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Fishery characterisation and catch per unit effort for John dory in JDO 1, to 2020/21

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EXECUTIVE SUMMARY

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John dory (*Zeus faber*, JDO) is a common inshore demersal fish found predominantly around the north of the North Island, but as far south as Tasman Bay in the South Island. The commercial catch is mainly taken as a bycatch of the bottom trawl and Danish seine fisheries, with 50% of the 2020/21 catch taken from JDO 1, 33% from JDO 7, and 17% from JDO 2.

The JDO 1 Quota Management Area (QMA) is not a single stock, but instead there are thought to be three sub-stocks: Bay of Plenty (BPLE), east Northland and Hauraki Gulf (ENHG), west coast North Island, including the north-western part of JDO 2 (WCNI). Standardised catch per unit effort (CPUE) indices for these three areas are used to monitor trends in abundance. In this study we updated the fishery characterisation for these three subareas and the standardised CPUE indices to 2020/21.

Except for some small changes in targeting, the fisheries in the three subareas have been undertaken in a similar way for the last two decades. Two recent changes have been the use of bottom trawl with a Modular Harvest System since 2016, and a changeover since about 2020 to recording almost exclusively with electronic data reporting.

In BPLE the standardised CPUE index declined in an irregular manner from 1994/95 to 2020/21 to 51% of its initial level. For ENHG the index declined from 1994/95 to 2012/13 then increased to be at 43% of its initial level in 2020/21. For WCNI the standardised index has fluctuated without trend since 1994/95.

Standardised CPUE indices were used to evaluate historical and current stock status, against a B_{MSY} proxy target level, chosen to be the mean value of the indices over the reference years 1996–2011. For BPLE, ENHG, and WCNI the stock status in 2020/21 was near the target level, and relative fishing mortality proxy was below the mean value for the reference years.

Trends in standardised CPUE, may be confounded with changes in reporting or gear, factors that can be difficult to account for in a standardisation. For this reason, it is useful to corroborate (or otherwise) trends in standardised CPUE against that from trawl surveys. For the BPLE and ENHG trawl survey recruited biomass indices showed a congruence with the standardised indices, but not for WCNI.

[1] National Institute of Water and Atmospheric Research, New Zealand.

1. INTRODUCTION

John dory (*Zeus faber*, JDO) became part of the Quota Management System (QMS) in 1986/87, and currently there are five Quota Management Areas (QMAs) in place (Figure 1). Two of these encompass the North Island coast: JDO 1 (northern North Island); and JDO 2 (rest of the North Island). The research here is concerned with JDO 1 (northern North Island) under the Fisheries New Zealand project JDO2021-02, with an overall objective to monitor the relative abundance of John dory in JDO 1.

JDO 1 is a Group 2 stock complex, characterised by moderate levels of benefit to fishers, and moderate levels of information available to monitor their status (Fisheries New Zealand 2019). Their primary measure of stock status is standardised CPUE, against a B_{MSY}-compatible reference point defined by the mean value of the standardised CPUE series over selected years with stable CPUE indices. This type of monitoring does not provide for future population biomass estimates but evaluates the current status of the stock and historically.

John dory are taken by the inshore fisheries targeting mainly John dory, red gurnard, snapper, tarakihi, and trevally. The JDO 1 QMA is not a single stock, but instead there are thought to be three sub-stocks (Dunn & Jones 2013) (Figure 2):

(1) Bay of Plenty

(2) east Northland and Hauraki Gulf

(3) west coast North Island (including the north-western part of JDO 2)

The first part of the research under JDO2021-02 was a characterisation of the JDO 1 fishery (Objective 1), which informed the updated standardised CPUE indices analyses to the 2020/21 fishing year and their interpretation (part of Objective 2). Objective 2 included:

a) derivation of standardised CPUE

b) evaluation of changes in CPUE against a B_{MSY}-compatible reference

c) comparison of the standardised CPUE and trawl survey biomass series

d) plots of relative fishing mortality for each of the three sub-stocks of JDO 1.

The previous JDO 1 fisheries characterisation and standardised CPUE analysis went up to the 2016/17 fishing year (Langley 2018).

Fishing years in this report will be denoted in two ways: (i) 2016/17 fishing year referring to 1 October 2016 to 30 September 2017, and (ii) the abbreviated form 2017 signifying the 2016/17 fishing year.

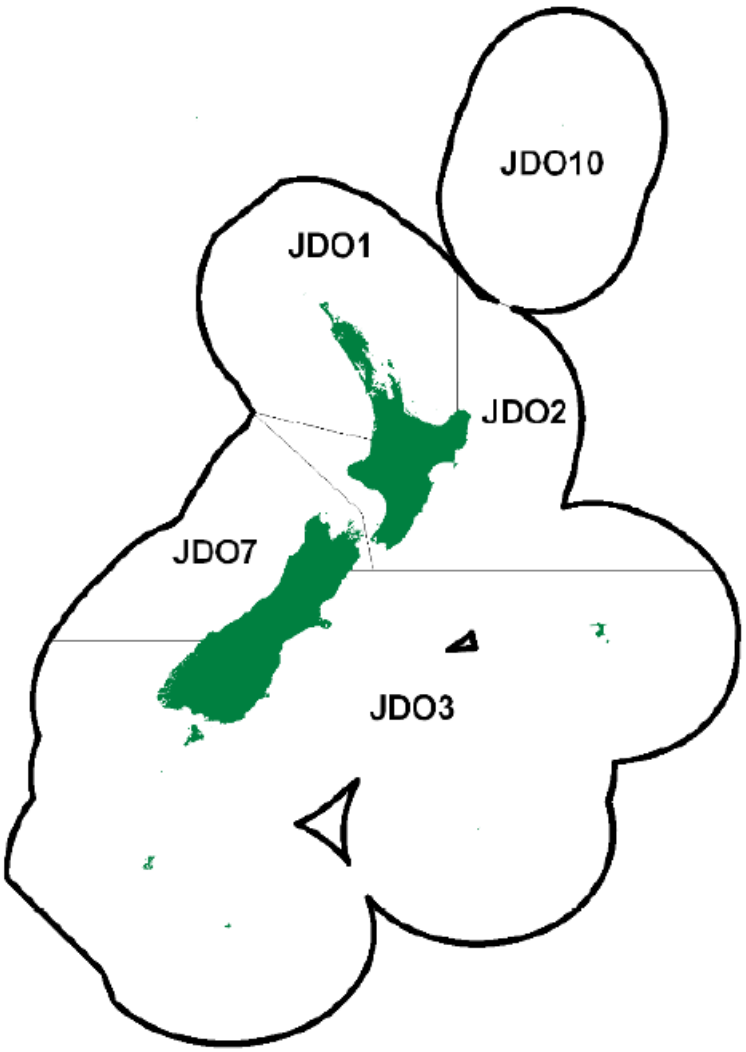

Figure 1: QMAs for John dory (from Fisheries New Zealand 2021).

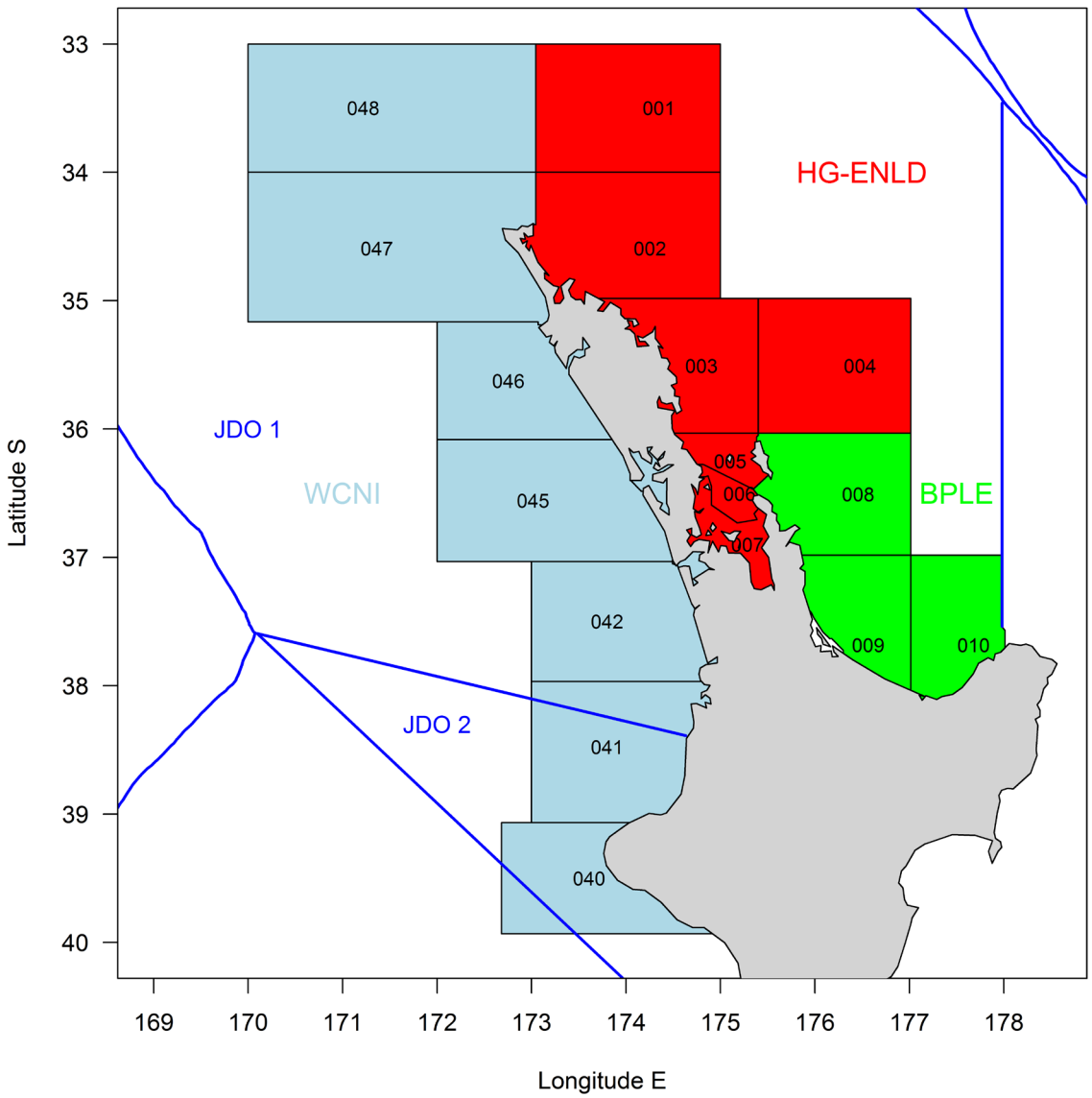

Figure 2: The three sub-stocks for JDO 1 and Statistical Areas 001–010 and 040–048. Reproduced with permission (figure 1 of Langley 2018). BPLE is Bay of Plenty, HG-ENLD is Huaraki Gulf-east Northland (referred to in remainder of report as ENHG), and WCNI is west coast North Island.

2. METHODS

2.1 The JDO 1 fishery

John dory is a common inshore demersal fish found predominantly around the north of the North Island, but as far south as Tasman Bay in the South Island. The commercial catch is mainly taken as a bycatch of the bottom trawl and Danish seine fisheries, with 50% of the 2020/21 catch taken from JDO 1, 33% from JDO 7, and 17% from JDO 2 (Fisheries New Zealand 2022).

The total allowable commercial catch (TACC) for JDO 1 was 704 t from 1989/90 to 2017/18, after which it was dropped to 354 t. Landings have declined since 1998/99 and have often been substantially under the TACC, with landings in 2020/21 of 287 t (towards a TACC of 354 t). The predominant commercial fishing method in JDO 1 is bottom trawl within target fisheries for snapper (*Chrysophrys auratus*, SNA), John dory, and trevally (*Pseudocaranx georgianus*, TRE). Some catch is taken using Danish seine targeting snapper and John dory. Recreational catch in JDO 1 is difficult

to estimate, but is much less than the commercial catch, and was estimated to be 26 t in 2017/18 (Wynne-Jones et al. 2019).

A stock structure analysis by Dunn & Jones (2013) incorporated catch distribution, commercial CPUE trends, research survey biomass trends, location of spawning and nursery grounds, patterns in length and age composition, and anecdotal information from the commercial fishery. Although the stock structure is uncertain, this analysis suggested five stocks for John dory:

(1) Hauraki Gulf and East Northland

(2) Bay of Plenty

(3) west coast North Island (including the north-western part of JDO 2)

(4) southeast North Island

(5) northern South Island.

For the three JDO 1 sub-stock areas (Hauraki Gulf & East Northland, Bay of Plenty, west coast North Island), Dunn & Jones (2013) calculated standardised CPUE indices. These same areas were used for subsequent calculation of standardised indices (Langley 2015, 2018) and were updated to the 2020/21 year for this study.

An updated characterisation for JDO 1 and the northwestern part of JDO 2 was conducted including catch distribution and catch changes between years. The characterisation showed if there had been changes in fishing methods and targeting, which has implications for the data used in standardised CPUE analyses and the interpretation of the results (for example, reportedly the use of Modular Harvest System (MHS) gear had become increasingly important in the Hauraki Gulf). A component of the characterisation was an updated catch history for the three nominal sub-stock areas, used to calculate a relative fishery mortality for a sub-stock by dividing by the associated standardised CPUE (part of Objective 2).

2.2 Characterisation data

Trawl catch and effort information for the period 1 October 1989 to 30 September 2021 includes data collected using four types of Fisheries New Zealand reporting forms and protocols. Catch Effort Landing Return forms (CELR) were predominantly utilised over the earliest part of the catch and effort series (1990–95). CELR forms only allowed fishers to record information at an amalgamated daily catch level. The adoption of Trawl Catch Effort Processing Return (TCEPR) forms by some inshore vessels in 1995 meant that fishers could provide catch and effort data at the tow level. TCEPR and CELR forms were replaced in 2007 with the Trawl Catch Effort Return (TCER) form which also allowed inshore fishers to report catches at the tow level. In October 2017, paper form reporting was replaced by the Electronic Reporting System (ERS) for vessels greater than 28 m and in October 2018 all inshore trawl vessels were required to report using the ERS. Each of these reporting changes introduced changes in the spatial resolution of the data, the number of catch species fishers could report, and in the type of effort information required.

Catch and effort, daily processed, and landed data were extracted from the Fisheries New Zealand Enterprise Data Warehouse (EDW) and consisted of all fishing and landing events associated with fishing trips that reported a non-null, non-zero, positive catch or landing of John dory reported in JDO 1 and the northern part of JDO 2 (large-scale General Statistical Areas 040 and 041) between 1 October 1989 and 30 September 2021. To obtain a full account of zero-event tows and trips, a second extract was obtained from Fisheries New Zealand to obtain effort data from trips that also fished in these areas and depth ranges and for species typically associated with catching John dory but that did not report or land John dory. Landings were allocated to effort via a trip-based and prorated estimated catch following Starr (2007) and Langley (2014).

2.3 Standardisation CPUE data

Three separate standardisations were done: Bay of Plenty (BPLE), east Northland and Hauraki Gulf (ENHG), and west coast North Island (WCNI). For the standardisations a subset of the characterisation data was used, consisting of bottom trawl (BT) data as recorded on event-based forms: TCEPR, TCER, and ERS. Reasonable quantities of event-based records are only available from 1995 onward, so the standardised CPUE data covered the period 1995–2021. The proportion of zero data catch records was corrected for changes in the number of species fishers could report between reporting forms (e.g., top 5 TCEPR cf. top 8 TCER).

CPUE analyses were restricted to vessels demonstrating a 'reasonable' degree of involvement and continuity in the fishery. In particular, for each fishery (BPLE, ENHG, WCNI), core vessels were selected based on a minimum number of trawls per year for a minimum number of years, with the core vessels taking at least 70% of the catch over the period 1995–2021.

For WCNI the standardisation dataset excluded General Statistical Areas 040 and 048 from which little catch was taken (but these areas were included for the characterisation dataset).

2.4 Standardisation procedure

The standardisation model used a lognormal model for the positive catch with an assumed normal error distribution, combined with a binomial model for the presence/absence of John dory catch. The predictor variables offered to the lognormal and binomial models were very similar to Langley (2018) models, except for some additional potential predictor variables such as vessel experience (Table 1).

In contrast to the previous standardisation, continuous predictor variables were fitted using cubic splines rather than polynomial (via the *ns* function within the splines *R* package (R Core Team 2020)). Polynomial functions are global rather than local, so individual observations can have large effects on remote parts of the curve. They are also vulnerable to edge effects and sensitive to outliers. Splines are more flexible than polynomials, act locally, and are less sensitive to outliers, making them more suitable for ecological data in which covariate effects may be complex (Hoyle 2020).

Both the lognormal and binomial models started with fishing year in the model and used forward variable selection based on minimising the Akaike information criteria (AIC), with 1% decline in R-squared for acceptance of predictor variable. The standard range of residual diagnostics and coefficient-distribution-influence plots (after Bentley et al. 2012) are presented.

Table 1: Predictor variables offered to standardisation models, with bounds where set. Continuous variables were offered as natural cubic splines with three degrees of freedom (but five for latitude and longitude). GUR is red gurnard, BAR is barracouta, and TAR is tarakihi.

Variable	Definition	Data type	Bounds
Vessel	Fishing vessel category	Categoric	
FishingYear	Fishing year	Categoric	1994/95–2020/21
Season	Season of year	Categoric (4)	
Month	Month	Categoric (12)	1–12
Stat	Statistical area	Categoric	Exclude Statistical Areas 040 and 048
Latitude	Latitude at the start location of trawl	Continuous	
Longitude	Longitude at the start location of trawl	Continuous	
Loc2	Start location of trawl categorised by 0.2 degree latitude/longitude cell	Categoric	At least 100 records for each cell
Target	Declared target species for trawl	Categoric	SNA, GUR, JDO, TRE, BAR, TAR
Duration	Natural logarithm of trawl duration (hours)	Continuous	Ln(0.5–6)
Effort speed	Trawl speed (knots)	Continuous	2.0–5.0
Distance	Natural log of trawl distance (duration * speed)(NM)	Continuous	Ln(1–25)
Vessel experience	Number of years in the fishery	Continuous	
StartTime	Hour at the start of trawl	Continuous	0–23
Effort height	Headline height of trawl gear (m)	Continuous	0.5–10
Effort depth	Fishing depth (m)	Continuous	< 150 (BPLE) < 200 (HG-ENLD) < 200 (WCNI)

2.5 Stock status evaluated against B_{MSY}-compatible reference points

There are no stock assessments for JDO 1 in which absolute biomass is estimated, so no comparison of absolute biomass against B_{MSY} can be done. Instead B_{MSY}-compatible reference points have been used for the three sub-stocks of JDO 1 (Ministry of Fisheries 2008, Fisheries New Zealand 2021). The reference points were derived from the sub-stock standardised CPUE indices, using the mean values over the period 1995/96 to 2010/11 as previously chosen by the Inshore Finfish Working Group, to define a target level for each sub-stock. Using the default Harvest Strategy Standard definitions (Ministry of Fisheries 2008), the Soft Limit was set at one half of the reference point value and the Hard Limit at one quarter of the reference point value. The reference points and associated Soft and Hard Limits were updated, and the current and historical status of the three sub-stocks evaluated against these.

2.6 Corroboration of standardised CPUE against trawl surveys

Inshore research trawl biomass surveys were used by Dunn & Jones (2013) as part of the information to inform John dory stock structure deliberations. For areas that are part of the same connected stock the research trawl biomass trends may be similar (no movement between areas), or perhaps with opposite trends (if there is movement between areas). Areas with no correlation between trawl biomass estimates are probably different stocks, so trawl surveys may be used to explore both stock structure and movement hypotheses.

An additional use is corroboration (or otherwise) of trends in standardised CPUE, which may be confounded with changes in reporting or gear, factors that can be difficult to account for in a standardisation. For the Hauraki Gulf, recent inshore trawl surveys were conducted in 2019 and 2020 to estimate the abundance of juvenile snapper (Parsons et al. 2021). These also provided new biomass estimates for John dory and red gurnard (*Chelidonichthys kumu*), after a gap of 19 years (Hauraki Gulf) and 20 years (Bay of Plenty).

We derived updated JDO 1 trawl survey recruited biomass indices as comparative indices to the fishery-dependent CPUE indices for John dory. The relevant survey indices to the three JDO 1 sub-stock regions are the Hauraki Gulf survey, the Bay of Plenty survey, and the northern area component of the west coast North Island survey.

Note that there was change in the gear configuration following the 1988 trawl surveys, which may have caused a change in the catchability of John dory. Hence surveys between 1982 and 1988 are to be considered a separate biomass series from those 1989 onward, for all areas in JDO 1.

2.7 Relative fishing mortality

Annual relative fishing mortality proxy for a sub-stock (e.g., JDO 1: east Northland and Hauraki Gulf) was calculated by dividing the total catch for each fishing year by the associated standardised CPUE index. These were plotted and evaluated for trends.

3. JDO 1 FISHERY CHARACTERISATION

Catch from the ENHG area dominated JDO 1 catch before 2010, but has steadily declined since 2007, and the catch in 2021 was about the same for the three subareas of BPLE, ENHG, and WCNI (Figure 3). Since 2020 most of the JDO 1 catch was reported on the event-based ERS trawl form, with reporting transferring over from CELR, TCER, and TCEPR forms (Figure 4).

The dominant fishing method in all three subareas is bottom trawl, with Danish seine important in BPLE and ENHG (Figure 5). Since 2016, some bottom trawls have occurred using a patented Modular Harvest System (MHS) developed by the Precision Seafood Harvesting (PSH) programme (see Figure 5, coded under the fishing method PRB).

For all three subareas, more catch is taken in the months October to March, but with steady amounts in the months outside this (Figure 6). The predominantly targeted fish varies by subarea: John dory, snapper, tarakihi, and trevally (BPLE); John dory and snapper (ENHG); red gurnard, tarakihi, and trevally (WCNI) (Figure 7). In BPLE less of the catch was taken as a target fishery in 2021 compared with previous years; in WCNI snapper has steadily declined as a target fishery since about 2016.

In BPLE the catch was evenly spread across the three large-scale statistical areas that make it up—Statistical Areas 008, 009, and 010 (Figure 8). In ENHG the catch was concentrated in the adjacent Statistical Areas 003 and 005 with catch declining in Statistical Area 006 (outer Hauraki Gulf). For WCNI catch was evenly spread over the adjacent Statistical Areas 042, 045, 046, and 047 with smaller catches from the southern Statistical Area 041 and very little from Statistical Area 040. High resolution spatial maps of bottom trawl catch and raw CPUE reflect the patterns already noted, with an emphasis on how far offshore catch extended and areas of higher catch rates (Figure 9).

Except for some small changes in targeting, the fisheries in the three subareas were undertaken in much the same way for the last two decades. Two recent changes were the use of bottom trawl with a Modular Harvest System since 2016, and a changeover from predominantly 2020 to recording using the ERS.

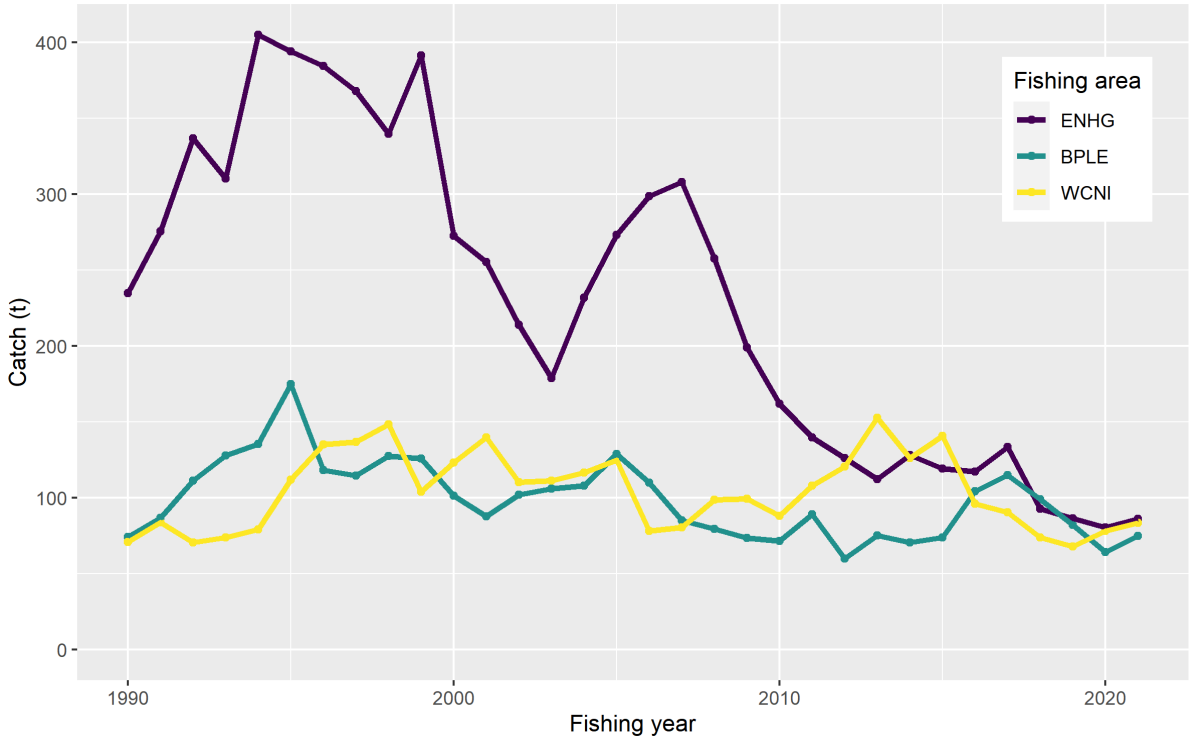

Figure 3: Annual catches of John dory by fishery area: Bay of Plenty (BPLE), east Northland and Hauraki Gulf (ENHG), and west coast North Island (WCNI).

