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Fishery characterisation and catch per unit effort for red gurnard in GUR 1 to 2020/21, with an exploration of stock structure in New Zealand waters

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EXECUTIVE SUMMARY

McKenzie, A[1].; Moore, B.R.[1] (2023). Fishery characterisation and catch per unit effort for red gurnard in GUR 1 to 2020/21, with an exploration of stock structure in New Zealand waters.

***New Zealand Fisheries Assessment Report 2023/16.* 75 p.**

Red gurnard (GUR, *Chelidonichthys kumu*) is a common bycatch species of inshore fisheries throughout New Zealand. About 60% of the current GUR 1 catch is from the west coast North Island where it is mainly caught in the bottom trawl fishery targeting trevally and red gurnard. The other 40% is from East Northland, Hauraki Gulf, and Bay of Plenty from the bottom longline, bottom trawl and Danish seine fisheries targeting mainly snapper, trevally, John dory, and red gurnard.

The GUR 1 Quota Management Area is not a single biological stock. There are thought to be three sub-stocks: Bay of Plenty (BPLE); east Northland and Hauraki Gulf (ENHG); and west coast North Island, including the north-western part of GUR 8 (WCNI). Standardised catch per unit effort (CPUE) indices for these three areas, using bottom trawl data, are used to monitor trends in abundance. In this study we updated the fishery characterisation for these three sub-stocks and the standardised CPUE indices to 2020/21. We also examined length, sex, and gonad stage compositional data collected during trawl surveys conducted in GUR 1, 2, 3, 7, and 8, as well as growth and maturity schedules, to assess their utility in providing evidence for stock structure.

Except for some changes in targeting, the fisher behaviour in the three subareas has been reasonably constant for the last two decades. Two recent changes were the use of bottom trawl with a Modular Harvest System since 2015/16, and a changeover to electronic reporting starting in 2017/18. Bottom trawl catch and effort declined substantially in ENHG after 2017.

In BPLE the standardised CPUE index increased from 1995/96 to 2000/01, then fluctuated without trend, and in 2020/21 was about twice the value in 1995/96. For ENHG the index had peaks in 2004/05 and 2015/16, and in 2020/21 was 81% of the value in 1995/96. For WCNI the standardised index increased in an irregular manner since 1995/96, and in 2020/21 was 27% more than at the start of the series.

Standardised CPUE indices were used to evaluate historical and current stock status against B_{MSY} proxy target levels, chosen to be the mean values of the indices over the reference years 1995/96–2011/12. For BPLE and WCNI the stock status in 2020/21 was above the target level, and relative fishing mortality proxy was below the mean value for the reference years, i.e., the overfishing threshold. For ENHG the stock status in 2020/21 was below the target level, and relative fishing mortality was above the overfishing threshold, suggesting that overfishing was occurring.

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. There was limited correspondence between trends for trawl survey recruited biomass indices and standardised indices: (i) for BPLE the standardised CPUE approximately doubled from the start to the end of the series, whereas the trawl survey indices declined by about 60% over the same period, (ii) in ENHG the standardised CPUE index was about the same at the end of the series as it was at the start, matching the pattern for the Hauraki Gulf trawl survey indices, but from 1997/98 to 2000/01 the standardised CPUE indices increased by 160% whereas the trawl survey indices declined by 85%, and (iii) for WCNI the standardised CPUE

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series increased by 27% from the start to the end of the series, whereas the trawl survey indices approximately halved over the same period.

Patterns in length, growth, and length at maturity suggest fine scale structuring of red gurnard populations in coastal waters around New Zealand. This conclusion is further supported by CPUE data, with fine scale differences in standardised CPUE indices observed between geographically adjacent areas including ENHG and BPLE (this study), as well as between the east and south coasts of the South Island in GUR 3 in previous analyses. Targeted studies are required to better define stock boundaries.

1. INTRODUCTION

Red gurnard (GUR, *Chelidonichthys kumu*) was included in the Quota Management System (QMS) in 1986/87, and currently there are six Quota Management Areas (QMAs) in place (Figure 1). Three of these encompass the North Island coastline: GUR 1 (northern North Island), GUR 2 (southeast North Island), and GUR 8 (southwest North Island). The research here is concerned with GUR 1 (northern North Island) and the northern part of GUR 8 under the project JDO2021-02, with an overall objective to monitor the relative abundance of the three sub-stocks of red gurnard in GUR 1.

GUR 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 allow for projections of future population biomass estimates but evaluates the current status of the stock and historically.

Red gurnard are taken by the inshore fisheries targeting mainly John dory (*Zeus faber*), red gurnard, snapper (*Chrysophrys auratus*), tarakihi (*Nemadactylus* spp.), and trevally (*Pseudocaranx georgianus*). Very little is known about the stock structure: “No information is available on stock separation of red gurnard” (Fisheries New Zealand 2021a, p. 1214). Instead, the QMAs are used as default management units. It is assumed there are three sub-stocks within GUR 1 (Figure 2):

1. West coast North Island,
2. East Northland and Hauraki Gulf, and
3. Bay of Plenty.

For GUR 1, these three sub-stocks are assessed separately, as the fisheries within the three sub-stocks act mostly independently of each other (Fisheries New Zealand 2021b).

The red gurnard part of the research under JDO2021-02 was a characterisation of the GUR 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) evaluating changes in CPUE against a B_{MSY}-compatible reference,

c) comparing the standardised CPUE to trawl survey biomass series,

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

The previous GUR 1 fisheries characterisation and standardised CPUE went up to the 2015/16 fishing year (Kendrick & Bentley 2017).

Under Objective 3, length, sex, and gonad stage compositional data collected during trawl surveys conducted in GUR 1, 2, 3, 7, and 8, as well as growth and maturity schedules, were explored to assess their utility in providing evidence for stock structure of red gurnard in New Zealand waters.

Fishing years in this report will be denoted in two ways: (i) 2015/16 fishing year referring to October 2015 to September 2016, and (ii) the abbreviated form 2016 signifying the 2015/16 fishing year.

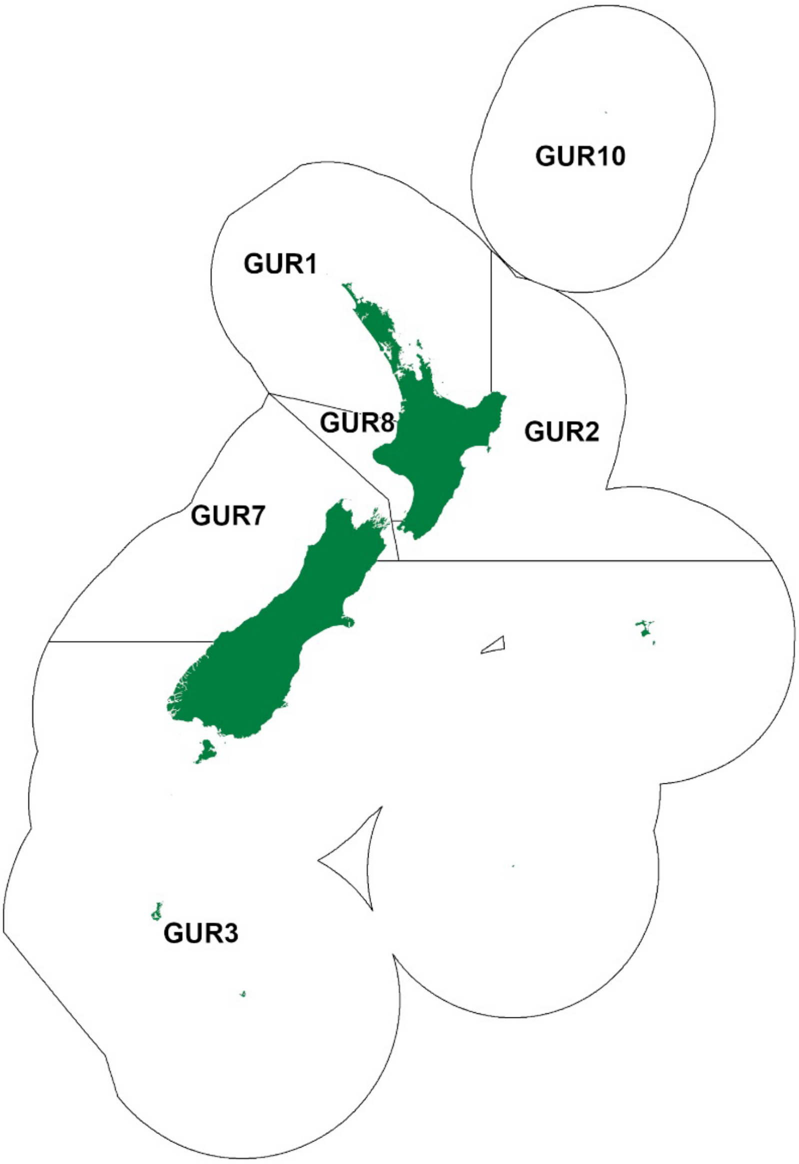

Figure 1: QMAs for red gurnard (from Fisheries New Zealand 2021a).

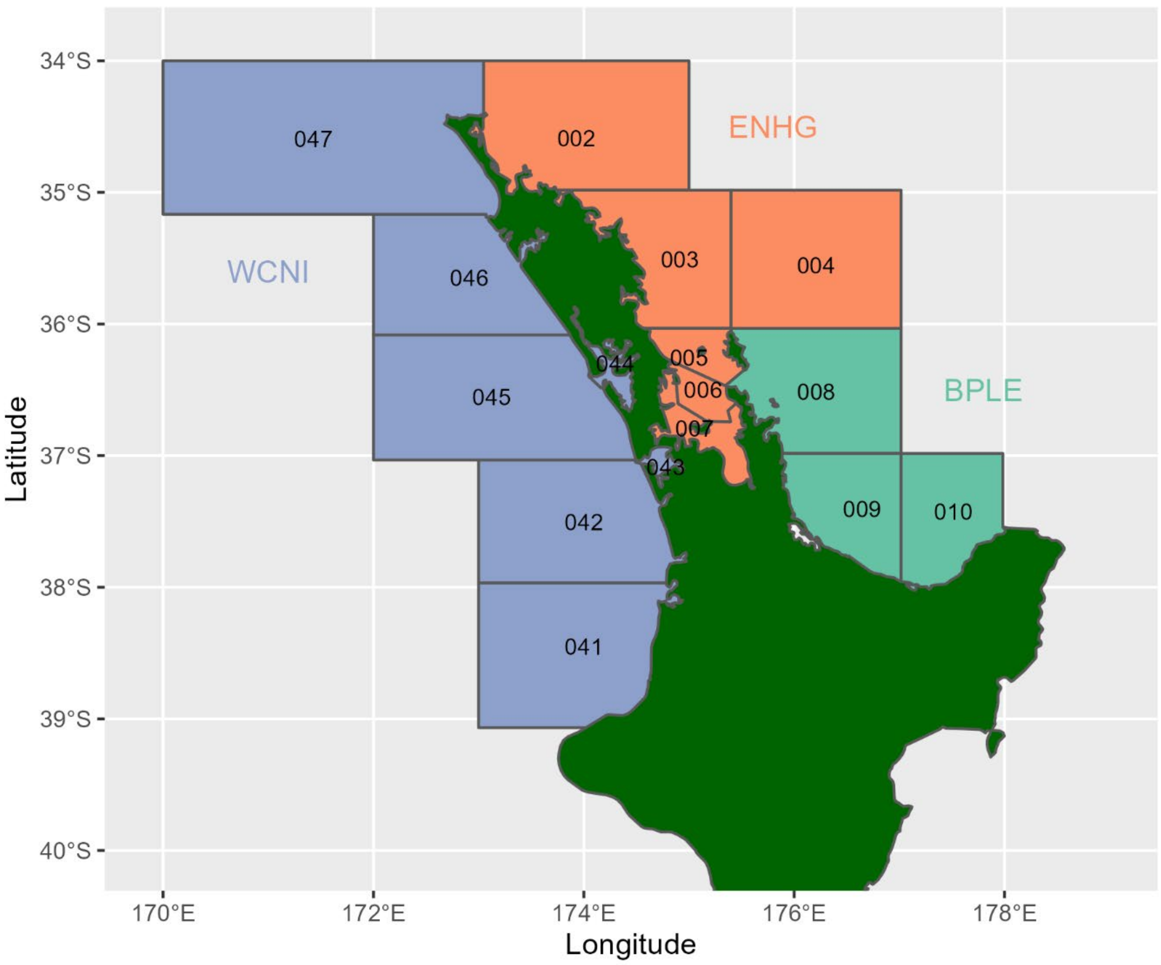

Figure 2: The three sub-stocks for GUR 1 and associated General Statistical Areas used for the characterisation and standardised CPUE analyses. Note that for WCNI (west coast North Island) the Statistical Areas 043 and 044 are inshore harbour areas. BPLE is Bay of Plenty and ENHG is east Northland and Hauraki Gulf.

2. METHODS

2.1 Characterisation and CPUE standardisations

2.1.1 Overview of the GUR 1 fishery

Red gurnard is a common bycatch species of inshore fisheries throughout New Zealand (Fisheries New Zealand 2021a). About 40% of the current GUR 1 catch is from East Northland, Hauraki Gulf, and Bay of Plenty from the bottom longline, bottom trawl, and Danish seine fisheries targeting mainly snapper, trevally, John dory, and red gurnard (Kendrick & Bentley 2017). The other 60% is from the west coast North Island where it is mainly caught in the bottom trawl fishery targeting trevally and red gurnard (Kendrick & Bentley 2017).

For 2019/20 the landings in GUR 1 were 745 t, which is 17% of the total red gurnard landings for that year (Fisheries New Zealand 2021a). The initial Total Allowable Commercial Catch (TACC) for GUR 1 in 1986/87 was 2010 t, based on the 1983 landings. There were some small increments in the TACC to 2287 t in 1994/95, followed by an increment of one tonne to 2288 t in 2010/11, where it has remained since. Landings have never met the TACC and have declined slowly since the early 2000s, perhaps a signal of declining abundance (Figure 3).

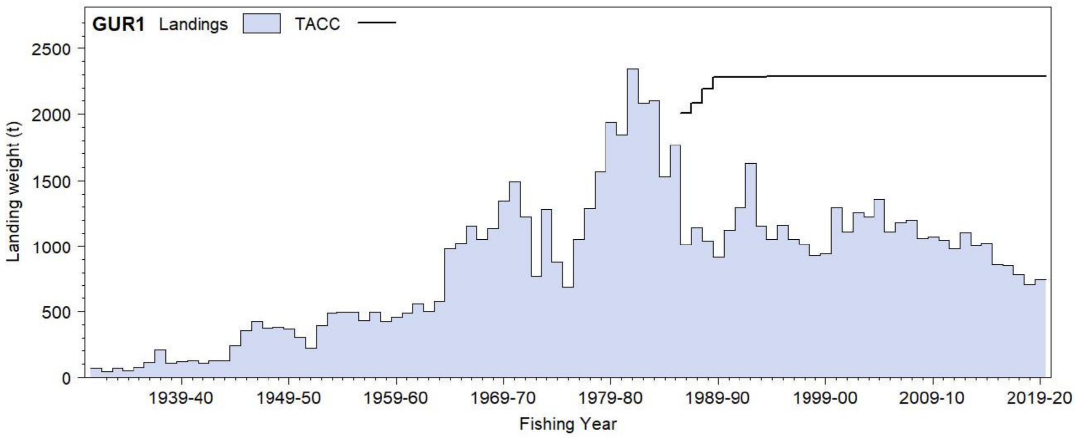

Figure 3: GUR 1 landings and TACC (Fisheries New Zealand 2021a).

The stock structure of red gurnard is unknown, but for assessment purposes, three sub-stocks are assumed for GUR 1:

(1) East Northland and Hauraki Gulf (ENHG)

(2) Bay of Plenty (BPLE)

(3) West coast North Island (including the north-western part of GUR 8) (WCNI)

An updated characterisation for GUR 1 and the north-western part of GUR 8 (Statistical Area 041) was conducted and this included 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 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).

For the three GUR 1 sub-stock areas (ENHG, BPLE, WCNI) standardised indices were calculated to 2016 by Kendrick & Bentley (2017), and these are updated to 2021 for this study.

2.1.2 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 (CEL) were predominantly utilised over the earliest part of the catch and effort series (1990–1995). CEL 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 vessels in 1995 meant that fishers could provide catch and effort data at the tow level. TCEPR and CEL forms were replaced in 2007 with the Trawl Catch Effort Return (TCER) form which also allowed 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 species fisheries 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 red gurnard reported in GUR 1 and the northern part of GUR 8 (large-scale Statistical Area 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 areas and depth ranges and for species typically associated with catching red gurnard but that did not report or land red gurnard. Landings were allocated to effort via a trip-based link and prorating estimated catch following Starr (2007) and Langley (2014).

2.1.3 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 were 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 1996 onward so the standardised CPUE data covered the period 1996–2021. 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. For each fishery (BPLE, ENHG, WCNI), core vessels were selected based on the criteria of a minimum number of trawls per year for a minimum number of years, with the core vessels taking at least 80% of the catch over the period 1996–2021.

For WCNI the standardisation dataset excluded large-scale Statistical Areas 043 and 044, inshore harbour regions from which little bottom trawl catch was taken (but these areas were included in the characterisation dataset). Similarly, for ENHG the Statistical Area 007 was excluded from the standardisation dataset.

2.1.4 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 red gurnard catch. The predictor variables offered to the lognormal and binomial models were the same as used for John dory by McKenzie (2023) (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 2022). 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; Akaike 1974), with 1% increase 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). Species codes are snapper (SNA), red gurnard (GUR), John dory (JDO), trevally (TRE), barracouta (BAR, *Thyrsites atun*), and tarakihi (TAR).

Variable	Definition	Data type	Bounds
Vessel	Fishing vessel category	Categoric	
Fishing Year	Fishing year	Categoric	1994/95–2020/21
Season	Season of year	Categoric (4)	
Month	Month	Categoric (12)	1–12
Stat	Statistical area	Categoric	
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	
Start Time	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 (ENHG) < 200 (WCNI)

2.1.5 Stock status evaluated against B_{MSY} compatible reference points

There are no stock assessments for GUR 1 in which absolute biomass is estimated, so no comparison of absolute biomass against B_0 or B_{MSY} can be done. Instead B_{MSY}-compatible reference points have been used for the three sub-stocks of GUR 1 (Ministry of Fisheries 2008, Fisheries New Zealand 2021b). The reference points were derived from the sub-stock standardised CPUE indices, using the mean values over the period 1995/96 to 2011/12 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 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.

2.1.6 Corroboration of standardised CPUE against trawl surveys

We derived updated GUR 1 trawl survey recruited biomass indices as comparative indices to the fishery-dependent CPUE indices for red gurnard. The relevant survey indices for the three GUR 1 sub-stock regions are the Hauraki Gulf survey, the Bay of Plenty survey (Parsons et al. 2021), and the northern area component of the west coast North Island survey (Jones et al. 2022).

Note that there was change in the gear configuration following the 1988 trawl surveys, which may have caused a change in the catchability of red gurnard. Hence surveys between 1982 and 1988 were considered a separate biomass series from those 1989 onward, for all areas in which surveys were conducted.

2.1.7 Relative fishing mortality

Annual relative fishing mortality proxy for a sub-stock (e.g., GUR 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.

2.2 Explorations of stock structure

Research trawl survey data were used to explore spatial patterns in biological characteristics of red gurnard, to derive hypotheses of stock structure. For these analyses, a 'stock' was considered a discrete assemblage of post-settlement fish for assessment purposes, making no assumption of dispersal of eggs/larvae or gene flow.

Explorations were run for four biological variables:

1. Length
2. Growth
3. Length at maturity
4. Sex ratios (females vs. males for mature fish)
5. Females in spawning state (running ripe condition)

Spatio-temporal patterns of these parameters can provide preliminary evidence of stock structure (Begg et al. 1999, Moore et al. 2011, 2012). Aggregations of large fish in particular areas at particular times may indicate spawning associations, while area and times with high proportions of juvenile fish may indicate nursey areas. Similarly changes in sex ratios among areas and times may indicate movement to or from spawning grounds. Differences in growth and maturity schedules among areas can indicate spatial heterogeneity, providing evidence on the degree to which assemblages are mixed (Moore et al. 2012).

2.2.1 Data extracts

Data were extracted from all available bottom trawl surveys in the *trawl* database. Length and sex information was derived from the *t_lgth* table, and combined length, sex and gonad stage information were derived from the *t_fish_bio* table. Associated survey information were derived from the *t_trip* and *t_station* tables. Data were groomed to exclude fish without associated survey position information and a small number of individuals over 70 cm in length (noting these lengths were larger than the maximum reported length for the species, and beyond the range of the majority of data in the trawl survey dataset).

2.2.2 Data analysis

Prior to analysis, each fish in the dataset was assigned to its associated QMA and statistical area of capture. To explore length frequencies at finer spatial scales, this information was then used to assign each fish to one of eleven ‘areas’ (Table 2).

Table 2: Areas used in the analyses of length composition data, and corresponding Quota Management Areas and statistical areas.

Area	Area code	Description
GUR 1: West Coast North Island	GUR 1: WCNI	GUR 1 Statistical Areas 042, 045, 046, 047
GUR 1: East Northland	GUR 1: ENLD	GUR 1 Statistical Areas 002, 003, 004
GUR 1: Hauraki Gulf	GUR 1: HAGU	GUR 1 Statistical Areas 005, 006, 007
GUR 1: Bay of Plenty	GUR 1: BOP	GUR 1 Statistical Areas 008, 009, 010
GUR 2	GUR 2	All statistical areas within GUR 2
GUR 3: East coast South Island	GUR 3: ECSI	GUR 3 Statistical Areas 018, 020, 022, & 024 to 45.85° S
GUR 3: South coast South Island	GUR 3: SCSI	GUR 3 Statistical Areas 025, 027, 029, 030, 031, 032, & 026 south of 45.85° S
GUR 7: West coast South Island	GUR 7	GUR 7 Statistical Areas 032, 033, 034, 035, 036, 037, 017
GUR 7: Tasman Bay-Golden Bay	GUR 7: TBGB	GUR 7 Statistical Area 038
GUR 8: Central	GUR 8	All inshore statistical areas within GUR 8

Summary statistics were compiled for the four biological characteristics outlined above. These included: 1) maps of the locations of 0+ fish (considered to be those individuals less than 15 cm; see Results); 2) examination of length frequency distributions by area; and 3) maps of aggregated (0.2 degree square) mean length, sex ratio, and proportion of females in running ripe condition (relative to the number of mature females in any other gonad state). Growth information was gleaned from published studies, and sex and area-specific von Bertalanffy growth function (VBGF) curves were plotted where information was available. Sex-specific maturity ogives were generated for each QMA, although GUR 1 was split into ‘GUR 1: East’ and ‘GUR 1: West’ components. Maturity state (i.e., ‘immature’ (fish with gonads in stage 1) or ‘mature’ (fish with gonads in stages 3 and above)), as determined from macroscopic staging data, was treated as a binomial response variable and modelled as a function of length with a logit link with a GLM. As samples were often sampled outside of the assumed spawning season (i.e., late spring and extends through to early autumn, with a peak in summer (Elder 1972, Clearwater & Pankhurst 1994)), individuals with stage 2 gonads were excluded from the analyses, as it is unclear whether these individuals are immature and developing, or mature and resting.

Generalised additive mixed models

To ensure any resulting spatio-temporal patterns in the raw length and sex ratio data were not merely an artefact of sampling, patterns in these variables were examined using spatial generalised additive mixed effect models (GAMMs). Spatial GAMMs are generalised additive models (GAMs) that include a random effect and a spatial spline. Models tested included 2-dimensional spatial splines, which were smoothers on position (i.e., longitude and latitude) or 3-dimensional spatio-temporal splines (i.e., longitude and latitude by season). Length models were run across both sexes combined and across all areas, as well as for each sex separately. Sex ratio models were run for GUR 3 only, as this was the only QMA with sufficient intra-annual temporal coverage, and were based on individuals ≥ 25 cm in length only (i.e., predominantly mature individuals). All models were also offered fishing depth (mean of shallowest and deepest points of the trawl) as either an individual variable or in an interaction with season, and all models included random effects of codend mesh size and vessel (using bs = ‘re’; Brodie et al. 2021) to account for differences in catchability of the various net mesh sizes and vessels in the time series, respectively. Length models were offered an additional random effect of year by QMA, to account for changes over time within a given QMA, while the single-QMA model of sex ratio was offered a stand-alone random effect of year. Model overfitting was avoided by setting the gamma parameter above the default of one (gamma=1.4 was used for all models) and by setting a low number of basis functions (k) (Wood 2017, 2020). Models were fitted using the ‘bam’ function within the *mgcv* package (Wood 2017) in R. Models fitted to length data used a Gaussian distribution, while those exploring sex ratio data (females or males) used a binomial distribution.

Model selection was performed based on AIC values. Variables that reduced the AIC by ≥ two were retained in future models. Variables that did not improve model fits were excluded from future models. Models with AIC values of within two were considered to describe the data equally well. In these instances, the model with the fewest terms was selected. Visual inspection of the model outputs and diagnostic plots (e.g., residuals vs. fitted values and Q-Q plots) was performed to check for model misspecification. For length models (i.e., those with a Gaussian error distribution), all residual diagnostics used deviance residuals. For sex ratio models (i.e., those with a binomial error distribution), residual diagnostics used randomised quantile residuals, implemented using the R package *statmod* (Dunn & Smyth 1996). Predictions from the selected model for each biological characteristic were generated for areas at or adjacent to survey locations using the ‘predict.gam’ function in *mgcv*.

3. RESULTS

3.1 GUR 1 fishery characterisation

Catch from the WCNI area dominated GUR 1 catch after 1992 with the catch from ENHG and BPLE about the same as each other (Figure 4). Since 2020 most of the GUR 1 catch was reported on the event-based ERS trawl form, with reporting transferring over from CEL and TCE forms (Figure 5).

Bottom trawl takes substantial red gurnard catch in all three subareas although of declining importance for ENHG, with Danish seine and bottom long line also important in BPLE and ENHG (Figure 6). Since 2016, some bottom trawls used a patented Modular Harvest System (MHS) developed by the Precision Seafood Harvesting (PSH) programme (see Figure 6, coded under the fishing method PRB).

For all three subareas, more bottom trawl red gurnard catch was taken in the months October to March, but with steady amounts in the months outside this (Figure 7). The predominantly targeted species for bottom trawl red gurnard catches varied by subarea: red gurnard (before 2011), John dory, snapper, tarakihi, and trevally (BPLE); red gurnard, John dory, and snapper (ENHG); red gurnard, snapper, and trevally (WCNI) (Figure 8). Currently, only in WCNI is red gurnard a target fishery.

In BPLE the bottom trawl catch was evenly spread across the two large-scale Statistical Areas 009 and 010, with less in the more northern Statistical Area 008 (Figure 9). In ENHG the bottom trawl catch was concentrated in the adjacent Statistical Areas 003, 005, and 006 with catch declining in all three since about 2017. For WCNI bottom trawl catch has predominantly come from Statistical Areas 042, 045, and 047 with less from Statistical Area 046 and the southern Statistical Area 041. 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 10).

