure G6: Comparison between the final gamma index for YBF_HG and an index from a similar model fit assuming lognormal errors.

APPENDIX H: MESH SIZE CHARACTERISATION

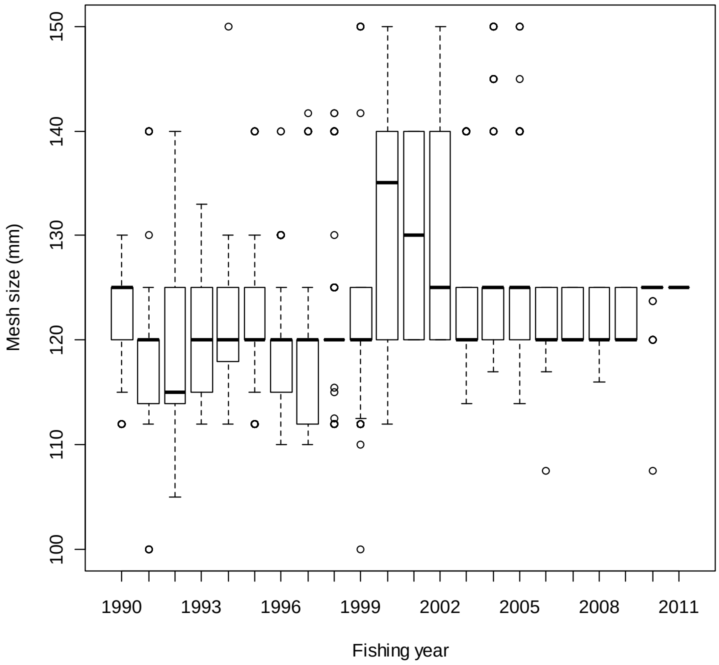


Figure H1: Distribution (truncated) of mesh sizes recorded by fishing year in the NW fishery.

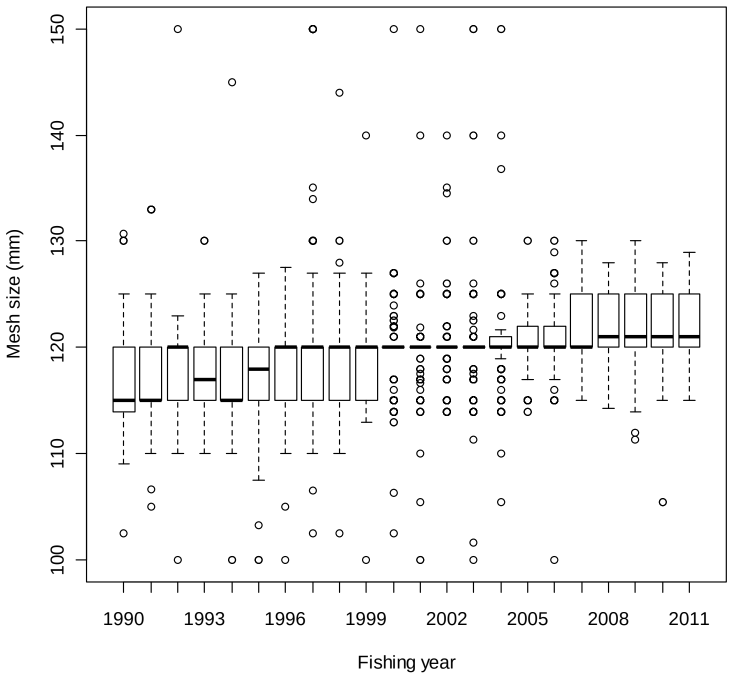


Figure H2: Distribution (truncated) of mesh sizes recorded by fishing year in the KH fishery.