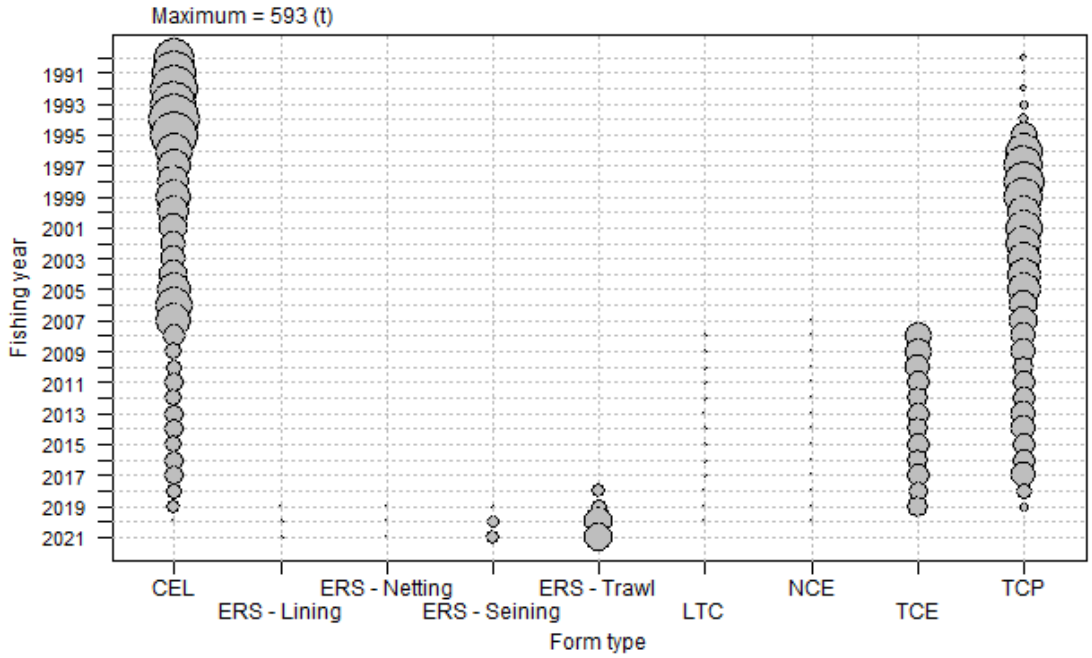

Figure 4: Annual catches of John dory by form type and fishing year. Form types are Catch Effort Landing Returns (CEL), Electronic Reporting System (ERS), Lining Trip Catch, Effort Return (LTC), Netting Catch, Effort and Landing Return (NCE), Trawl Catch Effort Return (TCE), Trawl Catch Effort Processing Return (TCP).

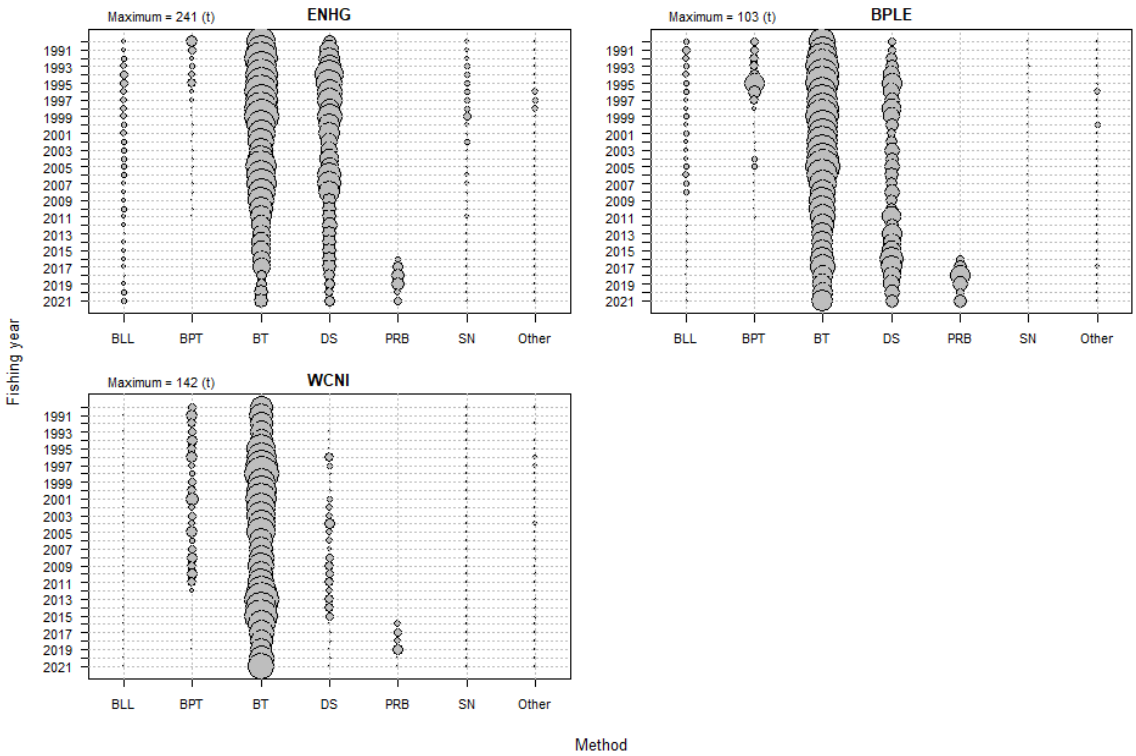

Figure 5: Annual catches of John dory by fishing method, fishing year, and fishery area. Methods are bottom long line (BLL), bottom pair trawl (BPT), bottom (single) trawl (BT), Danish seine (DS), bottom trawl using a Modular Harvest System (PRB), set net (SN), and Other.

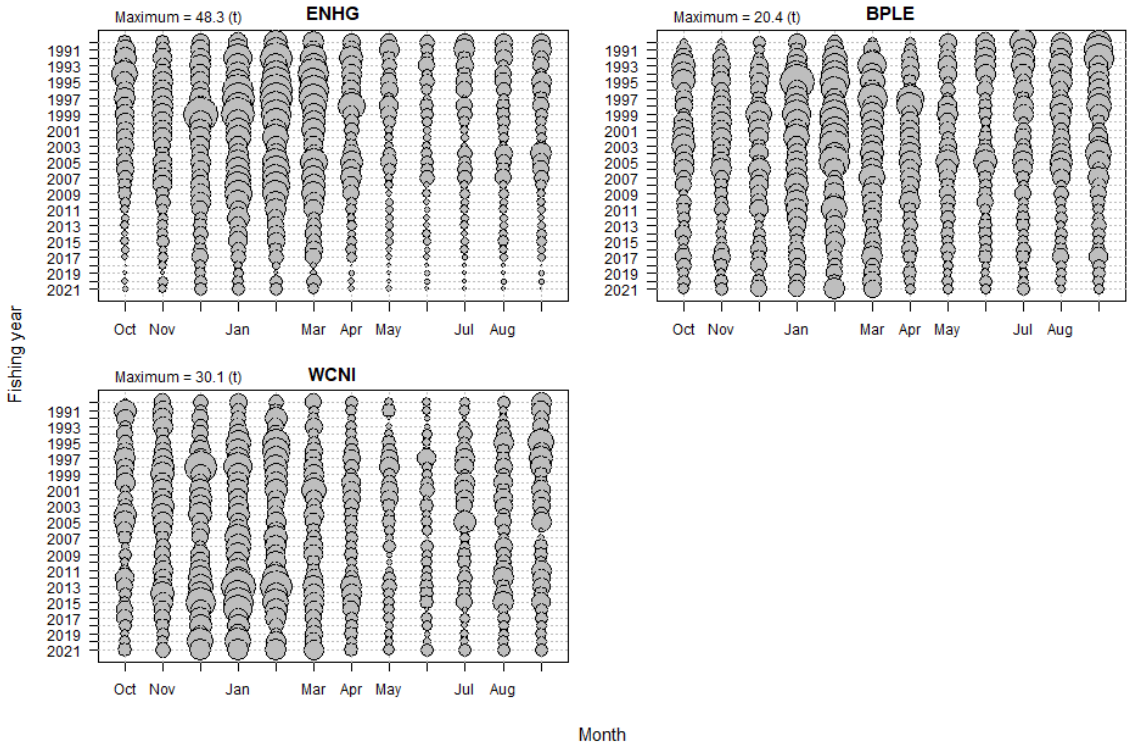

Figure 6: Annual bottom trawl catches of John dory by month, fishing year, and fishery area.

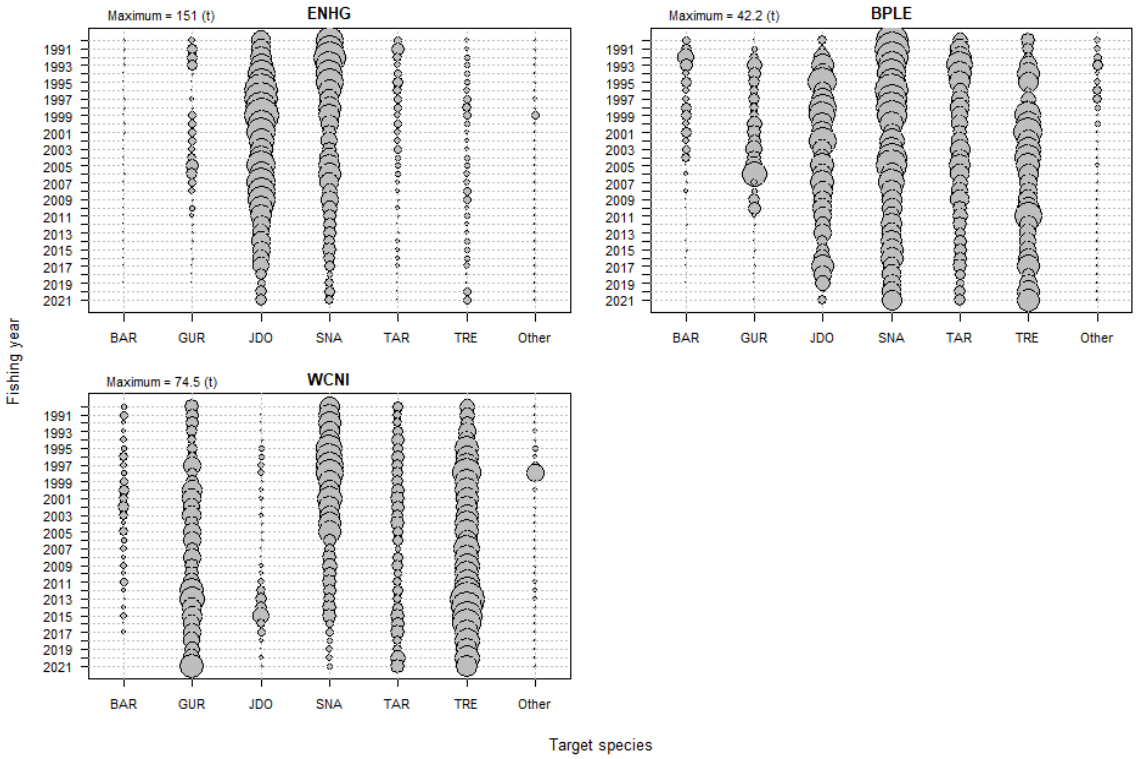

Figure 7: Annual bottom trawl catches of John dory by target fish species, fishing year, and fishery area.

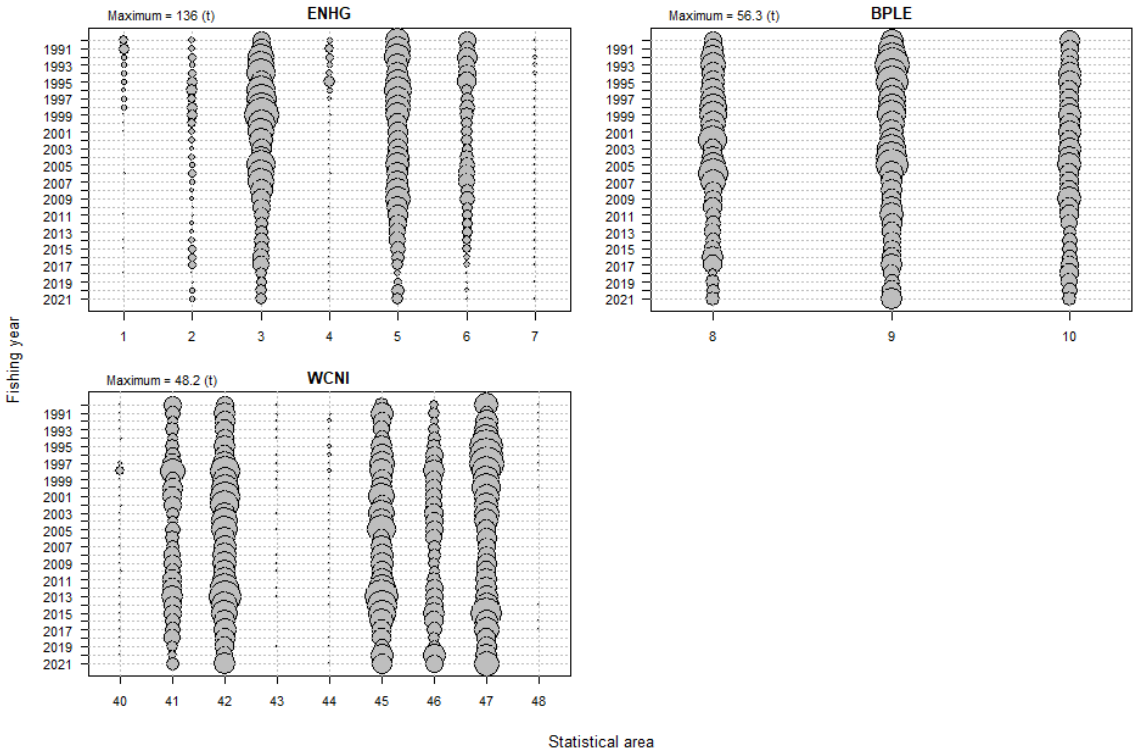

Figure 8: Annual bottom trawl catch of John dory by General Statistical Area (where '1' is Statistical Area 001, '2' is Statistical Area 002, etc.), fishing year, and fishery area.

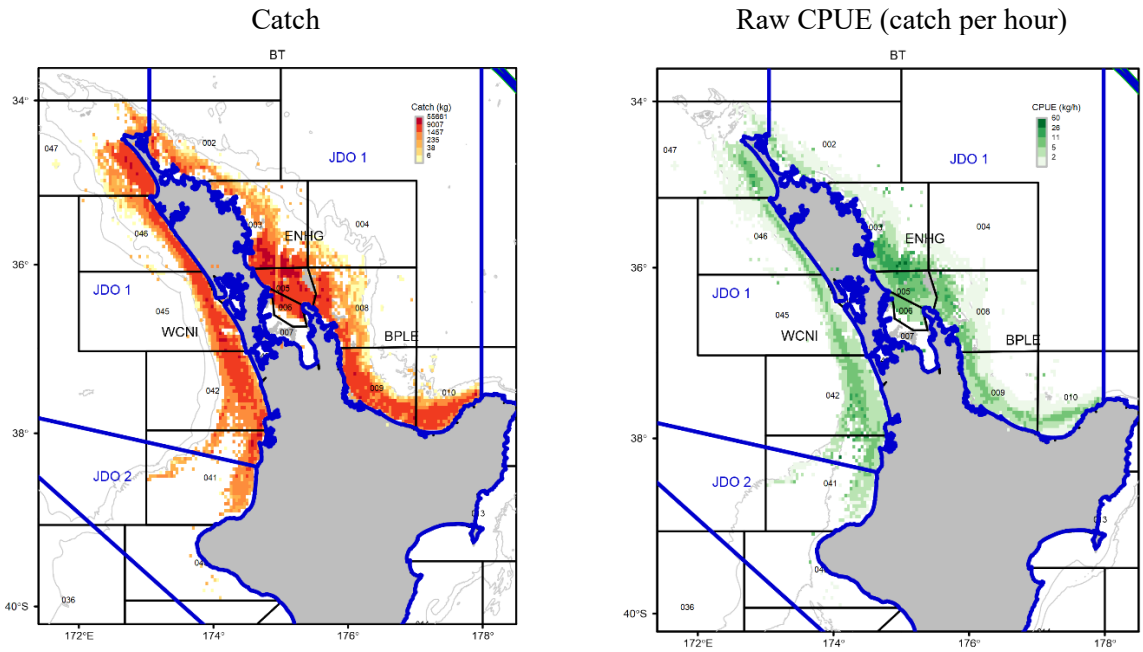

Figure 9: John dory catch (kg) and raw CPUE (kilograms per hour) for JDO 1 and northwestern part of JDO 2 based on bottom trawl data for 1990 to 2021 fishing years. Grid cell resolution is 0.08 degrees longitude by 0.08 degrees latitude, and catch or CPUE was not plotted if there were less than three fishing permit holders for a grid cell.

4. STANDARDISATIONS

In the follow sections standardised CPUE indices analyses for 1995 to 2021 are presented in turn for BPLE, ENHG, and WCNI.

4.1 Bay of Plenty standardised CPUE

Core vessels were selected based on the criterion of a minimum of five trawls per year for a minimum of five years, as used by Langley (2018). This retained about 90% of the catch in most years, and about 60–70% in the years 1995 to 1998 (Figures 10–11). There were 30 core vessels, and they showed very good overlap in effort from the start to the end of the fishery (Figure 12, Table 2).

The lognormal model explained 27% of the variation in the positive catch, with vessel (9%) and depth (5%) explaining the most variance (Table 3). Other variables accepted into the model were trawl duration, target species, start cell location, and month. Predictor variables additional to fishing year had a minor impact on the standardised index (Figure 13, Appendix 1). Diagnostics for the model were good (Figure 14).

The binomial model explained 15% of the variation in the proportion of non-zero catch, with target species the most important predictor variable explaining 6% of the variance (Table 4). Other variables that entered the model were start cell location, vessel, and start latitude. Diagnostics for the binomial model were very good (Figure 15).

The combined index is similar to the lognormal index and a raw geometric mean CPUE, showing an irregular downward decline from 1995 to 2021 to half its initial level (Figures 16–17). The combined index is similar to the previous standardised index (Langley 2018) with the decline signalled in 2016 continuing, and a subsequent increase in 2020 and 2021 for the updated index (Figure 18).

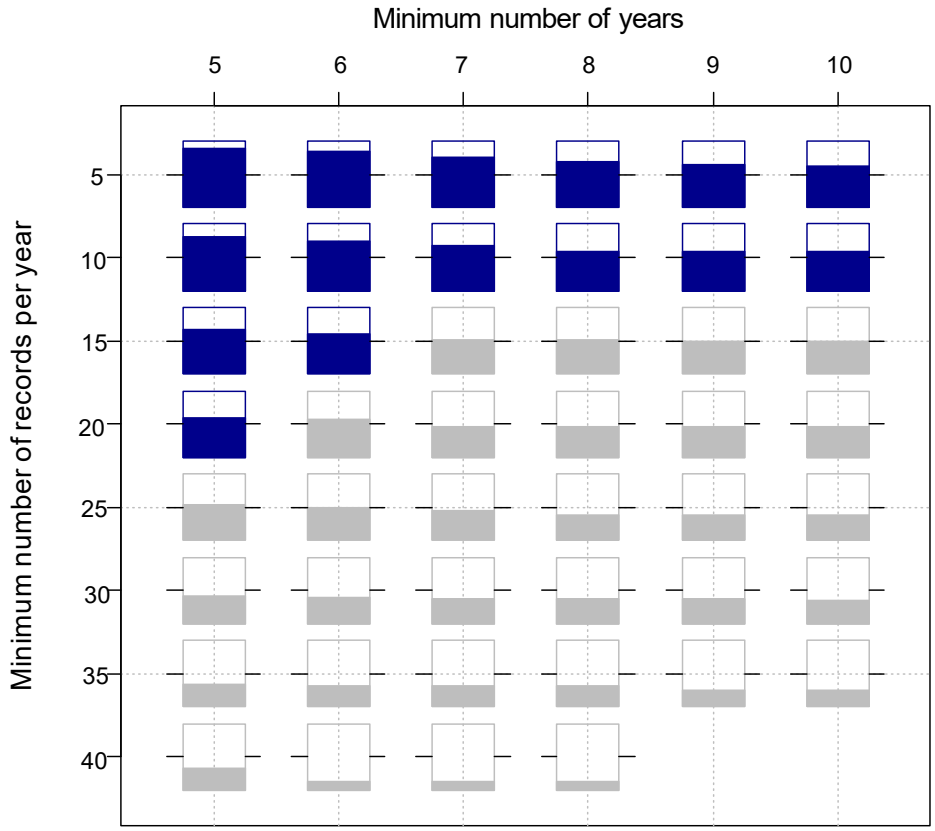

Figure 10: Proportion of the Bay of Plenty John dory catch taken when subsetting data with the requirement of minimum number of records (i.e., trawls) per year, for a minimum number of years. Each bar shows the percentage of total catch retained from 1995 to 2021 under the criterion, where the horizontal line for each bar represents 50%. Bar with a fill colour of blue retain 50% or more of the catch, otherwise they are coloured grey.

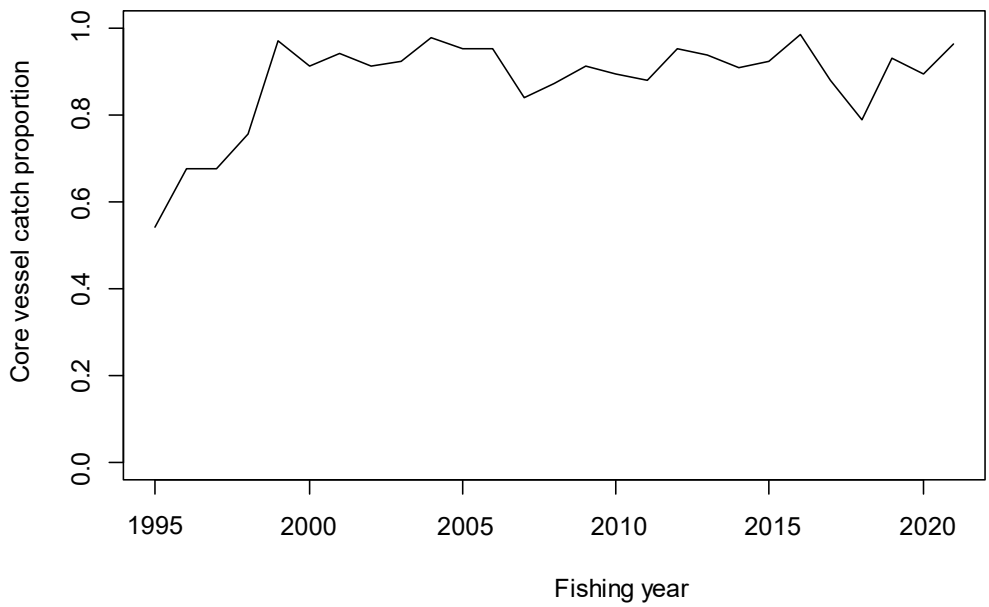

Figure 11: Proportion of the Bay of Plenty catch retained by fishing year, after subsetting on vessels, retaining those with a minimum of five records (i.e., trawl) per year for a minimum of five years.

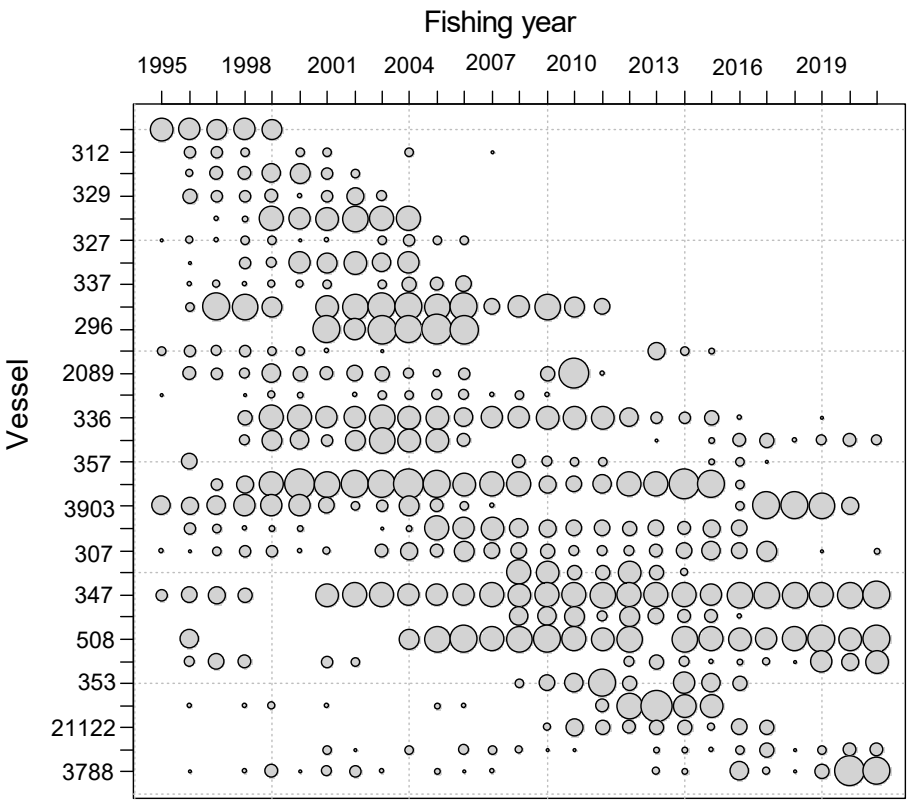

Figure 12: Bay of Plenty and number of trawls for core vessels by vessel and fishing year. The area of the circles is proportional to the number of trawls.

Table 2: Summary of Bay of Plenty core vessel catch and effort for bottom trawl CPUE data.