Except for some changes in targeting, the fisheries in the three subareas were undertaken in much the same way for the last two decades. ENHG has the most changes with a declining bottom trawl catch that no longer targets red gurnard. Two recent changes for all areas were the use of bottom trawl with a Modular Harvest System since 2016, and a changeover to recording using the ERS, predominantly from 2020.

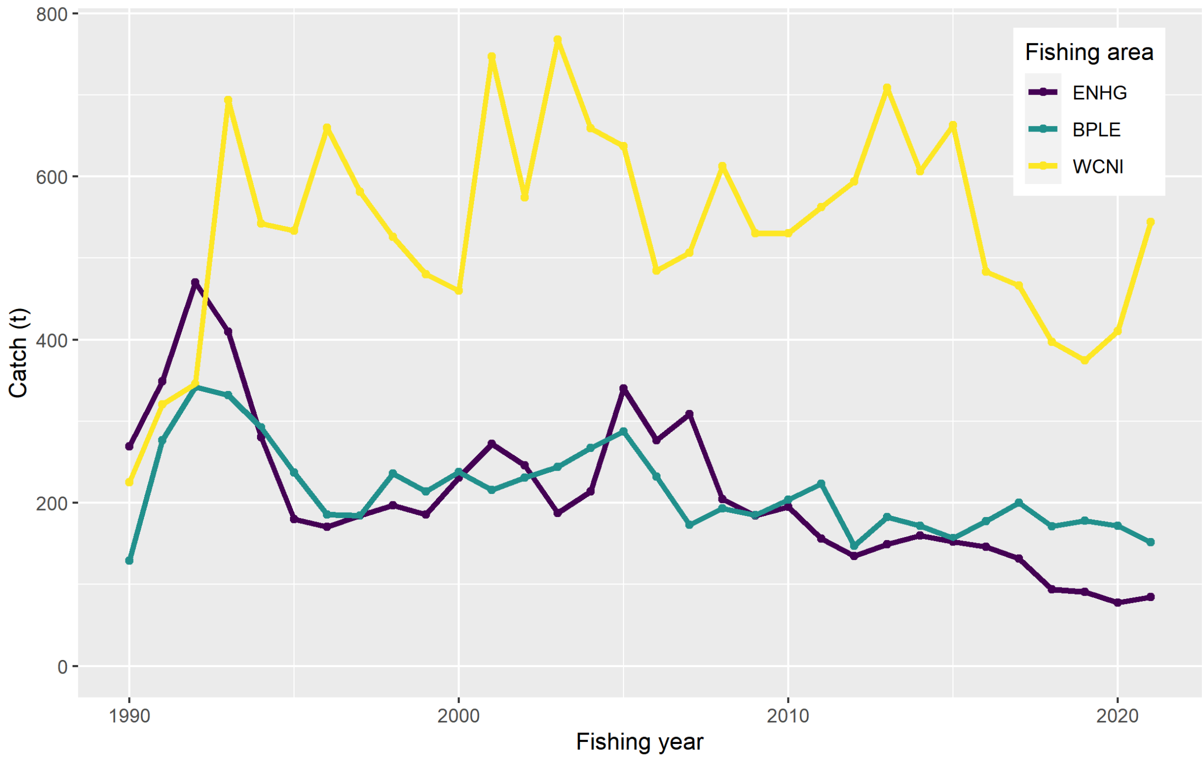

Figure 4: Annual catches of red gurnard by fishery area: Bay of Plenty (BPLE), east Northland and Hauraki Gulf (ENHG), and west coast North Island (WCNI).

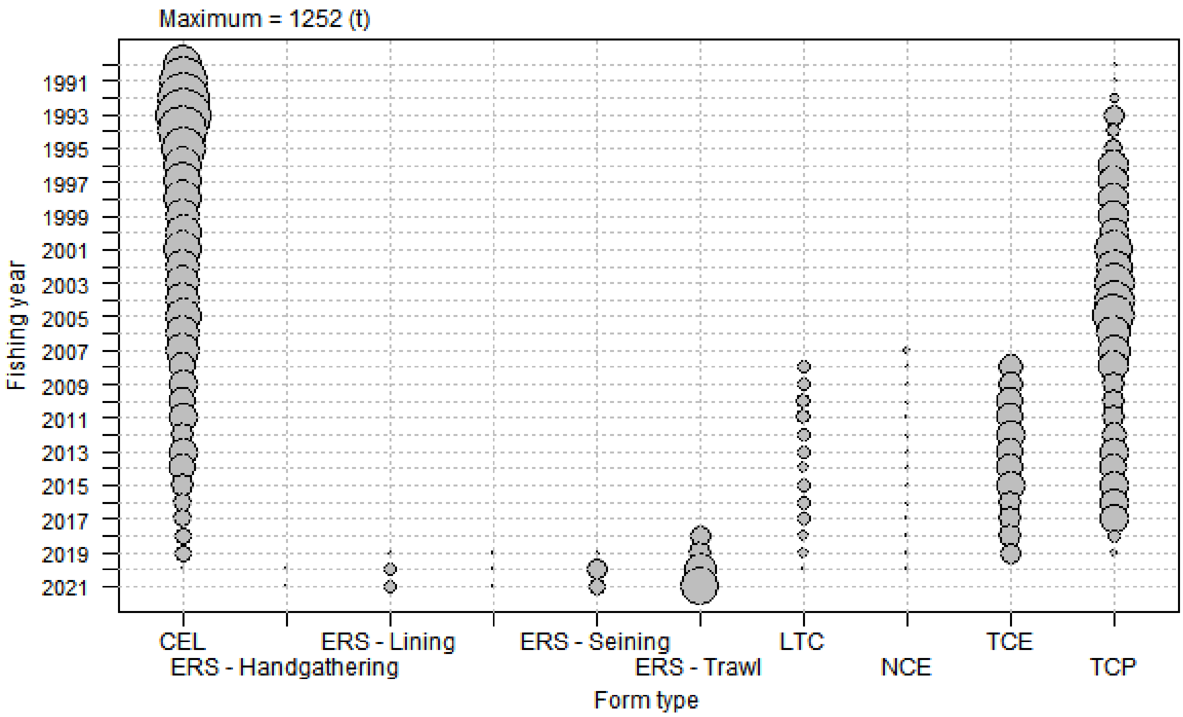

Figure 5: Annual catches of red gurnard by form type and fishing year. Form types are Catch Effort Landing Returns (CEL), Electronic Reporting System (ERS), Lining Trip Catch, Effort Return (LTC), Netting Catch, Effort and Landing Return (NCE), Trawl Catch Effort Return (TCE), Trawl Catch Effort Processing Return (TCP).

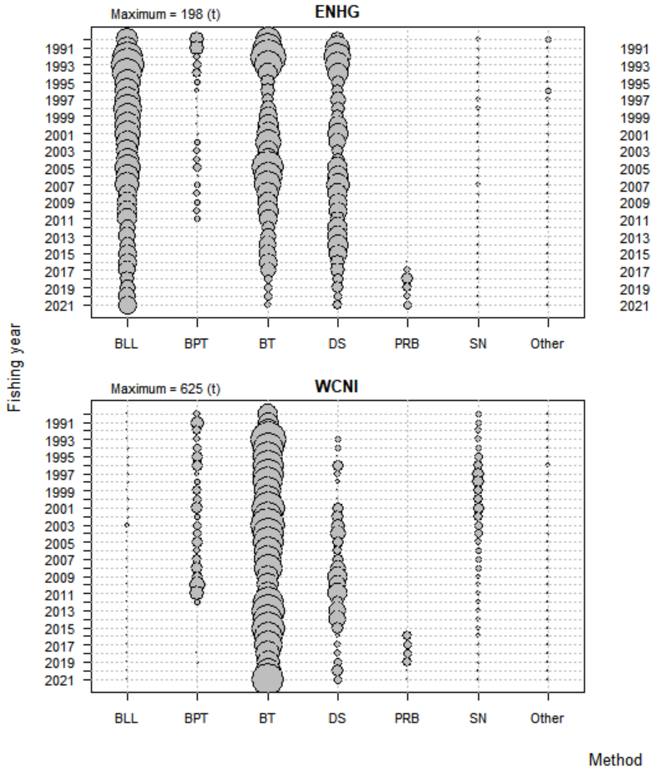

Figure 6: Annual catches of red gurnard by fishing method, fishing year, and fishery area. Methods are bottom long line (BLL), bottom pair trawl (BPT), bottom (single) trawl (BT), Danish seine (DS), bottom trawl using a Modular Harvest System (PRB), set net (SN), and Other.

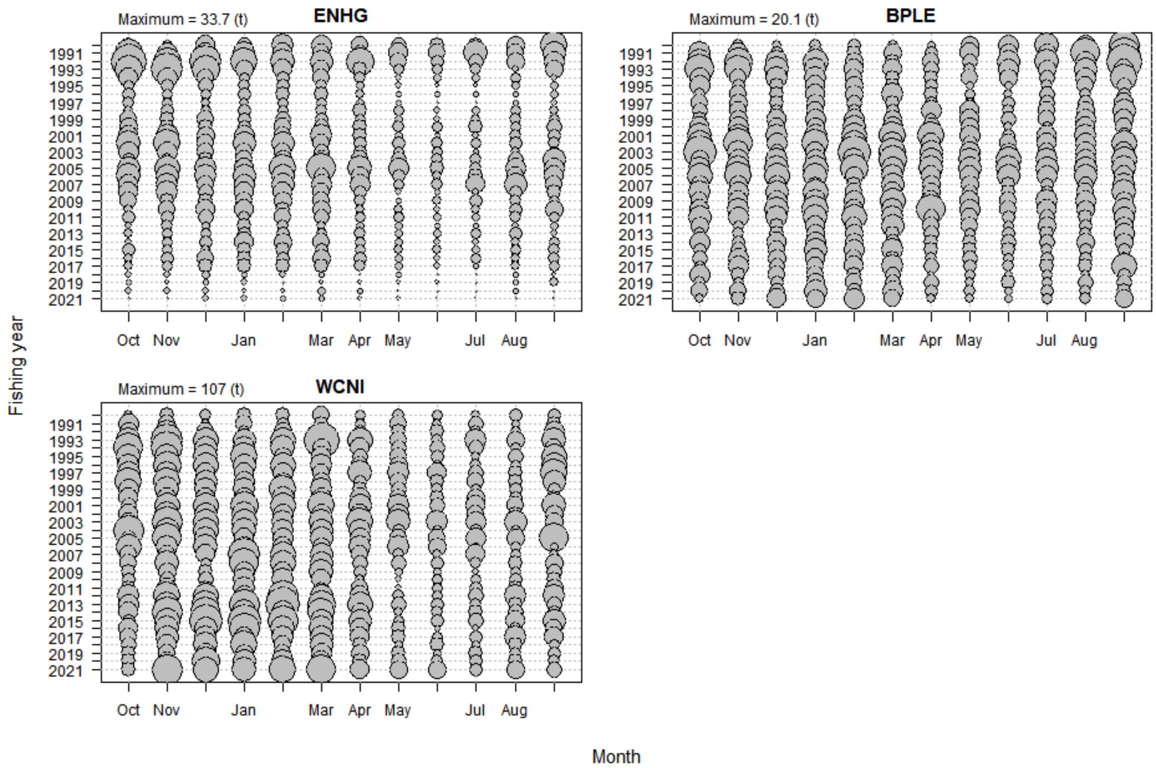

Figure 7: Annual bottom trawl catches of red gurnard by month, fishing year, and fishery area.

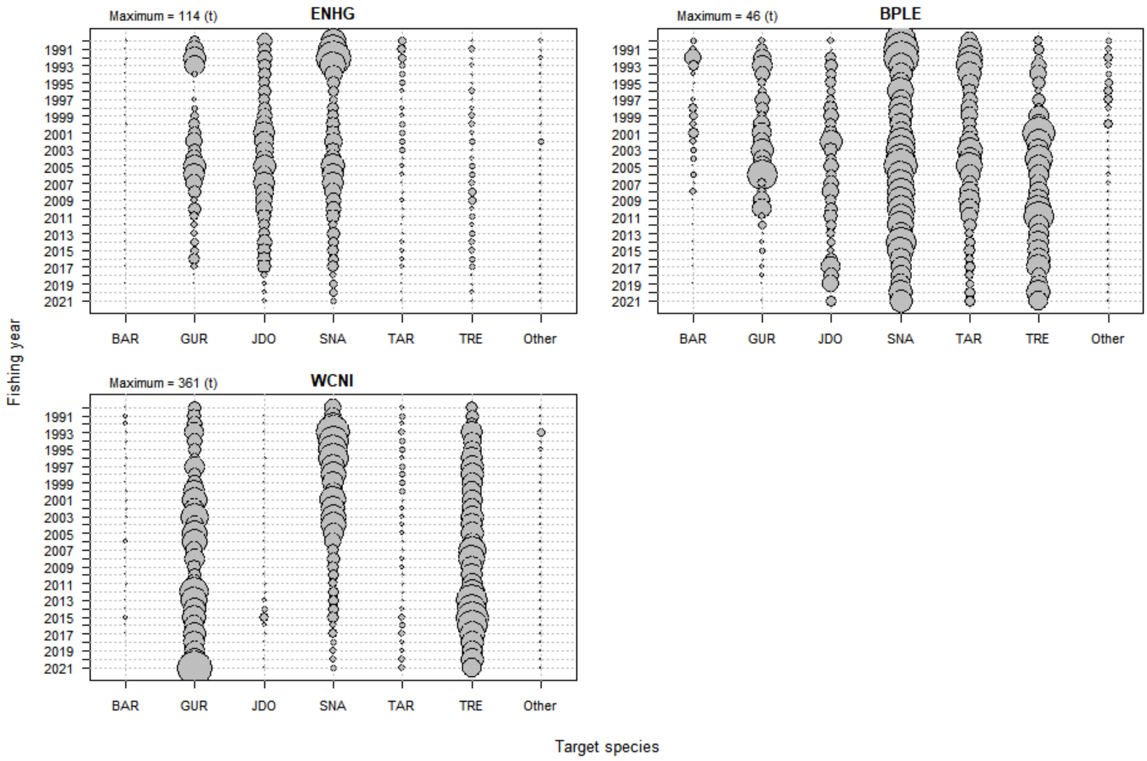

Figure 8: Annual bottom trawl catches of red gurnard by target species, fishing year, and fishery area. Target species codes are defined in Table 1.

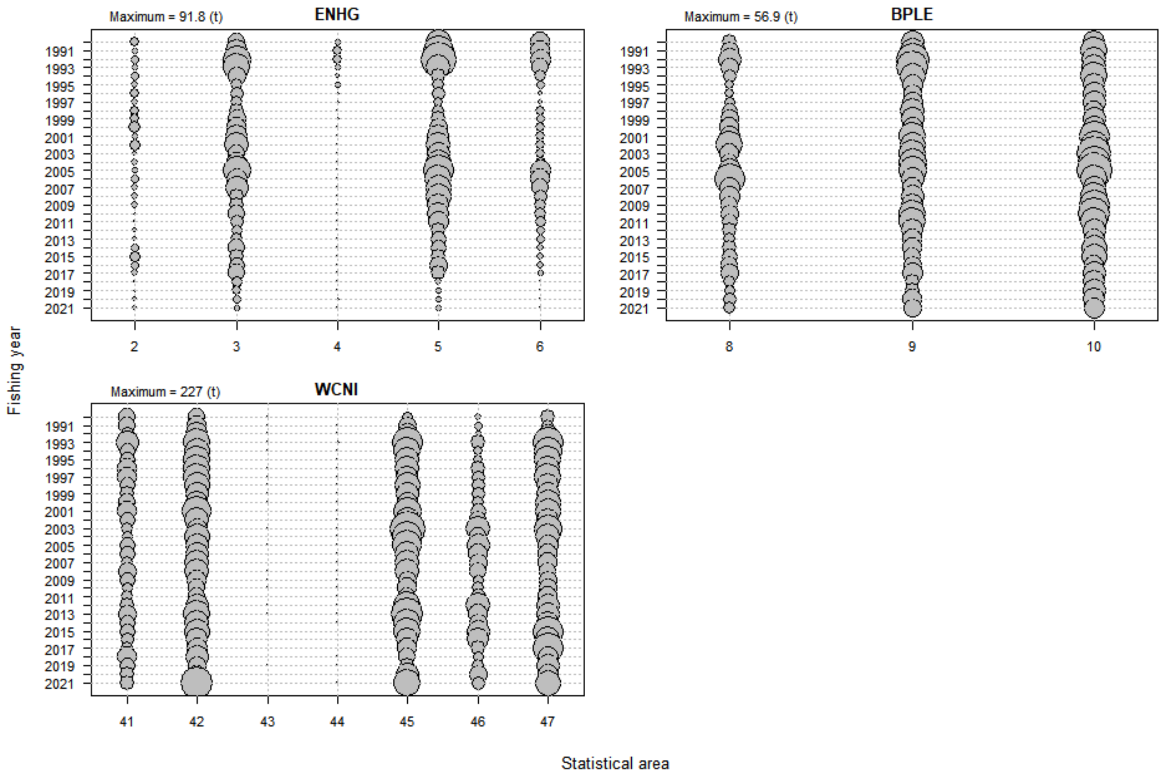

Figure 9: Annual bottom trawl catches of red gurnard by broad-scale statistical area (where '2' is Statistical Area 002, etc.), fishing year, and fishery area.

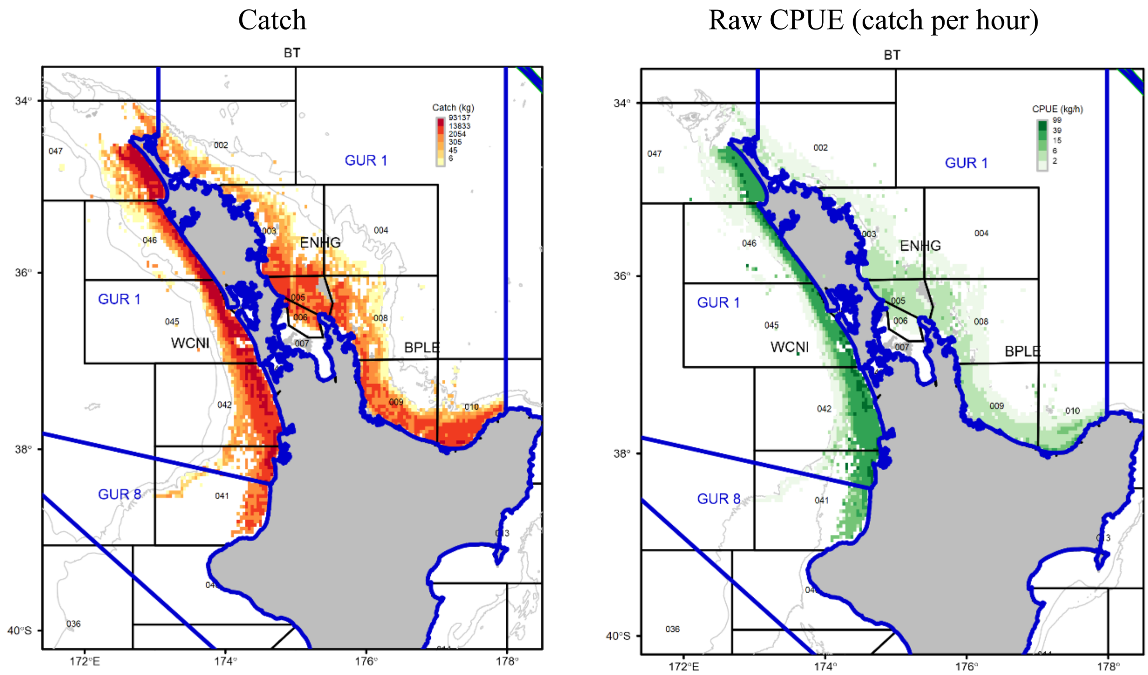

Figure 10: Catch and raw CPUE (catch in kilograms per hour) for bottom trawl data from GUR 1 and the northern part of GUR 8 for 1990 to 2021. Grid cell resolution is 0.08 degrees longitude by 0.08 degrees latitude, and catch or CPUE was not plotted if there was less than three fishing permit holders for a grid cell.

3.2 CPUE standardisations

In the following sections standardised CPUE indices analyses are presented for in turn: BPLE, ENHG, and WCNI.

3.2.1 Bay of Plenty standardised CPUE

Core vessels were selected based on the criteria of a minimum of three trawls per year for a minimum of three years, which was the same as used by Kendrick & Bentley (2017). This retained nearly 100% of the catch in most years, and 80% or more before 2000 (Figures 11–12). There were 44 core vessels, and they showed very good overlap in effort from the start to the end of the fishery (Figure 13, Table 3).

The lognormal model explained 24% of the variation in the positive catch, with vessel (14%) the most important predictor variable (Table 4). Other variables accepted into the model were start cell location ('Loc2'), trawl distance, trawl start latitude, and month. Predictor variables additional to vessel had a minor impact on the standardised index (Figure 14, Appendix 1). Diagnostics for the model were good (Figure 15).

The binomial model explained 19% of the variation in the proportion of non-zero catch, with start cell position the most important predictor variable explaining 9% of the variance, followed by vessel (4%) (Table 5). Other variables that entered the model were target species and fishing depth. Diagnostics for the binomial model were good (Figure 16).

The combined index increased from 1996 to 2001 (as did the binomial component for non-zero catch) and fluctuated cyclically but without trend after that (Figure 17). A geometric raw CPUE showed a similar pattern of fluctuations to the combined index, but their magnitude was different (Figure 18). The combined index was similar to the previous standardised index, with the increase to 2016 continuing for one more year, followed by a decline to 2019 then an increase (Figure 19).

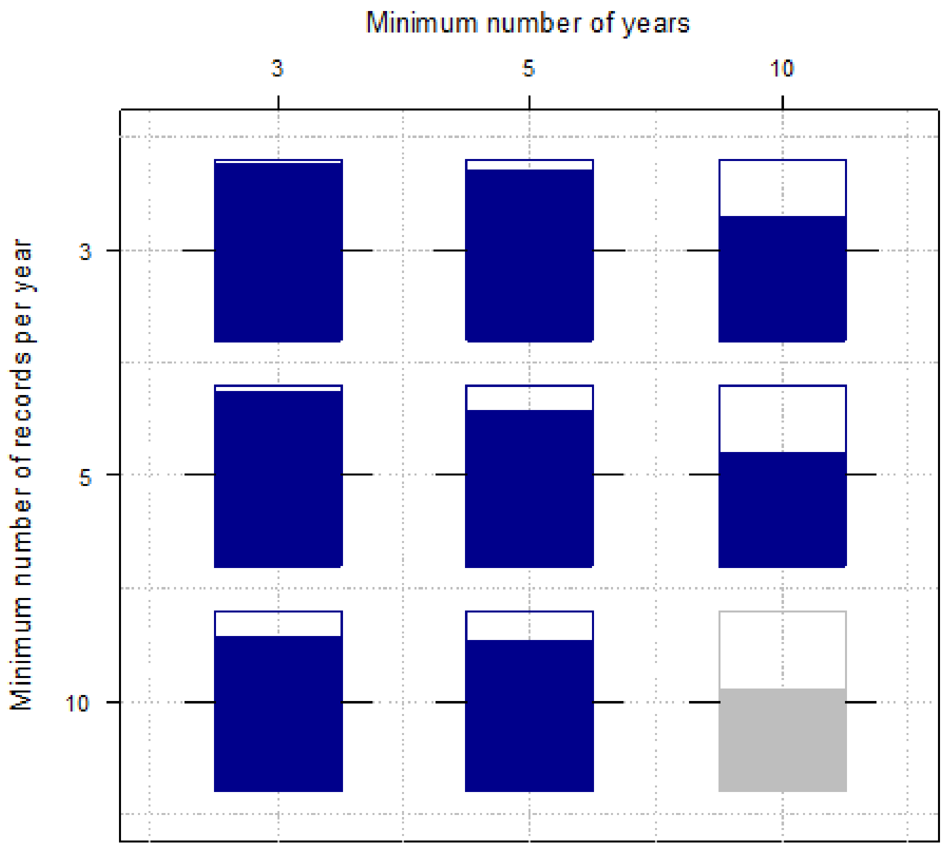

Figure 11: Proportion of the Bay of Plenty catch taken when subsetting data with the requirement of minimum number of records (i.e., trawls) per year, for a minimum number of years. Each bar shows the percentage of total catch retained from 1996 to 2021 under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 60% or more of the catch, otherwise they are coloured grey.

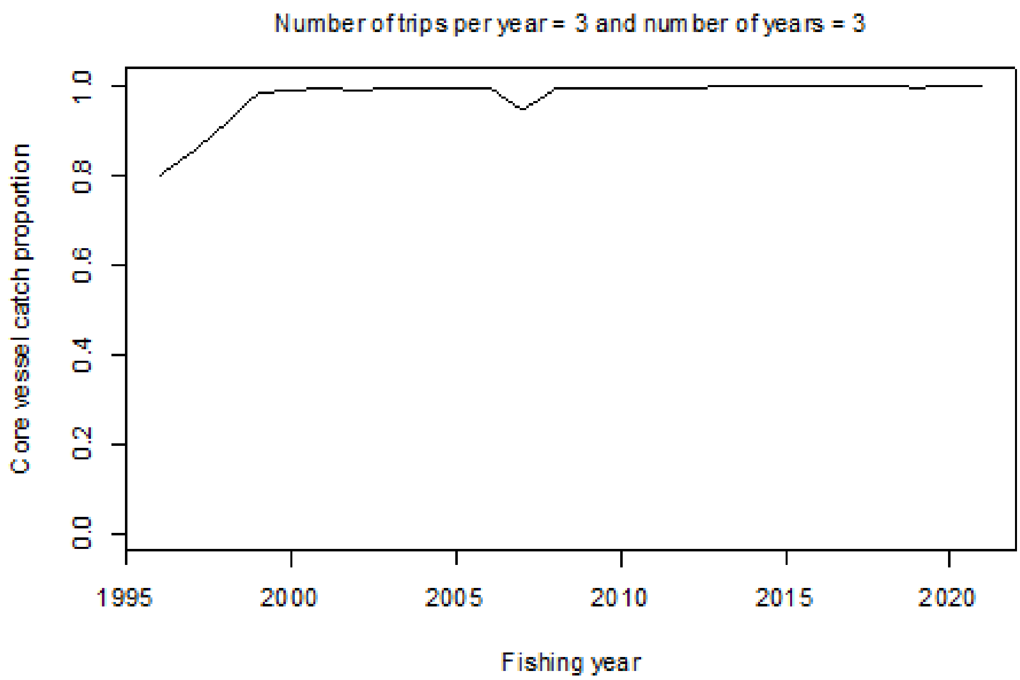

Figure 12: Proportion of the Bay of Plenty catch retained by fishing year, after subsetting on vessels, retaining those with a minimum of three records (i.e., trawls) per year for a minimum of three years.