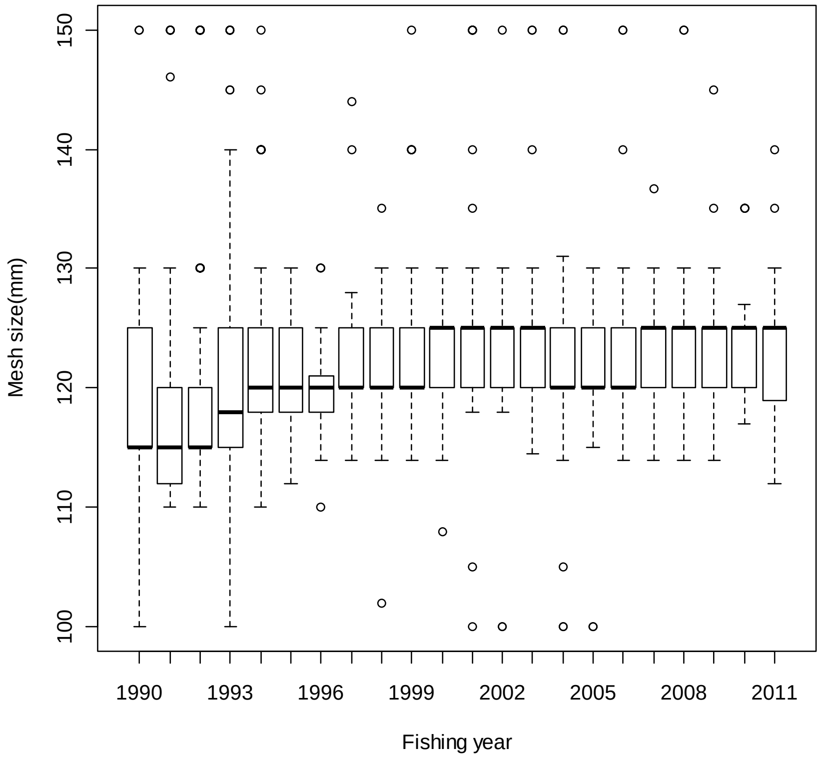


Figure H3: Distribution (truncated) of mesh sizes recorded by fishing year in the MH fishery.

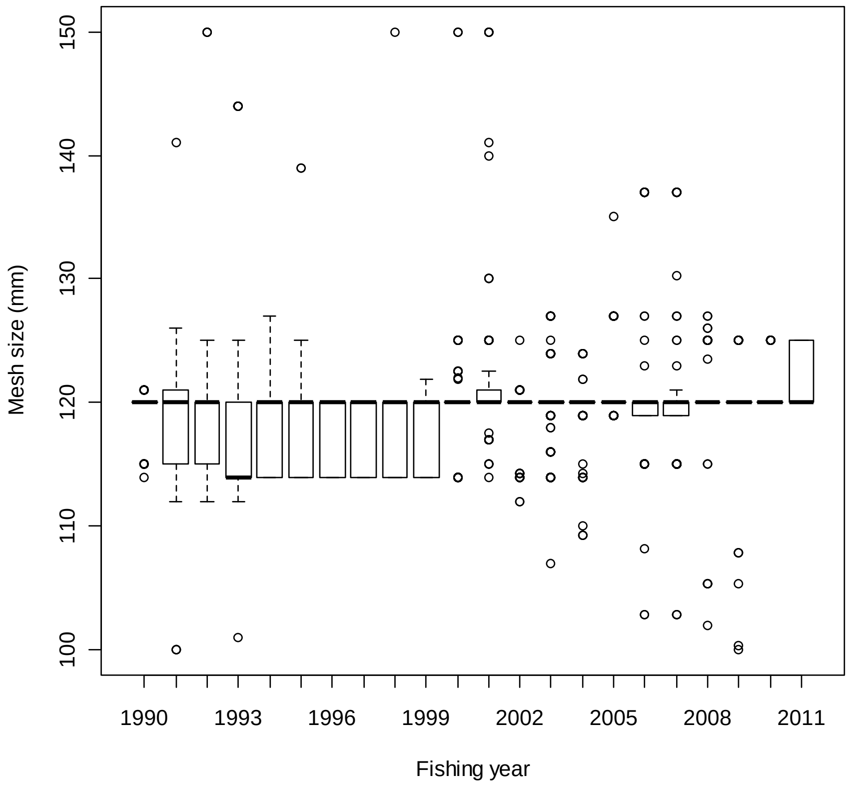


Figure H4: Distribution (truncated) of mesh sizes recorded by fishing year in the LW fishery.