Fishing year	Number vessels	Number trips	JDO catch (t)	Number trawls	Percent zero catch
1995	5	65	13.3	457	41.4
1996	19	185	34.8	1 341	40.4
1997	15	213	41.1	1 615	45.6
1998	22	242	50.4	1 760	39.3
1999	18	338	66.4	2 794	48.1
2000	17	265	44.3	2 364	46.2
2001	21	339	52.7	2 821	54.2
2002	18	349	49.4	2 549	48.0
2003	18	407	60.5	3 335	52.9
2004	18	438	72.4	3 761	48.6
2005	17	383	71.6	3 684	48.9
2006	17	347	43.9	2 770	50.6
2007	12	214	40.8	1 879	42.1
2008	13	298	45.4	2 311	36.0
2009	15	314	51.8	2 417	35.1
2010	14	324	49.5	2 330	41.7
2011	14	285	48.2	2 178	42.6
2012	12	309	40.2	2 446	48.1
2013	14	297	35.6	2 121	54.6
2014	16	319	34.6	2 585	60.6
2015	15	292	34.8	2 095	56.5
2016	15	217	48.1	1 689	47.1
2017	10	199	47.2	1 740	39.9
2018	7	132	26.7	1 176	43.2
2019	9	191	30.8	1 563	44.2
2020	7	200	32.7	1 543	33.4
2021	7	181	38.2	1 491	30.2

Table 3: Variables accepted into the lognormal component of the Bay of Plenty standardisation model (1% additional deviance explained), and the order in which they were accepted into the model, their degrees of freedom (Df), and total variance explained (R-squared).

Predictors	Df	R-squared
fish_year	26	0.03
vessel	29	0.12
ns(effort_depth, df = 3)	3	0.17
ns(log_duration, df = 3)	3	0.21
target	5	0.23
Loc2	95	0.25
month	11	0.27

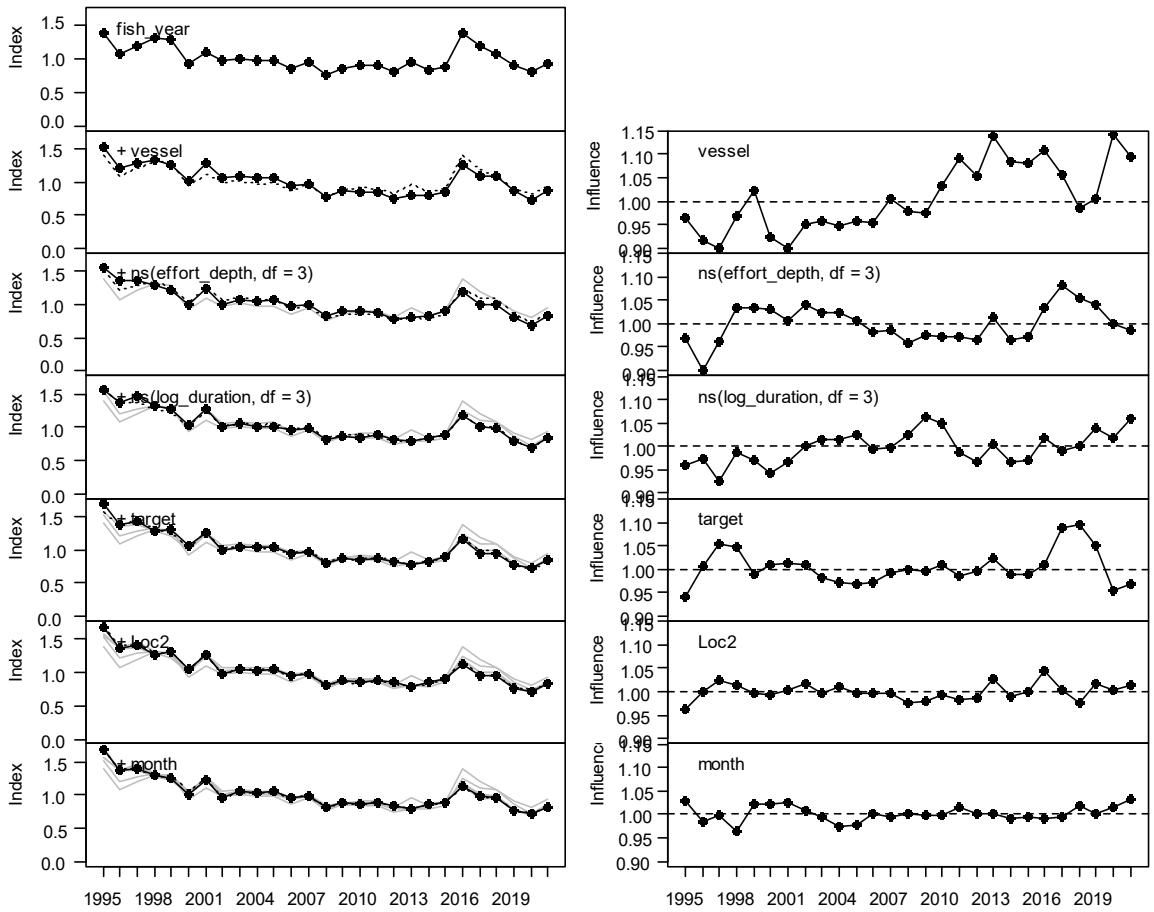

Figure 13: Stepwise influence plots showing the impact of sequentially adding predictor variables for the lognormal component of the Bay of Plenty standardisation for 1995 to 2021 (see Table 3).

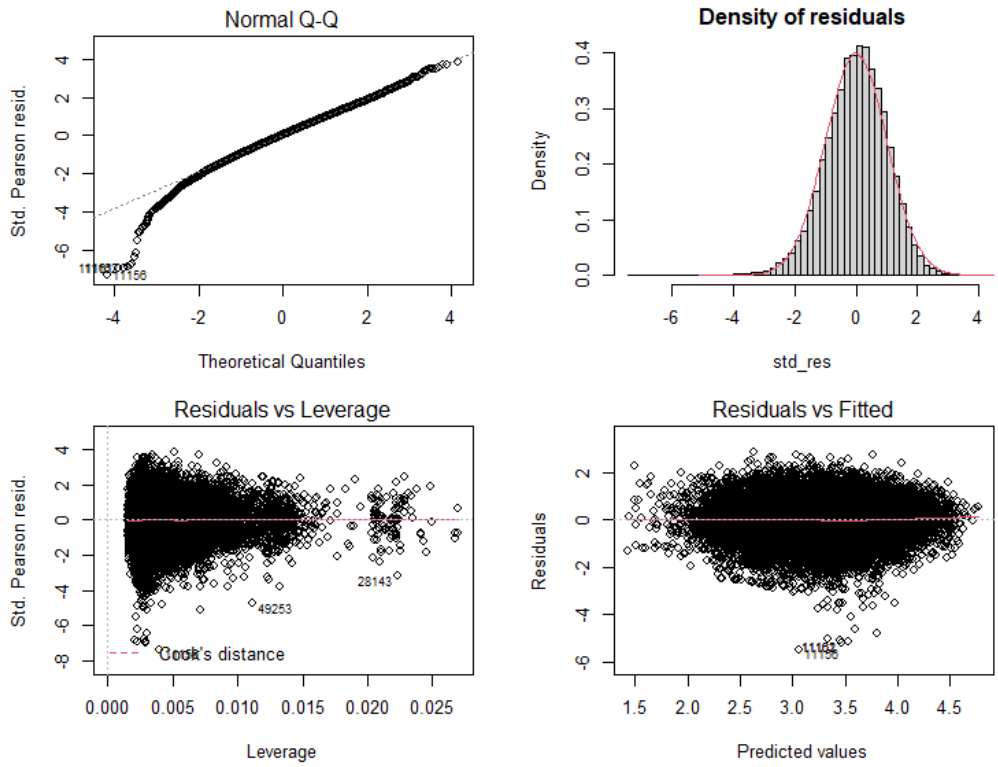

Figure 14: Residuals for the lognormal component of the Bay of Plenty standardisation model.

Table 4: Variables accepted into the binomial component of the Bay of Plenty standardisation model (1% additional deviance explained), and the order in which they were accepted into the model, their degrees of freedom (Df), and total variance explained (R-squared).

Predictors	Df	R-squared
fish_year	26	0.01
target	5	0.07
Loc2	42	0.10
vessel	29	0.13
ns(start_latitude, df = 5)	5	0.15

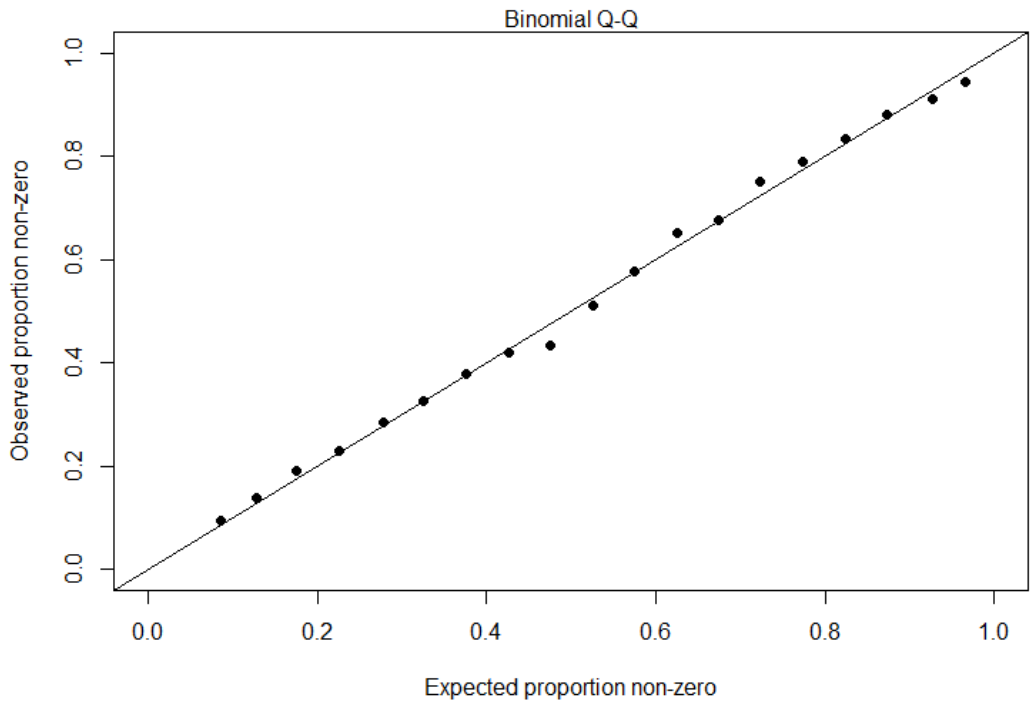

Figure 15: Diagnostic for the binomial component of the Bay of Plenty standardisation model.

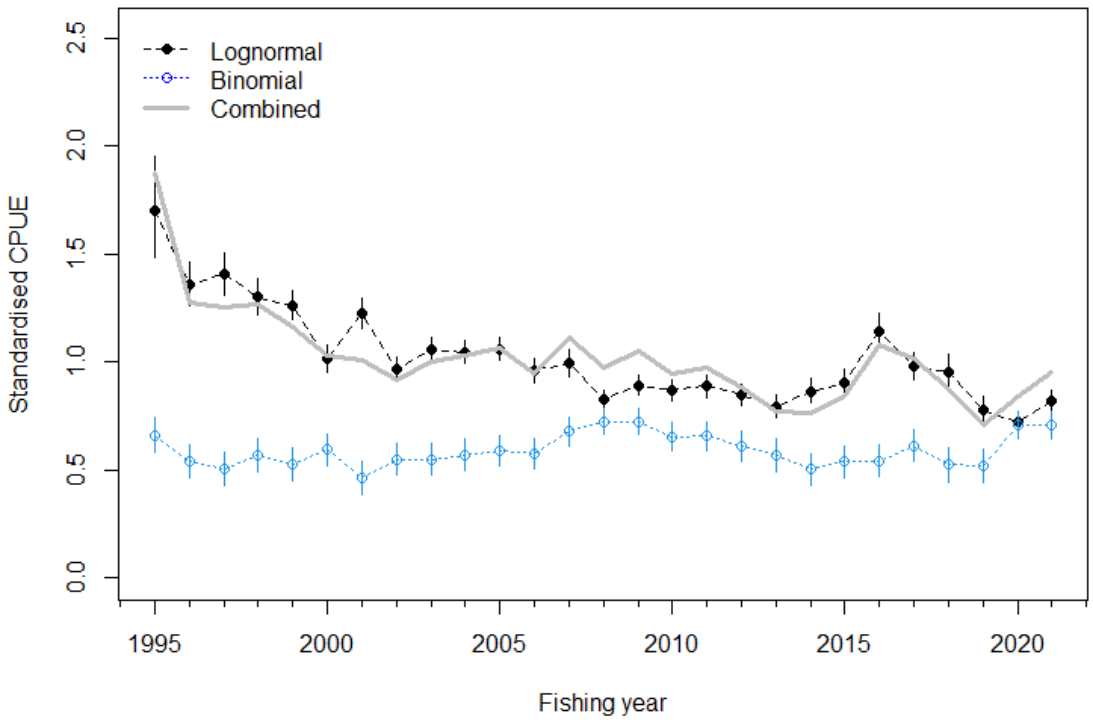

Figure 16: Binomial component, lognormal component, and combined index for the Bay of Plenty (part of JDO 1) standardisation model. Error bars are ± two standard deviations.

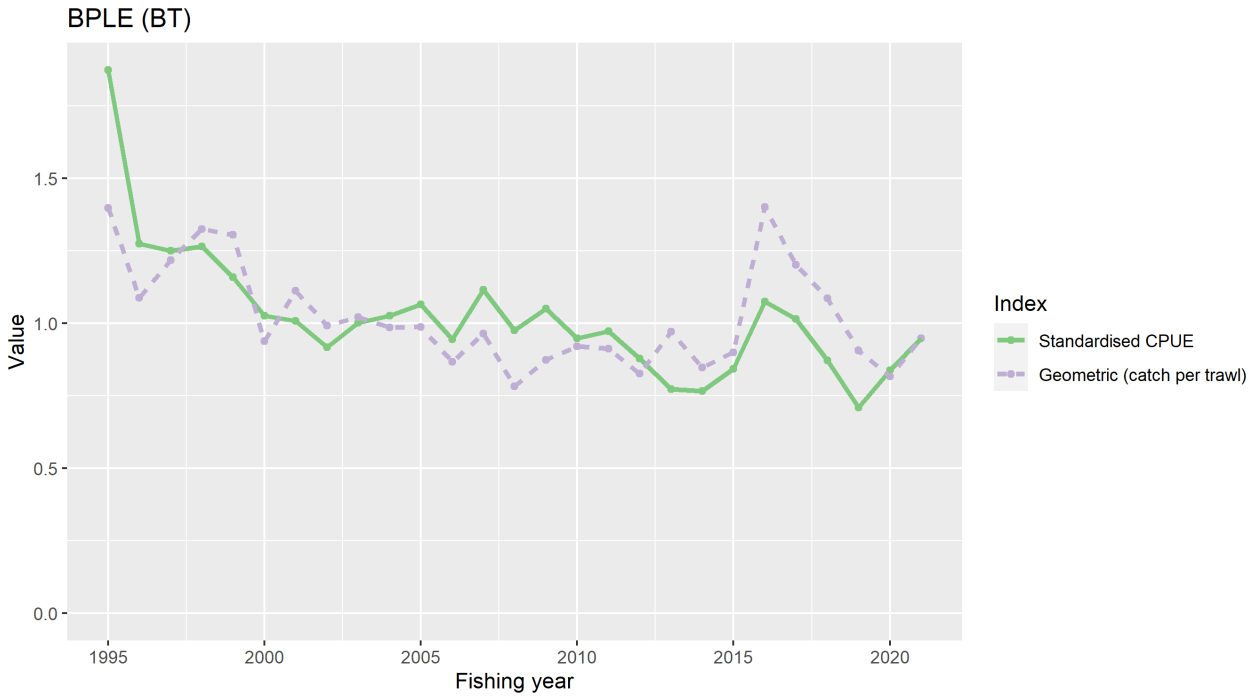

Figure 17: Combined index ('Standardised CPUE') and geometric mean CPUE comparison for Bay of Plenty.

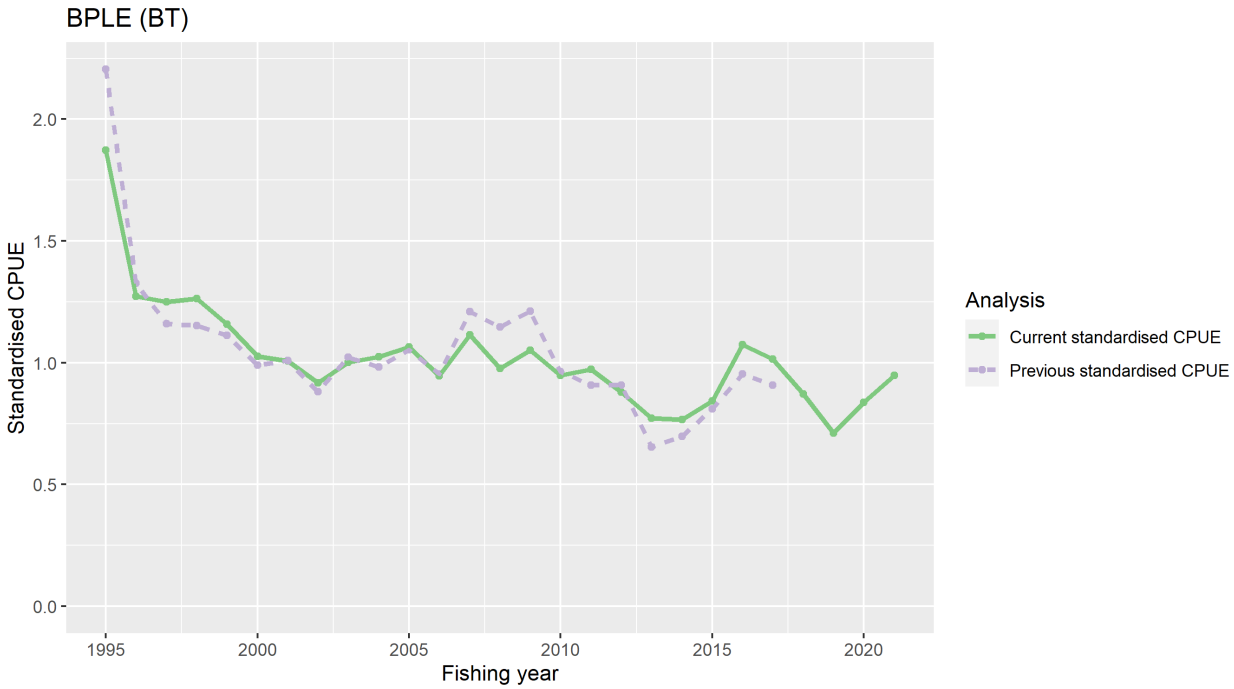

Figure 18: Combined index ('Current standardised CPUE') compared with the previous standardised CPUE index for Bay of Plenty (Langley 2018).

4.2 East Northland and Hauraki Gulf standardised CPUE

Core vessels were selected based on the criterion of a minimum of five trawls per year for a minimum of five years, as used by Langley (2018). This retained about 90% of the catch in most years and about 50–80% in the years 1995 to 2000 (Figures 19–20). There were 27 core vessels, and they showed very good overlap in effort from the start to the end of the fishery (Figure 21, Table 5).

The lognormal model explained 42% of the variation in the positive catch, with start cell (19%) and month (6%) explaining the most variance (Table 6). Other variables accepted into the model were vessel, trawl duration, and target species. Predictor variables additional to fishing year had a minor impact on the standardised index (Figure 22, Appendix 2). Diagnostics for the model were good (Figure 23).

The binomial model explained 26% of the variation in the proportion of non-zero catch, with target species the most important predictor variable explaining 14% of the variance (Table 7). Other variables that entered the model were vessel, start cell location, and month. Diagnostics for the binomial model were good (Figure 24).

The combined index was similar to the lognormal index and a raw geometric mean CPUE, showing a large drop from 1995 to 1996, followed by a decline to 2013 then an increase (Figures 25–26). The combined index was very similar to the previous standardised index (Langley 2018) with an increase starting in 2104 and continuing to 2021 (Figure 27).

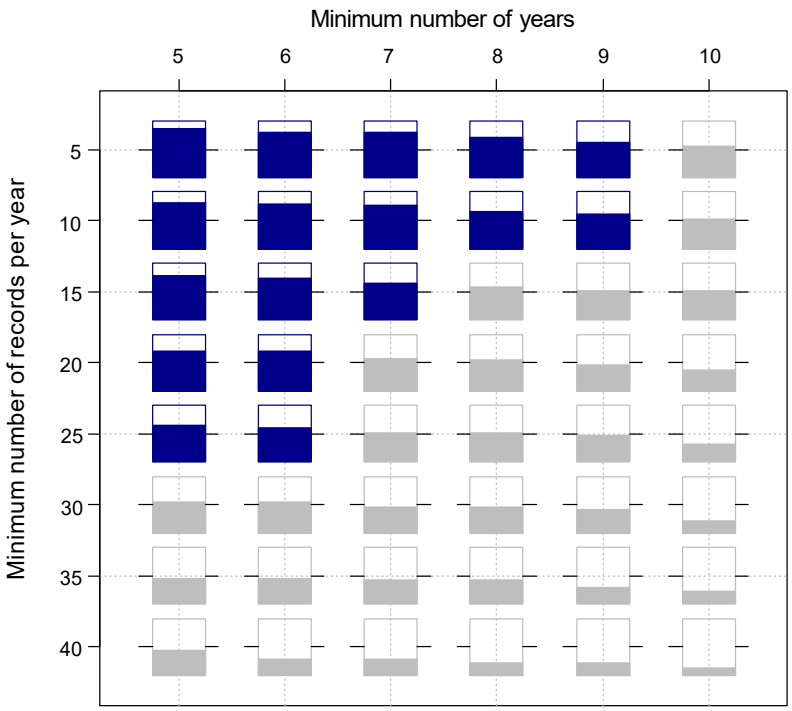

Figure 19: Proportion of the East Northland and Hauraki Gulf catch taken when subsetting data with the requirement of minimum number of records (i.e., trawls) per year, for a minimum number of years. Each bar shows the percentage of total catch retained from 1995 to 2021 under the criterion, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 50% or more of the catch, otherwise they are coloured grey.

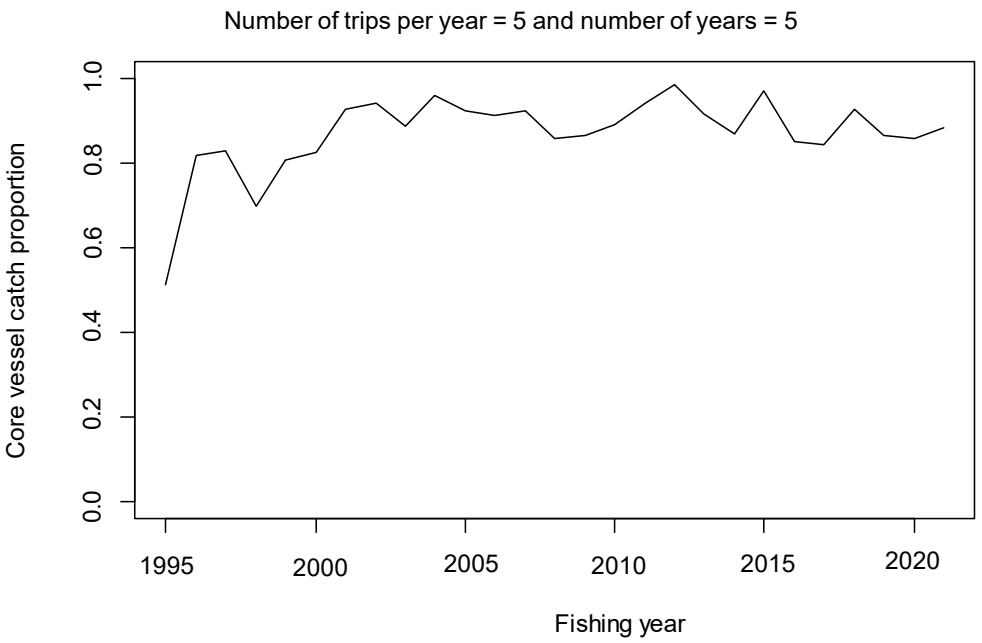

Figure 20: Proportion of the Bay of Plenty catch retained by fishing year, after subsetting on vessels, retaining those with a minimum of five records (i.e., trawls) per year for a minimum of five years.