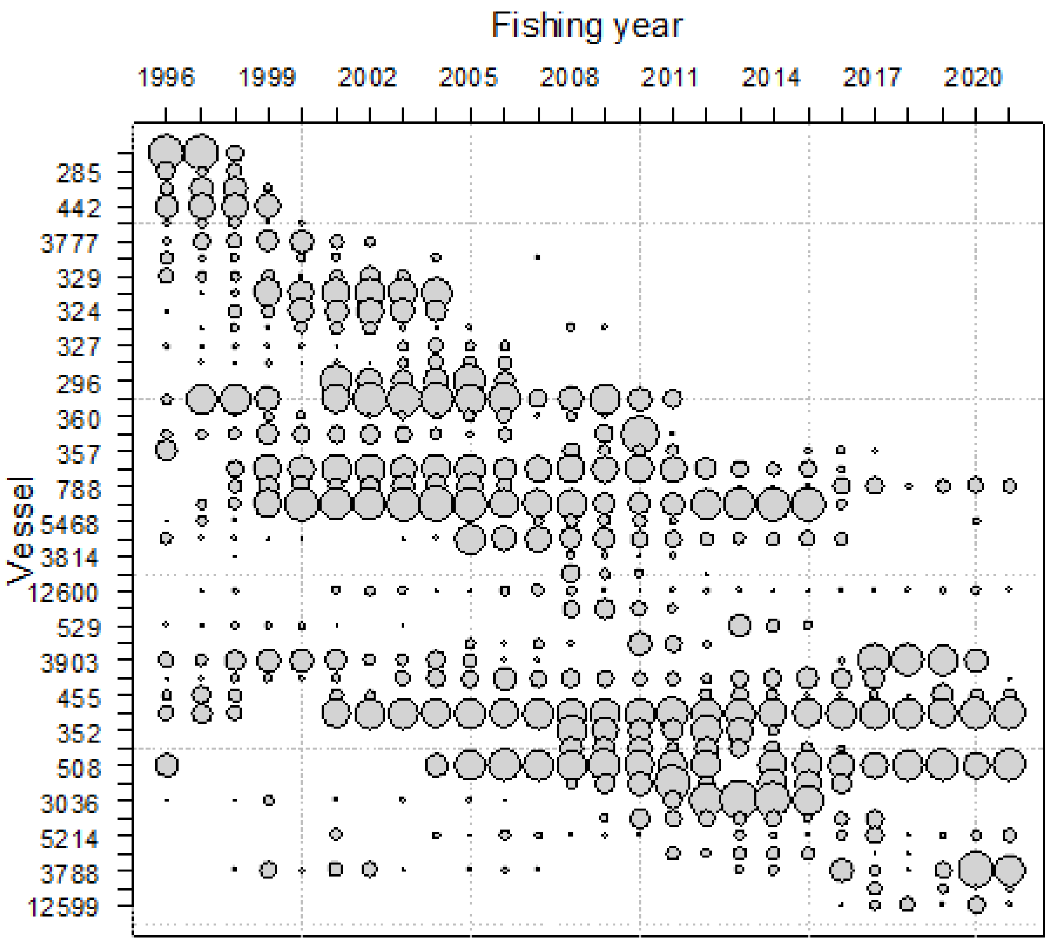

Figure 13: Bay of Plenty number of trawls for core vessels by vessel and fishing year. The area of the circles is proportional to the number of trawls.

Table 3: Summary of Bay of Plenty core vessel catch and effort for bottom trawl CPUE data.

Fishing year	Number vessels	Number trips	GUR catch (t)	Number trawls	Percent zero catch
1996	24	288	26.9	1 886	55.4
1997	22	322	26.3	2 213	60.1
1998	30	331	38.9	2 350	63.5
1999	21	349	46.5	3 035	62.1
2000	19	284	38.6	2 621	60.7
2001	23	361	72.1	3 148	42.2
2002	20	373	66.4	2 902	43.4
2003	21	423	85.9	3 539	48.9
2004	21	452	83.4	3 989	43.6
2005	19	410	88.4	3 896	35.2
2006	19	366	50.8	3 045	45.4
2007	15	240	41.8	2 133	36.1
2008	20	363	72.1	2 817	29.6
2009	21	363	77.2	2 879	32.7
2010	20	393	87.9	2 888	33.3
2011	20	336	77.4	2 674	38.3
2012	16	328	52.9	2 772	44.0
2013	16	325	43.4	2 420	45.2
2014	18	338	58.1	2 863	46.9
2015	17	302	52.8	2 333	43.7
2016	17	228	46.5	1 825	47.2
2017	14	221	58.5	2 078	41.4
2018	10	148	38.1	1 512	41.8
2019	12	202	39.3	1 707	43.4
2020	11	229	47.3	1 790	38.1
2021	10	190	40.5	1 598	38.0

Table 4: 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	25	0.03
vessel	43	0.17
Loc2	41	0.19
ns(log_distance, df = 3)	3	0.21
ns(start_latitude, df = 5)	5	0.22
month	11	0.24

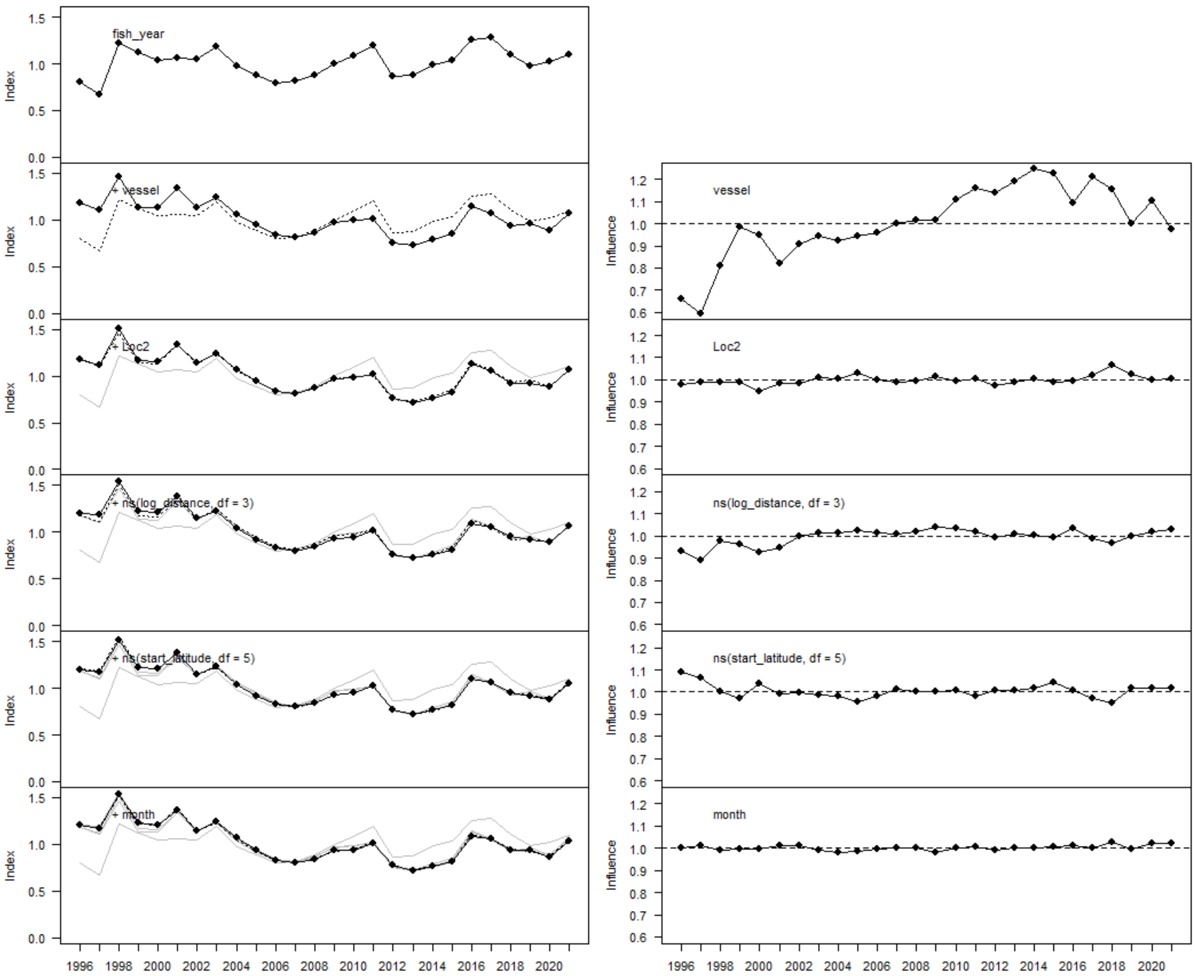

Figure 14: Stepwise influence plots showing the impact of sequentially adding predictor variables for the lognormal component of the Bay of Plenty standardisation (see Table 4).

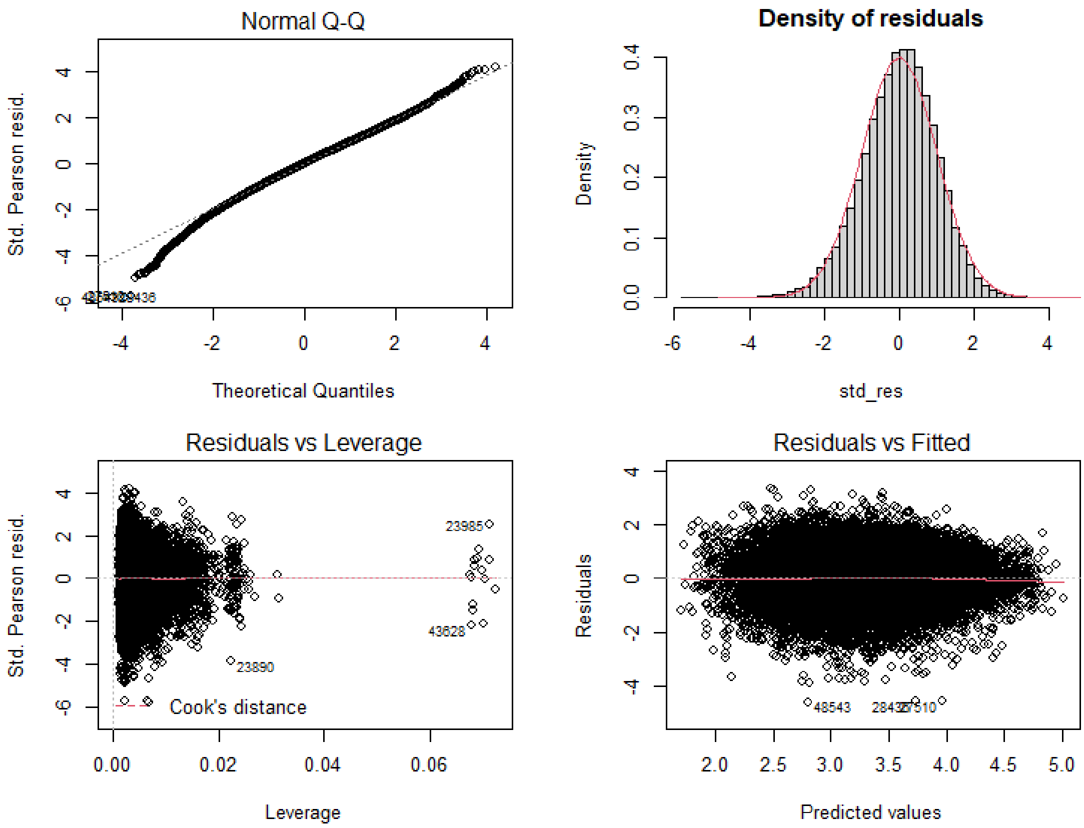

Figure 15: Residuals for the lognormal component of the Bay of Plenty standardisation model.

Table 5: 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	25	0.02
Loc2	41	0.11
vessel	43	0.15
target	5	0.18
ns(effort_depth, df = 3)	3	0.19

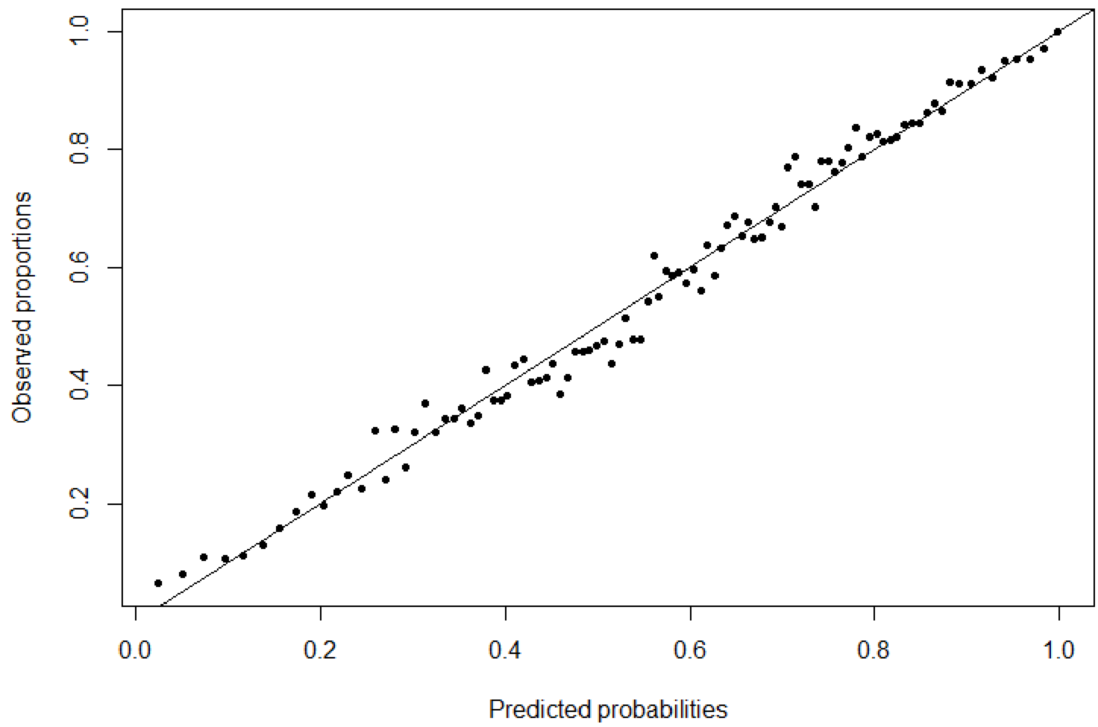

Figure 16: Diagnostic for the binomial component of the Bay of Plenty standardisation model.

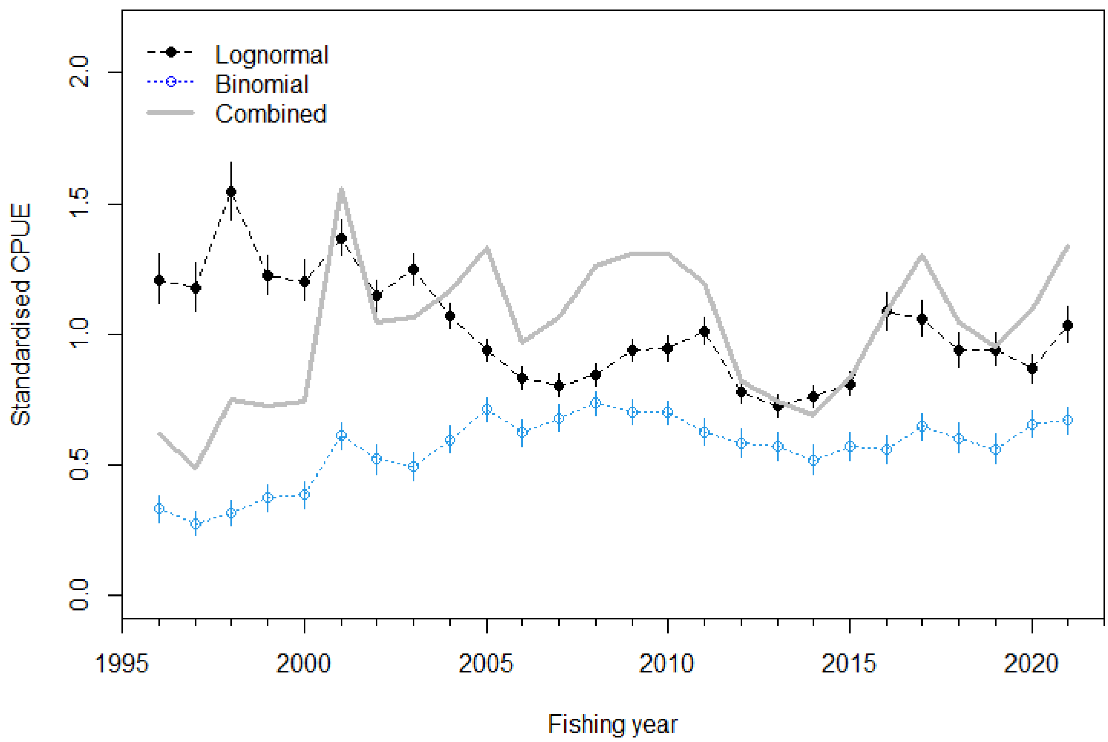

Figure 17: Binomial component, lognormal component, and combined index for the Bay of Plenty (part of GUR 1) standardisation model. Error bars are ± two standard deviations.

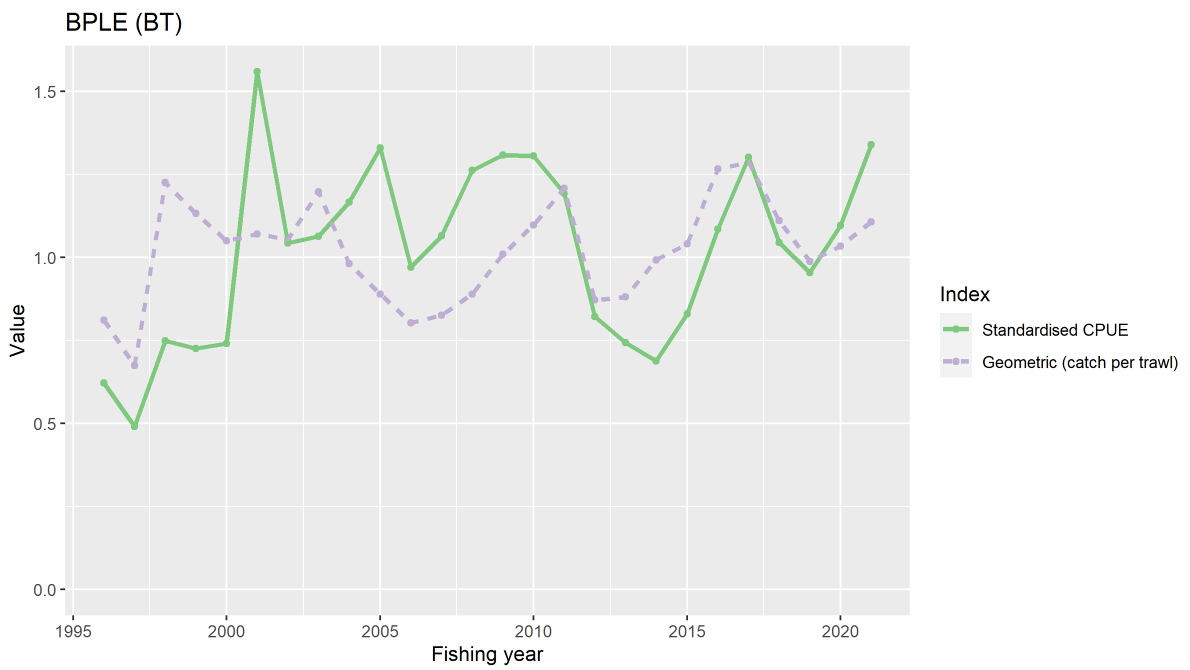

Figure 18: Combined index ('Standardised CPUE') and geometric mean CPUE compared for Bay of Plenty.

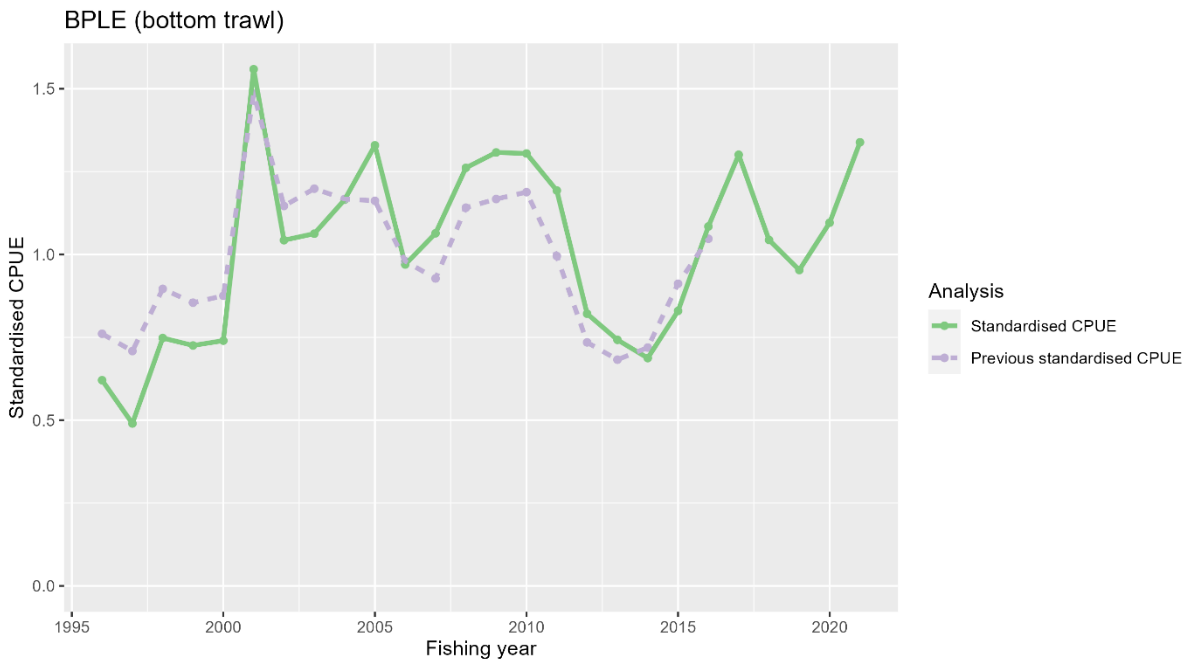

Figure 19: Combined index ('Standardised CPUE') and previous index compared for Bay of Plenty. The previous index went from 1996 to 2016, but raw data values were unavailable (Kendrick & Bentley 2017). Instead, previous index data values were approximated by digitising figure 7 on p. 1221 of Fisheries New Zealand (2021a), using the R package *digitize* (Poisot 2011), and scaled to have the same arithmetic mean value as the combined index over the years they have in common.

3.2.2 East Northland and Hauraki Gulf standardised CPUE

Core vessels were selected based on the criteria of a minimum of three trawls per year for a minimum of three years, which was the same as used by Kendrick & Bentley (2017). This retained more than 90% of the catch in most years, and at least 60% for other years (Figures 20–21). There were 40 core vessels, and they showed good overlap in effort from the start to the end of the fishery (Figure 22, Table 6).

The lognormal model explained 41% of the variation in the positive catch, with vessel (15%) and start cell location (9%) explaining the most variance (Table 7). Other variables accepted into the model were target species, month, and trawl distance. Predictor variables additional to vessel had a minor impact on the standardised index (Figure 23, Appendix 2). Diagnostics for the model were good (Figure 24).

The binomial model explained 22% of the variation in the proportion of non-zero catch, with target species the most important predictor variable explaining 9% of the variance (Table 8). Other variables that entered the model were vessel and start cell location. Diagnostics for the binomial model were good (Figure 25).

The combined index exhibited a cyclical pattern with two peaks: it increased from 1996 to 2005 followed by a decline to 2012, then increased to 2016 followed by a decline to 2021 (Figure 26). The geometric mean index showed a similar pattern to the combined index (Figure 27). The combined index was very similar to the previous standardised index with an increase to 2016, followed by a decline to 2021 for the updated index (Figure 28).

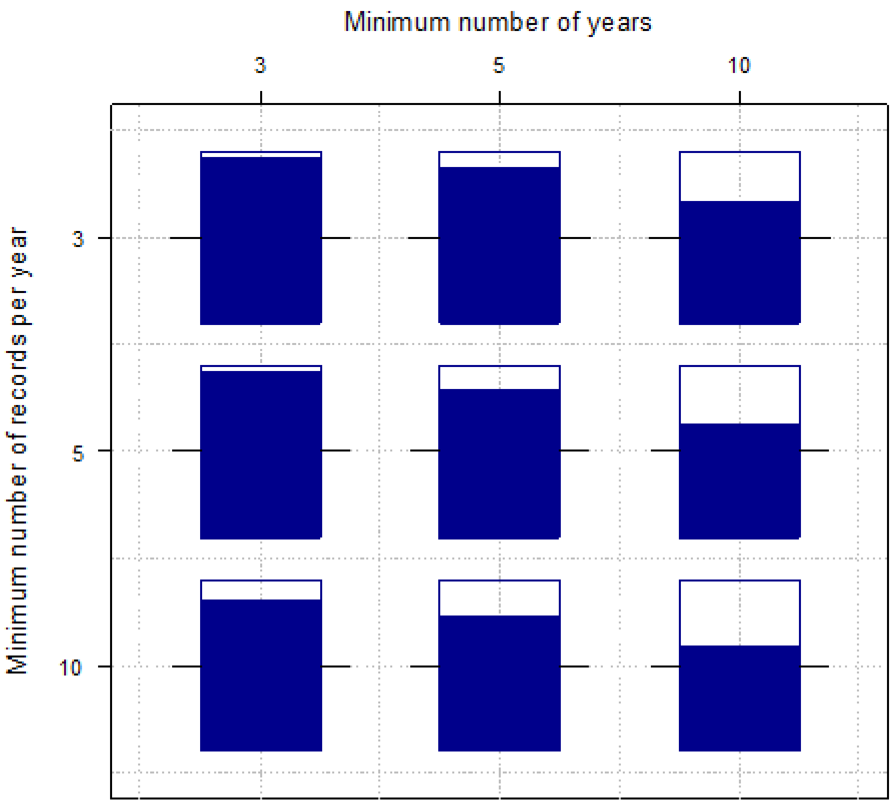

Figure 20: Proportion of the East Northland and Hauraki Gulf catch taken when subsetting data with the requirement of minimum number of records (i.e., trawls) per year, for a minimum number of years. Each bar shows the percentage of total catch retained from 1996 to 2021 under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 60% or more of the catch, otherwise they are coloured grey.