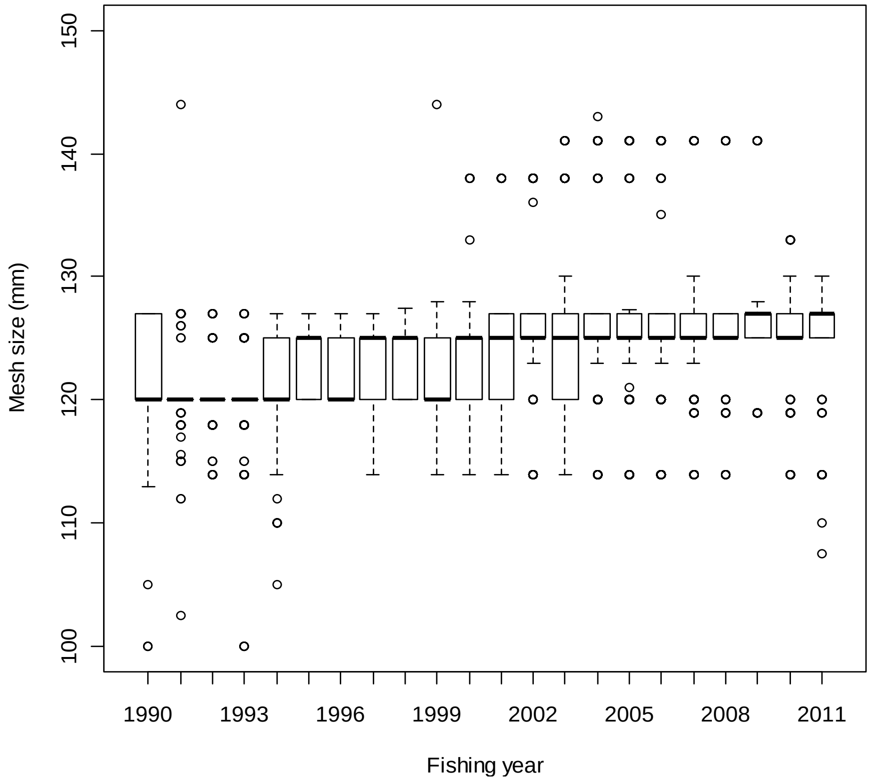


Figure H5: Distribution (truncated) of mesh sizes recorded by fishing year in the EN fishery.

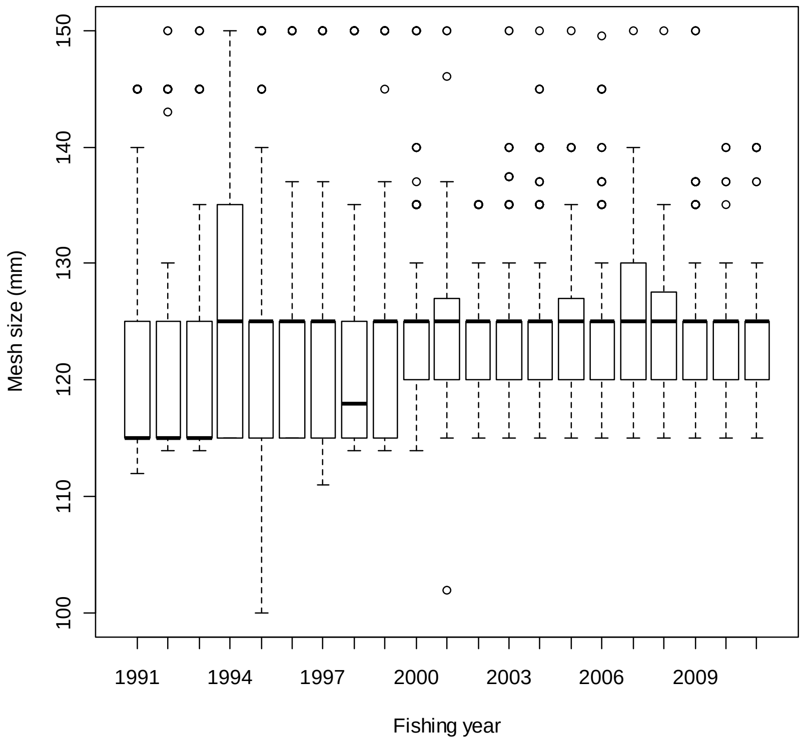


Figure H6: Distribution (truncated) of mesh sizes recorded by fishing year in the HG_YBF fishery.