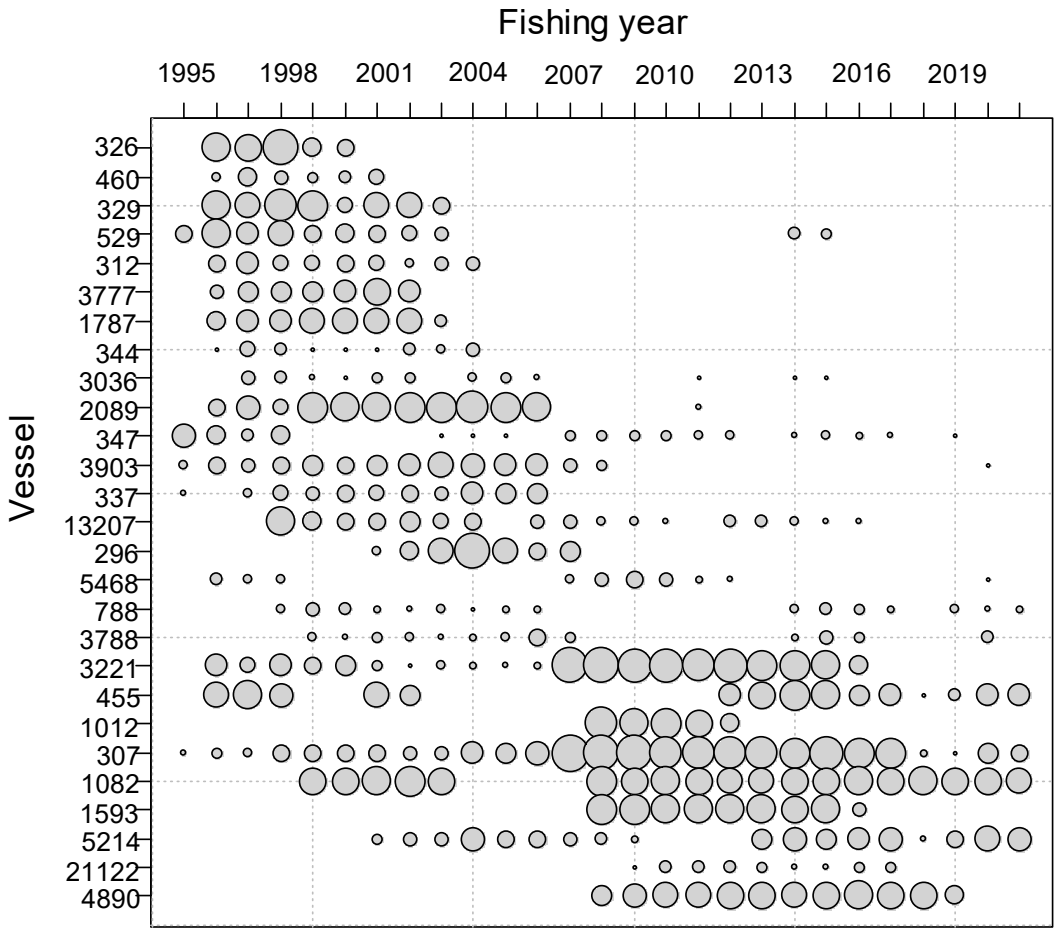

Figure 21: East Northland and Hauraki Gulf and number of trawls for core vessels by vessel and fishing year. The area of the circles is proportional to the number of trawls.

Table 5: Summary of East Northland and Hauraki Gulf core vessel catch and effort for bottom trawl CPUE data.

Fishing year	Number vessels	Number trips	JDO catch (t)	Number trawls	Percent zero catch
1995	5	25	7.8	217	53.9
1996	17	300	89.5	2 619	30.4
1997	17	353	120.6	3 079	29.3
1998	19	398	97.7	3 468	33.7
1999	17	330	111.2	3 094	28.8
2000	17	310	81.4	3 126	35.5
2001	20	364	110.0	3 374	26.4
2002	19	368	115.4	3 245	26.0
2003	18	262	78.8	2 217	23.1
2004	14	273	81.0	2 507	24.5
2005	12	192	54.7	1 978	24.9
2006	11	193	53.4	1 793	25.3
2007	9	211	67.1	2 074	16.0
2008	11	322	126.5	3 044	16.4
2009	11	310	121.3	3 449	23.7
2010	10	307	96.4	3 366	25.2
2011	11	273	83.2	3 232	28.6
2012	11	293	68.2	3 355	34.3
2013	10	281	61.0	3 577	39.9
2014	14	313	66.2	3 230	36.2
2015	14	323	72.3	2 998	34.5
2016	12	241	53.5	2 282	37.7
2017	8	196	52.3	2 062	33.0
2018	5	87	22.6	699	25.2
2019	7	92	18.3	744	22.0
2020	8	137	38.6	1 011	25.6
2021	5	109	33.8	829	14.6

Table 6: Variables accepted into the lognormal component of the East Northland and Hauraki Gulf standardisation model (1% additional deviance explained), and the order in which they were accepted into the model, their degrees of freedom (Df), and total variance explained (R-squared).

Predictors	Df	R-squared
fish_year	26	0.03
Loc2	41	0.22
month	11	0.28
vessel	26	0.34
ns(log_duration, df = 3)	3	0.39
target	5	0.42

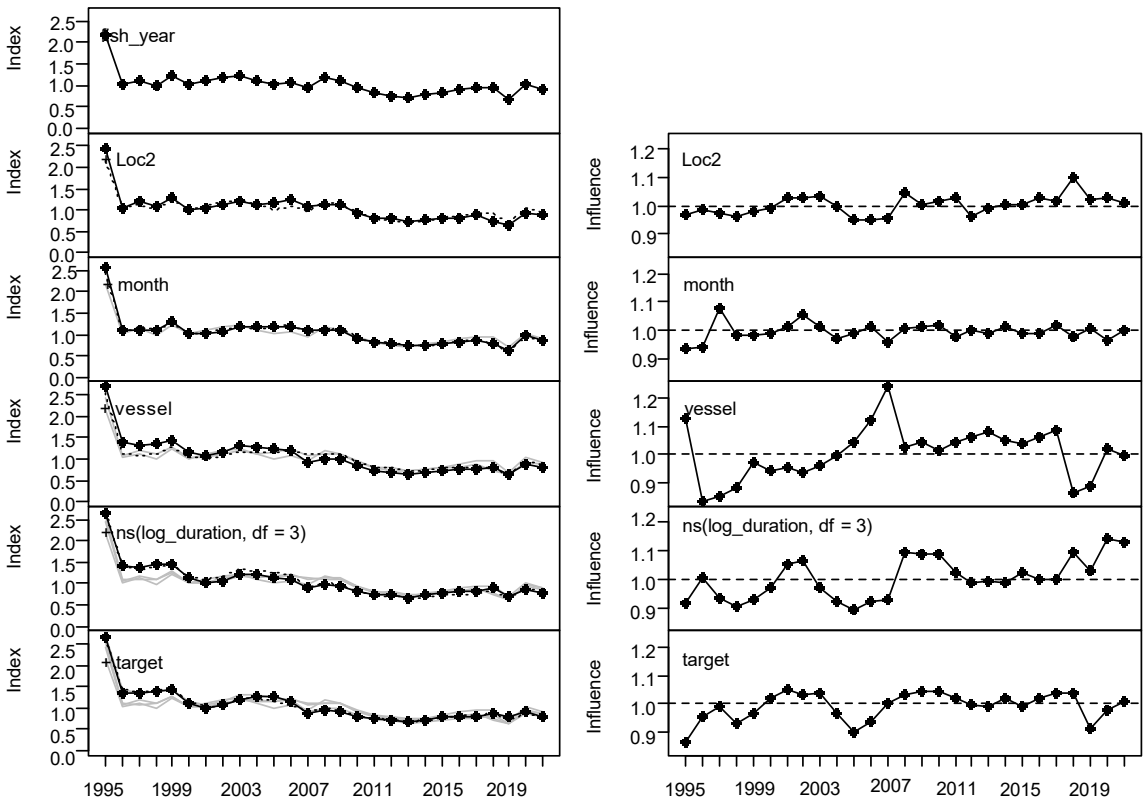

Figure 22: Stepwise influence plots showing the impact of sequentially adding predictor variables for the lognormal component of the East Northland and Hauraki Gulf standardisation (see Table 6), for 1995–2021 fishing years.

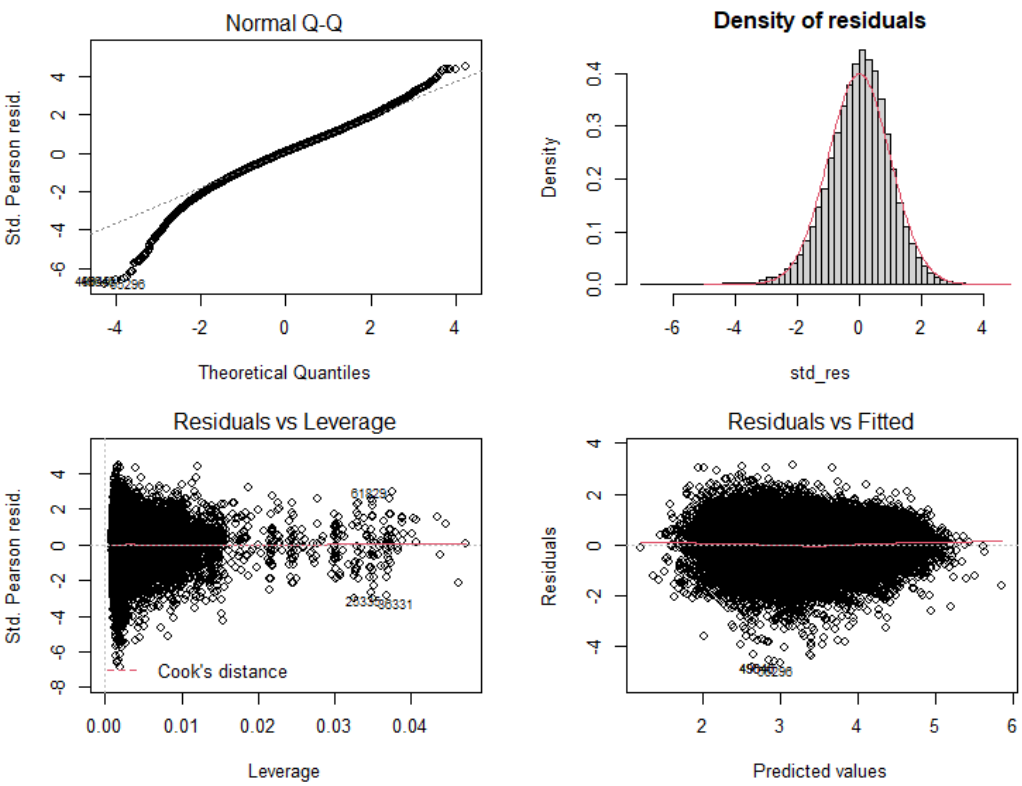

Figure 23: Residuals for the lognormal component of the East Northland and Hauraki Gulf standardisation model.

Table 7: Variables accepted into the binomial component of the East Northland and Hauraki Gulf standardisation model (1% additional deviance explained), and the order in which they were accepted into the model, their degrees of freedom (Df), and total variance explained (R-squared).

Predictors	Df	R-squared
fish_year	26	0.02
target	5	0.16
vessel	26	0.22
Loc2	41	0.24
month	11	0.26

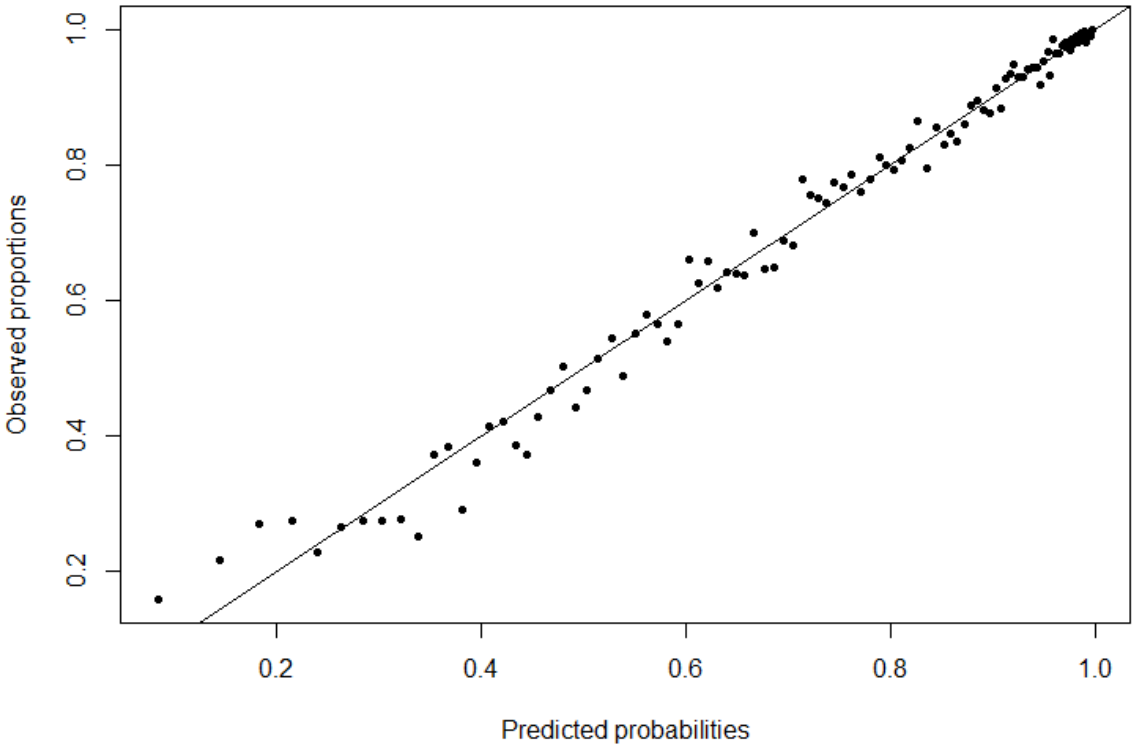

Figure 24: Diagnostic for the binomial component of the East Northland and Hauraki Gulf standardisation model.

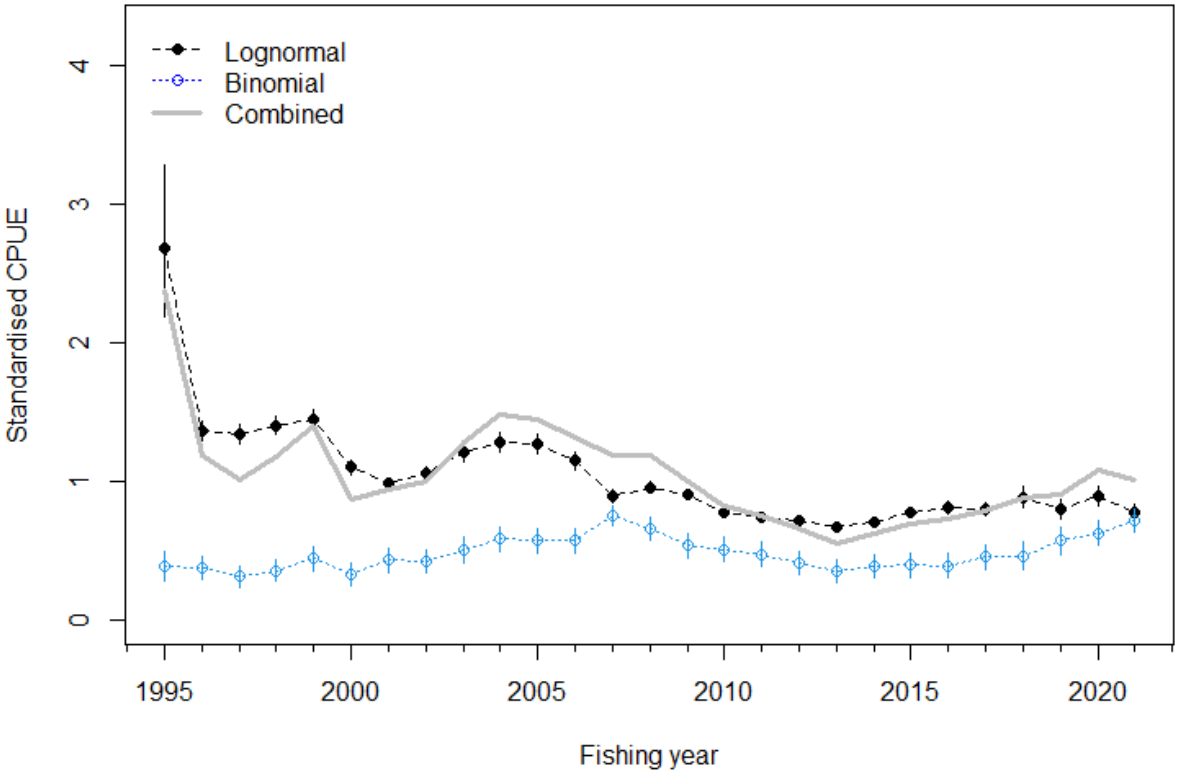

Figure 25: Binomial component, lognormal component, and combined index for the East Northland and Hauraki Gulf (part of JDO 1) standardisation model. Error bars are ± two standard deviations.

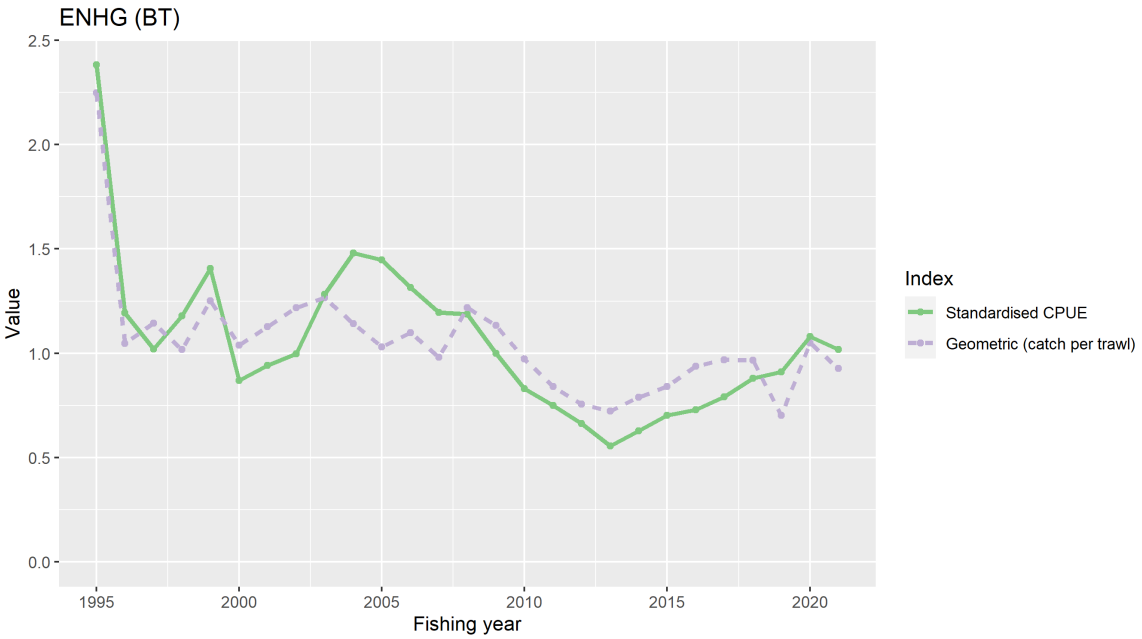

Figure 26: Combined index ('Standardised CPUE') and geometric mean CPUE comparison for East Northland and Hauraki Gulf.

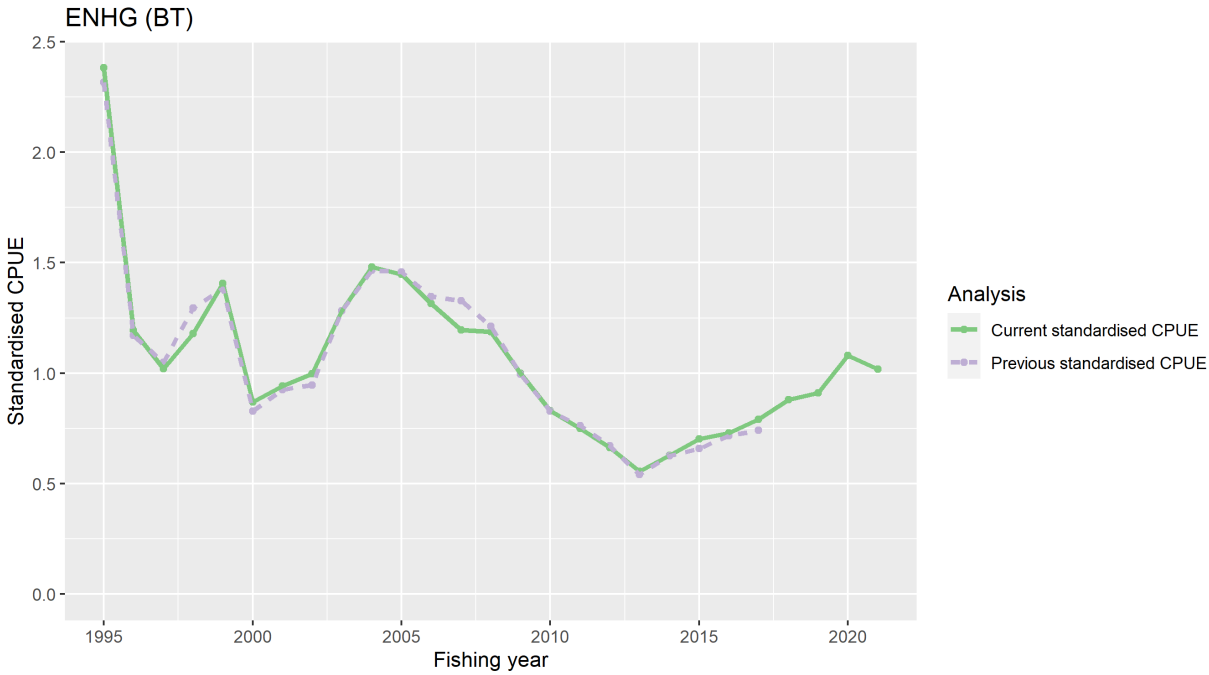

Figure 27: Combined index ('Current standardised CPUE') compared with the previous standardised CPUE index for East Northland and Hauraki Gulf (Langley 2018).

4.3 West coast North Island standardised CPUE

Core vessels were selected based on the criterion of a minimum of five trawls per year for a minimum of five years, as used by Langley (2018). This retained about 90% of the catch from 1998 to 2018 and about 50–80% for other years (Figures 28–29). There were 28 core vessels, and they showed good overlap in effort from the start to the end of the fishery (Figure 30, Table 8).

The lognormal model explained 40% of the variation in the positive catch, with vessel (29%) and start cell location (6%) explaining the most variance (Table 9). The other variable accepted into the model was trawl distance. The vessel predictor variable reduced the size of the drop from 1995 to 1996 and flattened out the standardised index (Figure 31, Appendix 3). Diagnostics for the model were good (Figure 32).

The binomial model explained 15% of the variation in the proportion of non-zero catch, with start cell location the most important predictor variable explaining 8% of the variance (Table 10). Other variables that entered the model were vessel and fishing depth. Diagnostics for the binomial model were good (Figure 33).

The combined index showed less of a decline from 1995 to 2001 compared with the lognormal index or raw geometric mean CPUE (Figures 34–35). The combined index was similar to the previous standardised index (Langley 2018) which declined from 2013 to 2017 and the new index increased after that (Figure 36).

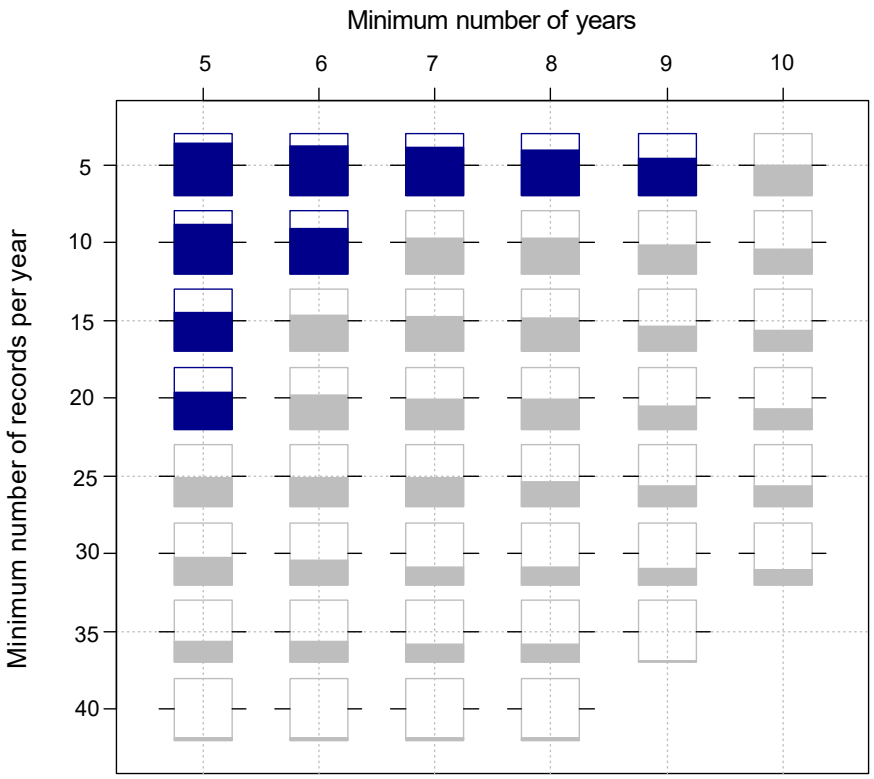

Figure 28: Proportion of the west coast North Island catch taken when subsetting data with the requirement of minimum number of records (i.e., trawls) per year, for a minimum number of years. Each bar shows the percentage of total catch retained from 1995 to 2021 under the criterion, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 50% or more of the catch, otherwise they are coloured grey.

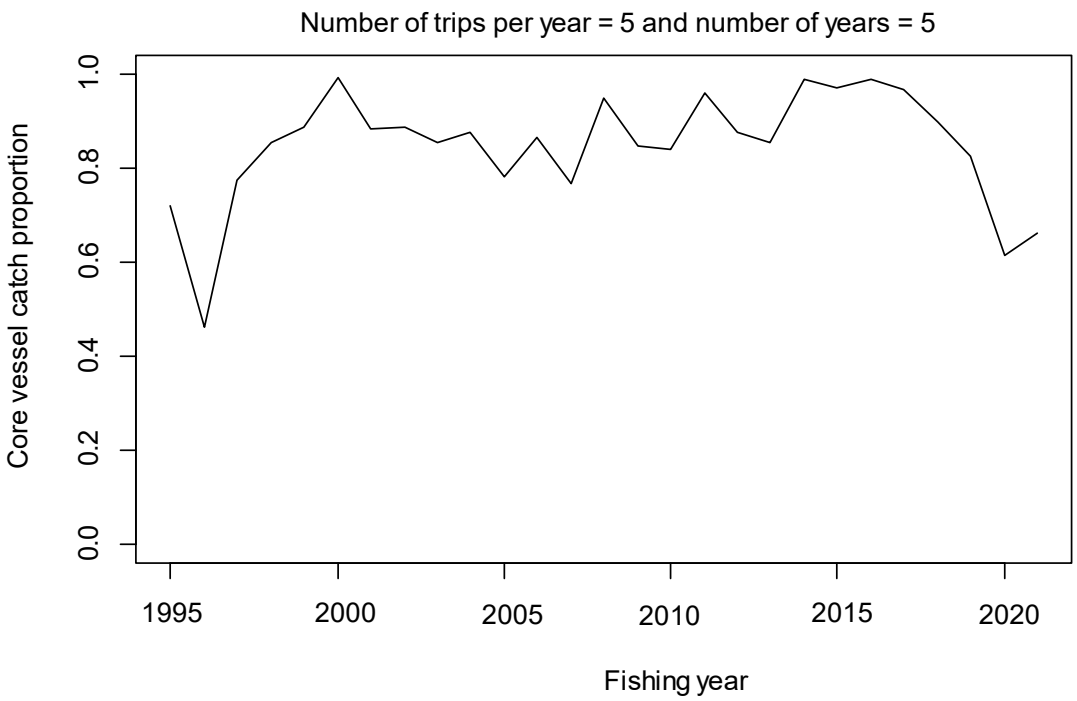

Figure 29: Proportion of the west coast North Island catch retained by fishing year, after subsetting on vessels, retaining those with a minimum of five records (i.e., trawls) per year for a minimum of five years.