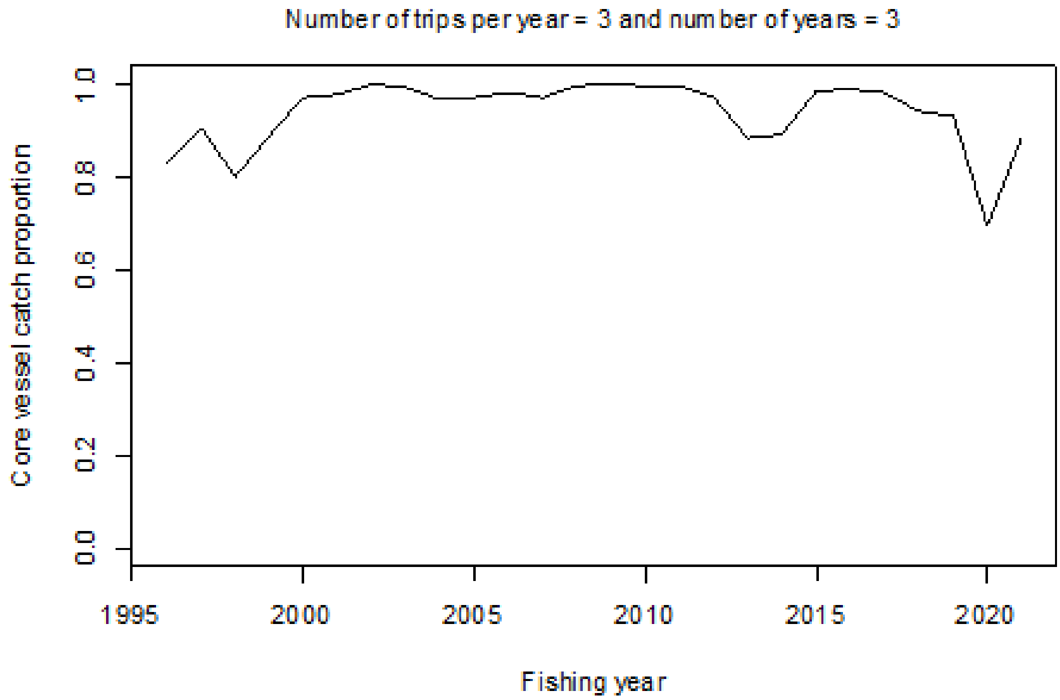

Figure 21: Proportion of the East Northland and Huraki Gulf catch retained by fishing year, after subsetting on vessels, retaining those with a minimum of three records (i.e., trawl) per year for a minimum of three years.

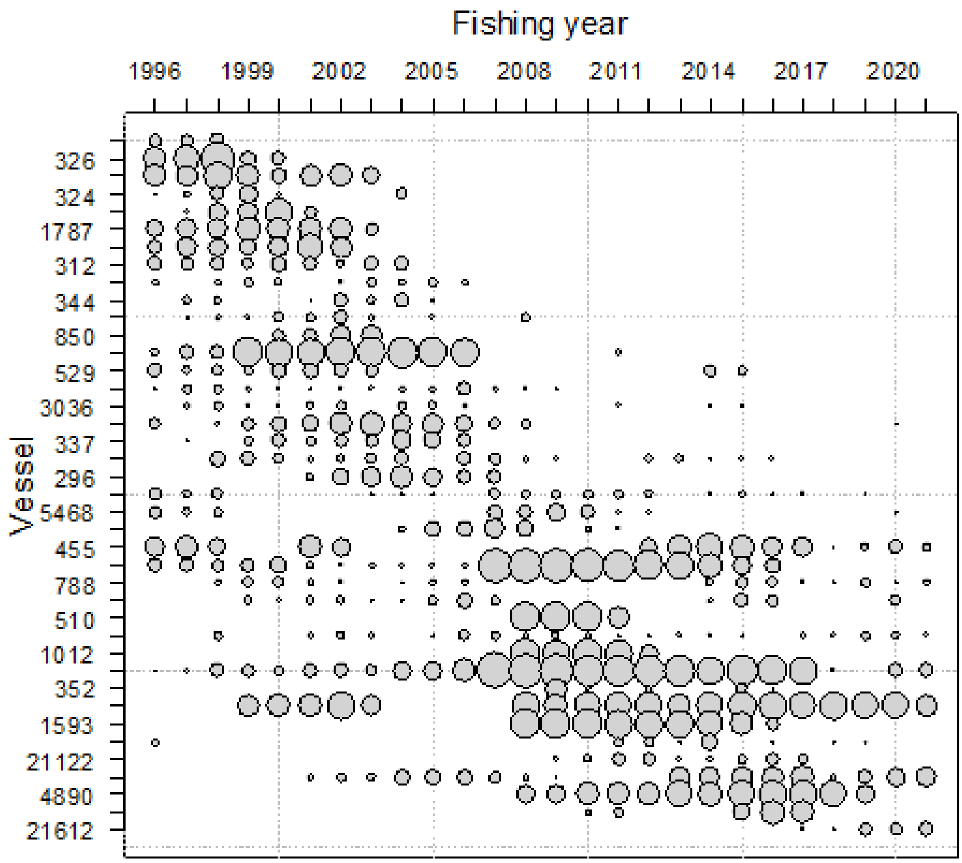

Figure 22: East Northland and Hauraki Gulf number of trawls for core vessels by vessel and fishing year. The area of the circles is proportional to the number of trawls.

Table 6: Summary of East Northland and Hauraki Gulf core vessel catch and effort for bottom trawl CPUE data.

Fishing year	Number vessels	Number trips	GUR catch (t)	Number trawls	Percent zero catch
1996	22	330	13.0	2 761	78.0
1997	22	377	14.9	3 246	77.2
1998	26	464	21.9	4 013	78.4
1999	21	362	34.2	3 437	70.6
2000	22	358	45.8	3 464	63.7
2001	25	411	65.2	3 725	53.3
2002	24	414	87.7	3 608	43.9
2003	23	310	61.6	2 524	43.8
2004	19	292	58.4	2 589	58.2
2005	16	217	71.4	2 104	42.8
2006	16	231	63.5	1 942	39.9
2007	12	245	60.8	2 184	35.8
2008	16	396	79.1	3 511	31.3
2009	15	393	64.1	4 133	39.2
2010	15	367	68.5	3 819	37.3
2011	16	310	53.2	3 471	36.3
2012	14	300	28.5	3 382	57.9
2013	11	287	34.0	3 587	54.7
2014	17	339	43.7	3 368	54.2
2015	18	352	42.8	3 109	53.0
2016	15	282	50.3	2 485	39.8
2017	12	240	39.8	2 360	43.4
2018	9	109	11.7	763	28.2
2019	10	111	9.8	839	46.6
2020	10	154	7.5	1 089	71.2
2021	7	129	5.5	892	71.3

Table 7: 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	25	0.11
vessel	39	0.26
Loc2	42	0.35
target	5	0.38
month	11	0.40
ns(log_distance, df = 3)	3	0.41

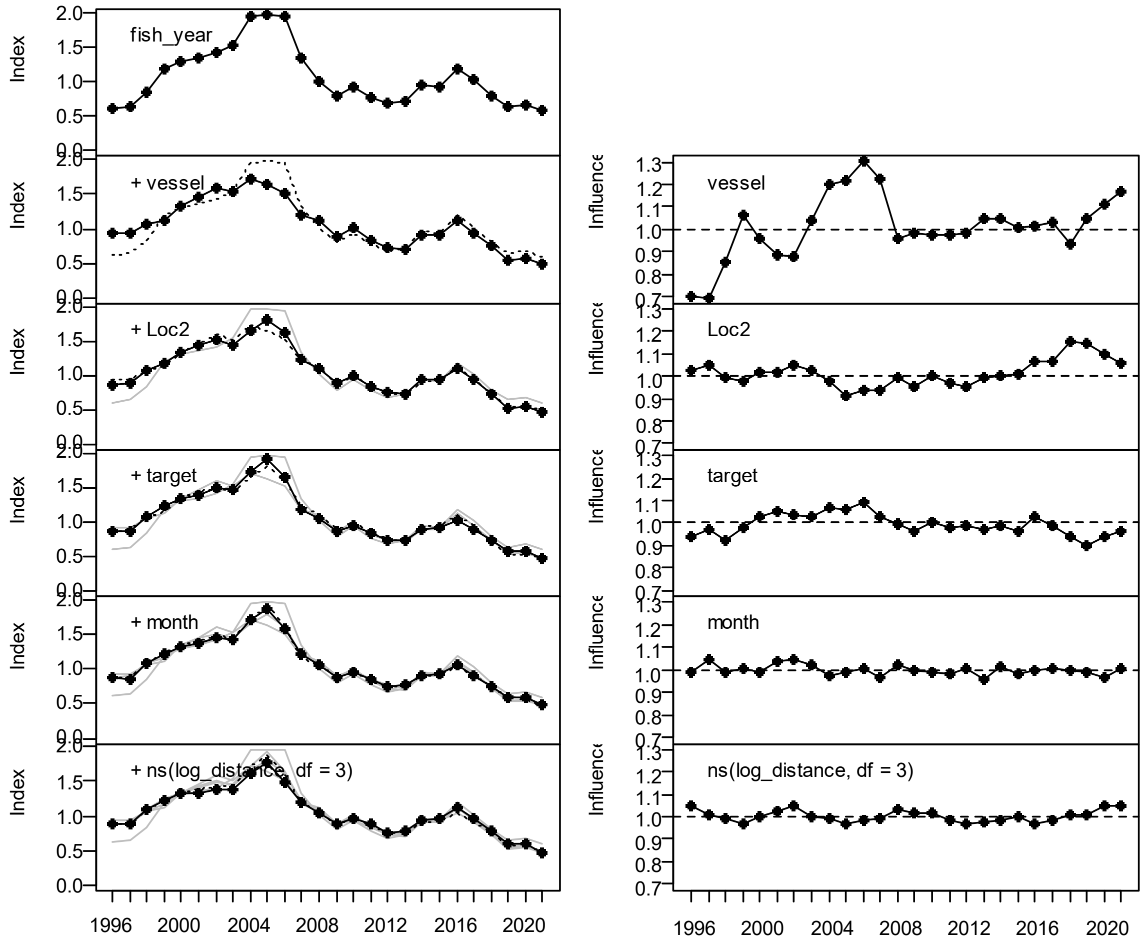

Figure 23: Stepwise influence plots showing the impact of sequentially adding predictor variables for the lognormal component of the East Northland and Hauraki Gulf standardisation (see Table 7).

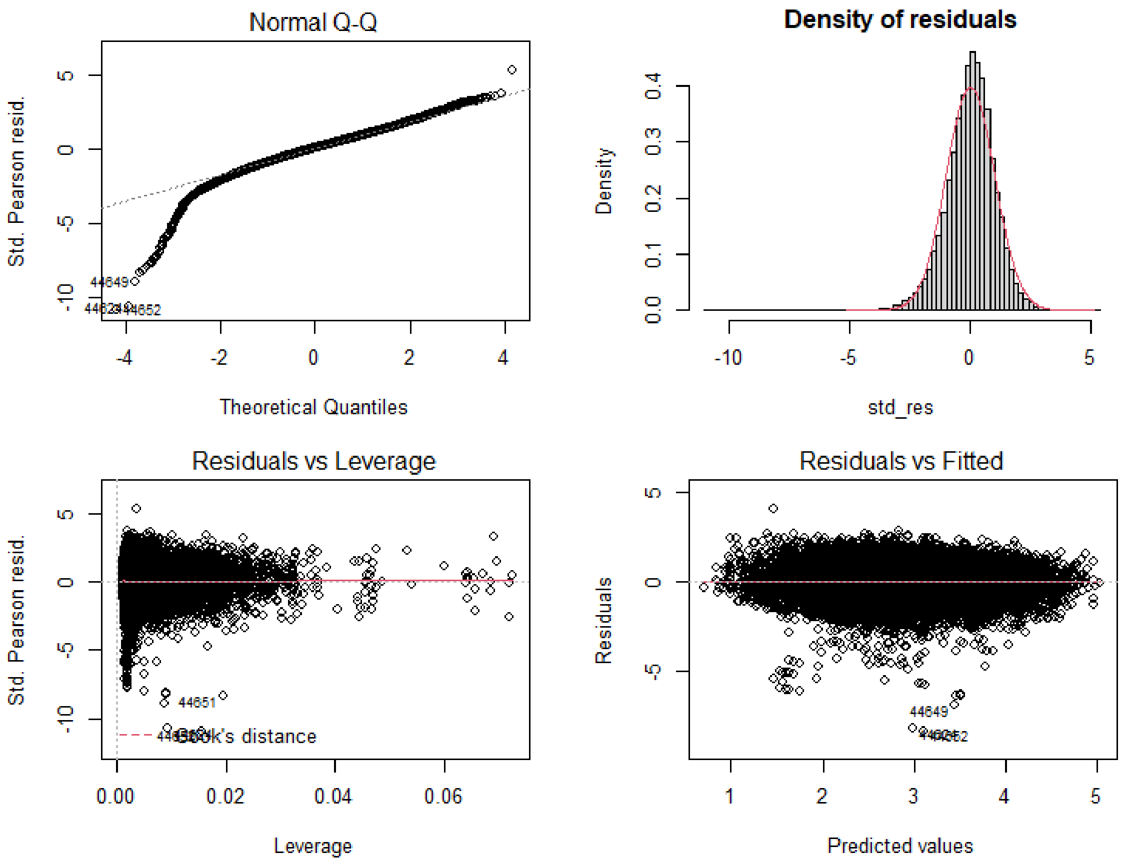

Figure 24: Residuals for the lognormal component of the East Northland and Hauraki Gulf standardisation model.

Table 8: 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	25	0.07
target	5	0.16
vessel	39	0.20
Loc2	42	0.22

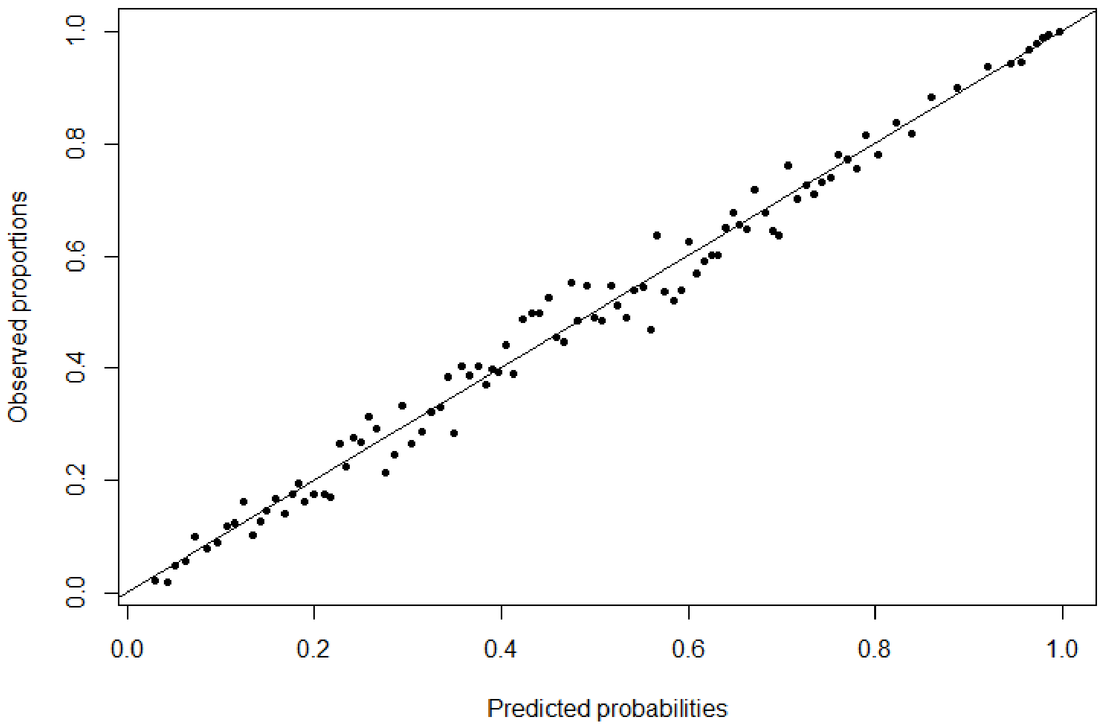

Figure 25: Diagnostic for the binomial component of the East Northland and Hauraki Gulf standardisation model.

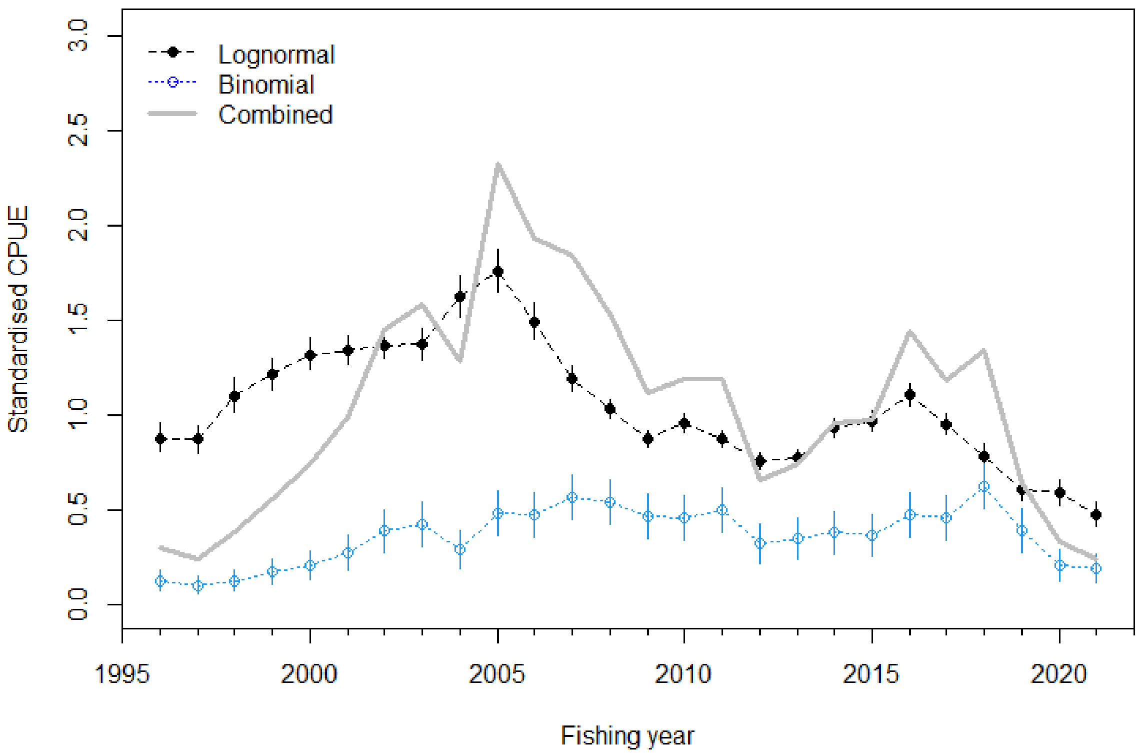

Figure 26: Binomial component, lognormal component, and combined index for the East Northland and Hauraki Gulf (part of GUR 1) standardisation model. Error bars are ± two standard deviations.

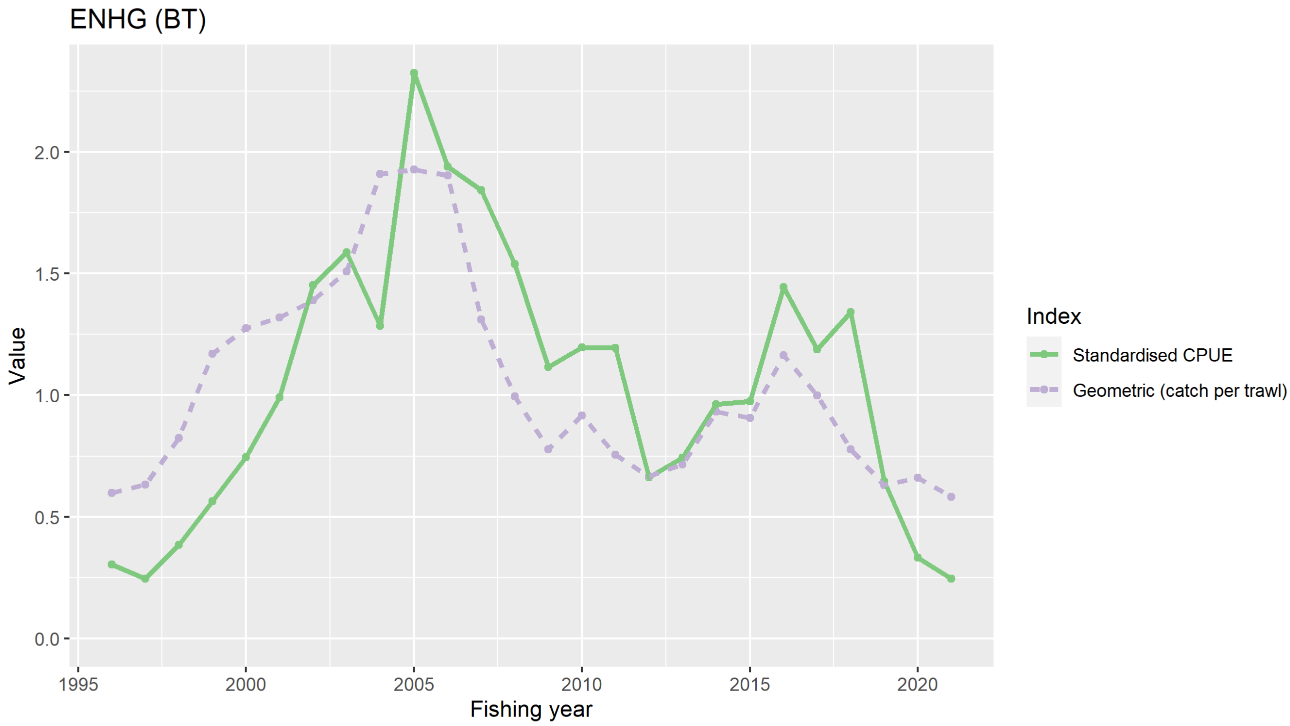

Figure 27: Combined index ('Standardised CPUE') and geometric mean CPUE compared for East Northland and Hauraki Gulf.

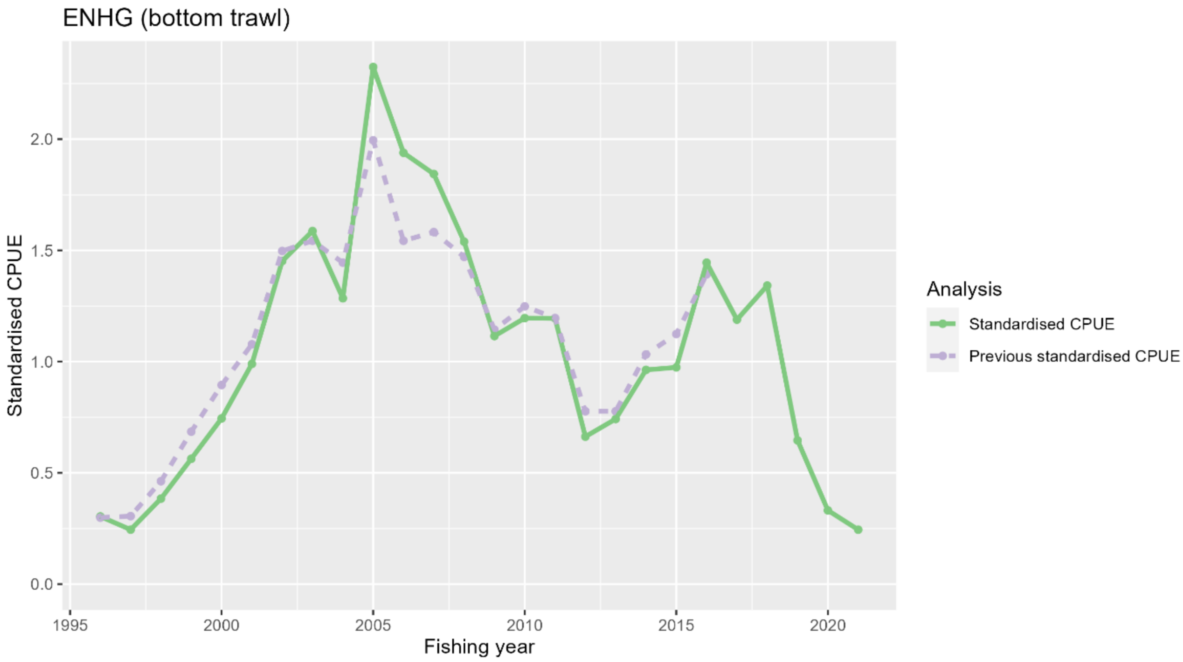

Figure 28: Combined index ('Standardised CPUE') and previous index compared for East Northland and Hauraki Gulf. The previous index went from 1996 to 2016, but raw data values were unavailable (Kendrick & Bentley 2017). Instead, previous index data values were approximated by digitising figure 6 on p. 1220 of Fisheries New Zealand (2021a), using the R package *digitize* (Poisot 2011), and scaled to have the same arithmetic mean value as the combined index over the years they have in common.

3.2.3 West coast North Island standardised CPUE

Core vessels were selected based on the criteria of a minimum of three trawls per year for a minimum of three years, which was the same as used by Kendrick & Bentley (2017). This retained nearly 100% of the catch in many years, and at least 80% for other years (Figures 29–30). There were 31 core vessels, and they showed good overlap in effort from the start to the end of the fishery (Figure 31, Table 9).

The lognormal model explained 31% of the variation in the positive catch, with vessel (14%) and start cell location (8%) explaining the most variance (Table 10). The other variables accepted into the model were target species, trawl distance, and fishing depth. The vessel predictor variable increased the standardised index over the years 2004 to 2008, and decreased it over the years to 2010 to 2019 (Figure 32, Appendix 3). Diagnostics for the model were good (Figure 33).

The binomial model explained 41% of the variation in the proportion of non-zero catch, with fishing depth the most important predictor variable explaining 29% of the variance (Table 11). Other variables that entered the model were vessel, start cell location, and target species. Diagnostics for the binomial model were good (Figure 34).

The combined index was similar to the lognormal component with a cyclical pattern and general increase from 1996 to 2015 then a decline (Figure 35). The geometric mean CPUE showed a similar pattern of fluctuations to the combined index, but of different magnitude, and an increase from 2019 to 2021 instead of a slight decline (Figure 36). The combined index was very similar to the previous standardised index over the years in common (1996 to 2016), then stayed essentially flat after 2016 (Figure 37).

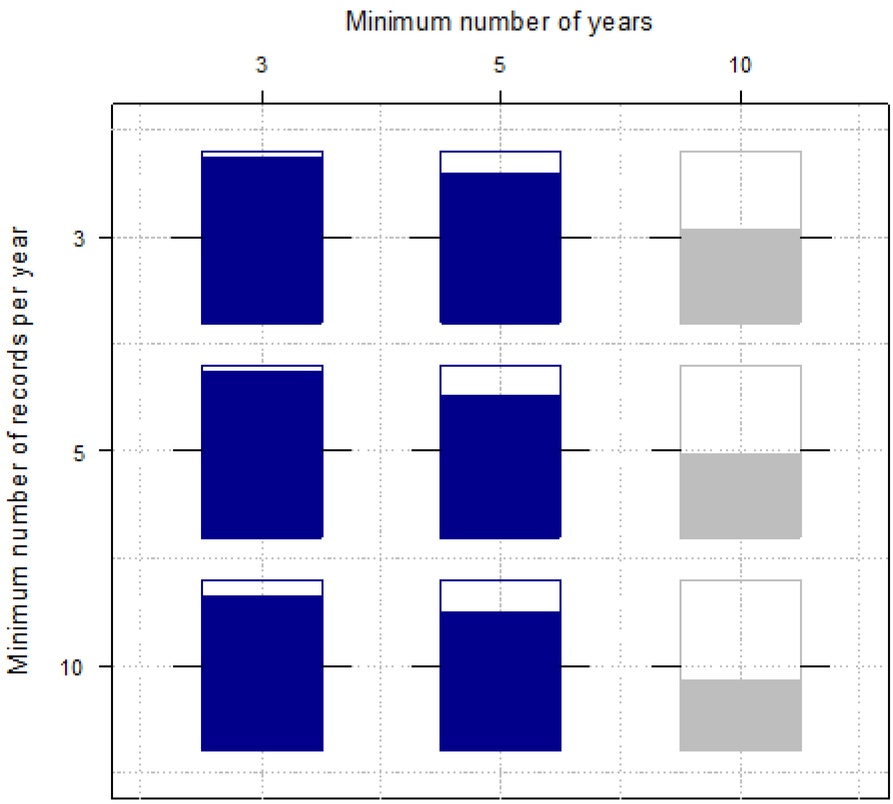

Figure 29: Proportion of the west coast North Island catch taken when subsetting data with the requirement of minimum number of records (i.e., trawls) per year, for a minimum number of years. Each bar shows the percentage of total catch retained from 1996 to 2021 under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 60% or more of the catch, otherwise they are coloured grey.