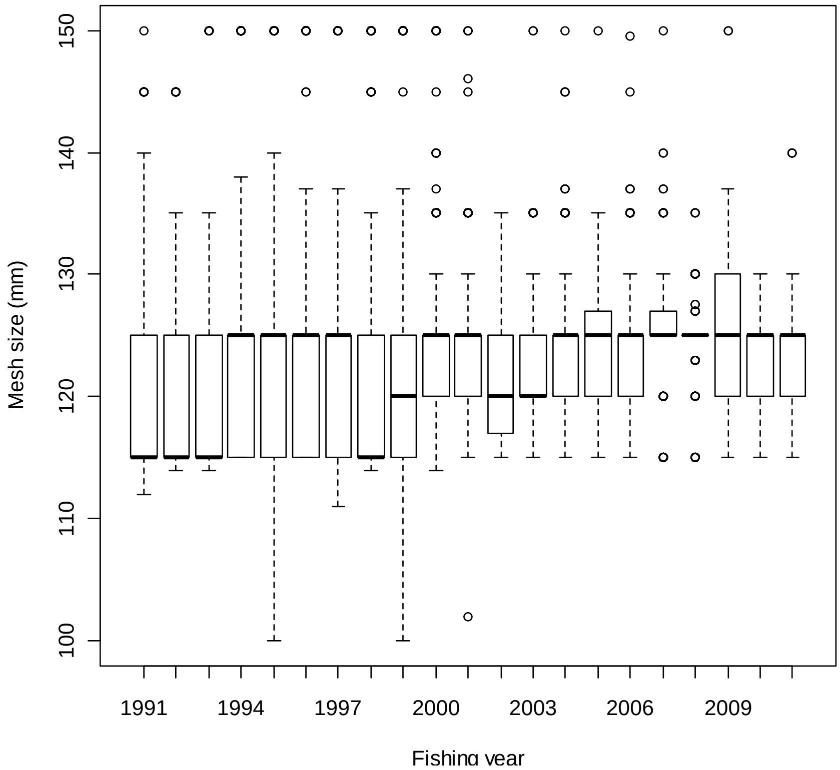


Figure H7: Distribution (truncated) of mesh sizes recorded by fishing year in the HG-SFL fishery.

APPENDIX I: CPUE INDICES

Table I1: Unstandardised CPUE (kg/km) for all vessels, and after core fleet selection, annual geometric mean and annual indices from the final log-logistic model of the (YBF) NW fishery with standard error.

Fishing Year	All arithmetic	Core arithmetic	Core geometric	Log-logistic index	Log-logistic se
1989–90	1.0204	0.9649	0.8725	1.2740	0.03832
1990–91	1.1547	1.1481	1.1214	1.2272	0.03665
1991–92	0.8966	0.8791	0.8246	0.9815	0.02830
1992–93	1.0530	0.9397	0.8422	0.9842	0.03086
1993–94	0.9533	0.9296	0.9411	1.1287	0.02884
1994–95	1.1578	1.1202	1.0330	1.1987	0.02728
1995–96	1.1466	1.1012	0.8920	1.0371	0.03039
1996–97	1.5378	1.4960	1.2460	1.3855	0.03327
1997–98	1.2186	1.2845	1.1311	1.3877	0.03156
1998–99	1.4190	1.5589	1.5401	1.4191	0.03347
1999–00	0.8558	0.8356	0.8596	0.9260	0.03584
2000–01	0.9506	0.9115	0.9190	1.0594	0.03329
2001–02	1.1859	1.2712	1.3017	1.2492	0.03704
2002–03	1.1489	1.1941	1.2804	1.1549	0.04062
2003–04	1.3119	1.3799	1.5314	1.2348	0.03043
2004–05	1.1424	1.1560	1.2176	0.9935	0.03294
2005–06	0.9388	0.9259	1.0435	0.9155	0.04481
2006–07	0.7749	0.7311	0.8109	0.6742	0.04780
2007–08	0.8225	0.8036	0.8985	0.7642	0.04904
2008–09	0.6913	0.7803	0.8560	0.6928	0.04737
2009–10	0.6431	0.6673	0.7679	0.6237	0.05314
2000–11	0.6045	0.6089	0.6373	0.4887	0.04708