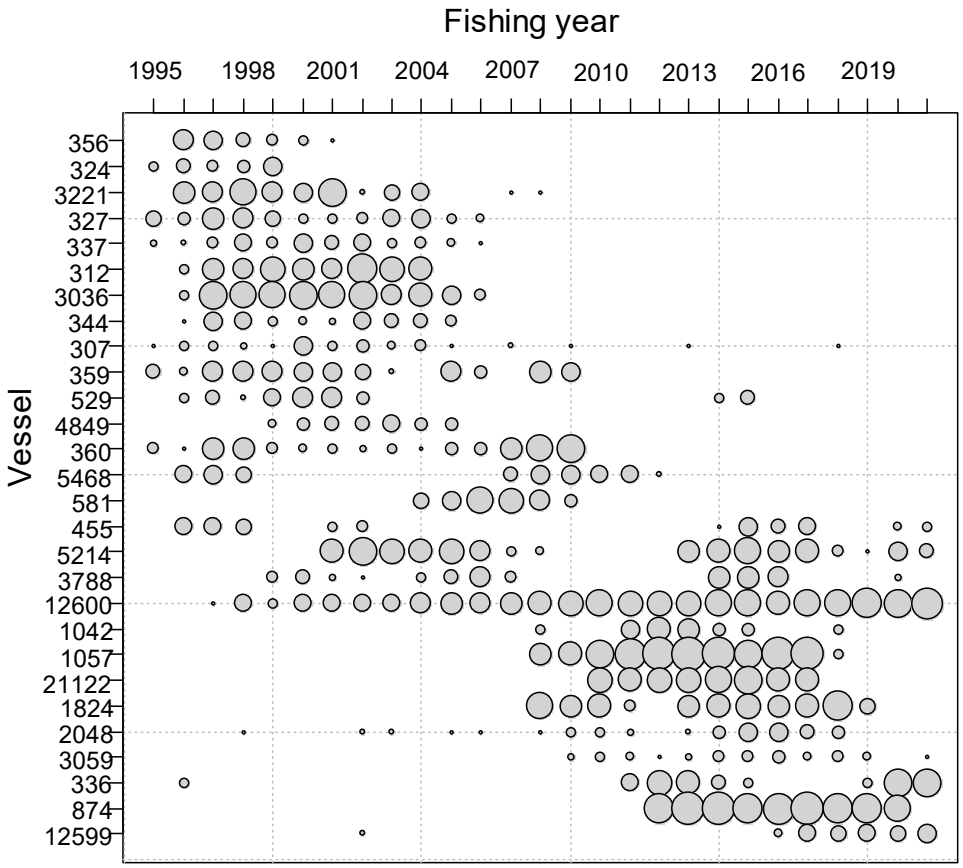

Figure 30: West coast North Island and number of trawls for core vessels by vessel and fishing year. The area of the circles is proportional to the number of trawls.

Table 8: Summary of west coast North Island core vessel catch and effort for bottom trawl CPUE data.

Fishing year	Number vessels	Number trips	JDO catch (t)	Number trawls	Percent zero catch
1995	5	25	7.8	217	53.9
1996	17	300	89.5	2 619	30.4
1997	17	353	120.6	3 079	29.3
1998	19	398	97.7	3 468	33.7
1999	17	330	111.2	3 094	28.8
2000	17	310	81.4	3 126	35.5
2001	20	364	110.0	3 374	26.4
2002	19	368	115.4	3 245	26.0
2003	18	262	78.8	2 217	23.1
2004	14	273	81.0	2 507	24.5
2005	12	192	54.7	1 978	24.9
2006	11	193	53.4	1 793	25.3
2007	9	211	67.1	2 074	16.0
2008	11	322	126.5	3 044	16.4
2009	11	310	121.3	3 449	23.7
2010	10	307	96.4	3 366	25.2
2011	11	273	83.2	3 232	28.6
2012	11	293	68.2	3 355	34.3
2013	10	281	61.0	3 577	39.9
2014	14	313	66.2	3 230	36.2
2015	14	323	72.3	2 998	34.5
2016	12	241	53.5	2 282	37.7
2017	8	196	52.3	2 062	33.0
2018	5	87	22.6	699	25.2
2019	7	92	18.3	744	22.0
2020	8	137	38.6	1 011	25.6
2021	5	109	33.8	829	14.6

Table 9: Variables accepted into the lognormal component of the west coast North Island standardisation model (1% additional deviance explained), and the order in which they were accepted into the model, their degrees of freedom (Df), and total variance explained (R-squared).

Predictors	Df	R-squared
fish_year	26	0.04
vessel	27	0.33
Loc2	75	0.39
ns(log_distance, df = 3)	3	0.40

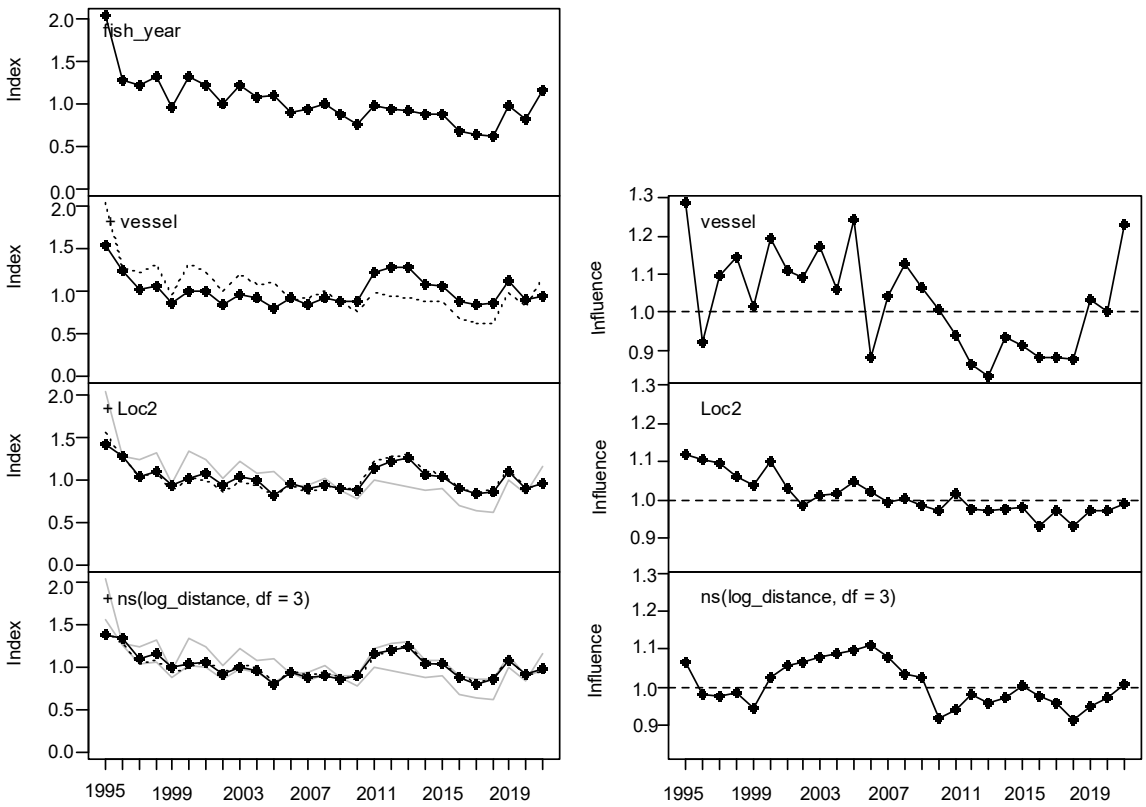

Figure 31: Stepwise influence plots showing the impact of sequentially adding predictor variables for the lognormal component of the west coast North Island standardisation (see Table 9).

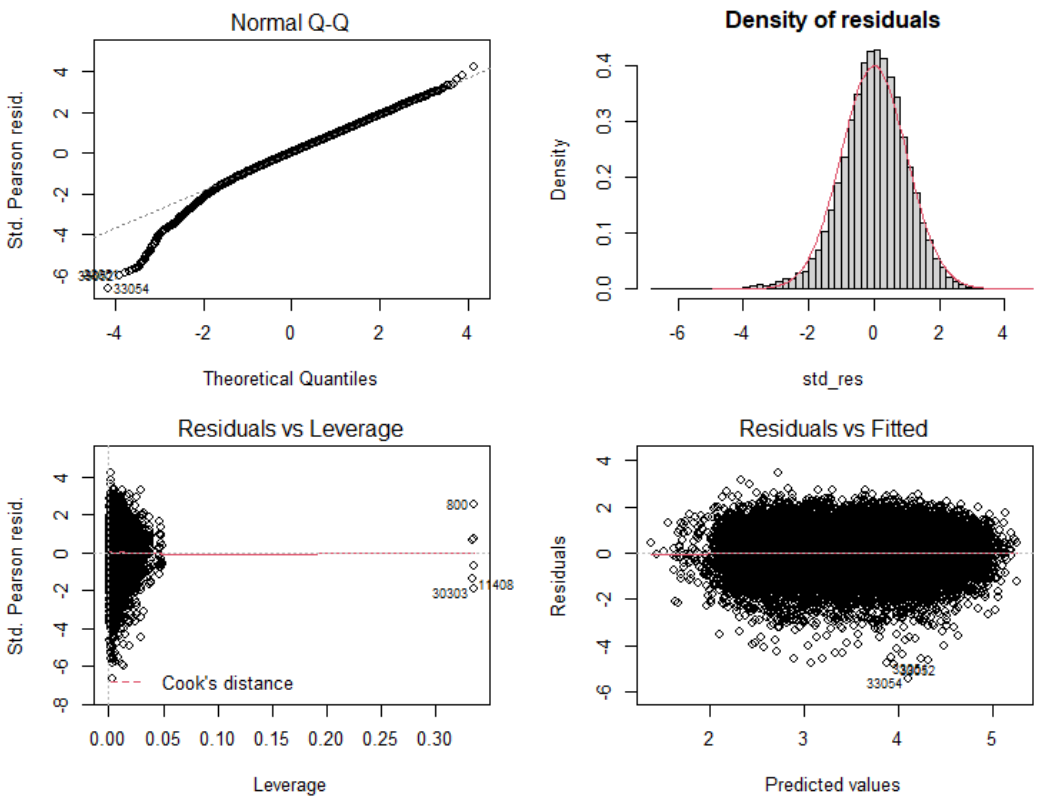

Figure 32: Residuals for the lognormal component of the west coast North Island standardisation model.

Table 10: Variables accepted into the binomial component of the west coast North Island standardisation model (1% additional deviance explained), and the order in which they were accepted into the model, their degrees of freedom (Df), and total variance explained (R-squared).

Predictors	Df	R-squared
fish_year	26	0.03
Loc2	75	0.11
vessel	27	0.14
ns(effort_depth, df = 3)	3	0.15

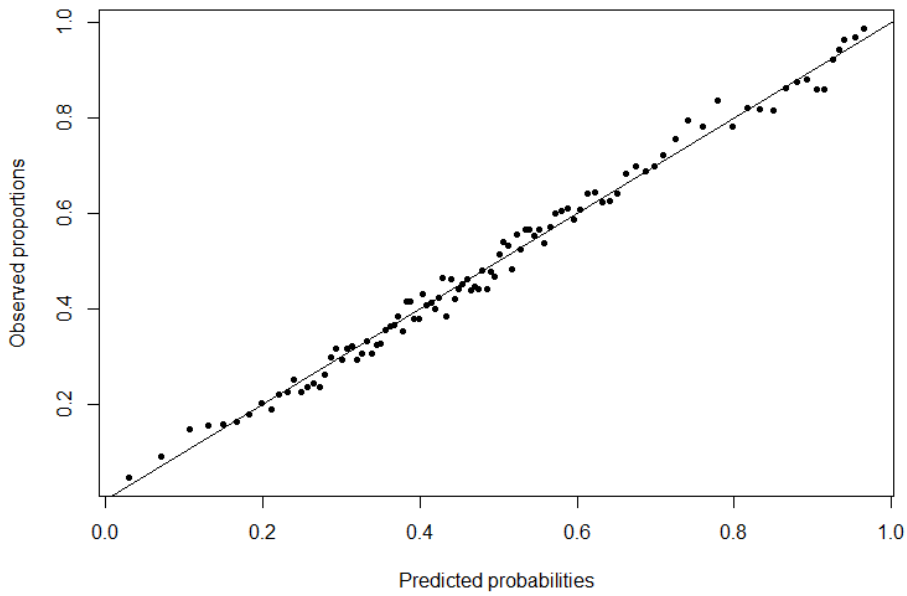

Figure 33: Diagnostic for the binomial component of the west coast North Island standardisation model.

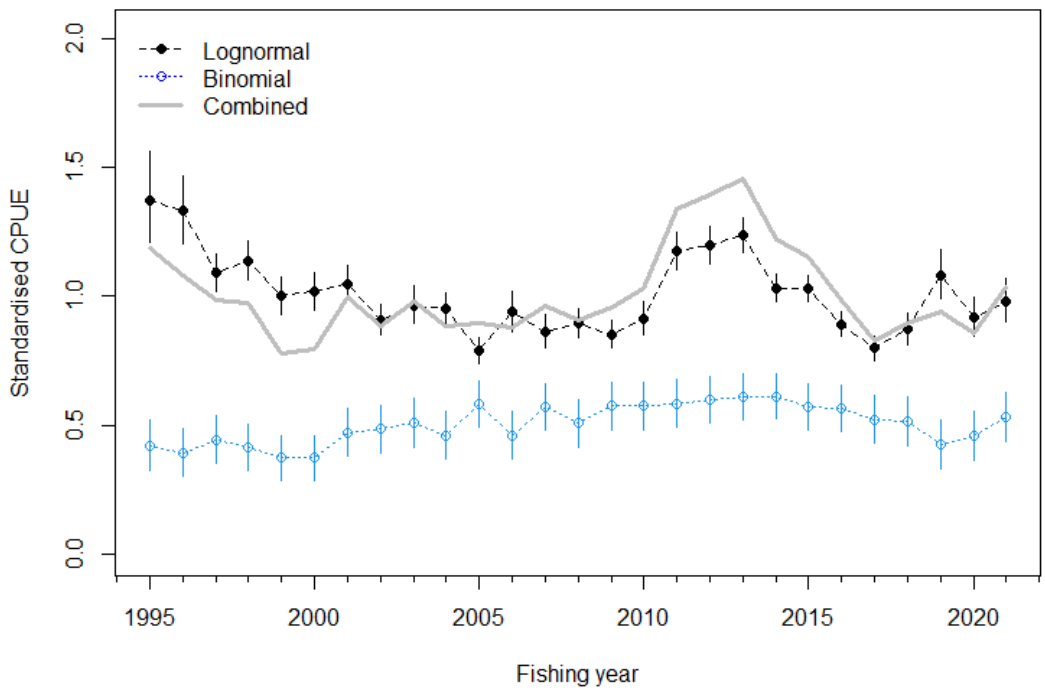

Figure 34: Binomial component, lognormal component, and combined index for the west coast North Island (part of JDO 1) standardisation model. Error bars are ± two standard deviations.

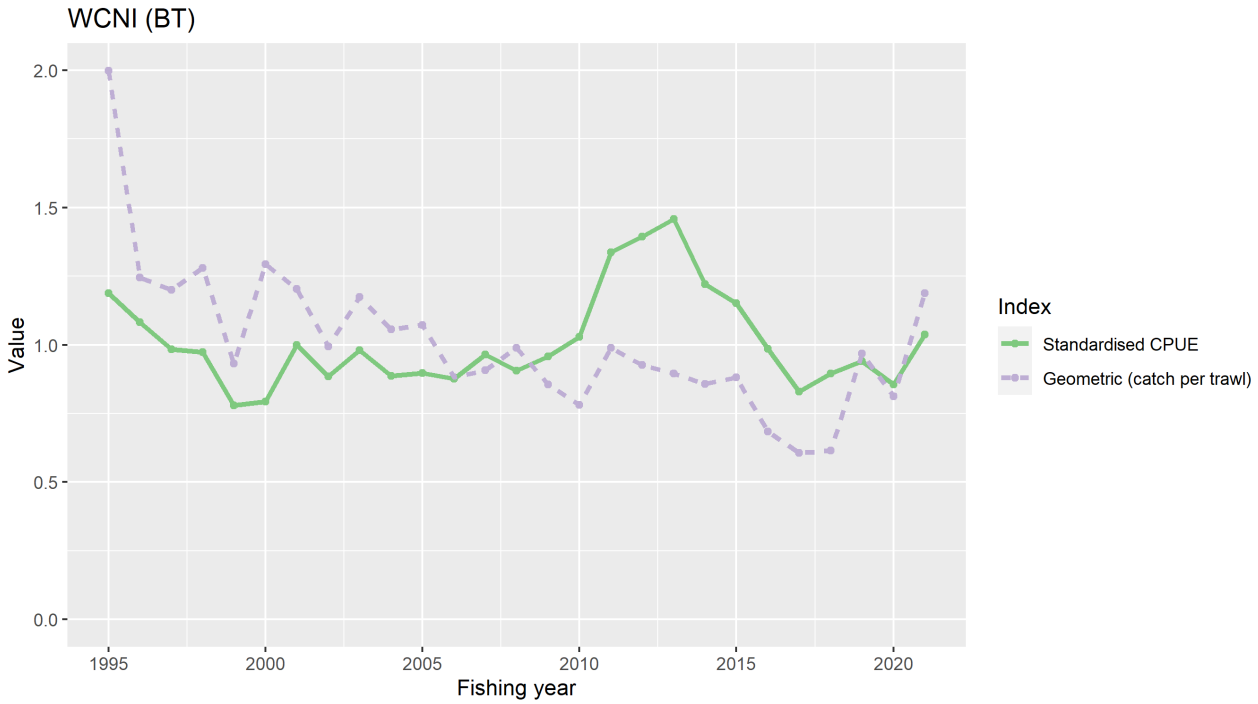

Figure 35: Combined index ('Standardised CPUE') and geometric mean CPUE comparison for west coast North Island.

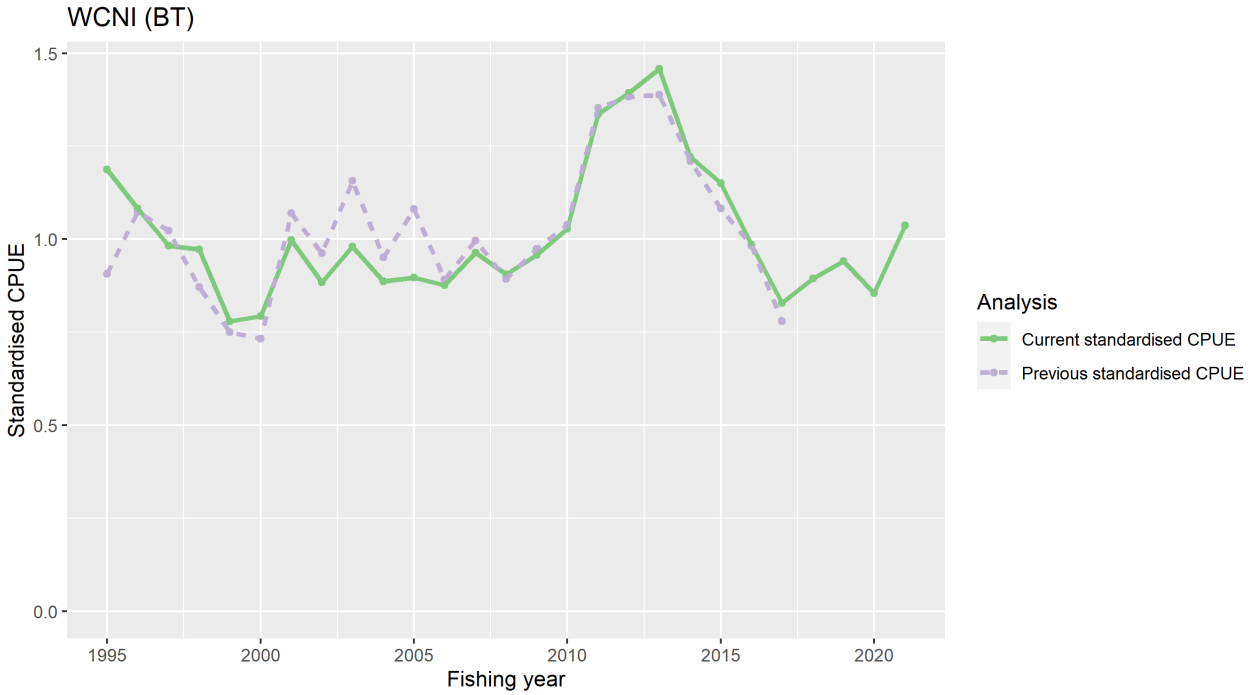

Figure 36: Combined index ('Current standardised CPUE') compared with the previous standardised CPUE index for west coast North Island (Langley 2018).

4.4 Comparison of standardised CPUE by area

The three areas BPLE, ENHG, and WCNI are thought to be sub-stocks of JDO 1, and their standardised CPUE indices need not follow the same trends (Figure 37). Although some years of the

east coast BPLE and ENHG indices have a similar pattern (e.g., the decline from 2010 to 2015, followed by an increase) other parts do not, and the pattern for WCNI is quite different.

The indices for each area are tabulated in Appendix 4.

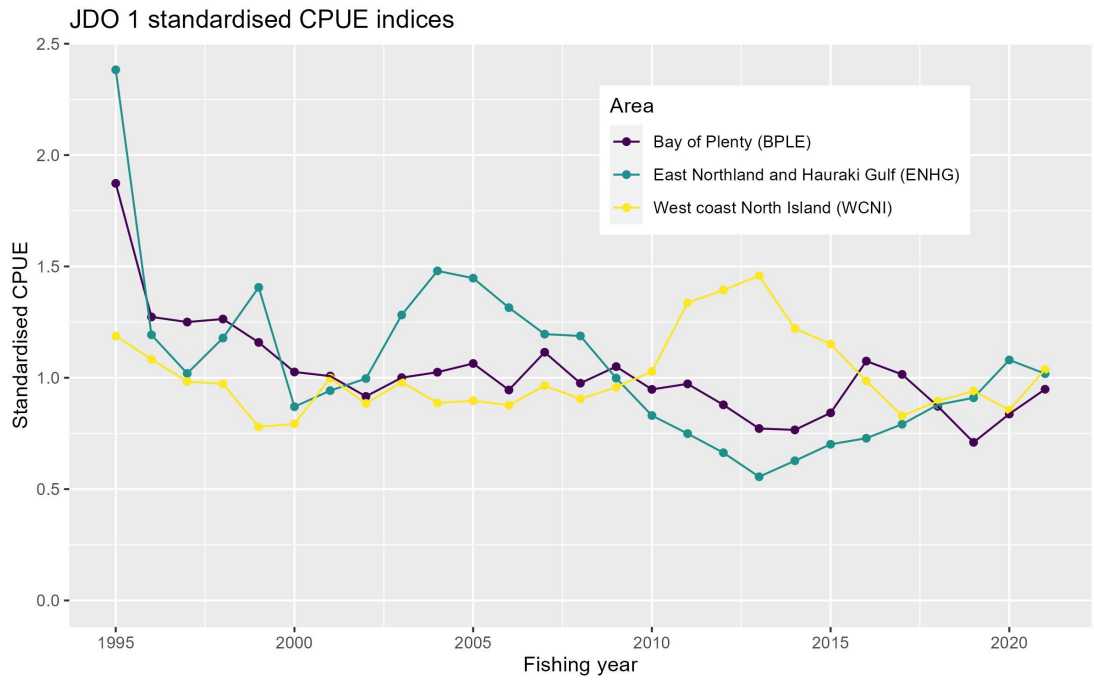

Figure 37: Standardised CPUE for the three areas: BPLE, ENHG, WCNI.

5. STOCK STATUS, TRAWL SURVEYS, AND RELATIVE FISHING MORTALITY

In BPLE since 2000 the standardised indices have been below target or sometimes slightly above, but always above the soft limit (Figure 38). Relative fishing mortality proxy from 2017 to 2019 was above the mean value for the reference years, but below the mean value for 2020 to 2021 (Figure 39). The trawl survey recruited biomass indices, where they overlap with the standardised indices, show similar declines or increases (see Figure 38).

In ENHG the standardised indices declined from 2004 to 2013 to reach the soft limit, then increased to just below the target in 2020 and 2021 (Figure 40). In 2007 the relative fishing mortality proxy was slightly above the mean value for the reference years and declined to about 35% of this level in 2021 (Figure 41). The trawl survey recruited biomass indices, which index the Hauraki Gulf, showed a mixed correspondence with trends in the standardised indices (see Figure 40). From 1995 to 1998 the trawl indices increased but the standardised indices decreased; from 1998 to 2001 the trawl indices decreased and were about the same level in 2020 to 2001, which is similar to the pattern for the standardised indices.