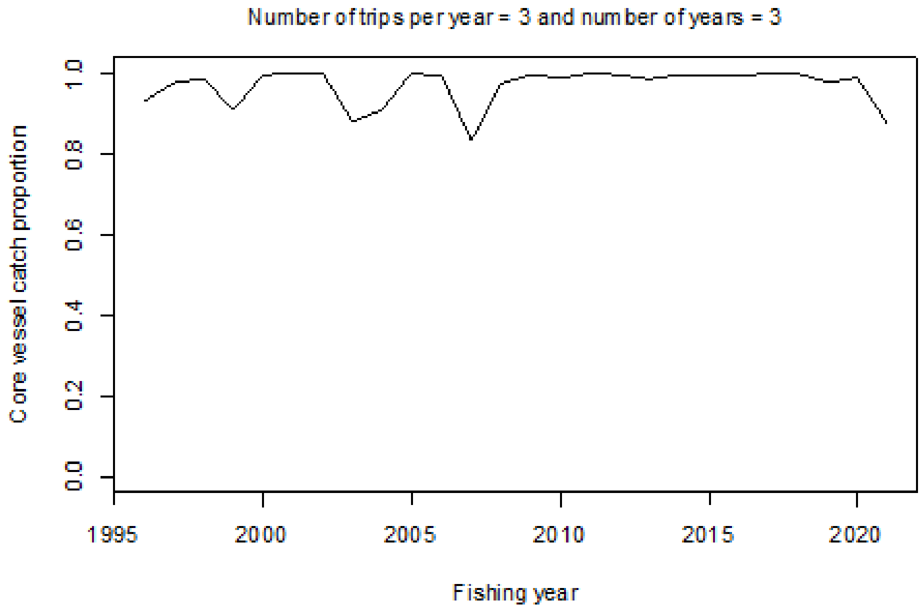

Figure 30: Proportion of the west coast North Island catch retained by fishing year, after subsetting on vessels, retaining those with a minimum of three records (i.e., trawl) per year for a minimum of three years.

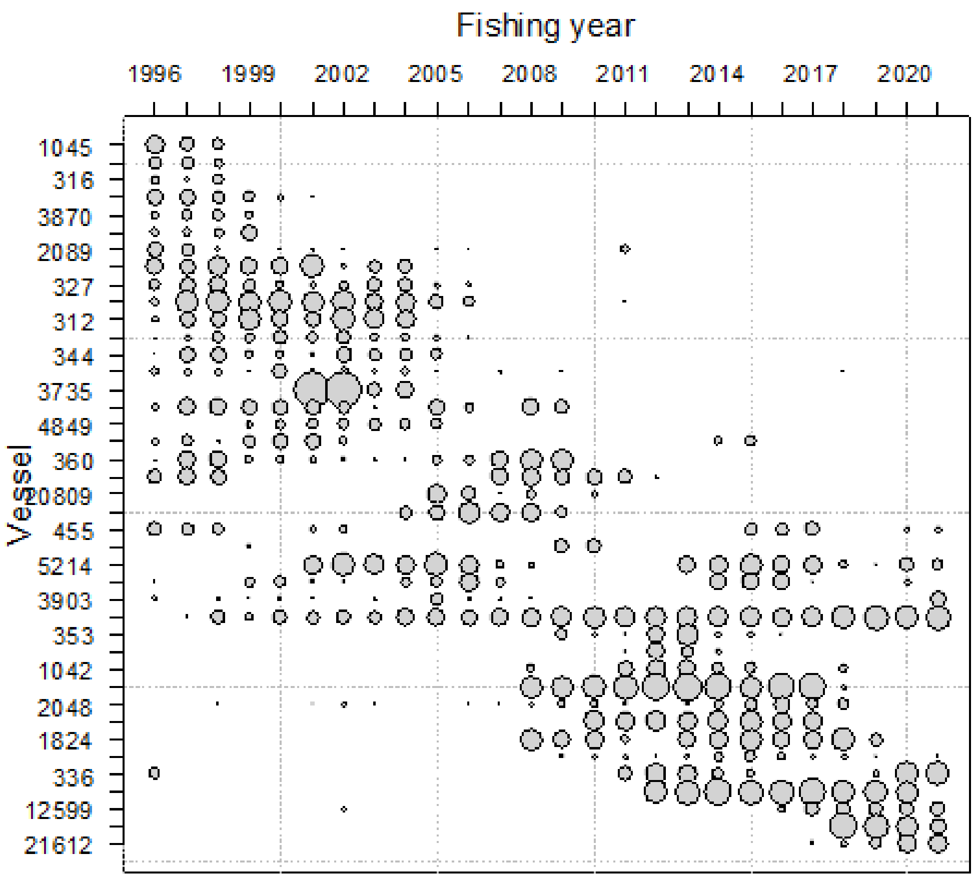

Figure 31: West coast North Island number of trawls for core vessels by vessel and fishing year. The area of the circles is proportional to the number of trawls.

Table 9: Summary of west coast North Island core vessel catch and effort for bottom trawl CPUE data.

Fishing year	Number vessels	Number trips	GUR catch (t)	Number trawls	Percent zero catch
1996	22	233	196.6	2 034	38.9
1997	20	338	259.5	3 121	39.7
1998	21	329	248.8	3 371	35.2
1999	19	242	199.0	2 995	34.7
2000	17	235	208.7	2 773	36.5
2001	18	320	344.5	2 965	25.0
2002	17	246	287.0	2 311	26.1
2003	15	199	341.9	2 030	23.2
2004	15	234	346.0	2 743	22.1
2005	14	224	399.1	2 637	25.5
2006	12	168	284.8	1 649	20.7
2007	11	128	272.3	1 593	14.4
2008	12	242	351.6	2 563	20.1
2009	11	225	238.6	2 411	22.3
2010	10	199	227.5	2 071	16.8
2011	13	193	223.8	2 010	20.6
2012	11	282	440.9	2 857	11.6
2013	12	349	495.9	3 332	10.7
2014	15	338	407.8	2 830	14.1
2015	14	347	517.3	3 079	13.2
2016	13	294	385.7	2 701	16.2
2017	11	288	332.9	2 495	16.8
2018	12	243	305.7	2 078	14.5
2019	9	194	255.2	1 568	16.7
2020	10	245	354.1	1 947	18.6
2021	9	201	281.3	1 586	22.0

Table 10: 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	25	0.04
vessel	40	0.18
Loc2	70	0.26
target	5	0.28
ns(log_distance, df = 3)	3	0.30
ns(effort_depth, df = 3)	3	0.31

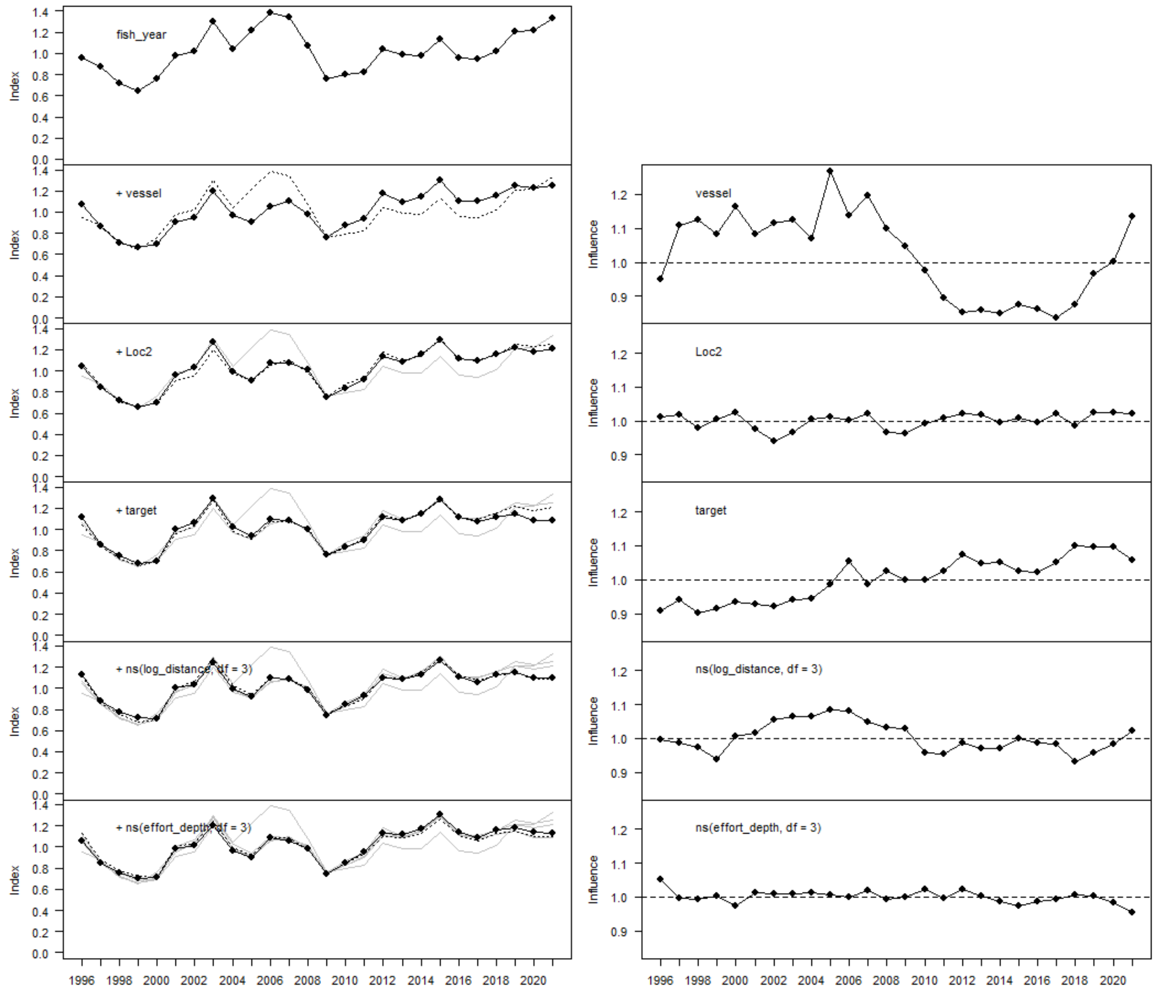

Figure 32: Stepwise influence plots showing the impact of sequentially adding predictor variables for the lognormal component of the west coast North Island standardisation (see Table 10).

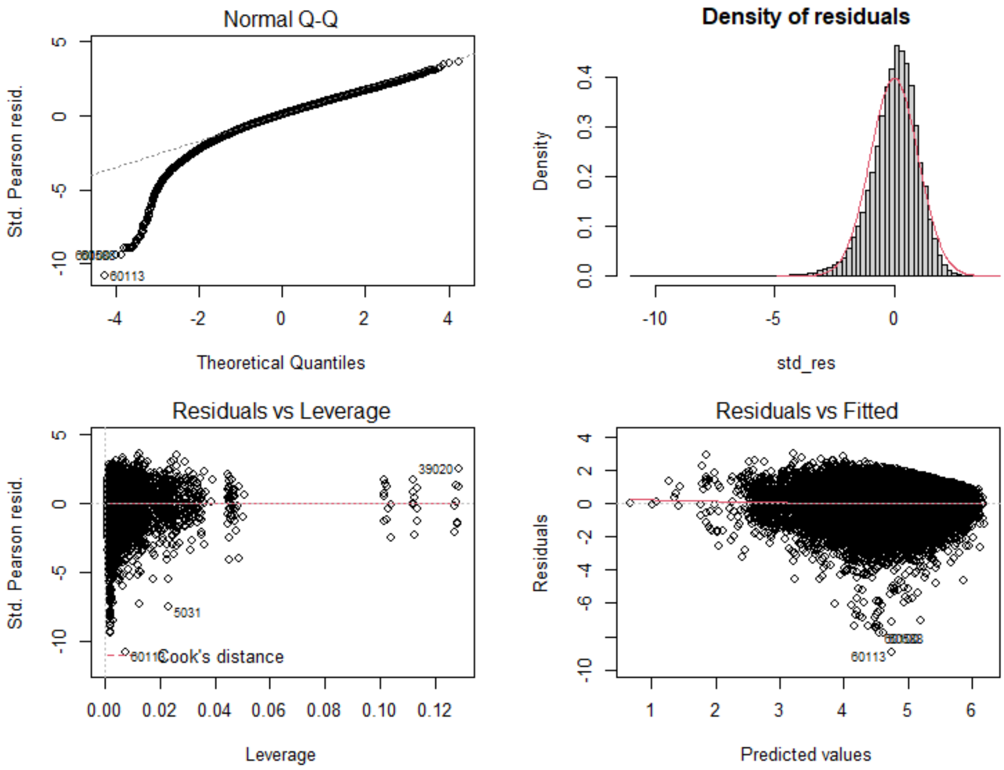

Figure 33: Residuals for the lognormal component of the west coast North Island standardisation model.

Table 11: 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	25	0.04
ns(effort_depth, df = 3)	3	0.33
vessel	40	0.37
Loc2	70	0.39
target	5	0.41

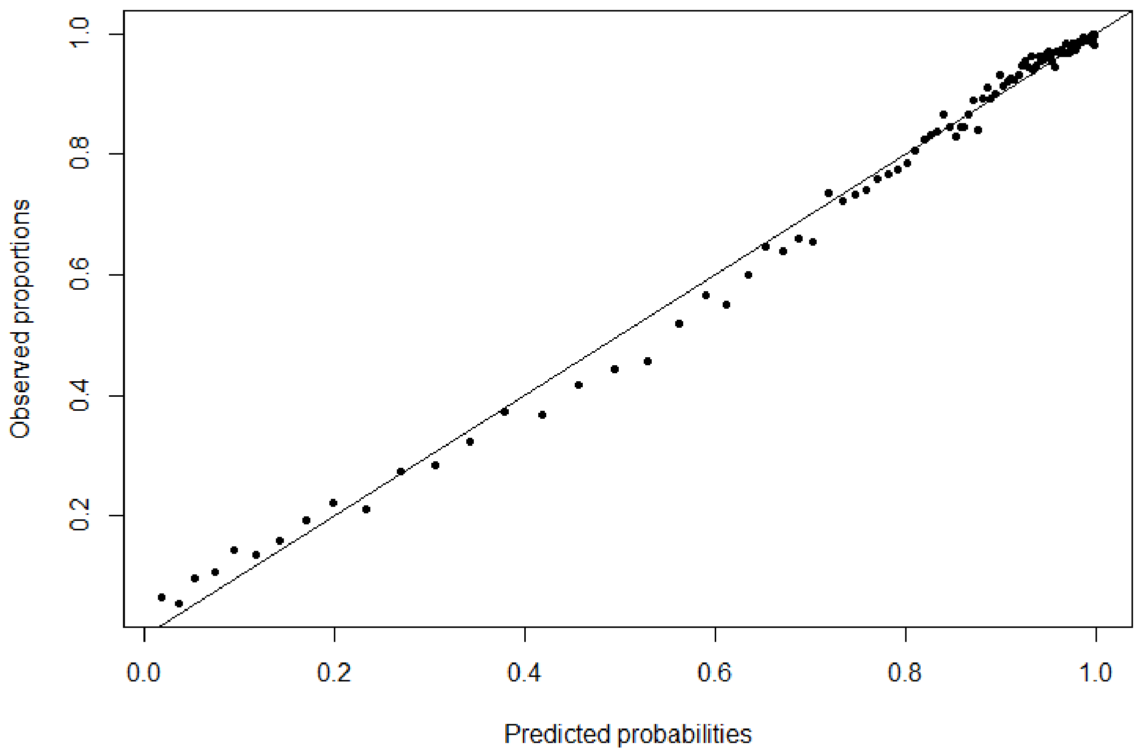

Figure 34: Diagnostic for the binomial component of the west coast North Island standardisation model.

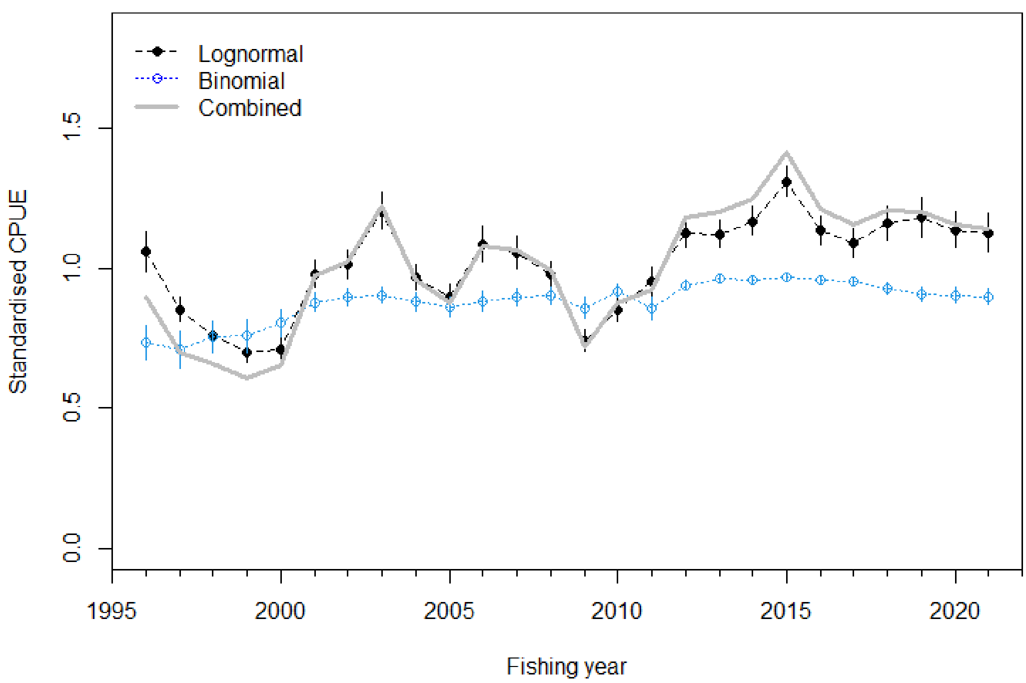

Figure 35: Binomial component, lognormal component, and combined index for the west coast North Island (part of GUR 1) standardisation model. Error bars are ± two standard deviations.

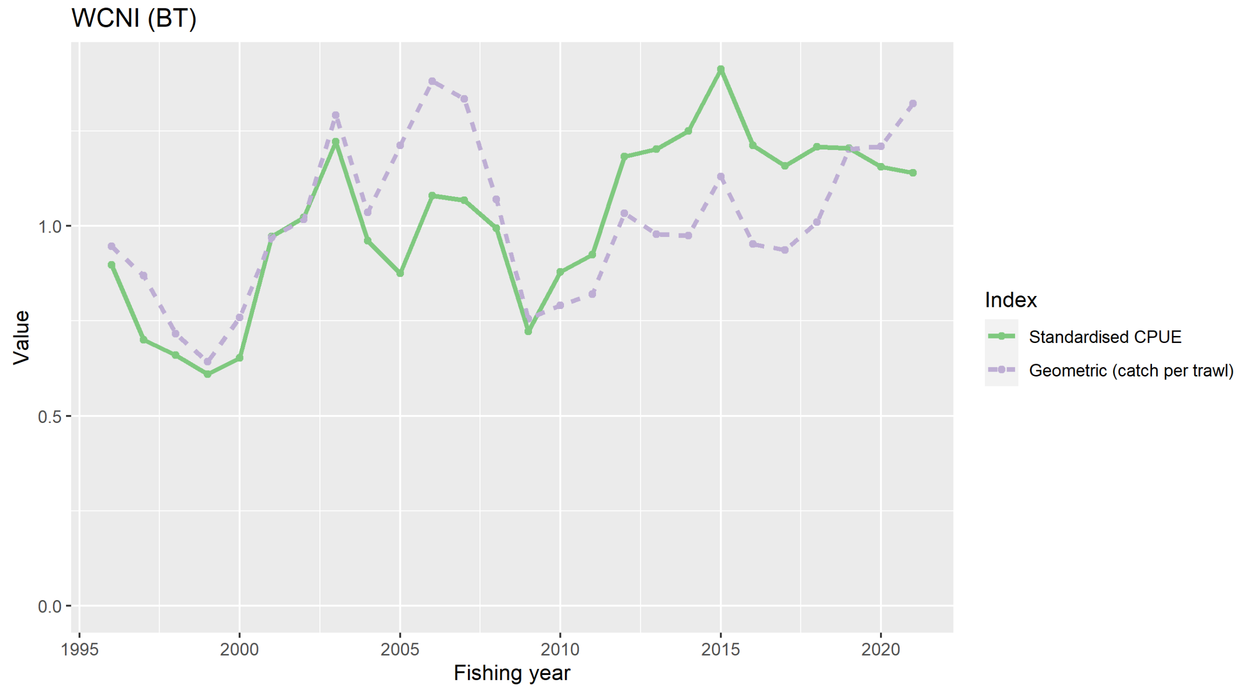

Figure 36: Combined index ('Standardised CPUE') and geometric mean CPUE compared for west coast North Island.

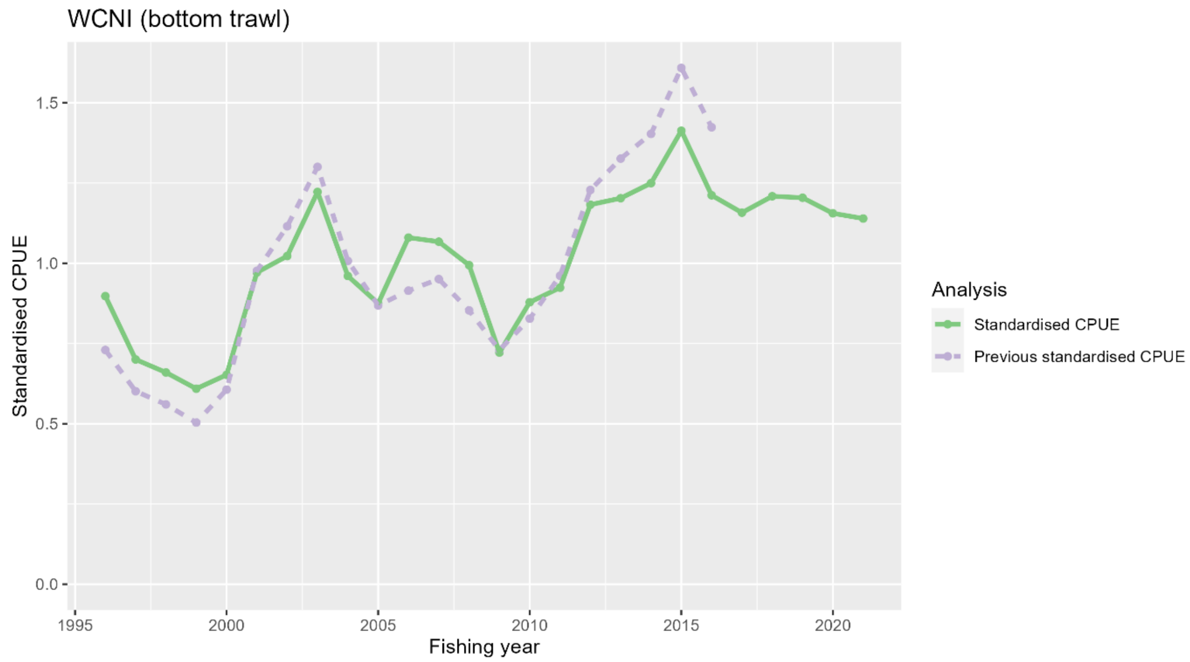

Figure 37: Combined index ('Standardised CPUE') and previous index compared for west coast North Island. The previous index went from 1996 to 2016, but raw data values were unavailable (Kendrick & Bentley 2017). Instead, previous index data values were approximated by digitising figure 5 on p. 1219 of Fisheries New Zealand (2021a), using the R package *digitize* (Poisot 2011), and scaled to have the same arithmetic mean value as the combined index over the years they have in common.

3.2.4 Comparison of standardised CPUE by area

The three areas BPLE, ENHG, and WCNI are thought to be sub-stocks of GUR 1, and, therefore, their standardised CPUE indices need not follow the same trends (Figure 38). Although some parts of the east coast BPLE and ENHG indices have a similar pattern (e.g., the increase from 1997 to 2001), other parts do not, and the pattern for WCNI is quite different from the other areas.

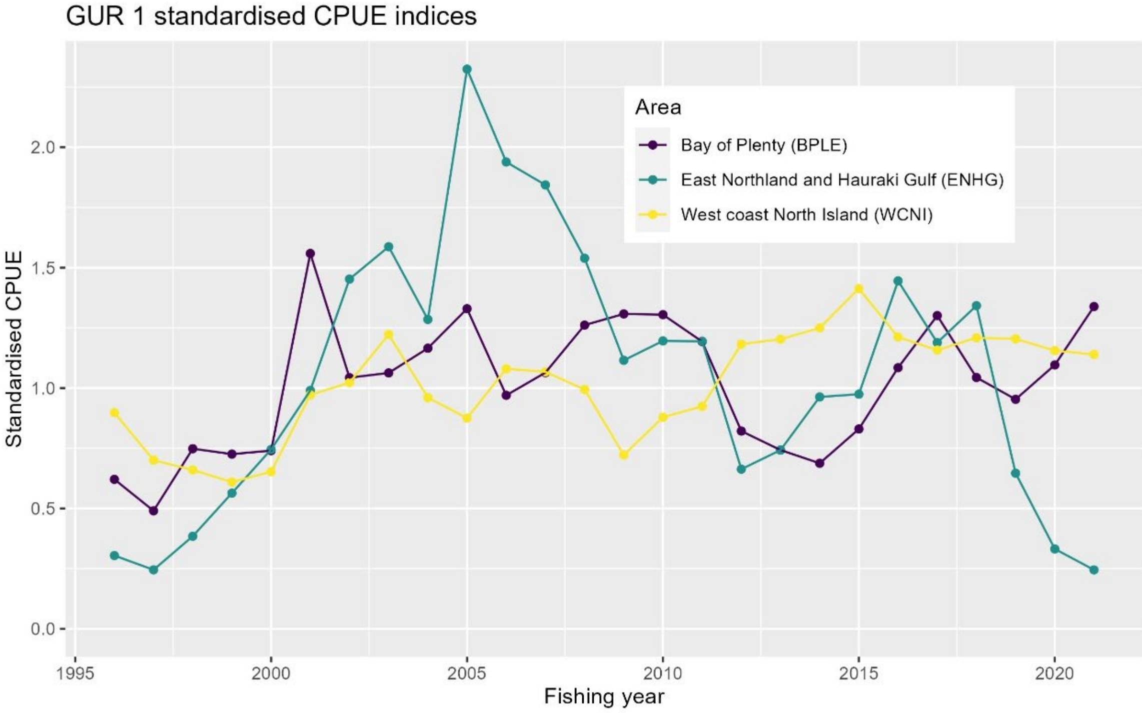

Figure 38: Standardised CPUE for the three areas: BPLE, ENHG, WCNI.