Table I2: Unstandardised CPUE (kg/km) for all vessels, and after core fleet selection, annual geometric mean and annual indices from the final log-logistic model of the (YBF) KH fishery with standard error.

Fishing Year	All arithmetic	Core arithmetic	Core geometric	Log-logistic index	Log-logistic se
1989–90	1.3743	1.4243	1.3855	1.3828	0.01996
1990–91	1.2051	1.2297	1.1847	1.2050	0.01911
1991–92	1.2550	1.3346	1.3701	1.3203	0.01927
1992–93	1.3475	1.4819	1.4218	1.3594	0.01910
1993–94	1.1243	1.1139	1.1166	1.1525	0.01696
1994–95	1.4360	1.3771	1.4675	1.5114	0.01538
1995–96	1.4097	1.3726	1.3940	1.3865	0.01489
1996–97	1.2541	1.2677	1.3233	1.3584	0.01340
1997–98	0.8997	0.8943	0.8598	0.9160	0.01228
1998–99	0.7865	0.7824	0.8112	0.8836	0.01138
1999–00	0.8435	0.8461	0.8633	0.8921	0.01100
2000–01	0.8496	0.8414	0.8566	0.8966	0.01028
2001–02	0.7452	0.7332	0.6846	0.7025	0.01124
2002–03	0.7926	0.7898	0.8139	0.8329	0.01167
2003–04	0.9385	0.9314	0.9640	0.9297	0.01129
2004–05	0.9608	0.8948	0.9034	0.8683	0.01219
2005–06	0.7307	0.6973	0.6990	0.7111	0.01214
2006–07	0.9166	0.9038	0.8930	0.9040	0.01340
2007–08	1.0963	1.1066	1.1209	1.0699	0.01345
2008–09	0.9883	1.0103	1.0031	0.9654	0.01316
2009–10	0.9002	0.9169	0.8778	0.8296	0.01361
2000–11	0.7091	0.6964	0.6709	0.6051	0.01348

Table I3: Unstandardised CPUE (kg/km) for all vessels, after core fleet selection, annual geometric mean and annual indices from the final log-logistic model of the (YBF) MH fishery with standard error.

Fishing Year	All arithmetic	Core arithmetic	Core geometric	Log-logistic index	Log-logistic se
1989–90	1.6048	1.7474	1.6424	1.3428	0.02413
1990–91	1.3423	1.4590	1.3950	1.4666	0.02277
1991–92	1.4109	1.5761	1.4608	1.4661	0.02149
1992–93	1.6751	1.8172	1.7036	1.6412	0.01968
1993–94	1.5090	1.5888	1.4609	1.4533	0.01876
1994–95	1.4106	1.4478	1.4331	1.3316	0.01874
1995–96	0.9997	0.9899	1.0419	0.9997	0.01924
1996–97	1.0267	1.0624	1.0999	1.0728	0.01899
1997–98	1.0771	1.1041	1.1257	1.0731	0.01788
1998–99	0.9857	0.9397	0.9477	0.9577	0.01664
1999–00	0.9629	0.9569	0.9259	0.9188	0.01645
2000–01	0.9066	0.8754	0.9176	0.9146	0.01629
2001–02	0.8685	0.8945	0.8708	0.8486	0.01852
2002–03	0.6857	0.6730	0.6765	0.7077	0.01756
2003–04	0.7795	0.7200	0.7453	0.7863	0.01717
2004–05	0.9319	0.8772	0.9436	0.9437	0.01694
2005–06	0.8899	0.8441	0.8771	0.9634	0.01758
2006–07	0.9931	0.9328	0.8668	1.0092	0.01786
2007–08	0.9999	0.9514	1.0015	0.9655	0.01895
2008–09	0.6699	0.6479	0.6693	0.6671	0.02326
2009–10	0.5923	0.5765	0.6147	0.6606	0.02570
2010–11	0.6395	0.6123	0.6213	0.6386	0.02371