In WCNI the standardised indices fluctuated near the target level since 1995 (Figure 42). Relative fishing mortality proxy increased from 1995 to 1998 then declined in an irregular manner to be about 70% of the mean value over the reference years in 2021 (Figure 43). The trawl survey recruited biomass indices showed different trends from the standardised indices (see Figure 42). For example, the trawl survey indices tripled from 1995 to 1997 but the standardised indices decreased over this period; from 2019 to 2021 the trawl survey indices decreased by a factor of two-thirds but the standardised indices were fluctuating and basically flat.

In summary for BPLE, ENHG, and WCNI the stock status in 2021 is near the target level, and relative fishing mortality proxy is below the mean value for the reference years. For the BPLE and ENHG the

trawl survey recruited biomass indices show a congruence with the standardised indices, but not for WCNI.

For tabulated standardised CPUE indices see Appendix 4, recruited trawl survey biomass indices Appendix 5, and catch by subarea Appendix 6.

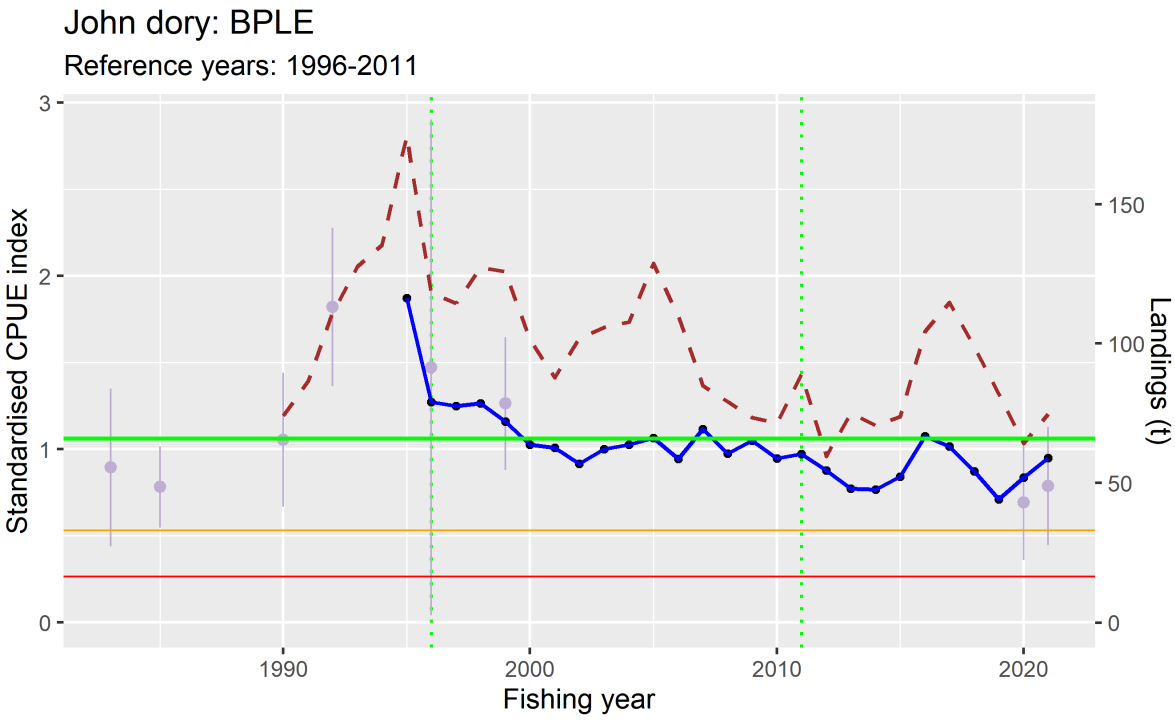

Figure 38: Standardised CPUE indices for John dory in Bay of Plenty from combined binomial and lognormal models of catch rate in bottom trawl tows in a mixed target fishery (blue line). Solid horizontal lines indicate the target (green), soft limit (orange), and hard limit (red). The commercial catch from the area is also presented (dashed brown line), and trawl survey recruited biomass indices (purple with error bars ± two standard deviations).

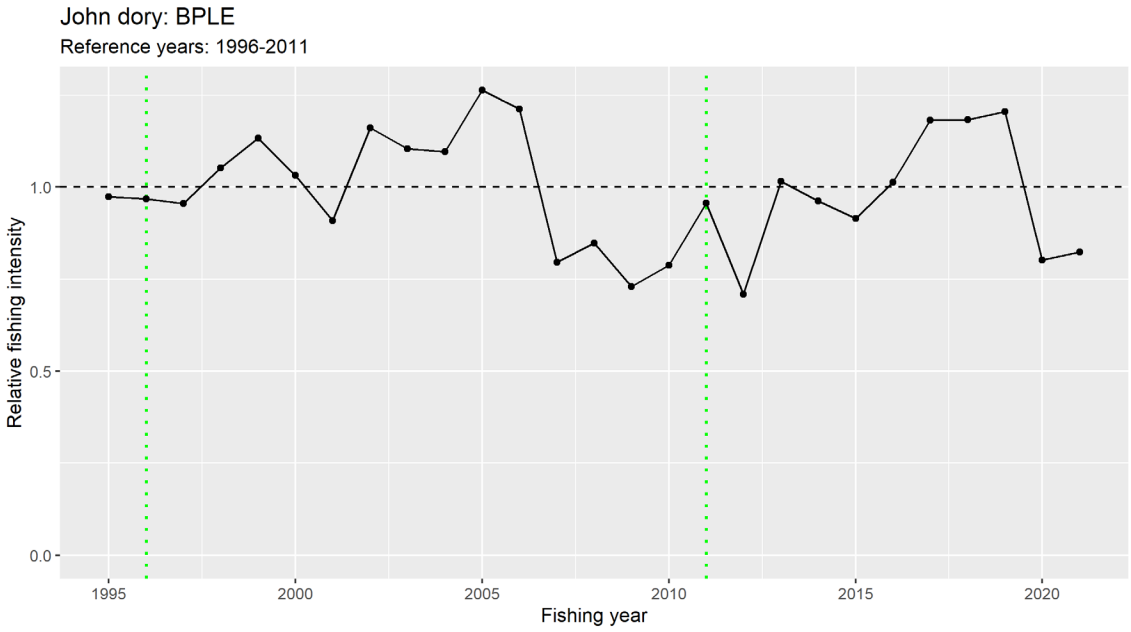

Figure 39: Relative fishing mortality proxy for John dory in Bay of Plenty, derived from total area catch divided by CPUE indices from the recent CPUE analysis (black points). The dashed horizontal line represents the average fishing mortality in the period used to define the reference points (vertical green dotted lines).

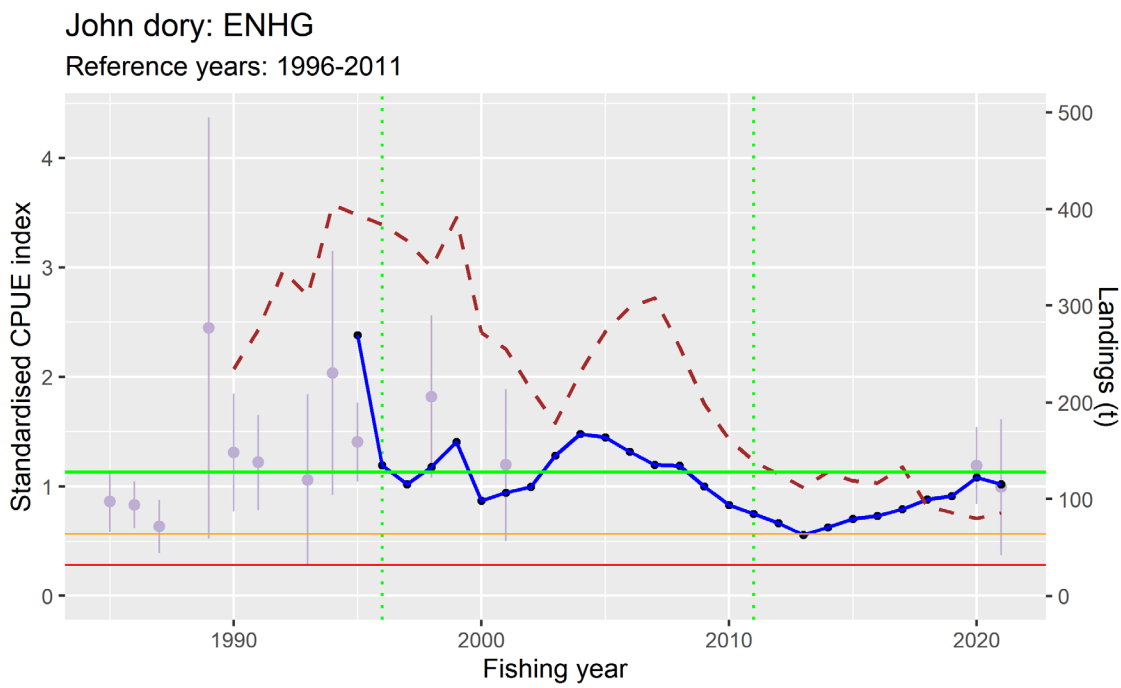

Figure 40: Standardised CPUE indices for John dory in east Northland and Hauraki Gulf from combined binomial and lognormal models of catch rate in bottom trawl tows in a mixed target fishery (blue line). Solid horizontal lines indicate the target (green), soft limit (orange), and hard limit (red). The commercial catch from the area is also presented (dashed brown line), and trawl survey recruited biomass indices (purple with error bars ± two standard deviations).

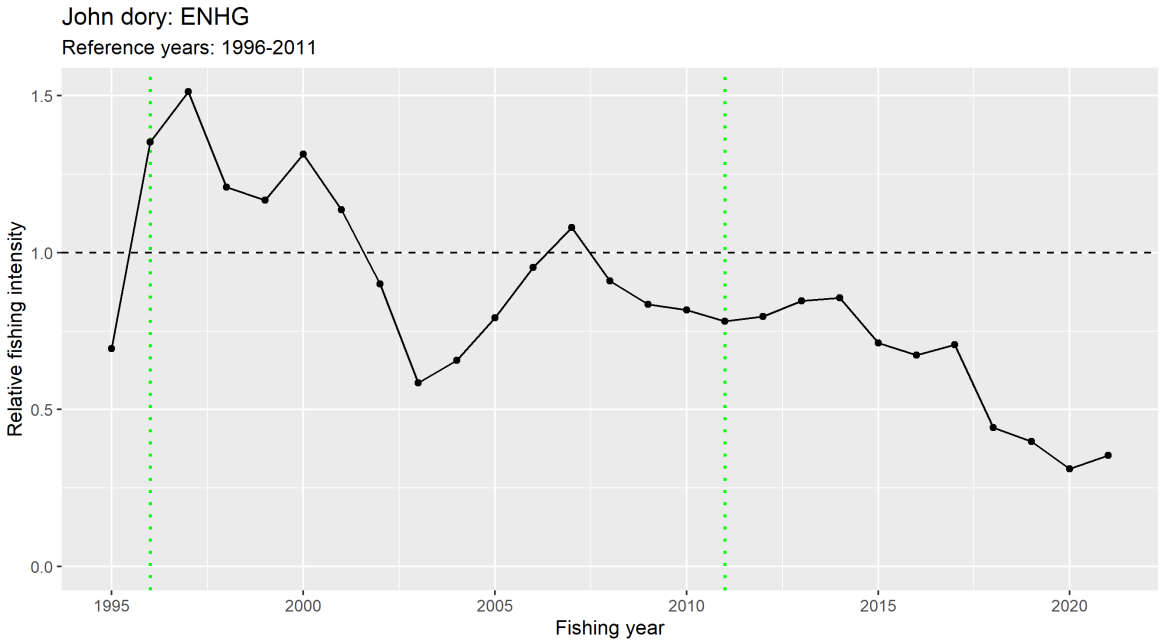

Figure 41: Relative fishing mortality proxy for John dory in east Northland and Hauraki Gulf, derived from total area catch divided by CPUE indices from the recent CPUE analysis (black points). The dashed horizontal line represents the average fishing mortality in the period used to define the reference points (vertical green dotted lines).

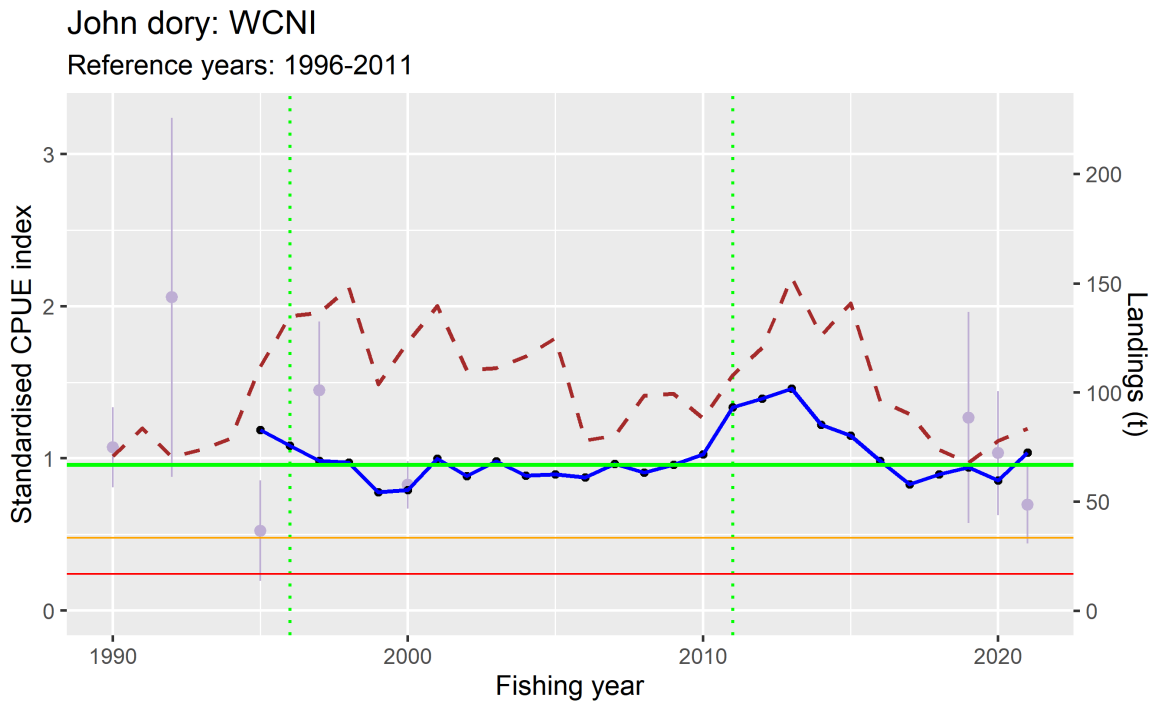

Figure 42: Standardised CPUE indices for John dory in west coast North Island from combined binomial and lognormal models of catch rate in bottom trawl tows in a mixed target fishery (blue line). Solid horizontal lines indicate the target (green), soft limit (orange), and hard limit (red). The commercial catch from the area is also presented (dashed brown line), and trawl survey recruited biomass indices (purple with error bars ± two standard deviations).

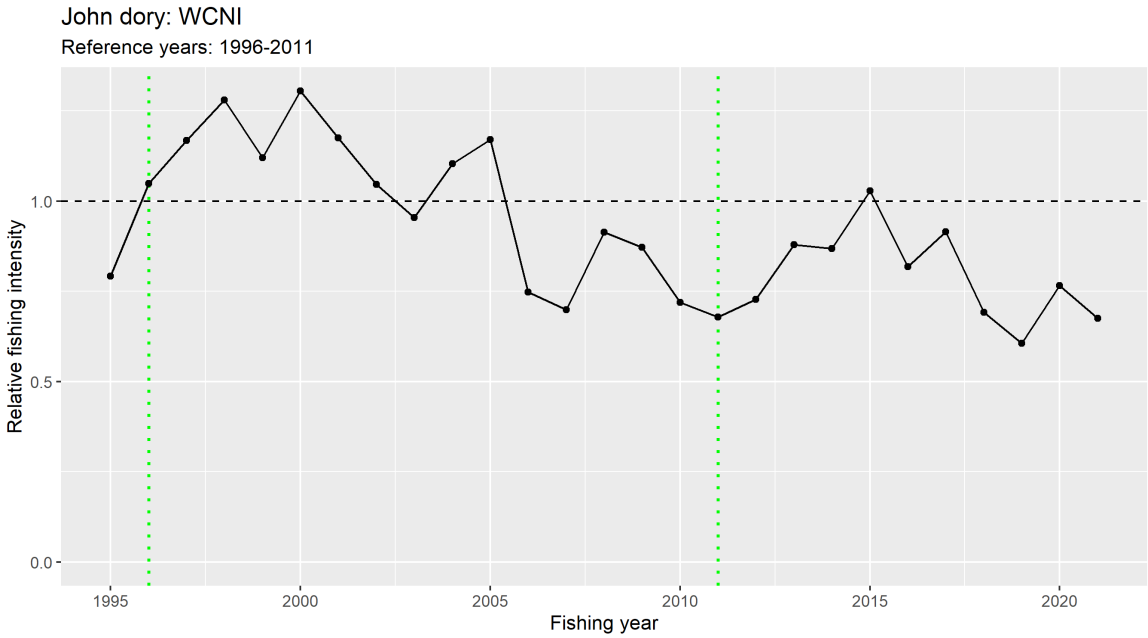

Figure 43: Relative fishing mortality proxy for John dory in west coast North Island, derived from total area catch divided by CPUE indices from the recent CPUE analysis (black points). The dashed horizontal line represents the average fishing mortality in the period used to define the reference points (vertical green dotted lines).

6. DISCUSSION

It is assumed, based on a variety of data sources, that BPLE, ENHG, and WCNI form separate sub-stocks (Dunn & Jones 2013). The standardised indices show different trends, although with some similarities between BPLE and ENHG, which corroborates this assumption (see Figure 37). A further assumption is that the standardised CPUE indices track abundance, which is corroborated by comparison with trawl survey biomass indices for BPLE and ENHG, but not for WCNI (see Figures 38, 40, 42).

One of the main changes since the previous standardisation was the switch over to electronic reporting in 2020 (see Figure 4). This has the potential to change both fisheries operations and reported data, when compared with previous periods. A comparison of electronic period data to previous periods found that there was little appreciable difference in catch composition (Langley & Middleton 2021). Differences were found in the distribution of depth, location, and trawl duration, but it was thought these were more likely due to inter-annual variability than changes in the reporting regime.

Since 2016 more catch was taken by bottom trawl using a modular harvest system, denoted by fishing method PRB/PSH (see Figure 5), which likely has a different catchability than the standard bottom trawl. If, in the future, PRB/PSH came to dominate the fishery then the CPUE data used and standardisation approach would need to be reconsidered. However, currently PRB is not the main fishing method, and these data are not used in the standardised CPUE analyses.

7. ACKNOWLEDGEMENTS

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APPENDIX 1: BPLE STANDARDISATION DIAGNOSTICS

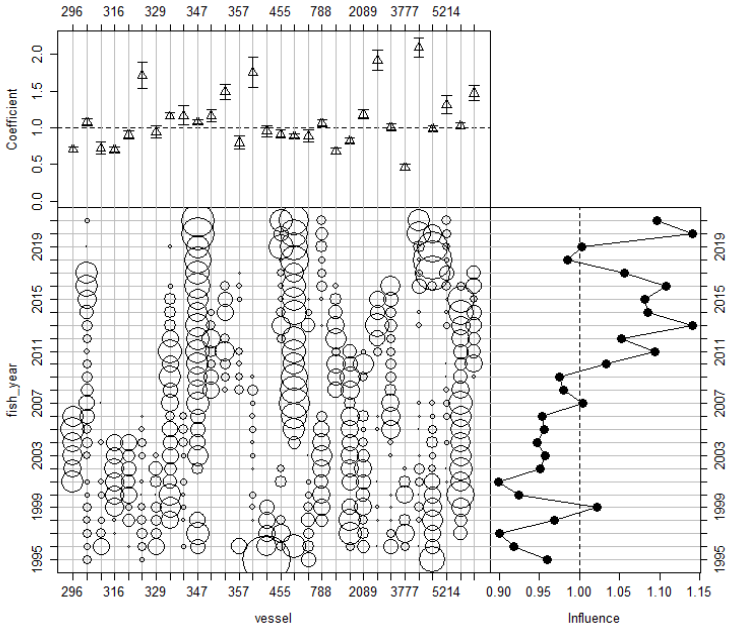

Figure 44: Influence plot for the *vessel* variable from the BPLE lognormal CPUE model.

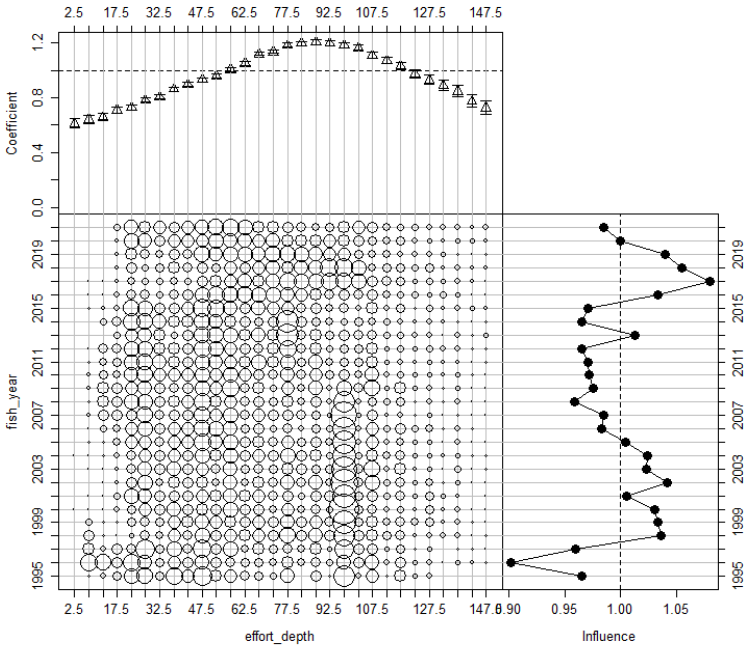

Figure 45: Influence plot for the *Effort depth* variable from the BPLE lognormal CPUE model.

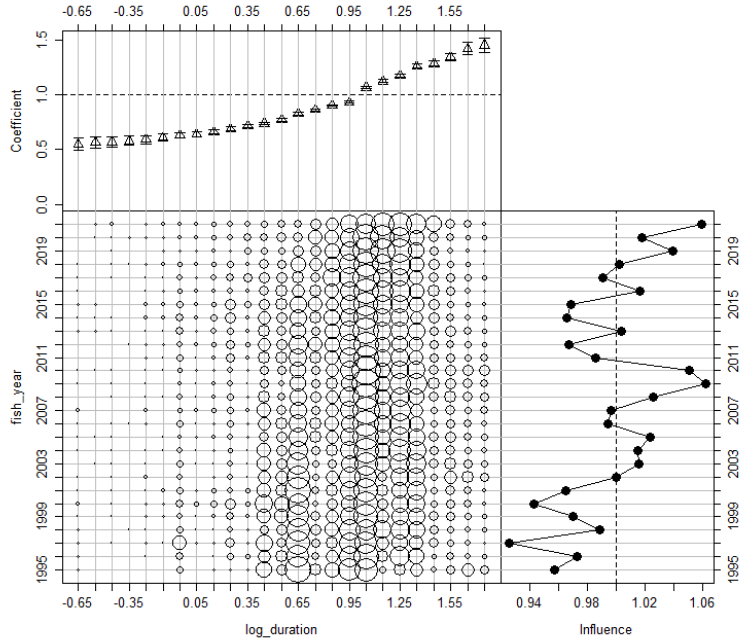

Figure 46: Influence plot for the *Duration* variable from the BPLE lognormal CPUE model.

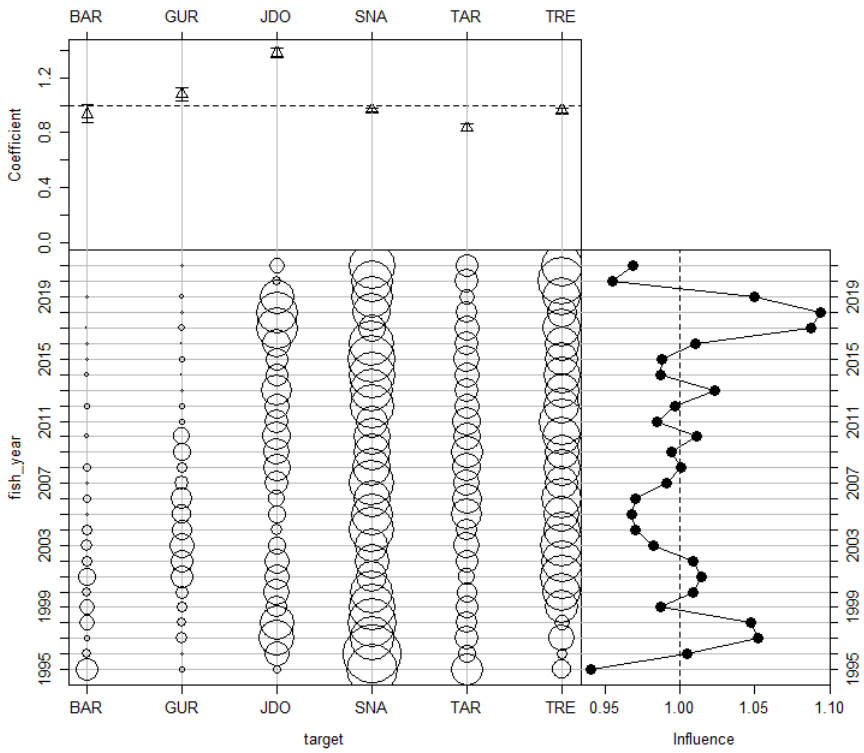

Figure 47: Influence plot for the *Target* variable from the BPLE lognormal CPUE model.