3.3 Stock status, trawl surveys, and relative fishing mortality

3.3.1 Bay of Plenty

In the BPLE the standardised indices have fluctuated cyclically about the target level, but always above the soft limit, except in 1997 (Figure 39). Relative fishing mortality proxy from 1996 to 2000 was above the mean value for the reference years and fluctuated at or below the mean value since (Figure 40). The trawl survey recruited biomass indices, where they overlap with the standardised indices, are either essentially flat like the indices (1996 and 1999) or show opposite trends (2020 and 2021) (see Figure 39). Overall, both series suggest the stock has fluctuated cyclically but without trend.

3.3.2 East Northland and Hauraki Gulf

In ENHG the standardised indices increased from 1996 to 2005 to be above the target level, decreased until they fell below the target level by 2012, increased again to be above the target level between 2016 and 2018, but then decreased to be below the target level in 2020 and 2021 (Figure 41) Relative fishing mortality proxy was above the overfishing threshold in 1996 and 1997. It then declined to about 20% of this level in 2003, fluctuated without trend, then increased after 2018 and was above the threshold in 2021 (Figure 42). Note that after 2017 vessels switched to PSH gear and there was a substantial decline in bottom trawl catch and effort, and the standardised CPUE index may not track abundance. The trawl survey recruited biomass indices for the Hauraki Gulf, showed a mixed correspondence with trends in the standardised CPUE indices (see Figure 41). From 1998 to 2001 the trawl indices declined but the standardised indices increased; from 2020 to 2021 both the trawl indices and standardised indices declined.

3.3.3 West coast North Island

The WCNI the standardised CPUE indices increased after 2009 to be well above the target level in 2021 (Figure 43). Relative fishing mortality proxy declined after 1997 to be about 70% of the overfishing threshold in 2021 (Figure 44). The trawl survey recruited biomass indices showed different trends from the standardised indices (see Figure 43). For example, the trawl survey indices declined substantially from 1997 to 2000 but the standardised indices declined only slightly over this period; from 2019 to 2021 the trawl survey indices increased substantially but the standardised indices declined slightly.

In summary, for BPLE and WCNI the stock status in 2021 was above the target level, and relative fishing mortality proxy was below the overfishing threshold, whereas for ENHG the stock status in 2021 was below the target level, and relative fishing mortality was above the mean value for the reference years. There was limited correspondence between trends for trawl survey recruited biomass indices and standardised indices.

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

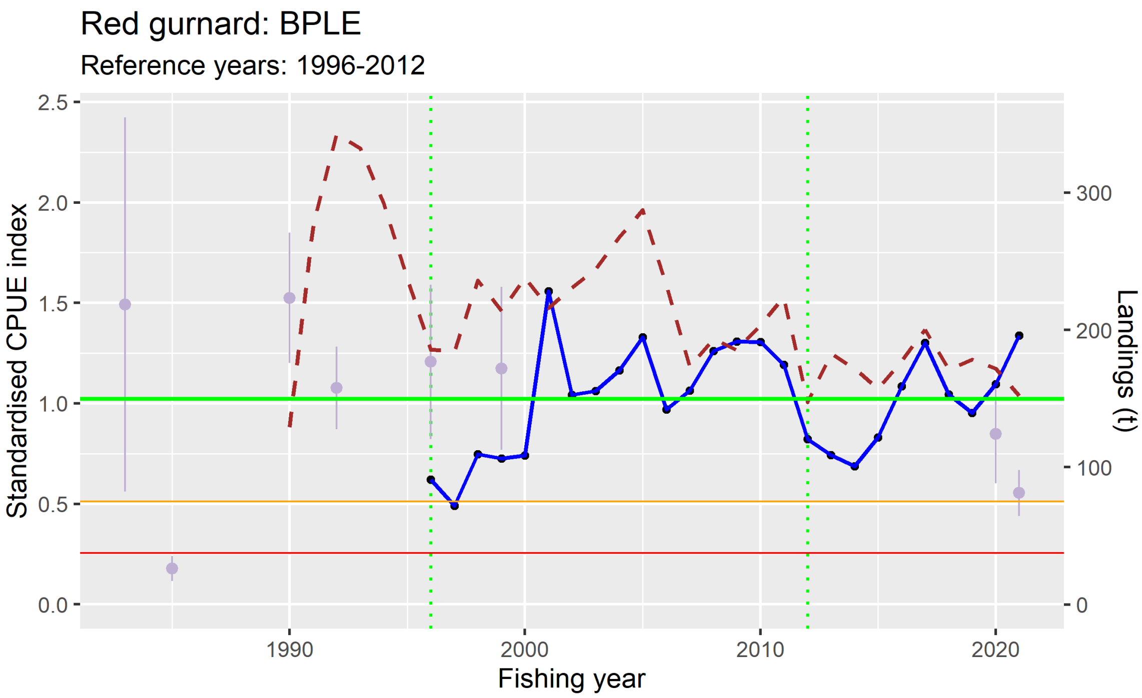

Figure 39: Standardised CPUE indices for red gurnard in the Bay of Plenty from combined binomial and lognormal models of catch rate in bottom trawl tows in a mixed target fishery (blue line). Solid horizontal lines indicate the target (green), soft limit (orange), and hard limit (red). The commercial catch from the area is also presented (dashed brown line), and trawl survey recruited biomass indices (purple with error bars ± two standard deviations).

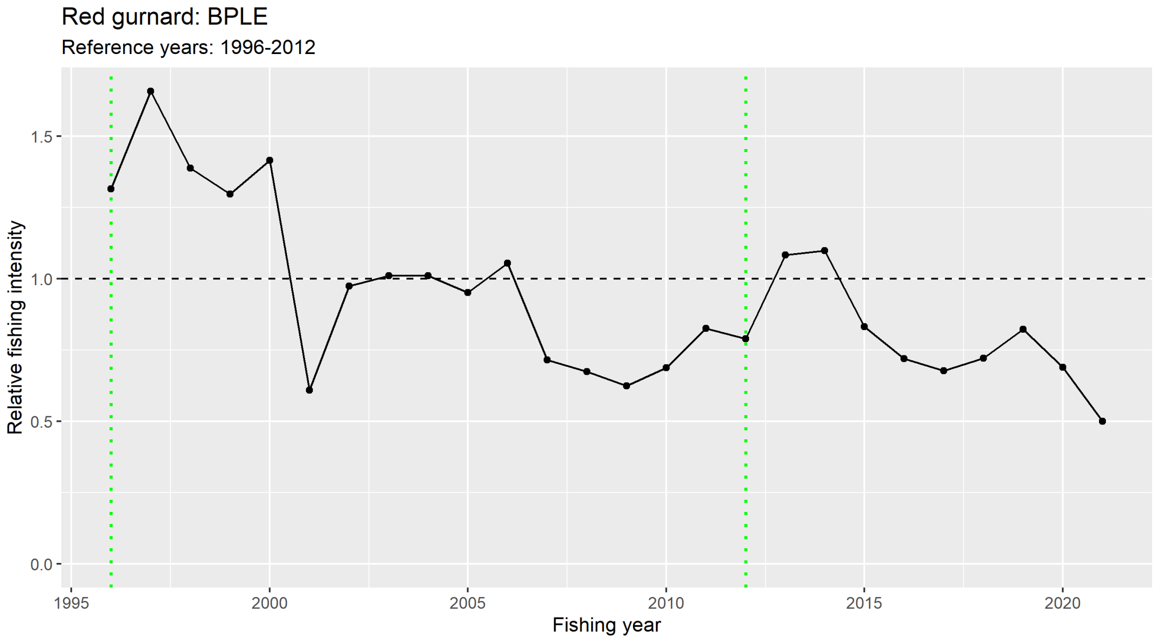

Figure 40: Relative fishing mortality proxy for red gurnard in the Bay of Plenty, derived from total area catch divided by CPUE indices from the recent CPUE analysis (black points). The dashed horizontal line represents the average fishing mortality in the period used to define the reference points (vertical green dotted lines).

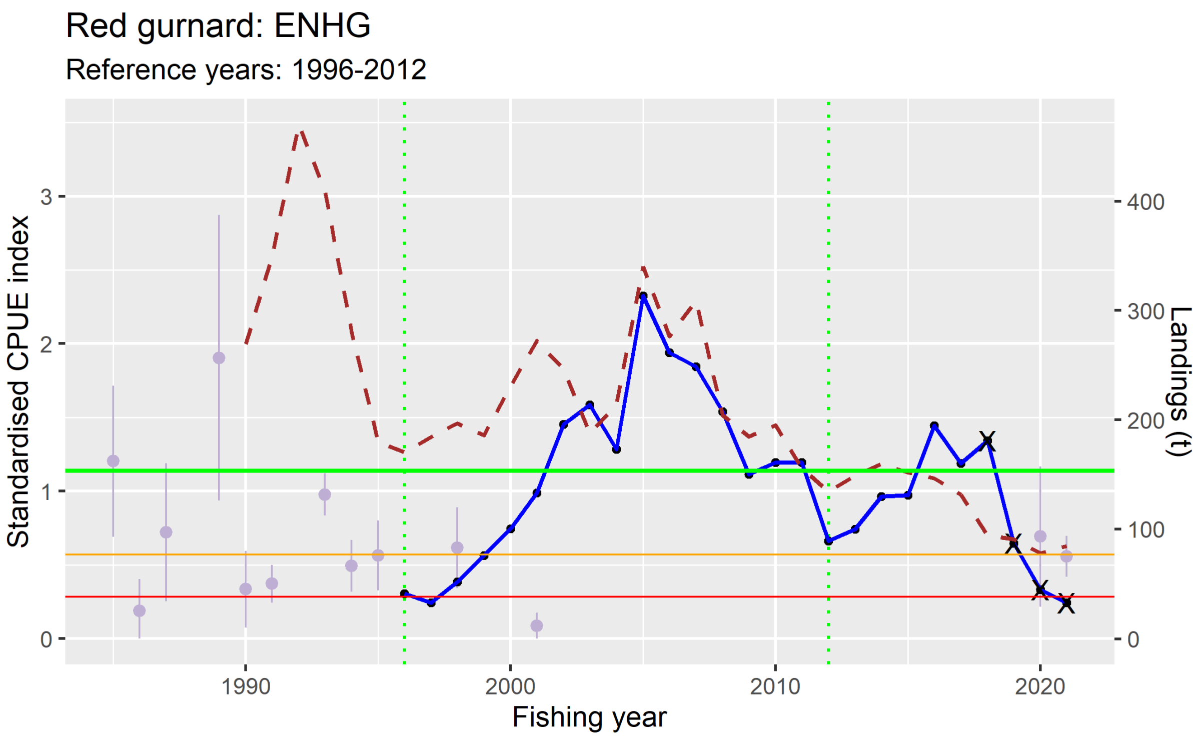

Figure 41: Standardised CPUE indices for red gurnard in east Northland and Hauraki Gulf from combined binomial and lognormal models of catch rate in bottom trawl tows in a mixed target fishery (blue line). Solid horizontal lines indicate the target (green), soft limit (orange), and hard limit (red). 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). For fishing years 2018 to 2021 standardised CPUE is plotted with a cross, marking when vessels switched to PSH gear, and a substantial decline in bottom trawl catch and effort.

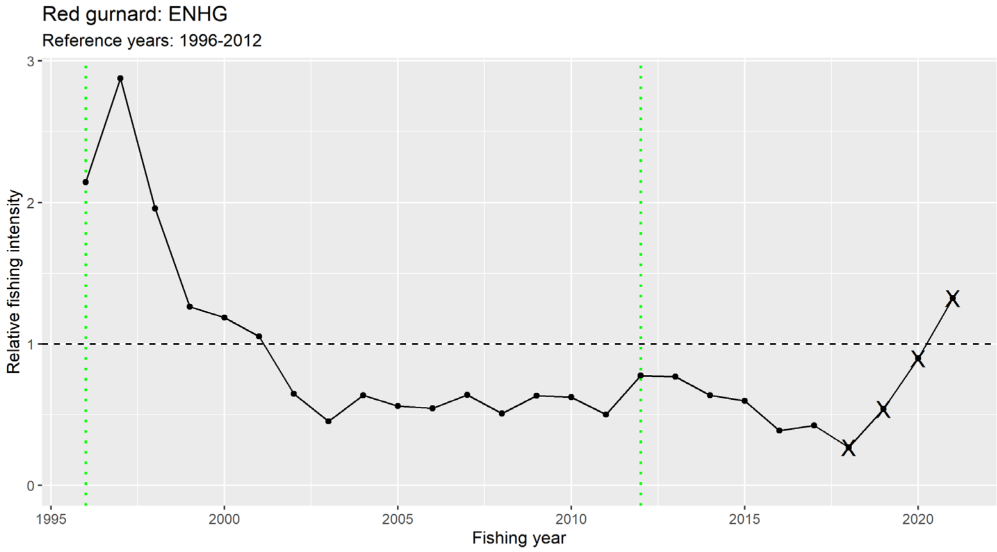

Figure 42: Relative fishing mortality proxy for red gurnard in east Northland and Hauraki Gulf, derived from total area catch divided by CPUE indices from the recent CPUE analysis (black points). The dashed horizontal line represents the average fishing mortality in the period used to define the reference points (vertical green dotted lines). For fishing years 2018 to 2021 standardised CPUE is plotted with a cross, marking when vessels switched to PSH gear, and a substantial decline in bottom trawl catch and effort.

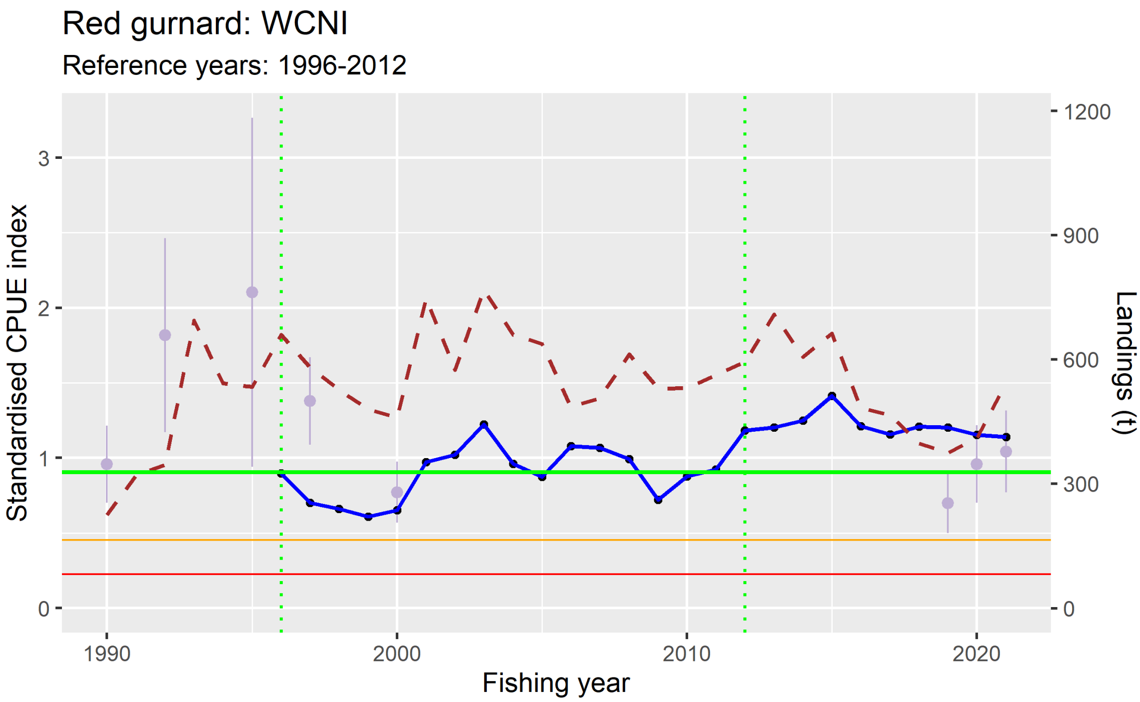

Figure 43: Standardised CPUE indices for red gurnard in west coast North Island from combined binomial and lognormal models of catch rate in bottom trawl tows in a mixed target fishery (blue line). Solid horizontal lines indicate the target (green), soft limit (orange), and hard limit (red). The commercial catch from the area is also presented (dashed brown line), and trawl survey recruited biomass indices (purple with error bars ± two standard deviations).

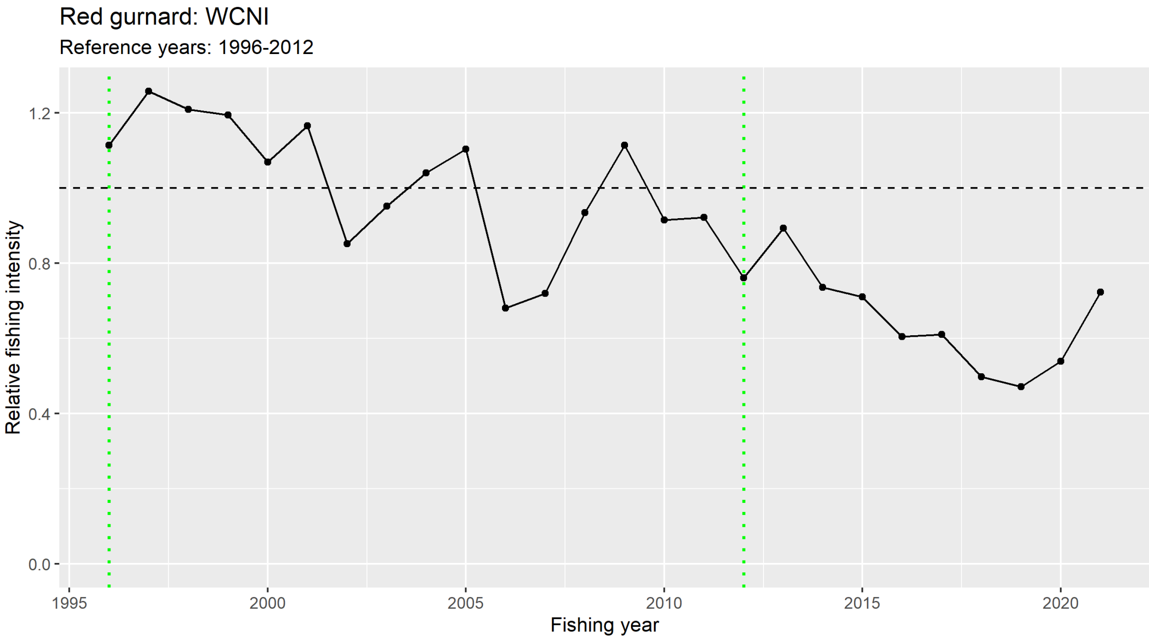

Figure 44: Relative fishing mortality proxy for red gurnard in west coast North Island, derived from total area catch divided by CPUE indices from the recent CPUE analysis (black points). The dashed horizontal line represents the average fishing mortality in the period used to define the reference points (vertical green dotted lines).

3.4 Explorations of stock structure

3.4.1 Data availability

Figure 45 shows the data available for red gurnard by data type and season from trawl surveys. Consistent with patterns in catch data (Figure 10), survey data indicate a continuous distribution of red gurnard off the west coast of the North Island in GUR 1 and the northern region of GUR 8, and throughout the Hauraki Gulf and Bay of Plenty (Figure 45). Similarly, around the South Island, survey data indicate a continuous distribution of red gurnard in GUR 7 from the western side of the Marlborough Sounds, through Tasman Bay-Golden Bay (TBGB), and down the west coast of the South Island to approximately Haast/Jackson Bay, as well as throughout GUR 3: ECSI (Figure 45).

While a large amount of length data exist for red gurnard from the WCNI, East Northland, Hauraki Gulf and Bay of Plenty, the majority of these records were collected prior to 2000 and do not have associated sex or gonad stage information (Figure 45, see also Figure 76), as red gurnard were not the target of several of these surveys (J. McKenzie, NIWA, pers. comm.).

Off the west coast of the South Island, data were largely restricted to autumn months, when the west coast South Island (WCSI) trawl survey is undertaken. Off the east coast of the South Island, in GUR 3, data were available for most seasons except for spring, with the majority of these data deriving from the east coast South Island (ECSI) trawl survey, which operated in autumn and winter in 1991 to 1994, 1996, and again in 2007–2009, 2012, 2014, 2016, 2018 and 2021, and in summer from 1996 to 2000 (Beentjes et al. 2022).

3.4.2 Patterns in length data

Red gurnard in the 0+ age group (i.e., individuals less than 15 cm length) were widespread in depths less than 50 m in most areas. Hotspots of juveniles included the North Island west coast, Hauraki Gulf, and Bay of Plenty in GUR 1, TBGB in GUR 7, and Pegasus Bay in GUR 3 (Figure 46).

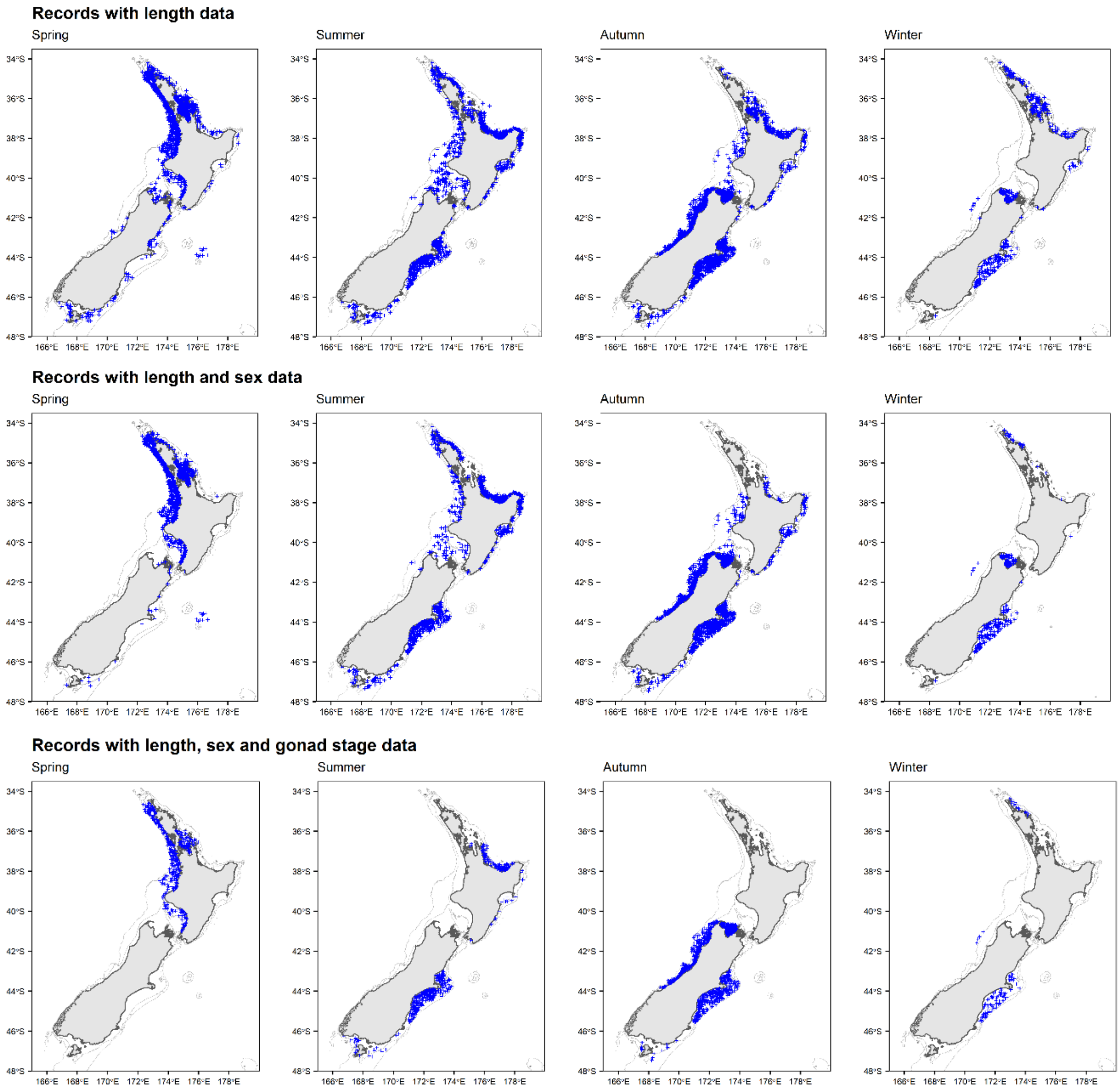

Figure 45: Summary of data availability by data type, geographic position, and season for red gurnard from trawl surveys. Note ‘sex’ refers to individuals specifically recorded as female or male, and excludes both juvenile individuals for which a sex determination could not be made and individuals for which sex was not assessed.

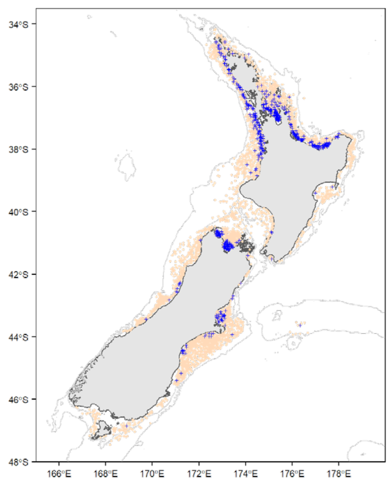

Figure 46: Locations where 0+ red gurnard have been recorded during trawl surveys (blue crosses). Pink circles indicate where red gurnard of any length have been observed.

Across all surveyed areas, smaller gurnard were uniformly observed inshore and larger individuals offshore. This pattern was evident for both sexes, and showed little variation within a given area among seasons (Figure 47). Moreover, there was no evidence for areas of aggregations of large fish within a given season. Differences among areas in length were evident, however. In general, there was a tendency for fish in the southern QMAs (i.e., GUR 3, GUR 7) to be larger than those in the north (i.e., GUR 1, GUR 2, and GUR 8) (Figure 47 and Figure 48). Red gurnard in TBGB were on average smaller than those off the west coast of the South Island, although a wide size range was observed in both areas. Red gurnard in GUR 3: SCSI were larger than those in GUR 3: ECSI (Figure 47 and Figure 48), and red gurnard in GUR 8 were, on average, considerably larger than those in nearby GUR 1: West (Figure 48). In GUR 1, red gurnard in the Hauraki Gulf were generally smaller than those in East Northland or the Bay of Plenty (Figure 48).