Table I4: Unstandardised CPUE (kg/km) for all vessels, after core fleet selection, annual geometric mean and annual indices from the final log-logistic model of the (YBF) LW fishery with standard error.

Fishing Year	All arithmetic	Core arithmetic	Core geometric	Log-logistic index	Log-logistic se
1989–90	0.8631	0.9203	0.9508	0.9487	0.03458
1990–91	0.9073	0.9040	0.8488	0.9186	0.03149
1991–92	0.9399	0.9416	0.9449	0.8851	0.02928
1992–93	1.0599	1.1197	1.1044	1.0743	0.02838
1993–94	1.1085	1.1139	1.0610	1.0822	0.03011
1994–95	1.0290	1.0162	1.0458	1.0925	0.02753
1995–96	0.9471	0.9532	0.8868	0.9874	0.02863
1996–97	1.0295	1.0855	1.1156	1.2298	0.02540
1997–98	0.9527	1.0237	1.0463	1.0152	0.02425
1998–99	1.0848	1.2280	1.2157	1.1546	0.02761
1999–00	0.9559	1.0985	1.0498	1.0345	0.02701
2000–01	1.0880	1.1521	1.0259	0.9876	0.02453
2001–02	1.0357	1.1727	0.9793	0.9393	0.02524
2002–03	0.8705	0.8519	0.8299	0.8268	0.02270
2003–04	0.8456	0.8469	0.8915	0.8763	0.02341
2004–05	0.7741	0.8307	0.8078	0.8129	0.02589
2005–06	0.9273	0.8734	0.8454	0.8608	0.02718
2006–07	1.1464	0.9783	0.9765	0.8896	0.03003
2007–08	1.0107	0.8517	0.9490	0.9667	0.02835
2008–09	1.1325	1.0204	1.1570	1.0943	0.03181
2009–10	1.1403	1.0369	1.1477	1.1645	0.03485
2010–11	1.3096	1.1304	1.2971	1.3448	0.03835

Table I5: Unstandardised CPUE (kg/km) for all vessels, after core fleet selection, annual geometric mean and annual indices from the final log-logistic model of the TOT_EN fishery with standard error.

Fishing Year	All arithmetic	Core arithmetic	Core geometric	Log-logistic index	Log-logistic se
1989–90	0.9622	0.8195	0.8837	0.9321	0.03073
1990–91	1.0458	1.1539	1.1878	1.0083	0.03783
1991–92	1.1655	1.1809	1.1631	1.2665	0.03229
1992–93	1.1893	1.1362	1.1711	1.2411	0.02536
1993–94	0.9388	0.8547	0.8388	0.9583	0.02112
1994–95	0.9445	1.0016	1.0425	1.1307	0.02204
1995–96	1.4789	1.1970	1.0077	1.0022	0.02731
1996–97	1.2664	1.5284	1.2515	1.2041	0.03581
1997–98	0.9662	0.8035	0.7652	0.9804	0.02855
1998–99	0.9640	0.9656	0.8553	0.9572	0.02535
1999–00	1.0206	1.0119	0.8545	0.9045	0.02379
2000–01	0.8770	0.9497	0.8701	0.9110	0.02555
2001–02	1.4036	1.3155	1.2076	1.0631	0.02353
2002–03	1.0200	0.9525	0.9765	0.9148	0.01847
2003–04	0.8956	0.9514	1.0024	0.9391	0.01772
2004–05	0.9661	1.0176	1.1006	1.0151	0.01704
2005–06	0.7753	0.8093	0.8409	0.8408	0.01855
2006–07	0.8033	0.8497	0.9179	0.8671	0.01893
2007–08	0.7355	0.7809	0.9061	0.8475	0.02044
2008–09	1.0416	1.0891	1.2047	1.0940	0.02146
2009–10	0.9989	1.0100	1.1345	1.0591	0.02203
2010–11	0.8772	0.9420	1.0480	1.0088	0.02090

Table I6: Unstandardised CPUE (kg/km) for all vessels, after core fleet selection, annual geometric mean and annual indices from the final gamma model of the YBF_HG fishery with standard error.