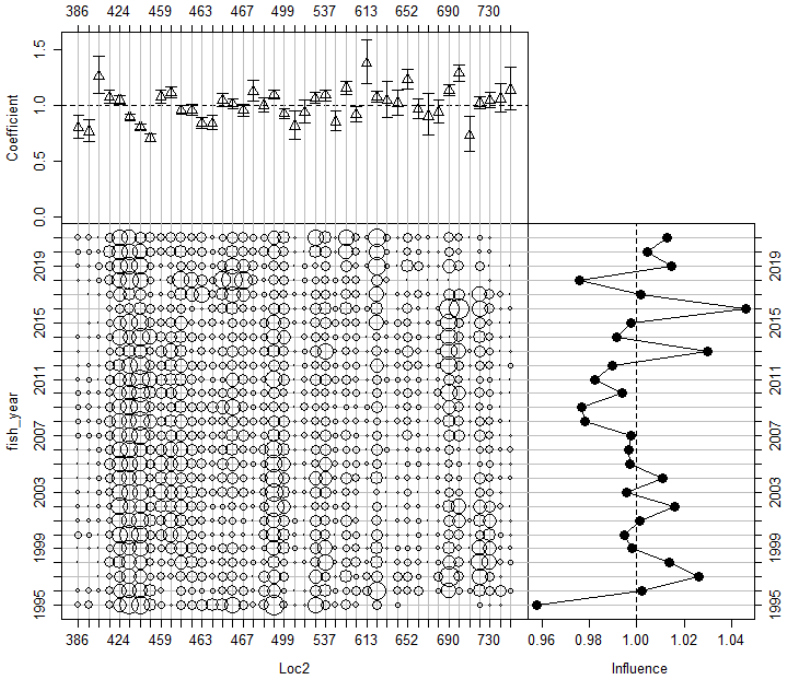

Figure 48: Influence plot for the *Loc2* variable from the BPLE lognormal CPUE model.

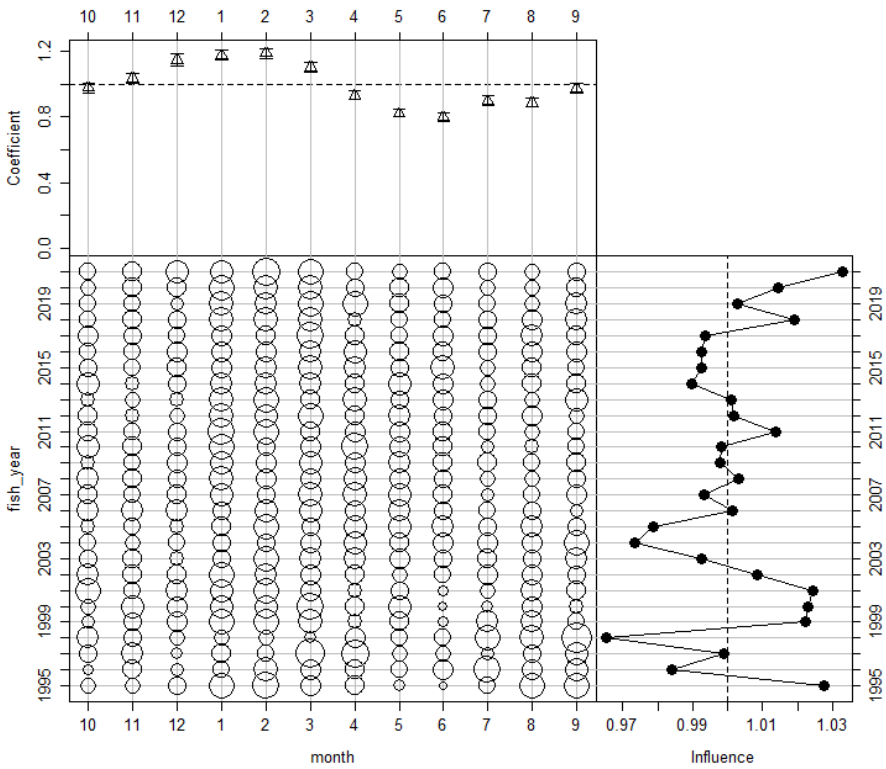

Figure 49: Influence plot for the *Month* variable (where '10' is October, etc.) from the BPLE lognormal model.

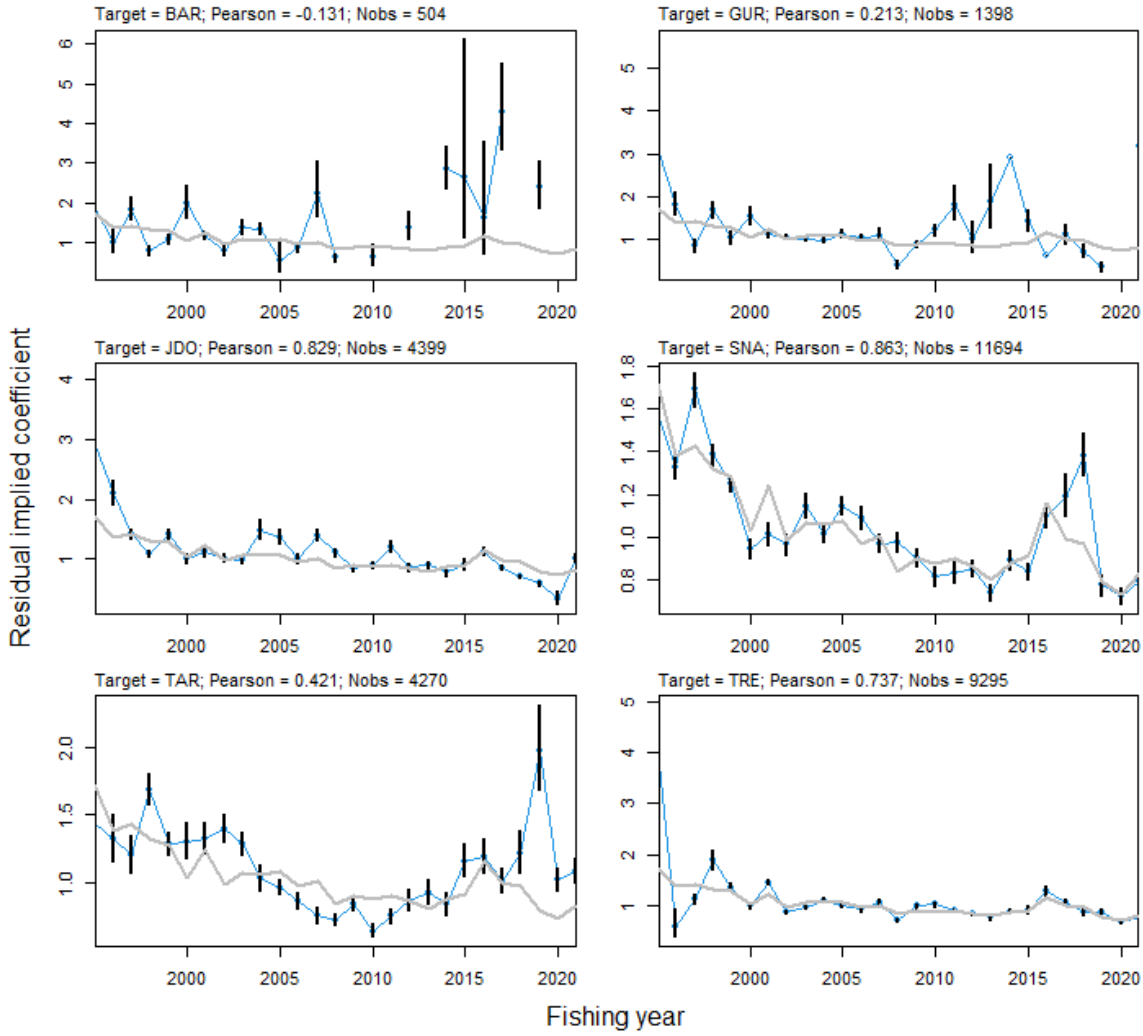

Figure 50: Annual implied residual coefficients (points joined by blue lines) for target species and the BPLE lognormal model, where the confidence intervals are one standard error. The grey line is the standardised index from the lognormal model.

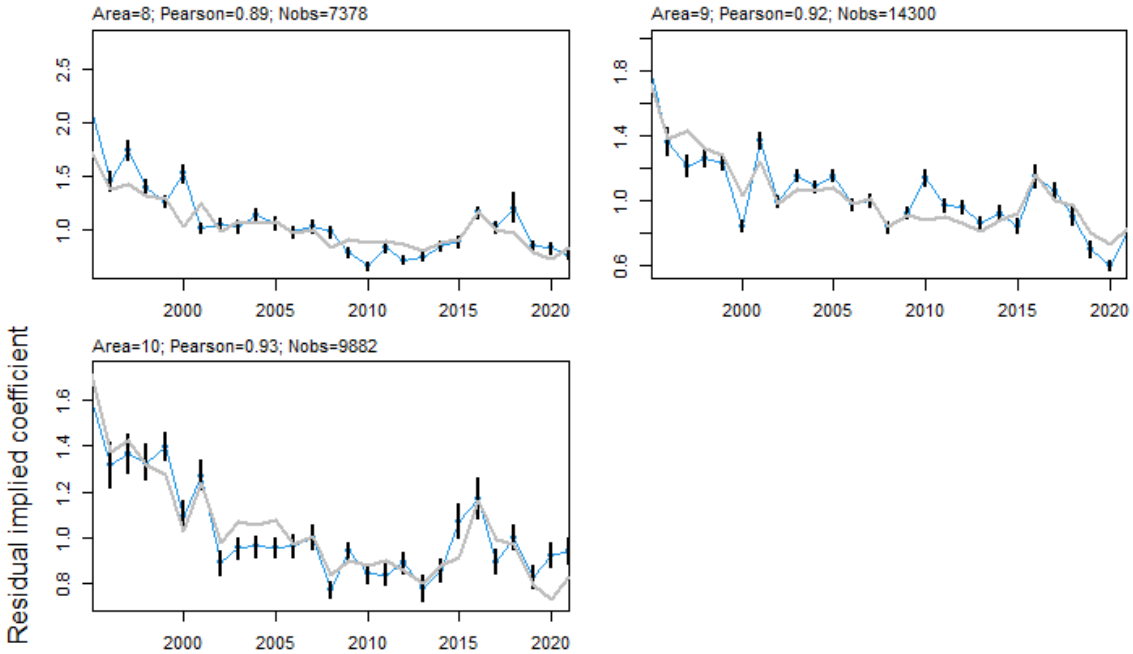

Figure 51: Annual implied residual coefficients (points joined by blue lines) for statistical area (where 'Area=8' is Statistical Area 008, etc.) and the BPLE lognormal model, where the confidence intervals are one standard error. The grey line is the standardised index from the lognormal model.

APPENDIX 2: ENHG STANDARDISATION DIAGNOSTICS

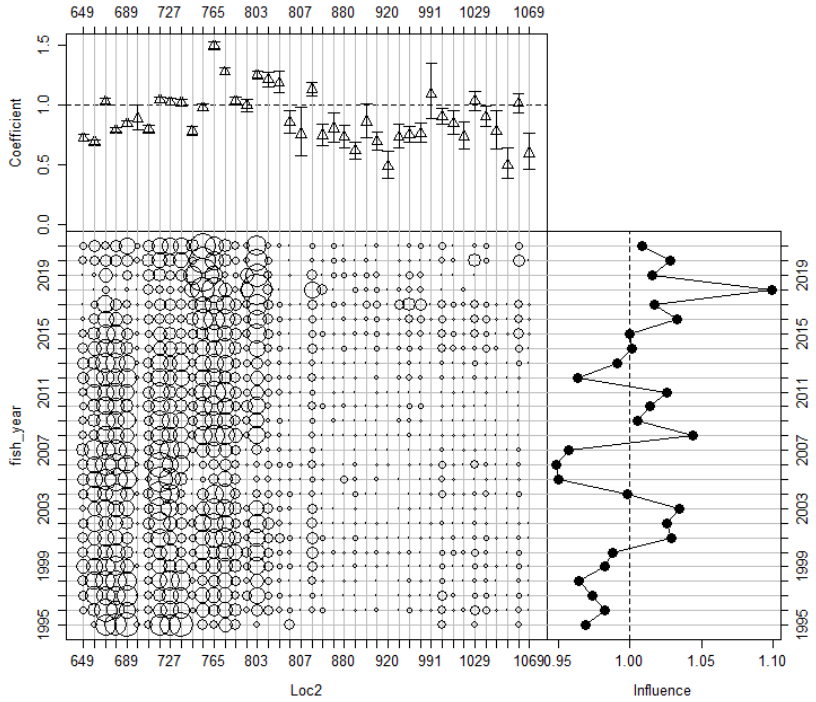

Figure 52: Influence plot for the *Loc2* variable from the ENHG lognormal CPUE model.

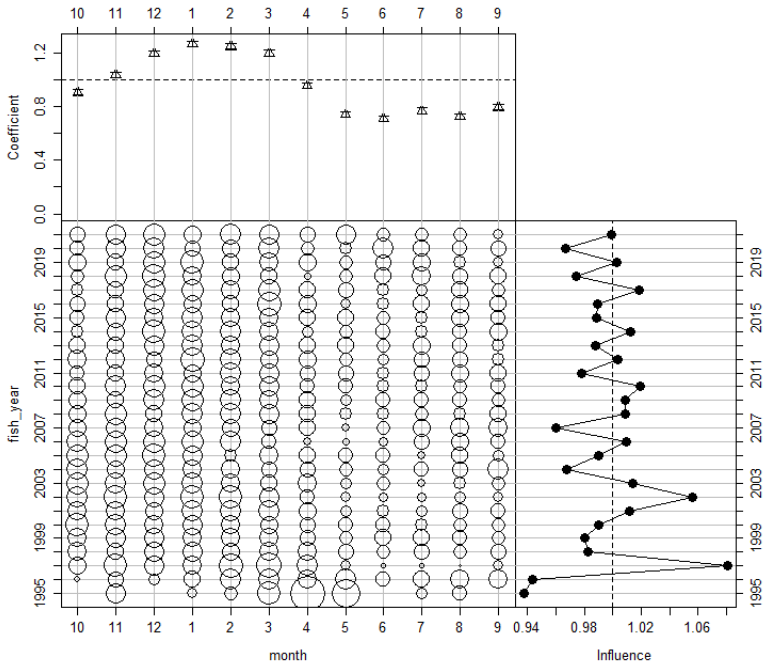

Figure 53: Influent plot for the *Month* variable (where '10' is October, etc.) from the ENHG lognormal CPUE model.

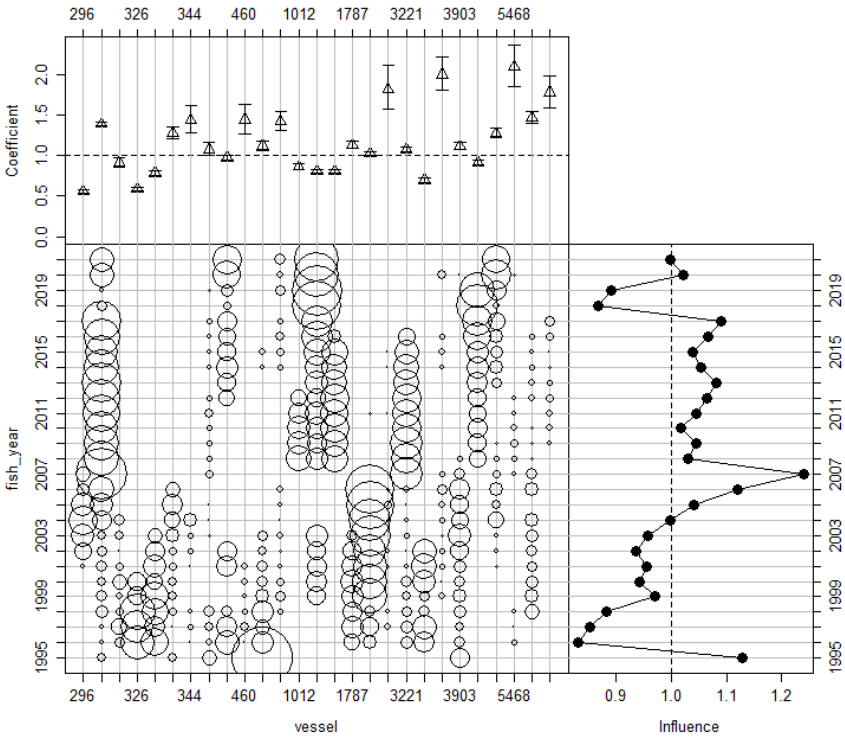

Figure 54: Influence plot for the *Vessel* variable from the ENHG lognormal model.

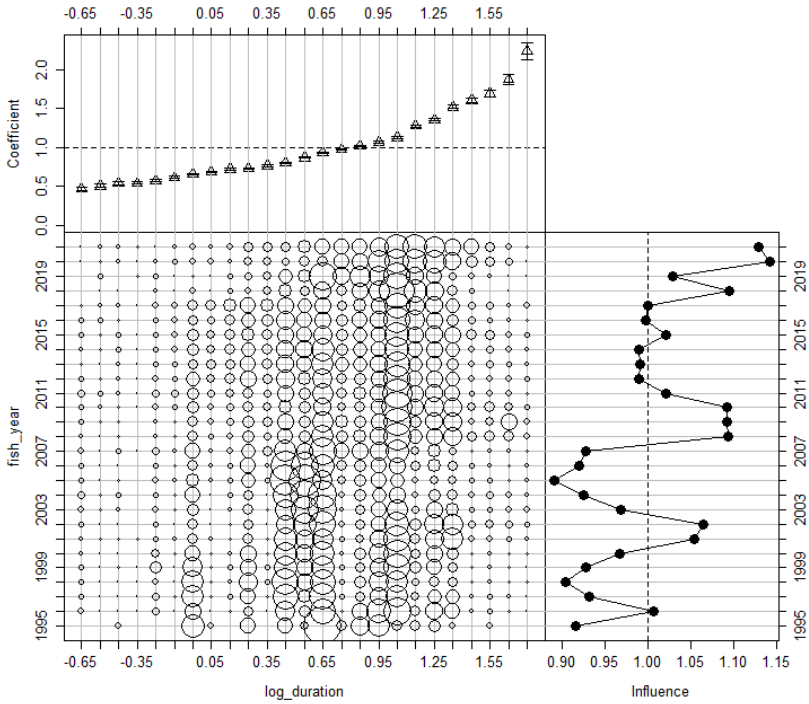

Figure 55: Influence plot for the *Duration* variable from the ENHG lognormal model.

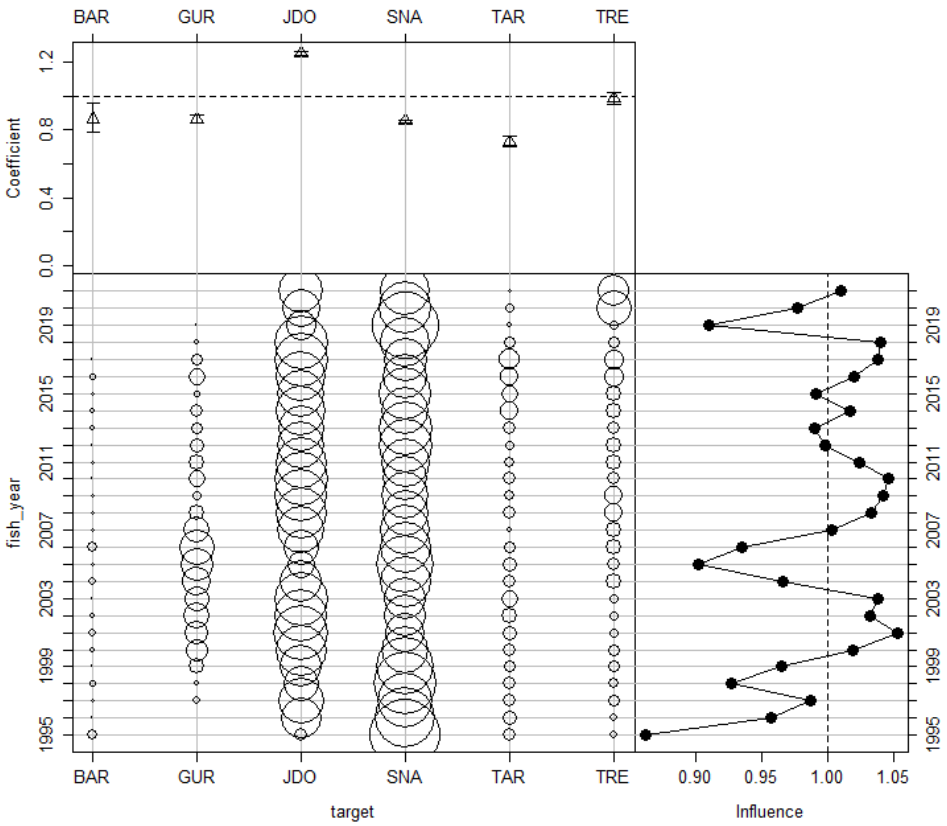

Figure 56: Influence plot for the *Target* variable from the ENHG lognormal model.

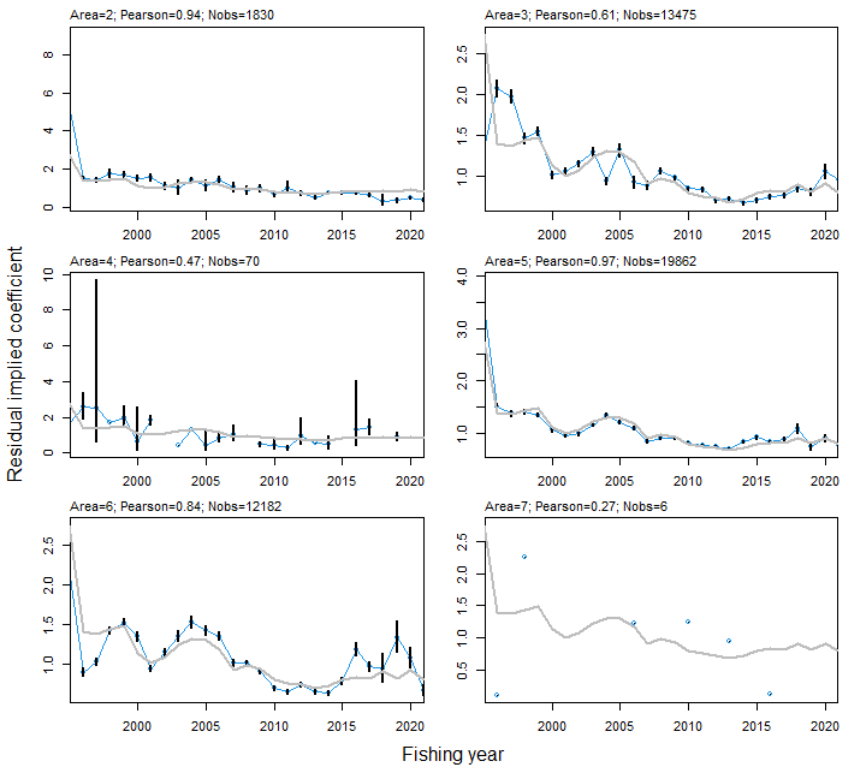

Figure 57: Annual implied residual coefficients (points joined by blue lines) for statistical area (where 'Area=2 is Statisical Area 002, etc.) and the ENHG lognormal model, where the confidence intervals are one standard error. The grey line is the standardised index from the lognormal model.

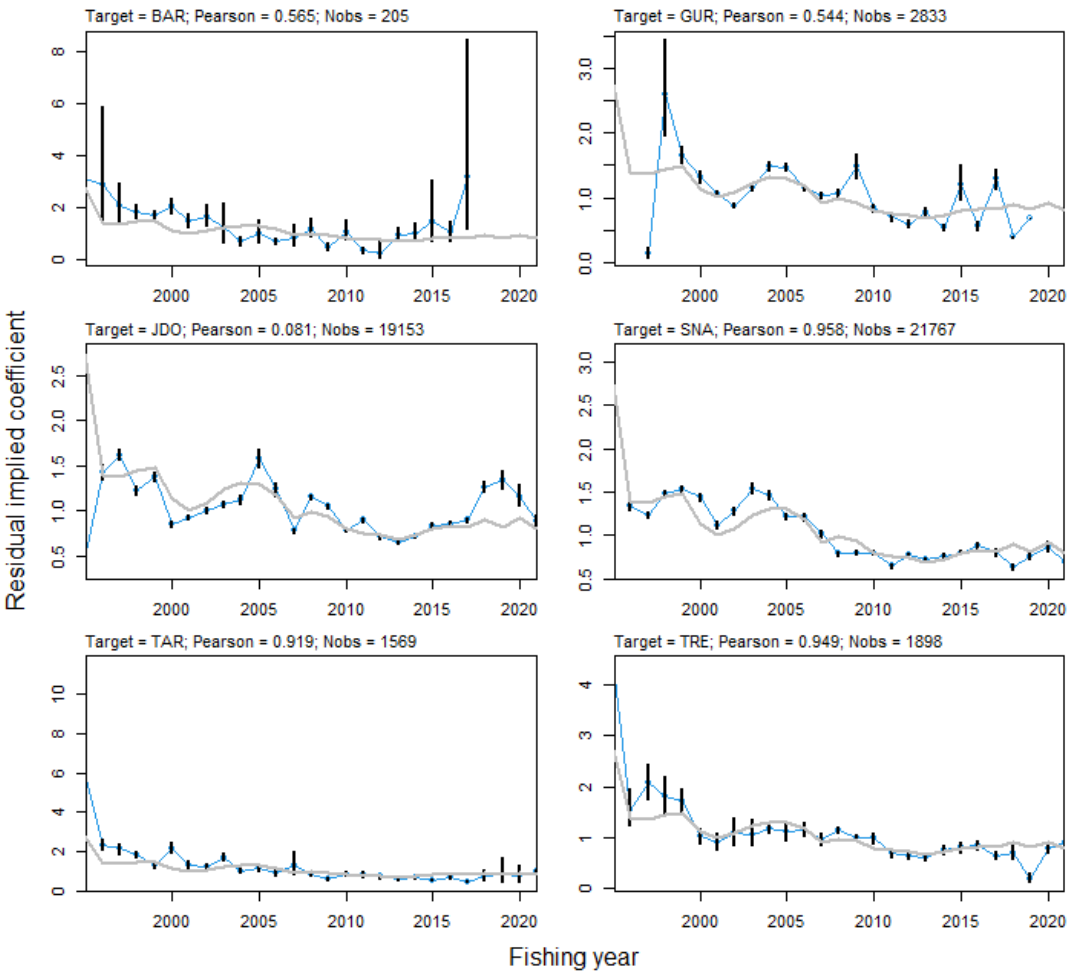

Figure 58: Annual implied residual coefficients (points joined by blue lines) for target species and the ENHG lognormal model, where the confidence intervals are one standard error. The grey line is the standardised index from the lognormal model.