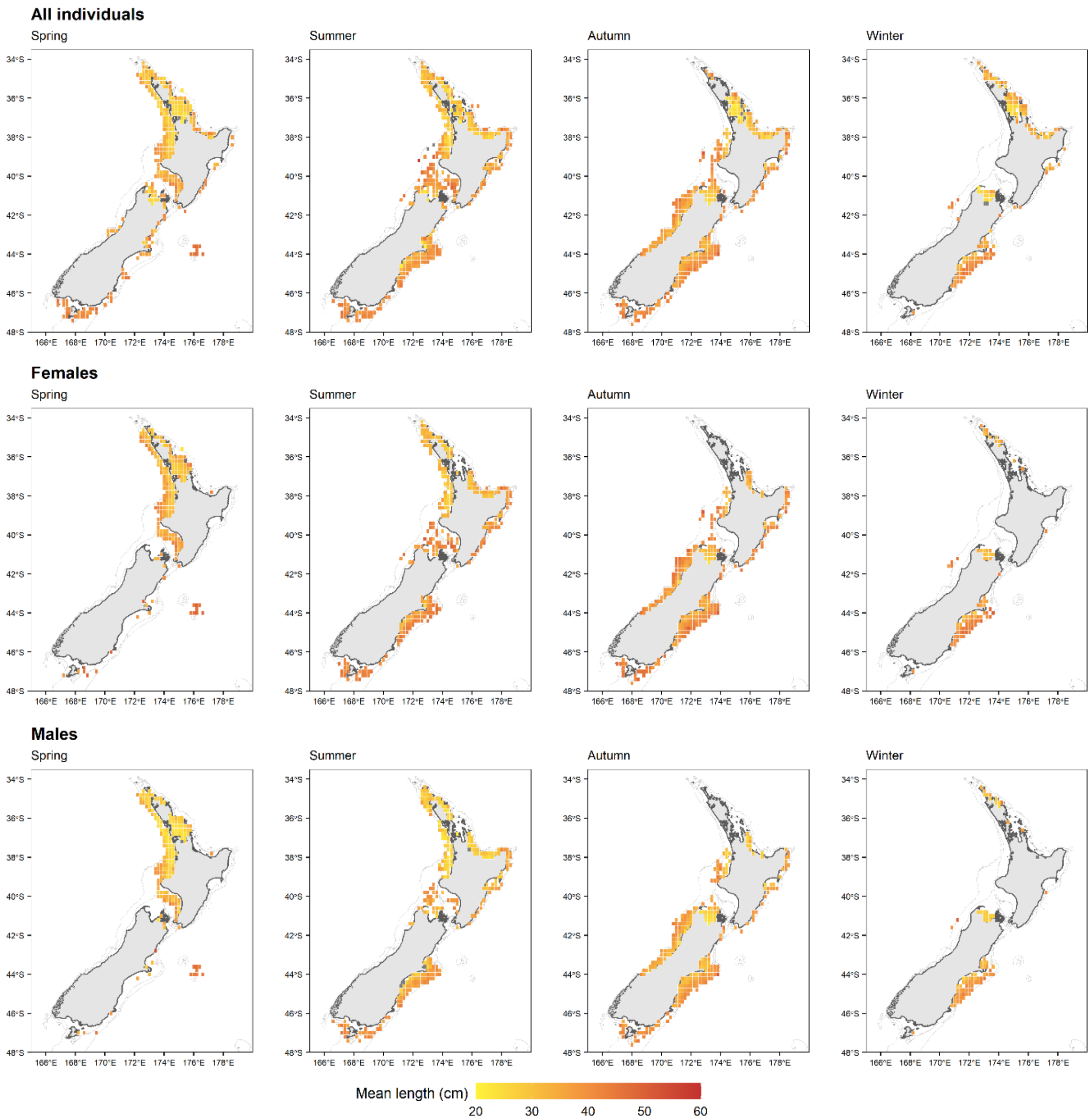

Figure 47: Mean length of red gurnard for all individuals combined (top row), females (middle row) and males (bottom row) by 0.2 degree cell by season. Depth contours of 100 m and 200 m are also displayed.

When spatial generalised additive mixed effect models (GAMMs) were applied to the length data, the selected models for both female and male red gurnard contained terms for fishing position (latitude and longitude) with an interaction with season, and an interaction between fishing depth and season, in addition to the random effects of year by QMA, vessel, and codend mesh size. Both models showed consistent patterns to those evident in the raw data, with smaller lengths inshore and larger lengths offshore predicted for both sexes (Figure 49). The model predicted the mean length of red gurnard to be fairly consistent within given depths and seasons, with no areas of aggregations of large fish predicted to occur (Figure 49). The selected models for females and males explained 65% and 75% of the deviance, respectively, and residuals from both models were randomly distributed in a narrow range around zero (Figure 77 and Figure 78).

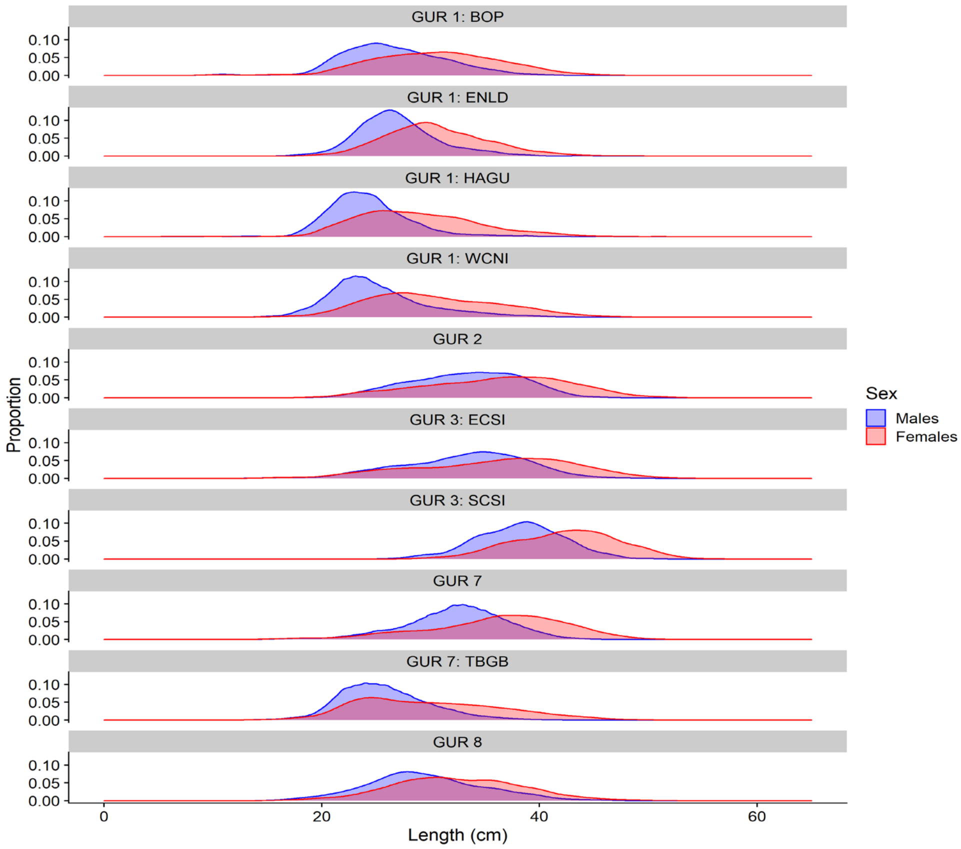

Figure 48: Unscaled length frequency distributions of red gurnard from trawl surveys by area. See Table 2 for area definitions.

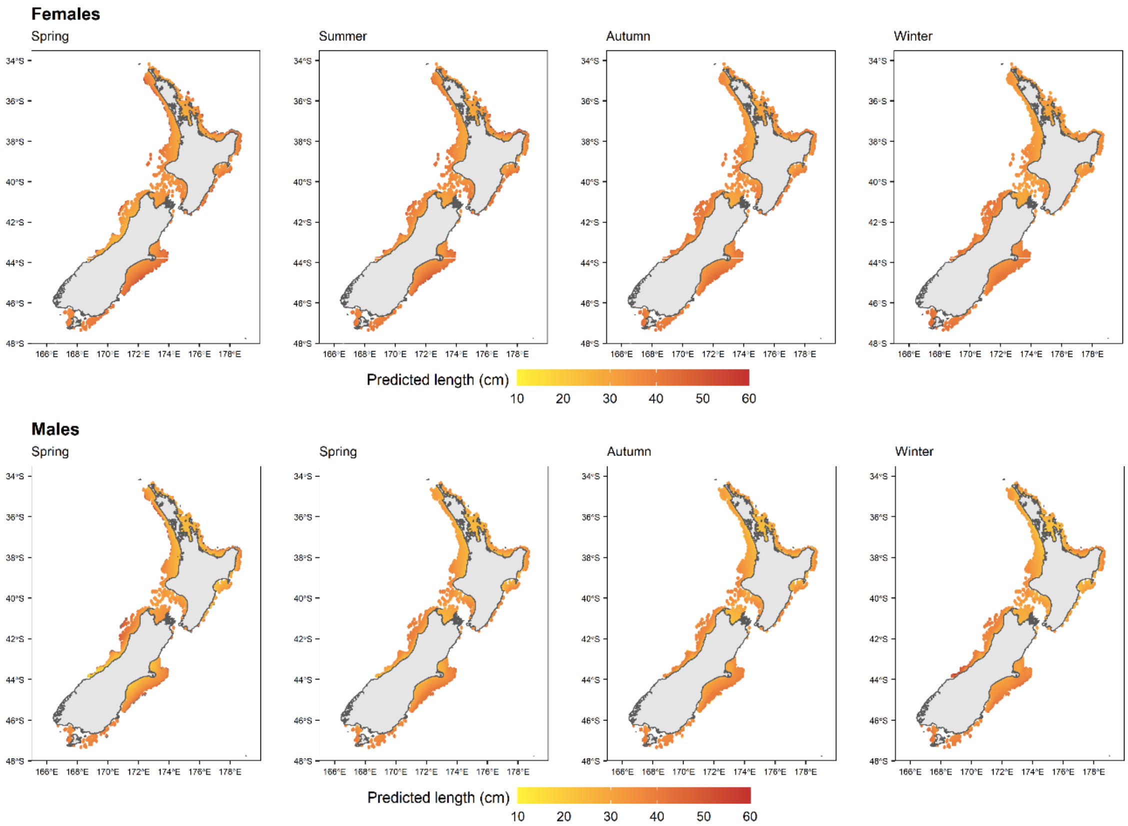

Figure 49: Predicted mean length of female (top row) and male (bottom row) red gurnard from the selected generalised additive mixed model.

3.4.3 Growth

There was considerable variation in the growth of red gurnard among areas, and between sexes within a given area, as indicated by differences in area-specific VBGF curves (Figure 50). For a given sex, populations in the south (i.e., GUR 3, GUR 7) reached larger lengths for a given age than populations in the north (i.e., GUR 1: West and GUR 1: East) (Figure 50). In all areas, females reached a larger length for a given age than males (Figure 50).

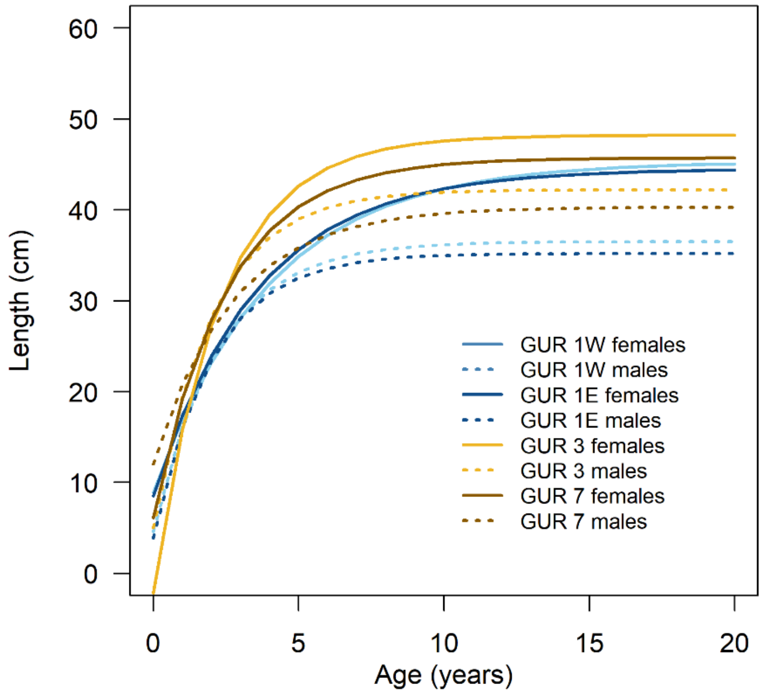

Figure 50: von Bertalanffy growth curves for red gurnard by sex and area. Based on information provided by Sutton (1997) and Stevenson (2000).

3.4.4 Length at maturity

There was considerable variation in the estimated length at maturity of red gurnard among regions (Table 12 and Figure 51). Populations in the northern QMAs (i.e., GUR 1, GUR 8) matured at smaller lengths than those in the southern QMAs (i.e., GUR 3, GUR 7), although there were several large immature males observed in GUR 3 that resulted in a poor fit to the assumed logistic relationship in this QMA (Table 12 and Figure 51).

Table 12: Lengths by which 50% (L_{50}) of female and male red gurnard have attained sexual maturity for each Quota Management Area. Values in parentheses represent 95% lower and upper confidence limits. Note it was not possible to estimate the length at maturity for GUR 2 due to small sample sizes.

	L_{50} estimate	
Area	Females	Males
GUR 1: West	23.7 (23.1–24.1)	21.4 (20.4–22.2)
GUR 1: East	21.1 (20.3–21.8)	24.2 (23.2–25.1)
GUR 3	37.6 (37.3–38.0)	40.9 (40.1–41.8)
GUR 7	33.2 (32.9–33.6)	30.3 (30.0–30.6)
GUR 8	26.1 (25.1–26.8)	24.9 (23.6–25.9)

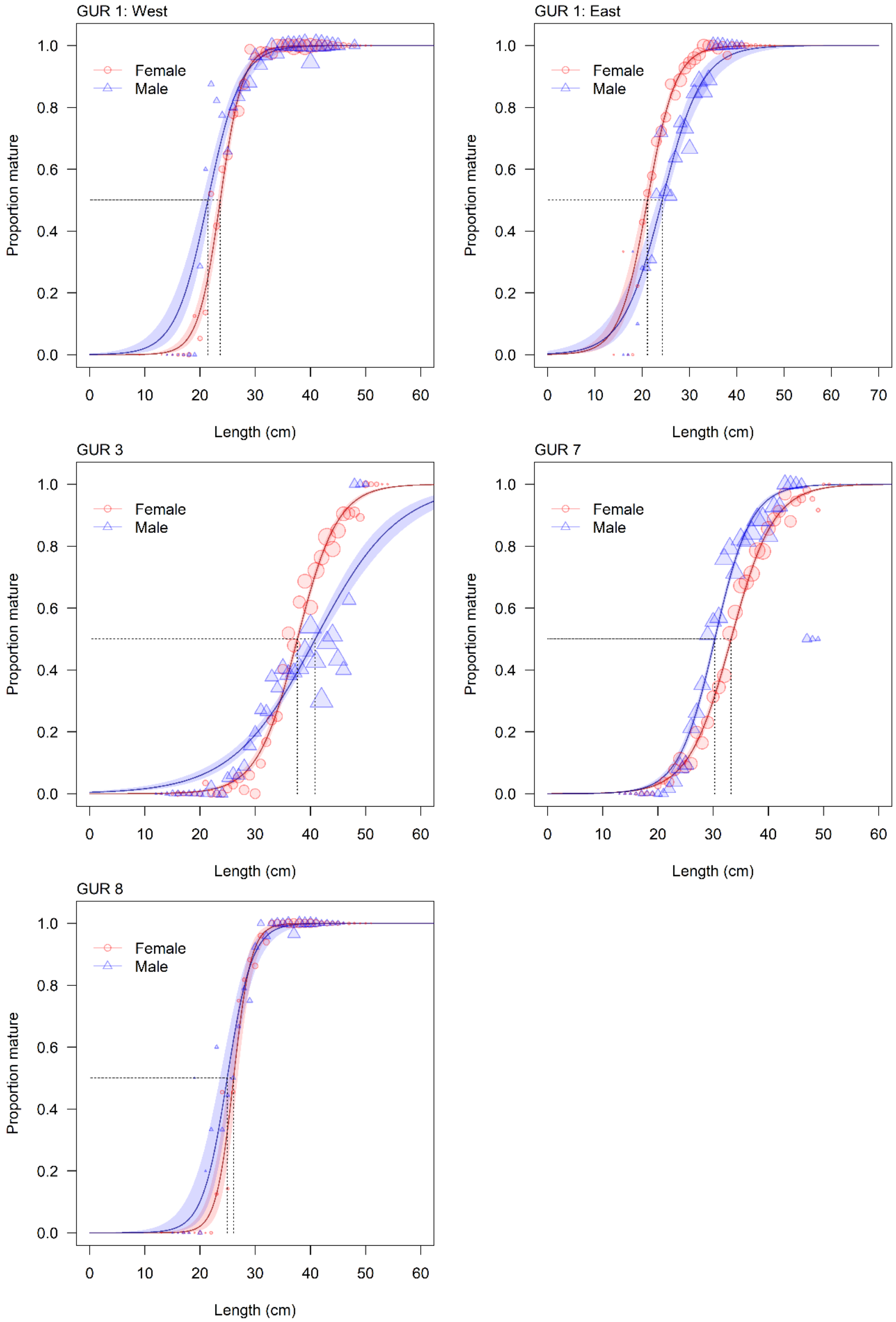

Figure 51: Predicted proportion of mature female and male red gurnard by length by Quota Management Area. Shaded areas indicate 95% confidence intervals. Points indicate the observed proportion of individuals deemed to be mature in each 1-cm length class and have been scaled relative to available sample sizes. Note it was not possible to estimate the length at maturity for GUR 2 due to small sample sizes.

3.4.5 Sex ratios

Patterns in sex ratios of adult fish (i.e., those greater than or equal to 25 cm in length) showed that during spring and summer, there was a strong spatial separation of red gurnard sexes, with a larger proportion of females observed inshore and males offshore (Figure 52). In GUR 3, where inter-seasonal data allowed for temporal comparisons, this spatial separation was not evident in autumn or winter, with females and males appearing to be mixed over the surveyed areas (Figure 52). Consistent with patterns in the raw data, the selected GAMM for GUR 3 predicted a higher proportion of females inshore during spring and summer, with a higher proportion of males offshore (although there were few individuals sampled in spring from this area to inform the prediction). In autumn and winter, females and males were predicted to be mixed, with little spatial separation (Figure 53). The selected model accounted for 53% of the deviance explained and model residuals were randomly distributed in a narrow range around zero (Figure 79).

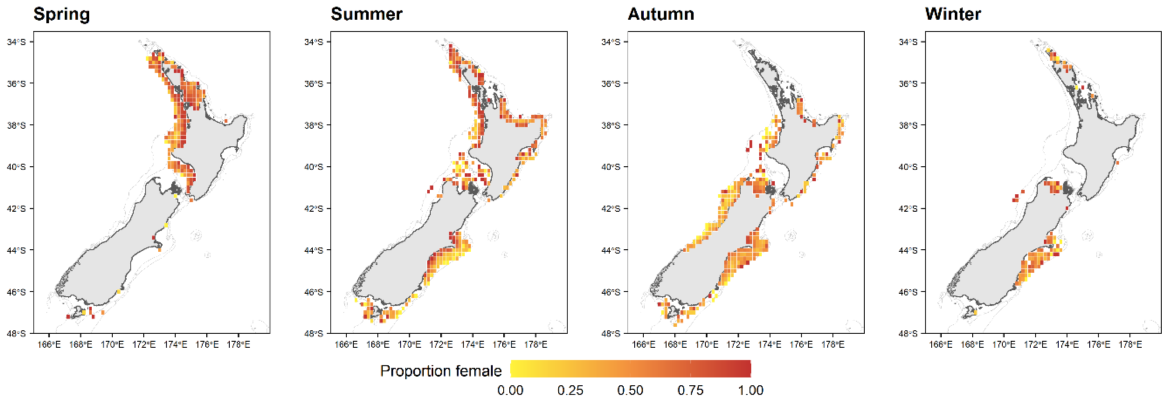

Figure 52: Proportion of female red gurnard (relative to males) by 0.2 degree cell by season. Depth contours of 100 m and 200 m are also displayed.

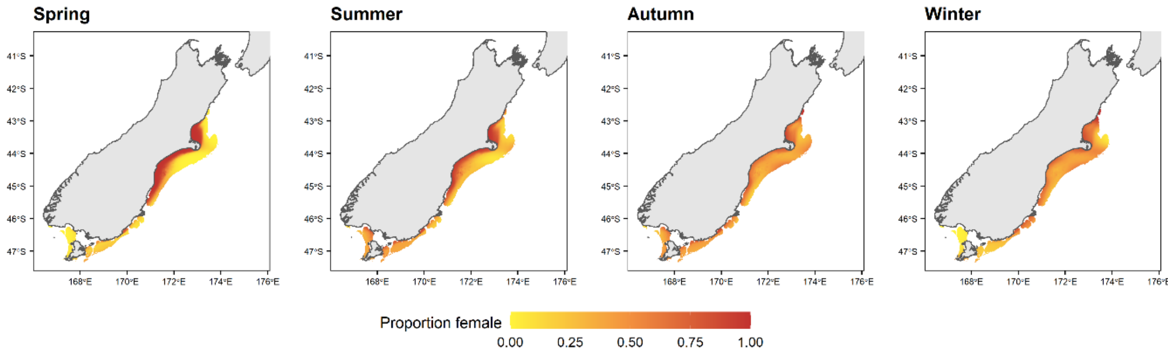

Figure 53: Predicted proportion of red gurnard that are female (relative to male) from the generalised additive mixed model for GUR 3 by season.

3.4.6 Females in running ripe condition

The proportion of female red gurnard observed in running ripe condition (i.e., gonads of stage 5) relative to mature females with gonads in all other stages is presented in Figure 54. Off the ECSI (i.e., GUR 3: ECSI), few individuals in running ripe condition were evident in summer, with higher relative proportions of running ripe females observed in GUR 3: SCSI (Figure 54). By autumn, however, relatively high proportions of running ripe females were evident across the ECSI, and relatively few running ripe females were evident in GUR 3: SCSI. At the same time, running ripe females were observed in TBGB and off the WCSI in GUR 7 (Figure 54). In winter, running ripe females were observed in the deepest areas off the ECSI

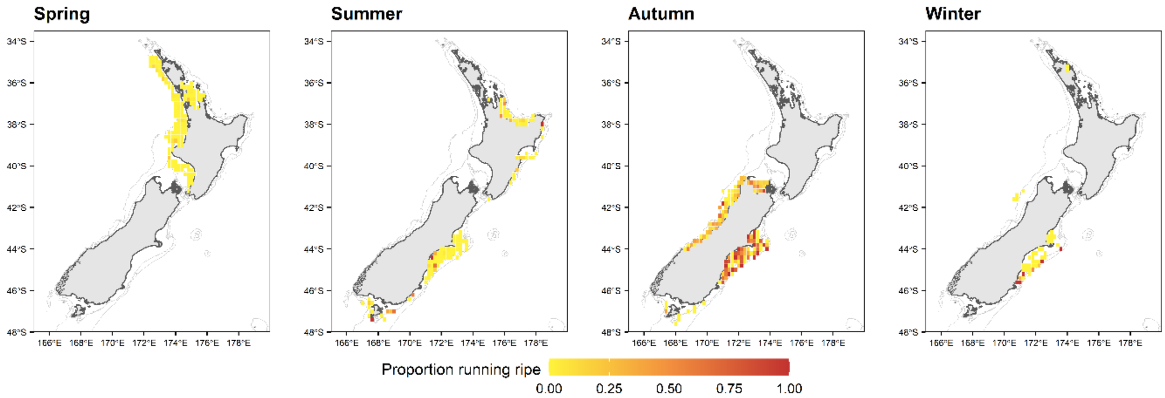

Figure 54: Proportion of female red gurnard in running ripe condition (relative to mature females in all other conditions) by 0.2 degree cell by season. Depth contours of 100 m and 200 m are also displayed.

4. DISCUSSION

It is assumed, for assessment purposes, that BPLE/ENHG/WCNI form separate sub-stocks. The standardised indices show different trends, although with some similarities between BPLE and ENHG, which corroborates this assumption (see Figure 38). A further assumption is that the standardised CPUE indices track abundance; however, there is limited correspondence between trends in the CPUE indices and trawl survey biomass indices (see Figures 39, 41, 43).

One of the main changes since the previous standardisation was the switch over to electronic reporting starting in 2018 (see Figure 5). This has the potential to change both fisheries operations and reported data, compared with previous periods. A comparison of electronic data period with 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, which likely has a different catchability than the standard bottom (single) trawl (see Figure 6). 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 in any area, and these data are not used in the standardised CPUE analyses.

In ENHG after 2017 some vessels had switched to PSH gear, and there was a substantial decline in bottom (single) trawl catch and effort. However, there were still approximately 700 bottom (single) trawls per year for the core vessels, which should be sufficient to construct a standardised index to track abundance (see Table 6). If bottom (single) trawl catch effort continued to decline, then bottom longline data may be an alternative to consider for calculating standardised indices (see Figure 6). Patterns in demographic parameters suggest fine-scale structuring of red gurnard populations in coastal waters around New Zealand. In GUR 1, the separation of red gurnard into west coast and eastern stocks is supported by length frequencies, growth patterns, and length at maturity schedules, as well as a discontinuity in catches around Cape Reinga (see Figure 10). Within the eastern component of GUR 1, differences in these parameters were observed between the Hauraki Gulf and Bay of Plenty populations, suggesting separate stocks occur in these areas, and length data also suggested the occurrence of non-homogeneous populations between the Hauraki Gulf and East Northland. This conclusion is further supported by CPUE data, with fine-scale differences in standardised CPUE indices observed between ENHG and BPLE (this study). The distribution of red gurnard off the west coast North Island was continuous between GUR 1 and the northern part of the west coast GUR 8 (to approximately the southern boundary of Statistical Area 041), suggesting these areas could be combined in future CPUE analyses.

For the southern QMAs, there was some indication of separation of red gurnard in the south and east of GUR 3, with length frequencies indicating much larger fish occur in the south. Previous CPUE analyses have also indicated that separate stocks or sub-stocks may exist between the east and south coasts of the South Island (Fisheries New Zealand 2022). In GUR 7, fish in TBGB were considerably smaller and younger than those off the west coast of the South Island (although a wide size range occurs in both areas). Based on length and age frequency information, it has been previously hypothesised that TBGB acts as a nursery area for the west coast of the South Island (Lyon & Horn 2011, Fisheries New Zealand 2022). TBGB was also found to support a relatively large proportion of females in spawning condition. Targeted studies into red gurnard stock structure, ideally adopting a holistic (multidisciplinary approach) are required to better assess the role of TBGB as a nursery area, and to better define the stock boundaries around New Zealand's coastal waters more broadly.