Fishing year	All arithmetic	Core arithmetic	Core geometric	Gamma index	Gamma se
1990–91	0.9587	1.0317	1.1501	1.3154	0.02208
1991–92	1.2721	1.4475	1.5711	1.3945	0.02301
1992–93	1.2589	0.9608	1.0919	1.1124	0.01957
1993–94	1.3104	0.9237	0.8667	0.9337	0.01872
1994–95	1.0090	1.0163	0.8636	0.9934	0.01857
1995–96	1.3245	1.3588	0.5180	0.5966	0.02278
1996–97	0.8869	0.9236	0.7993	0.8364	0.02038
1997–98	0.8773	0.8624	0.8036	0.8203	0.02168
1998–99	0.9919	1.0356	0.9412	0.9566	0.02142
1999–00	0.9081	0.9384	0.7293	0.8292	0.02009
2000–01	1.0226	0.9566	0.8075	0.9384	0.01885
2001–02	0.7257	0.7379	0.6361	0.5942	0.02122
2002–03	0.8242	0.8597	1.0225	0.9161	0.01987
2003–04	0.8307	0.8616	0.9424	0.8877	0.01973
2004–05	1.2281	1.2920	1.2311	1.2995	0.01860
2005–06	1.1611	1.1646	1.3180	1.2972	0.01985
2006–07	0.9155	0.9774	1.4779	1.4401	0.02226
2007–08	1.0173	1.0658	1.4192	1.3091	0.02424
2008–09	1.0423	1.0033	1.3486	1.1137	0.02425
2009–10	0.9678	1.0006	1.2995	1.0960	0.02449
2010–11	0.7796	0.8578	1.0046	0.9254	0.02483

Table I7: Unstandardised CPUE (kg/km) for all vessels, after core fleet selection, annual geometric mean and annual indices from the final lognormal model of the SFL_HG fishery with standard error.

Fishing year	All arithmetic	Core arithmetic	Core geometric	Lognormal index	Lognormal se
1990–91	1.3533	1.3441	1.1596	1.1939	0.03535
1991–92	1.4439	1.5619	1.6551	1.6818	0.03606
1992–93	1.8050	1.5330	1.5972	1.6526	0.03005
1993–94	4.4955	3.0020	2.5922	3.1310	0.02836
1994–95	2.7121	2.3318	2.1690	2.5775	0.02812
1995–96	1.9666	1.8143	1.7704	1.9235	0.03576
1996–97	1.3539	1.2640	1.1046	1.2013	0.03299
1997–98	1.2736	1.1860	1.1226	1.2649	0.03522
1998–99	1.4163	1.3433	1.1218	1.0516	0.03554
1999–00	2.1798	2.0832	1.4509	1.5369	0.03086
2000–01	1.2682	1.1191	0.9013	0.9261	0.02982
2001–02	0.6550	0.5433	0.5337	0.5870	0.03728
2002–03	0.3359	0.2704	0.4118	0.4184	0.03646
2003–04	0.6594	0.6346	0.5790	0.5452	0.03210
2004–05	1.0665	1.0846	0.9365	0.8837	0.03046
2005–06	1.3262	1.4772	1.1341	0.8010	0.03288
2006–07	0.4280	0.5085	0.6786	0.5741	0.04163
2007–08	0.4511	0.5279	0.7984	0.6520	0.05216
2008–09	0.4896	0.5263	0.7444	0.6894	0.05137
2009–10	0.3536	0.5790	0.6717	0.7073	0.04277
2010–11	0.2554	0.4265	0.4919	0.4935	0.04745