APPENDIX 3: WCNI STANDARDISATION DIAGNOSTICS

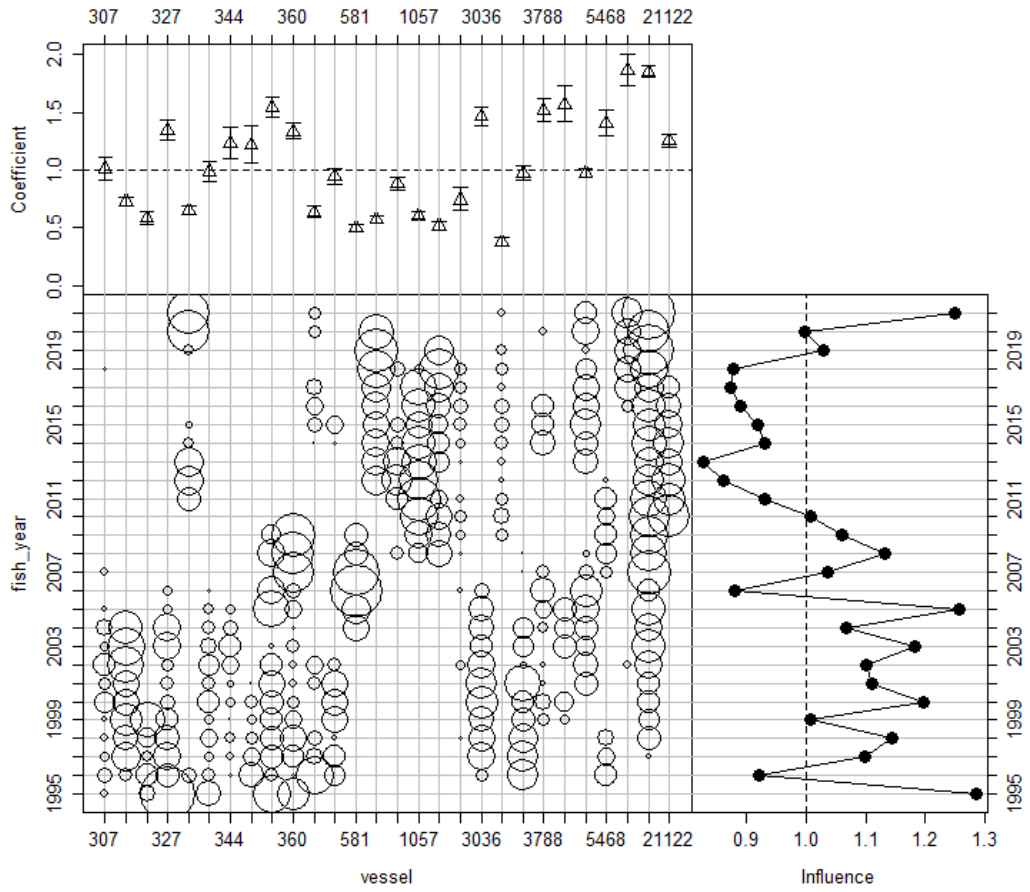

Figure 59: Influence plot for the *Vessel* variable from the WCNI lognormal model.

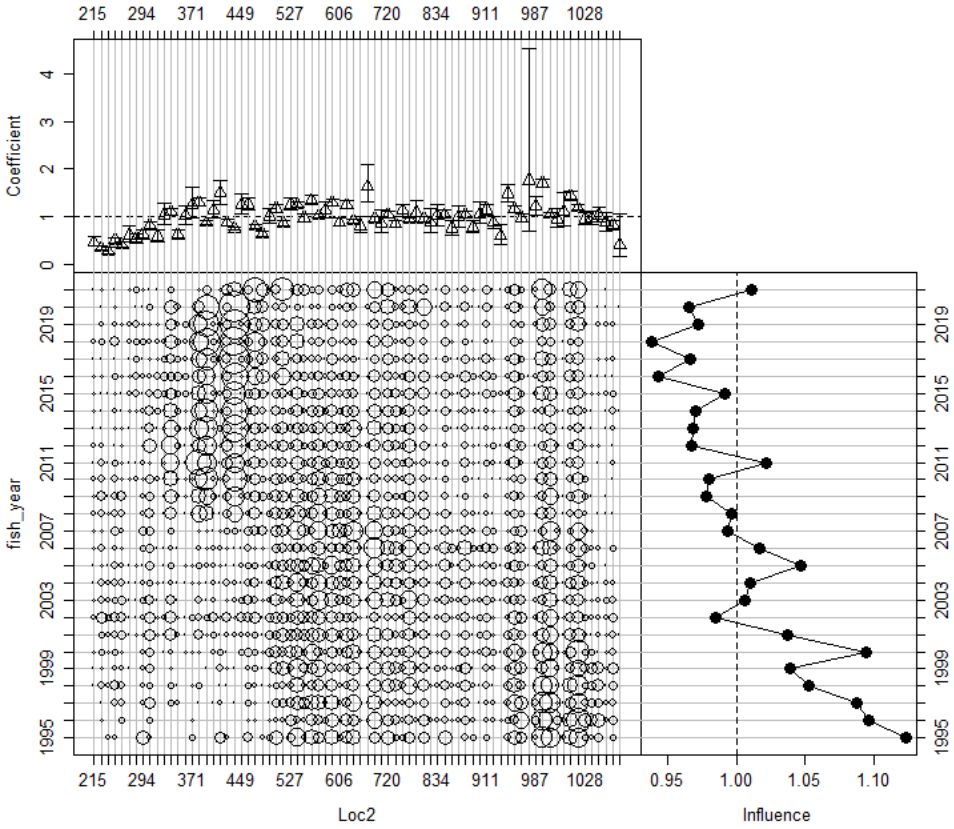

Figure 60: Influence plot for the *Loc2* variable from the WCNI lognormal model.

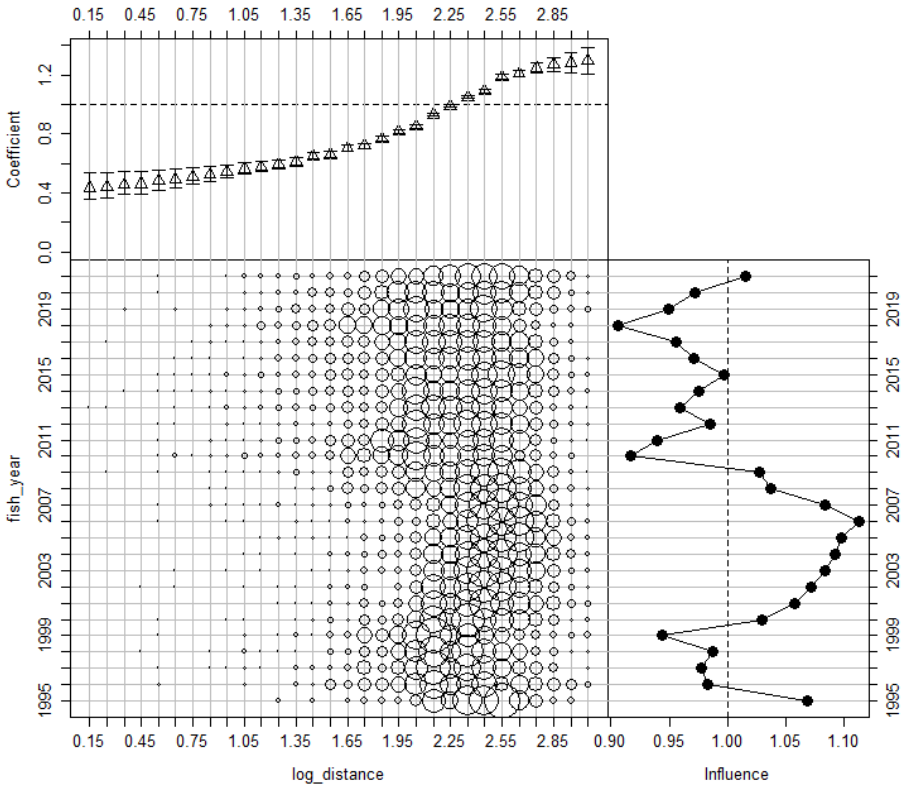

Figure 61: Influence plot for the *Distance* variable from the WCNI lognormal model.

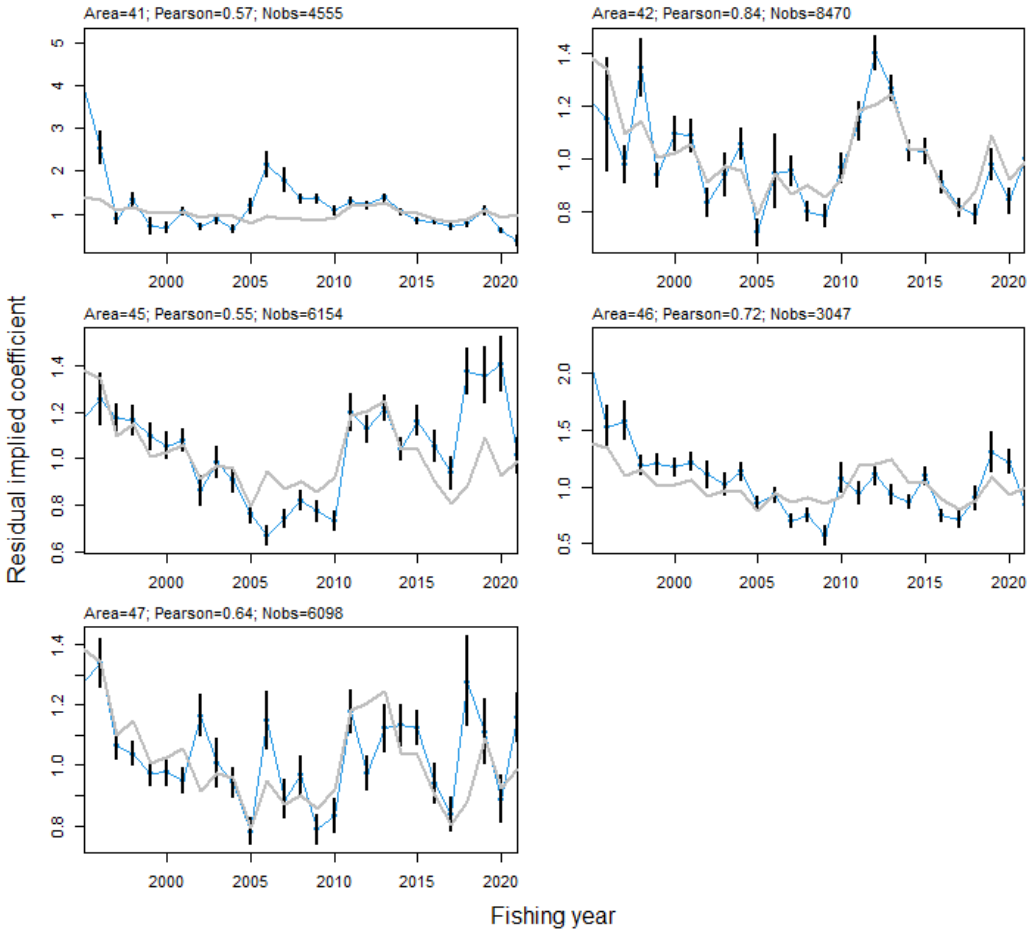

Figure 62: Annual implied residual coefficients (points joined by blue lines) for statistical area (where 'Area=41' is Statistical Area 041, etc.) and the WCNI lognormal model, where the confidence intervals are one standard error. The grey line is the standardised index from the lognormal model.

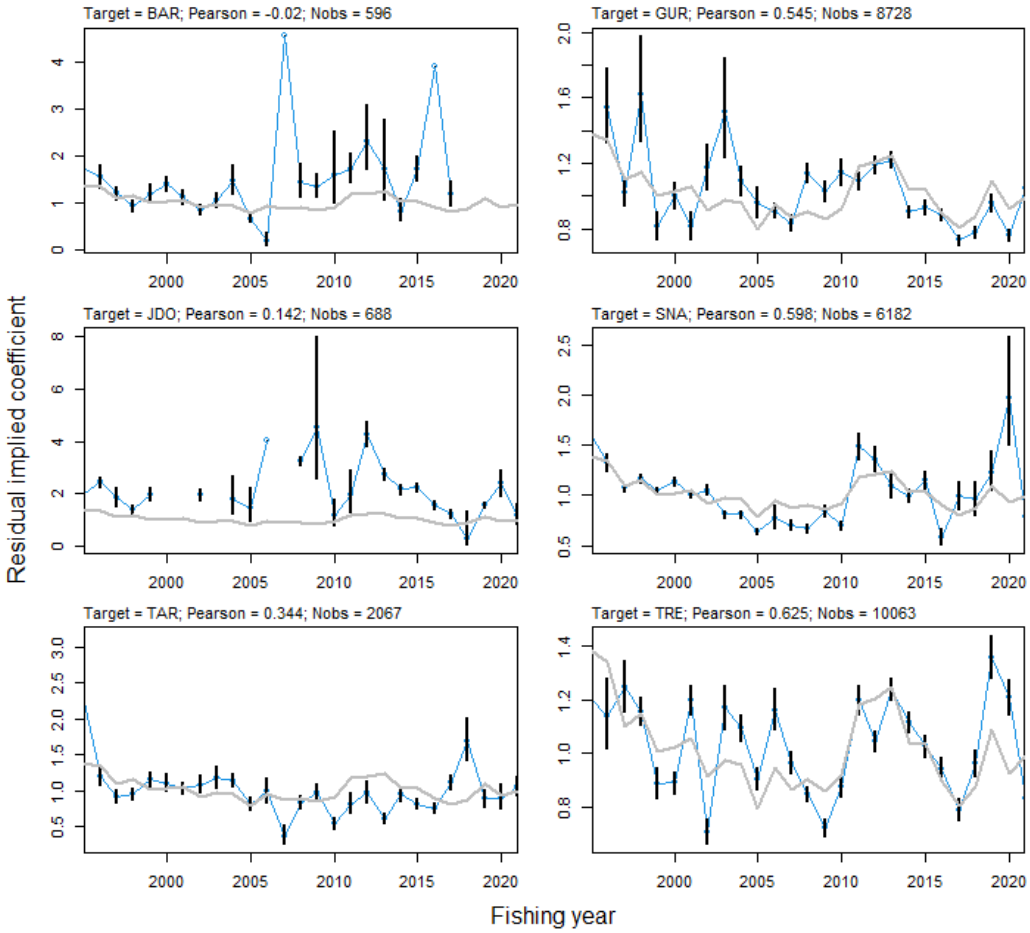

Figure 63: Annual implied residual coefficients (points joined by blue lines) for target species and the WCNI lognormal model, where the confidence intervals are one standard error. The grey line is the standardised index from the lognormal model.

APPENDIX 4: TABULATION OF STANDARDISED CPUE INDICES

Table 11: Bay of Plenty standardised CPUE components: lognormal with standard error (SE), binomial, and combined. The lognormal and combined indices are scaled to have a geometric mean of one.

Fishing year	lognormal	SE	binomial	combined
1995	1.699	0.069	0.660	1.873
1996	1.357	0.037	0.538	1.273
1997	1.405	0.035	0.505	1.250
1998	1.298	0.032	0.564	1.264
1999	1.260	0.027	0.526	1.159
2000	1.013	0.030	0.593	1.026
2001	1.221	0.029	0.462	1.008
2002	0.966	0.029	0.547	0.916
2003	1.053	0.027	0.548	1.001
2004	1.043	0.024	0.570	1.025
2005	1.060	0.024	0.586	1.064
2006	0.957	0.028	0.574	0.945
2007	0.991	0.031	0.677	1.115
2008	0.824	0.027	0.723	0.976
2009	0.889	0.026	0.721	1.050
2010	0.868	0.028	0.652	0.948
2011	0.886	0.029	0.655	0.973
2012	0.847	0.029	0.610	0.879
2013	0.790	0.034	0.566	0.772
2014	0.863	0.032	0.503	0.766
2015	0.901	0.034	0.537	0.842
2016	1.142	0.034	0.541	1.075
2017	0.979	0.033	0.610	1.015
2018	0.954	0.040	0.522	0.872
2019	0.780	0.035	0.519	0.710
2020	0.720	0.033	0.706	0.837
2021	0.815	0.033	0.706	0.948

Table 12: East Northland and Hauraki standardised CPUE components: lognormal with standard error (SE), binomial, and combined. The lognormal and combined indices are scaled to have a geometric mean of one.

Fishing year	lognormal	SE	binomial	combined
1995	2.684	0.101	0.390	2.383
1996	1.365	0.027	0.381	1.193
1997	1.341	0.025	0.314	1.020
1998	1.405	0.025	0.359	1.179
1999	1.446	0.024	0.445	1.406
2000	1.104	0.024	0.330	0.870
2001	0.986	0.022	0.434	0.942
2002	1.056	0.023	0.426	0.996
2003	1.209	0.026	0.509	1.282
2004	1.281	0.026	0.584	1.480
2005	1.267	0.029	0.573	1.447
2006	1.150	0.029	0.574	1.315
2007	0.894	0.026	0.754	1.196
2008	0.960	0.022	0.657	1.188
2009	0.907	0.022	0.540	0.999
2010	0.782	0.022	0.510	0.830
2011	0.740	0.023	0.474	0.749
2012	0.718	0.023	0.413	0.663
2013	0.672	0.023	0.352	0.555
2014	0.710	0.023	0.387	0.627
2015	0.781	0.024	0.396	0.701
2016	0.815	0.027	0.393	0.728
2017	0.799	0.028	0.458	0.791
2018	0.884	0.044	0.461	0.879
2019	0.797	0.042	0.574	0.910
2020	0.894	0.037	0.629	1.080
2021	0.781	0.038	0.721	1.018

Table 13: West coast North Island standardised CPUE components: lognormal with standard error (SE), binomial, and combined. The lognormal and combined indices are scaled to have a geometric mean of one.

Fishing year	lognormal	SE	binomial	combined
1995	1.372	0.064	0.423	1.188
1996	1.330	0.050	0.394	1.083
1997	1.089	0.034	0.444	0.983
1998	1.139	0.033	0.416	0.973
1999	1.000	0.036	0.375	0.779
2000	1.018	0.035	0.375	0.793
2001	1.049	0.032	0.472	0.998
2002	0.908	0.034	0.485	0.885
2003	0.965	0.037	0.509	0.980
2004	0.952	0.032	0.460	0.887
2005	0.787	0.032	0.584	0.897
2006	0.940	0.042	0.461	0.877
2007	0.862	0.038	0.571	0.964
2008	0.895	0.031	0.507	0.906
2009	0.852	0.031	0.575	0.958
2010	0.915	0.035	0.575	1.028
2011	1.174	0.032	0.584	1.337
2012	1.196	0.030	0.600	1.394
2013	1.236	0.026	0.609	1.458
2014	1.031	0.026	0.612	1.221
2015	1.029	0.026	0.571	1.151
2016	0.891	0.027	0.564	0.986
2017	0.798	0.029	0.523	0.829
2018	0.873	0.034	0.515	0.895
2019	1.082	0.045	0.425	0.941
2020	0.919	0.041	0.460	0.855
2021	0.982	0.042	0.534	1.038

APPENDIX 5: TABULATION OF TRAWL SURVEYS

Table 14: Estimates of John dory biomass (t) from Kaharoa trawl surveys. Estimates are recruited biomass (length >= 25 cm TL) survey. For the west coast North Island trawl survey, core strata are north of New Plymouth.

Year	Trip code	Biomass (t)	CV(%)
Bay of Plenty			
1983	KAH8303	105	25
1985	KAH8506	91	15
1990	KAH9004	123	18
1992	KAH9202	213	12
1996	KAH9601	172	49
1999	KAH9902	148	15
2020	KAH2001	81	24
2021	KAH2101	92	22
Hauraki Gulf			
1984	KAH8421	136	16
1985	KAH8517	131	13
1986	KAH8613	100	19
1988	KAH8810	385	39
1989	KAH8917	206	20
1990	KAH9016	192	18
1992	KAH9212	166	37
1993	KAH9311	320	27
1994	KAH9411	221	13
1997	KAH9720	287	20
2000	KAH0012	188	29
2019	KAH1907	187	15
2020	KAH2006	156	31
West coast North Island (core strata)			
1989	KAH8918	237	12
1991	KAH9111	455	29
1994	KAH9410	116	31
1996	KAH9615	320	16
1999	KAH9915	182	9
2018	KAH1806	280	27
2019	KAH1906	229	20
2020	KAH2005	154	18

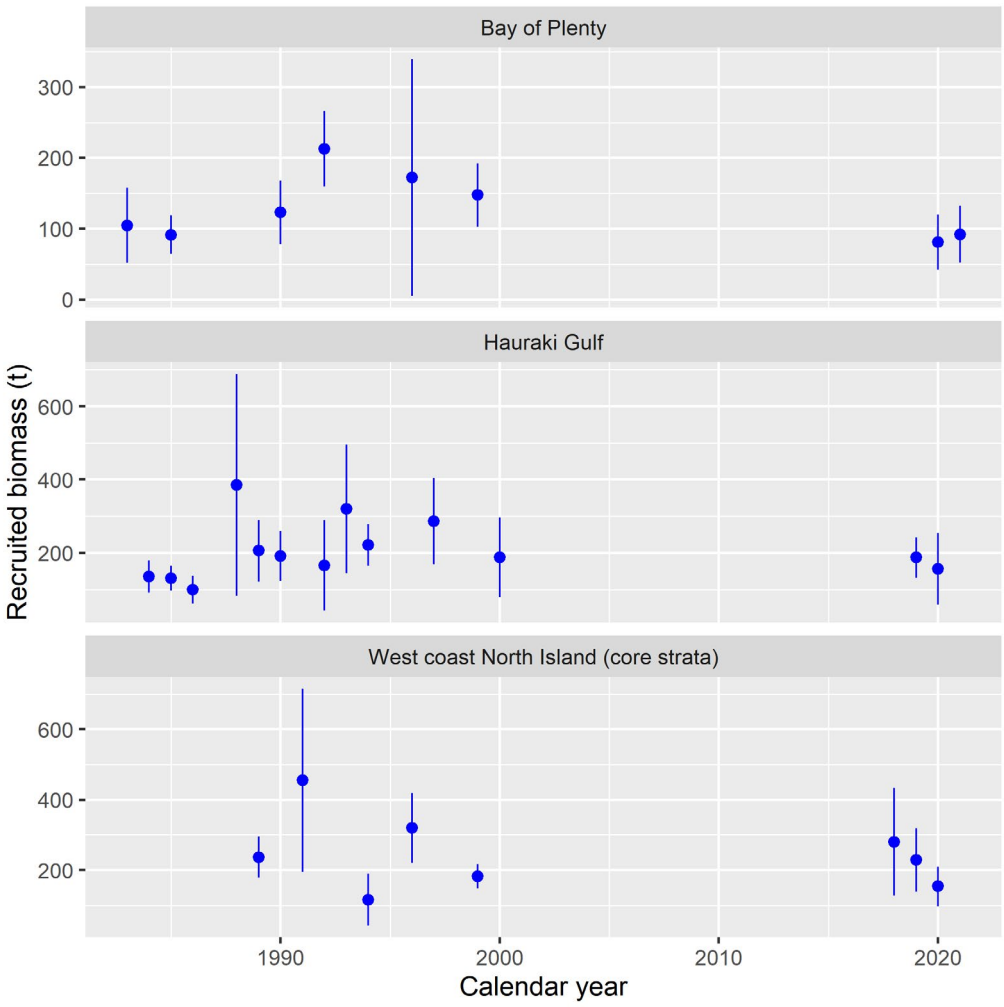

Figure 64: Estimates of recruited (length >= 25 cm) John dory biomass (t) from Kaharoa trawl surveys. Error bars are ± two standard deviations.

APPENDIX 6: TABULATION OF CATCH BY AREA

Table 15: Catch (t) by fishing area in JDO 1.

Fishing year	Bay of Plenty	East Northland and Hauraki Gulf	West coast North Island
1990	74.1	234.8	70.8
1991	86.5	275.5	83.7
1992	111.0	336.7	70.5
1993	127.7	310.2	73.8
1994	135.3	404.8	79.0
1995	174.6	394.1	111.9
1996	118.1	384.4	135.0
1997	114.5	367.8	136.5
1998	127.3	339.6	148.1
1999	125.8	391.3	103.8
2000	101.4	272.5	123.2
2001	87.8	255.4	139.6
2002	101.9	213.8	110.1
2003	105.8	178.8	111.2
2004	107.7	231.8	116.4
2005	128.9	273.2	124.8
2006	109.8	298.7	78.0
2007	84.9	308.0	80.2
2008	79.2	257.5	98.5
2009	73.5	198.9	99.3
2010	71.5	161.8	87.9
2011	89.1	139.5	107.9
2012	59.7	125.9	120.6
2013	75.1	112.0	152.5
2014	70.6	128.0	126.1
2015	73.9	119.2	140.8
2016	104.4	117.0	95.9
2017	114.9	133.3	90.3
2018	98.8	92.7	73.7
2019	81.9	86.3	67.9
2020	64.3	80.2	77.9
2021	74.8	85.9	83.4