Patterns in sex ratios and observations of female fish in running ripe condition suggest that fish in GUR 3 spawn predominantly in autumn, with spawning grounds appearing to be widespread. Spatio-temporal patterns in sex ratio data suggest that following spawning, females return to shallower inshore waters during spring and summer. This behaviour contrasts that reported for red gurnard in the Hauraki Gulf, where patterns in gonadosomatic index (GSI) data suggest red gurnard have a prolonged spawning period that commences in late spring and extends through to early autumn, with a peak in summer (Elder 1972, Clearwater & Pankhurst 1994). From available data it is unclear whether this reflects a temporal difference in spawning of red gurnard between northern and southern New Zealand or a shift in spawning period over time. Trawl survey data from the Hauraki Gulf suggested few red gurnard captured in spring and summer were spawning, although data from these surveys are predominantly restricted to late spring and early summer. Collection of monthly gonad stage and GSI data would help to better understand the spawning dynamics of red gurnard.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Akaike, H. 1974. A new look at the statistical model identification. *IEEE Transactions on Automatic Control 19*: 716–723.

Beentjes, M.P.; MacGibbon, D.J.; Ladroit, Y. (2022). Inshore trawl survey of Canterbury Bight and Pegasus Bay, April-June (KAH2104). *New Zealand Fisheries Assessment Report 2022/23*. 147 p.

Begg, G.A.; Hare, J.; Sheehan,. D.D. (1999). The role of life history parameters as indicators of stock structure. *Fisheries Research 43*: 141–163.

Bentley, N.; Kendrick, T.H.; Starr, P.J.; Breen, P.A. (2012) Influence plots and metrics: tools for better understanding fisheries catch-per-unit-effort standardizations. *ICES Journal of Marine Science 69*: 84–88.

Brodie, S.; Abrahms, B.; Bograd, S.J.; Carroll, G.; Hazen, E.L.; Muhling, B.A.; Pozo Buil, M.; Smith, J.A.; Welch, H.; Jacox, M.G. (2021). Exploring timescales of predictability in species distributions. *Ecography 44*: 832–844.

Clearwater, S.J.; Pankhurst, N.W. (1994). Reproductive biology and endocrinology of female red gurnard, *Chelidonichthys kumu* (Lesson and Garnot) (Family Triglidae) from the Hauraki Gulf, New Zealand. *Australian Journal of Marine and Freshwater Research 45*: 131–139.

Dunn, P.K.; Smyth, G.K. (1996). Randomized quantile residuals. *Journal of Computational and Graphical Statistics 5*: 236–244.

Elder, R.D. (1972). Studies on age and growth, reproduction and population dynamics of red gurnard, *Chelidonichthys kumu* (Lesson and Garnot), in the Hauraki Gulf, New Zealand. *Fisheries New Zealand Research Bulletin No. 12*. 62 p.

Fisheries New Zealand (2019). National Inshore Finfish Fisheries Plan. Fisheries New Zealand Discussion Paper No: 2019/18. https://www.mpi.govt.nz/dmsdocument/38045/direct

Fisheries New Zealand (2021a). Fisheries Assessment Plenary, May 2021: stock assessments and stock status. Compiled by the Fisheries Science and Information Group, Fisheries New Zealand, Wellington, New Zealand. 1782 p.

Fisheries New Zealand (2021b). Review of Sustainability Measures for Red gurnard (GUR 1), Fisheries New Zealand Discussion Paper No: 2021/11. https://www.mpi.govt.nz/dmsdocument/45490-Review-of-sustainability-measures-for-red-gurnard-GUR-1-for-202122

Fisheries New Zealand (2022). Fisheries Assessment Plenary, May 2022: stock assessments and stock status. Compiled by the Fisheries Science and Information Group, Fisheries New Zealand, Wellington, New Zealand. 1886 p.

Hoyle, S.D. (2020). Investigation of potential CPUE model improvements for the primary index of Southern Bluefin Tuna abundance. *New Zealand Fisheries Assessment Report 2020/35*. 37 p.

Jones, E.J.; Bian, R.; MacGibbon, D.J.; McKenzie, J.R.; Escobar-Flores, P.C.; Stevens, D.W.; Walsh, C.; O'Driscoll, R.L. (2022). Inshore trawl surveys off the west coast North Island, October–November 2018, 2019, and 2020. *New Zealand Fisheries Assessment Report 2022/63*. 156 p.

Kendrick, T.H.; Bentley, N. (2017). Updated CPUE Analyses for three substocks of red gurnard in GUR 1. (6 April 2017, Working Group paper held by Fisheries New Zealand.)

Langley. A.D. (2014). Updated CPUE analyses for selected South Island inshore finfish stocks. *New Zealand Fisheries Assessment Report 2014/40.*

Langley, A.D.; Middleton, D.A.J. (2021). Evaluation of the introduction of electronic reporting of catch and effort data from the inshore trawl fishery. *New Zealand Fisheries Assessment Report 2021/68*. 20 p.

Lyon, W.S.; Horn, P.L. (2011). Length and age of red gurnard (*Chelidonichthys kumu*) from trawl surveys off west coast South Island in 2003, 2005, and 2007, with comparisons to earlier surveys in the time series. *New Zealand Fisheries Assessment Report 2011/46*. 39 p.

McKenzie, A. (2023). Fishery characterisation and catch per unit effort for John dory in JDO 1, to 2020/21. *New Zealand Fisheries Assessment Report 2023/07.* 57 p.

Ministry of Fisheries (2008). Harvest Strategy Standard for New Zealand Fisheries. 27 p. Available at https://www.mpi.govt.nz/dmsdocument/728-harvest-strategy-standard-for-new-zealand-fisheries

Moore, B.R.; Welch, D.J.; Simpfendorfer, C.A. (2011). Spatial patterns in the demography of a large estuarine teleost: king threadfin, *Polydactylus macrochir*. *Marine and Freshwater Research 62*: 937–951.

Moore, B.R.; Simpfendorfer, C.A.; Newman, S.J.; Stapley, J.M.; Allsop, Q.; Sellin, M. J.; Welch, D.J. (2012). Spatial variation in life history reveals insight into connectivity and geographic population structure of a tropical estuarine teleost: king threadfin, *Polydactylus macrochir*. *Fisheries Research 125*: 214–224.

Parsons, D.M.; Bian, R.; D. Parkinson, D.J. MacGibbon (2021). Trawl surveys of the Hauraki Gulf and Bay of Plenty in 2019 and 2020 to estimate the abundance of juvenile snapper. *New Zealand Fisheries Assessment Report 2021/08*. 127 p.

Poisot, T. (2011). The digitize package: extracting numerical data from scatterplots. *The R Journal 3.1* (2011): 25–26.

R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Starr, P.J. (2007). Procedure for merging Ministry of Fisheries landing and effort data, version 2.0. Report to the Adaptive Management Programme Fishery Assessment Working Group: Document 2007/04. 17 p. (Unpublished document held by Fisheries New Zealand, Wellington.)

Stevenson, M.L. (2000). Assessment of red gurnard (*Chelidonichthys kumu*) stocks GUR 1 and GUR 2. *New Zealand Fisheries Assessment Report 2000/40*. 51 p.

Sutton, C.P. (1997). Growth parameters, and estimates of mortality for red gurnard (*Chelidonichthys kumu*) from off the east and west coasts of the South Island, New Zealand. New Zealand Fisheries Assessment Research Document 1997/1. 15 p. (Unpublished report held by NIWA library, Wellington.)

Wood, S.N. (2017). Generalized Additive Models: An Introduction with R, Second Edition. Chapman and Hall/CRC.

Wood, S.N. (2020). Inference and computation with generalized additive models and their extensions. *TEST 29*: 307–339.

APPENDIX 1: BPLE STANDARDISATION DIAGNOSTICS

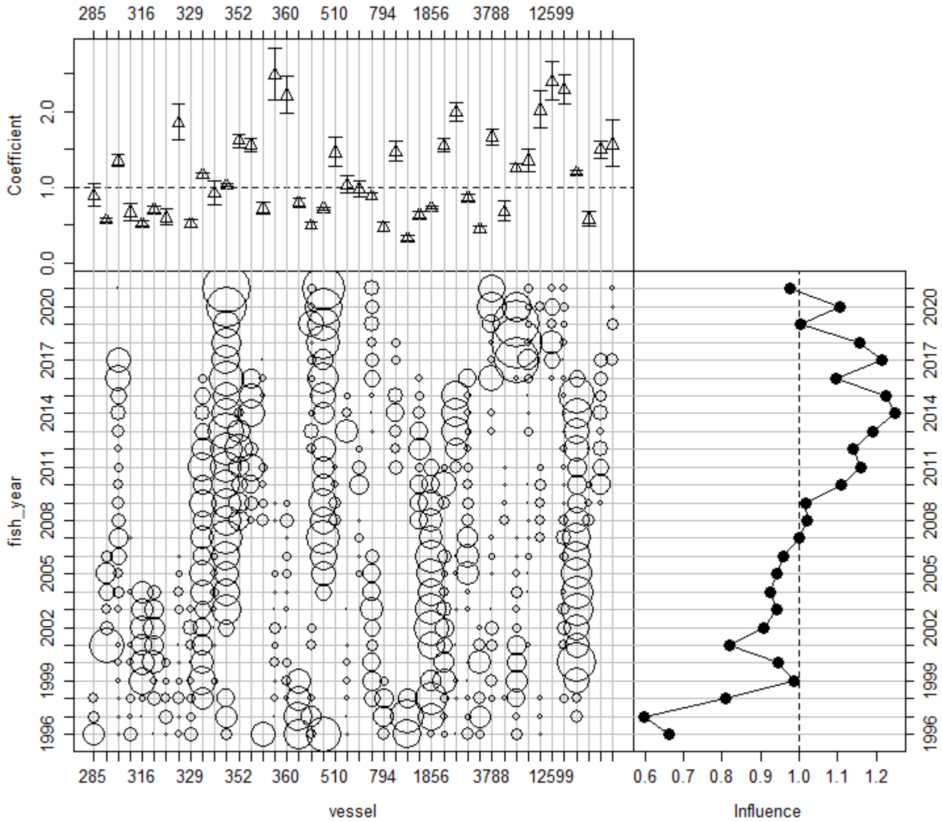

Figure 55: Influence plot for the *vessel* variable from the BPLE lognormal CPUE model.

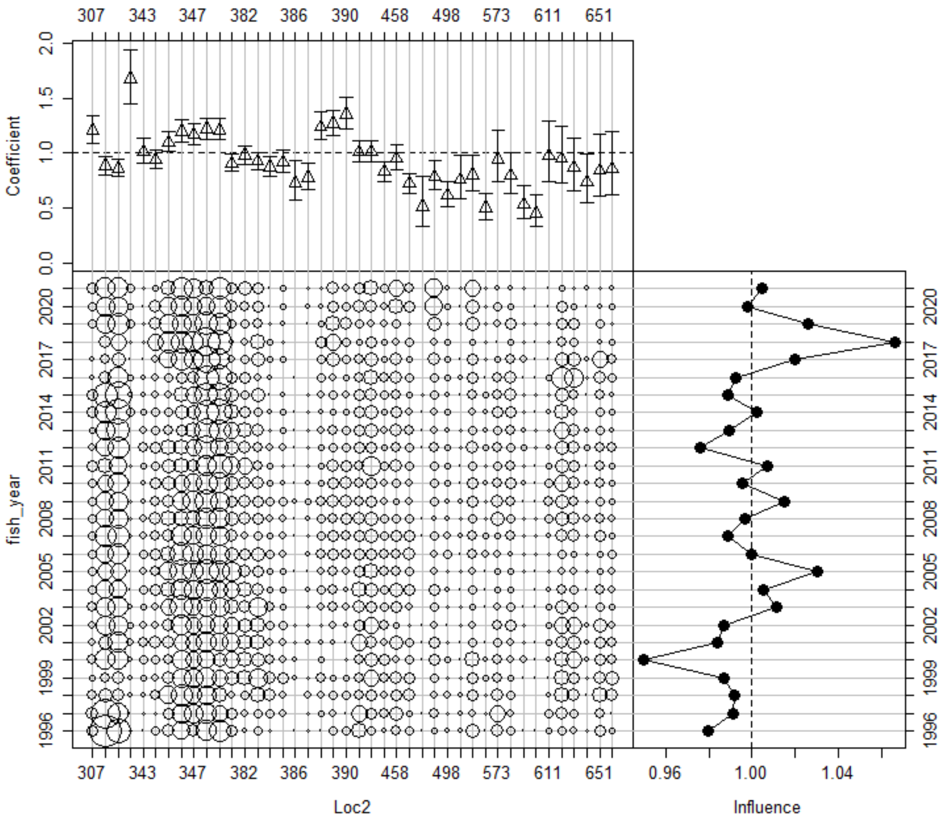

Figure 56: Influence plot for the *Loc2* variable from the BPLE lognormal CPUE model.

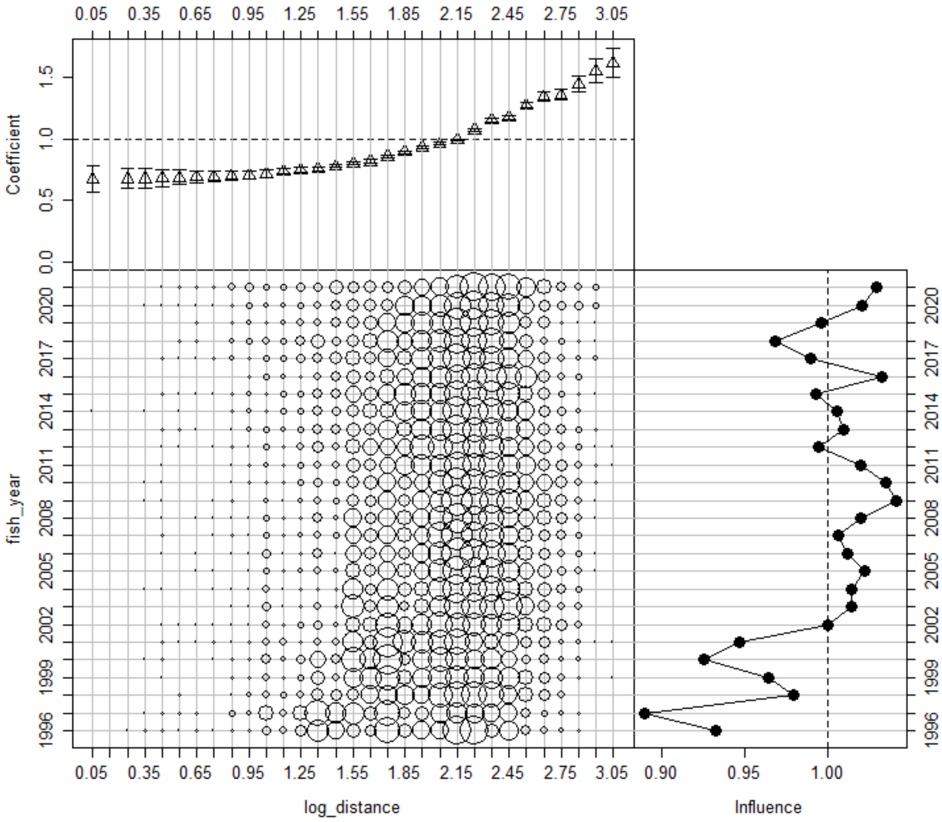

Figure 57: Influence plot for the *Distance* variable from the BPLE lognormal CPUE model.

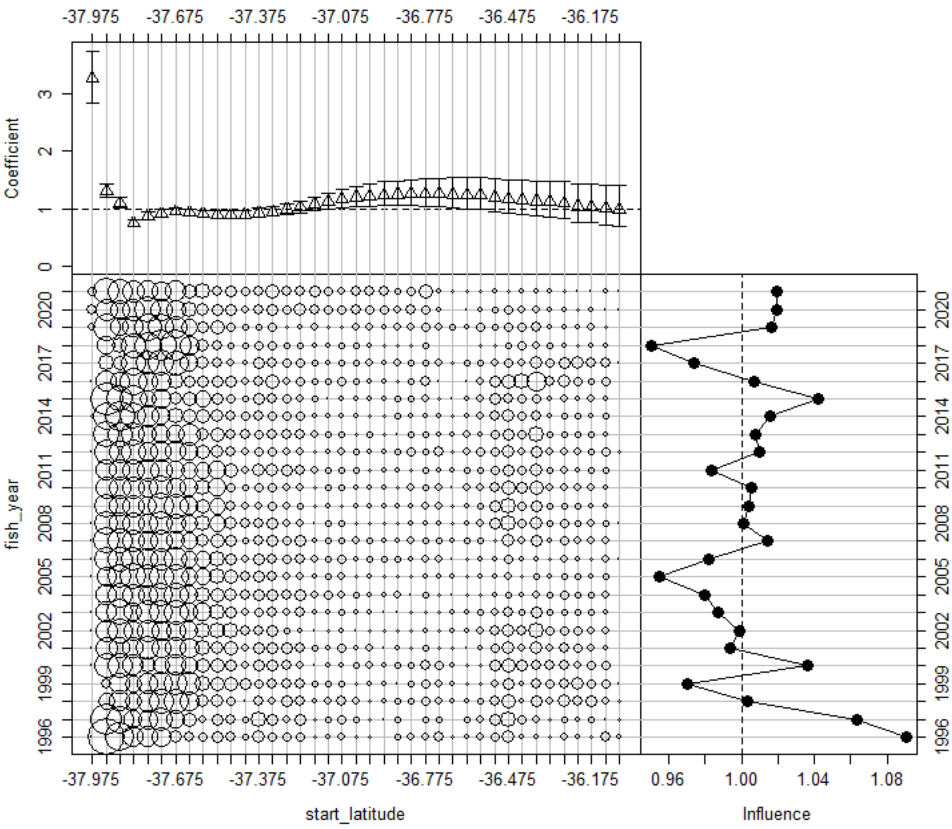

Figure 58: Influence plot for the *Latitude* variable from the BPLE lognormal CPUE model.

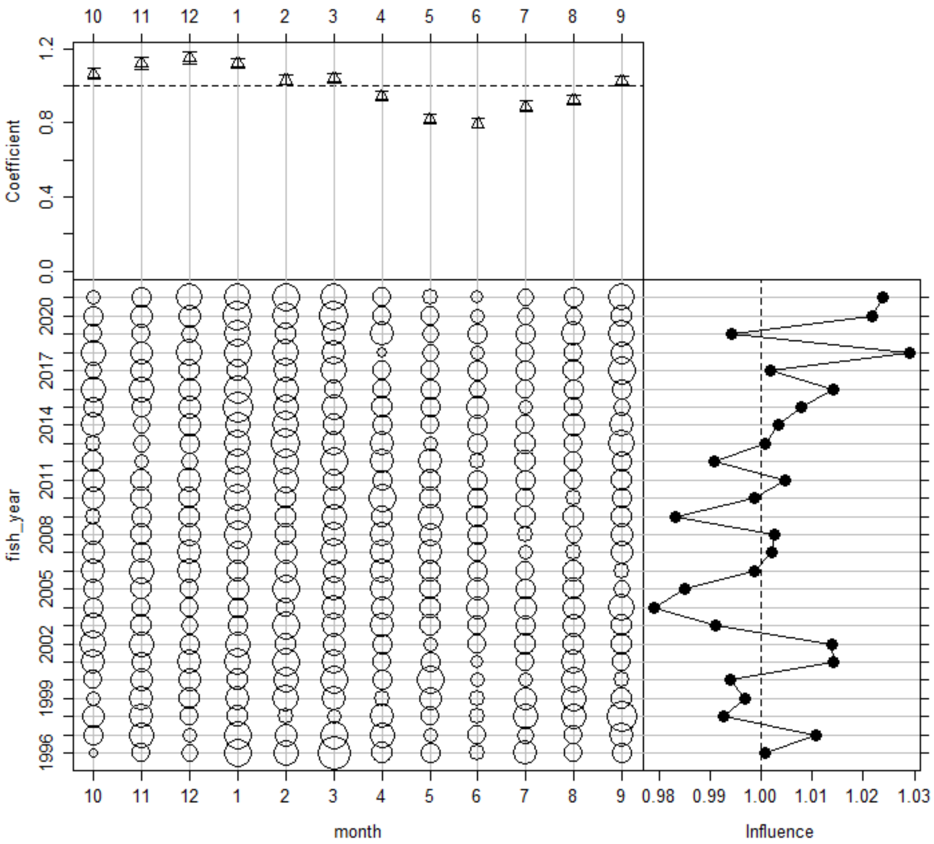

Figure 59: Influence plot for the *Month* variable from the BPLE lognormal CPUE model.

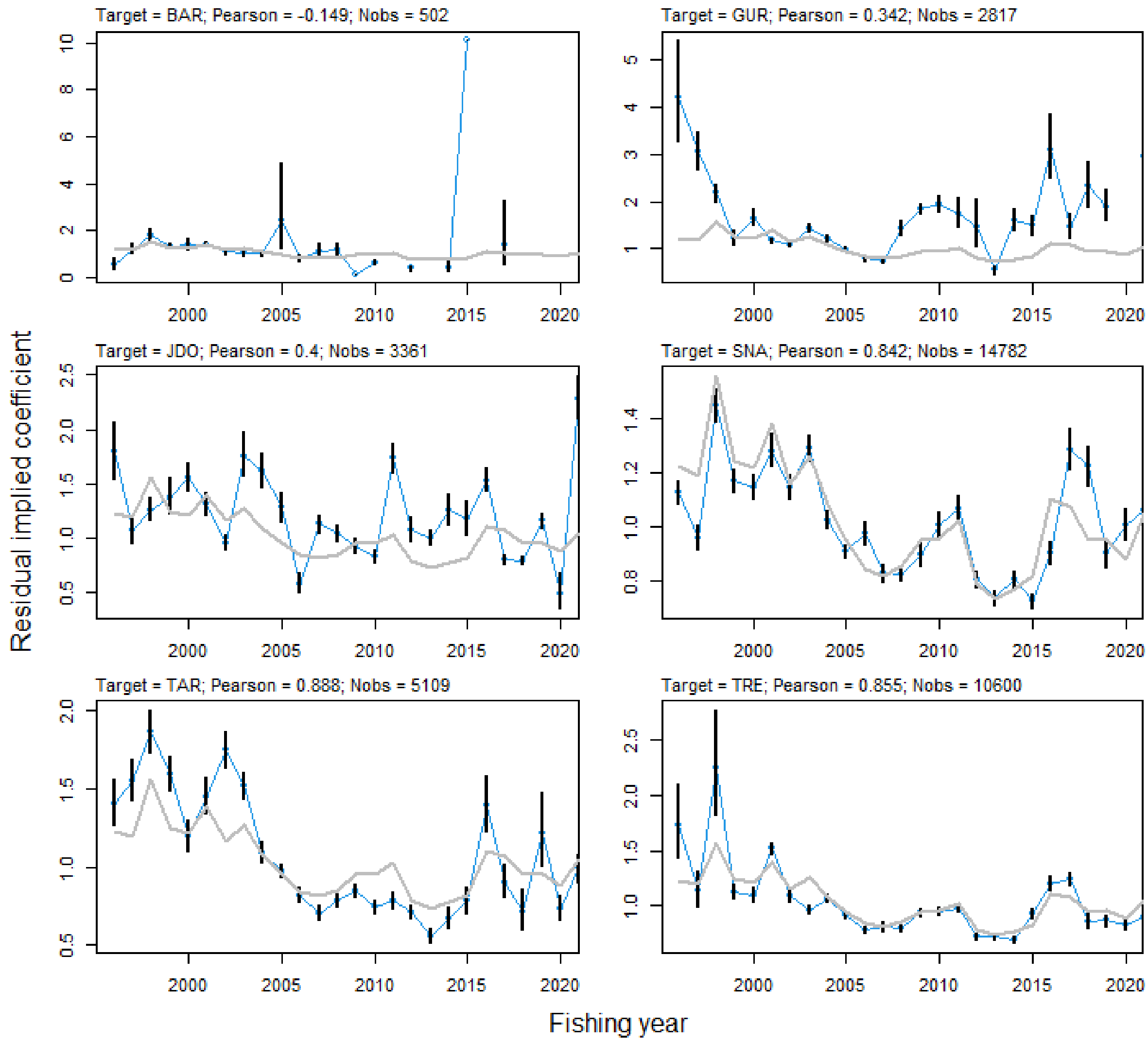

Figure 60: Annual implied residual coefficients (points joined by blue lines) for target species and the BPLE lognormal model, where the confidence intervals are one standard error. The grey line is the standardised index from the lognormal model. Species codes are barracouta (BAR), red gurnard (GUR), John dory (JDO), snapper (SNA), tarakihi (TAR), and trevally (TRE). Nobs: Number of trawls where the species was the target.

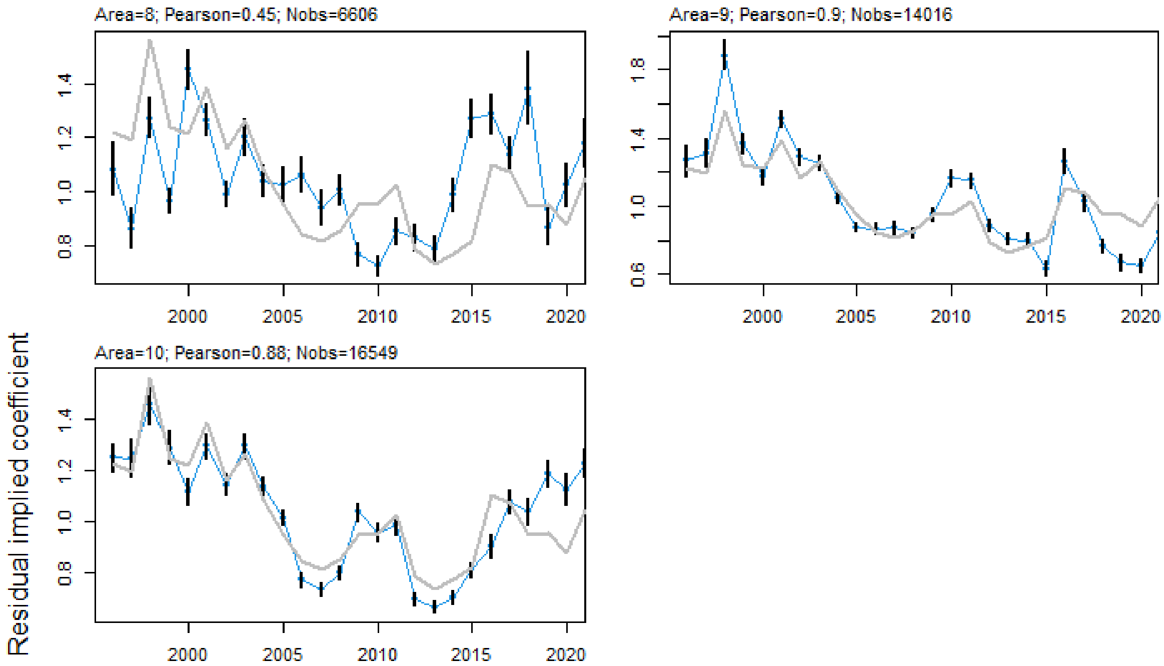

Figure 61: Annual implied residual coefficients (points joined by blue lines) for statistical area (where 'Area 8' is Statistical Area 008, etc.) and the BPLE lognormal model, where the confidence intervals are one standard error. The grey line is the standardised index from the lognormal model. Nobs: Number of trawls within the area.

APPENDIX 2: ENHG STANDARDISATION DIAGNOSTICS

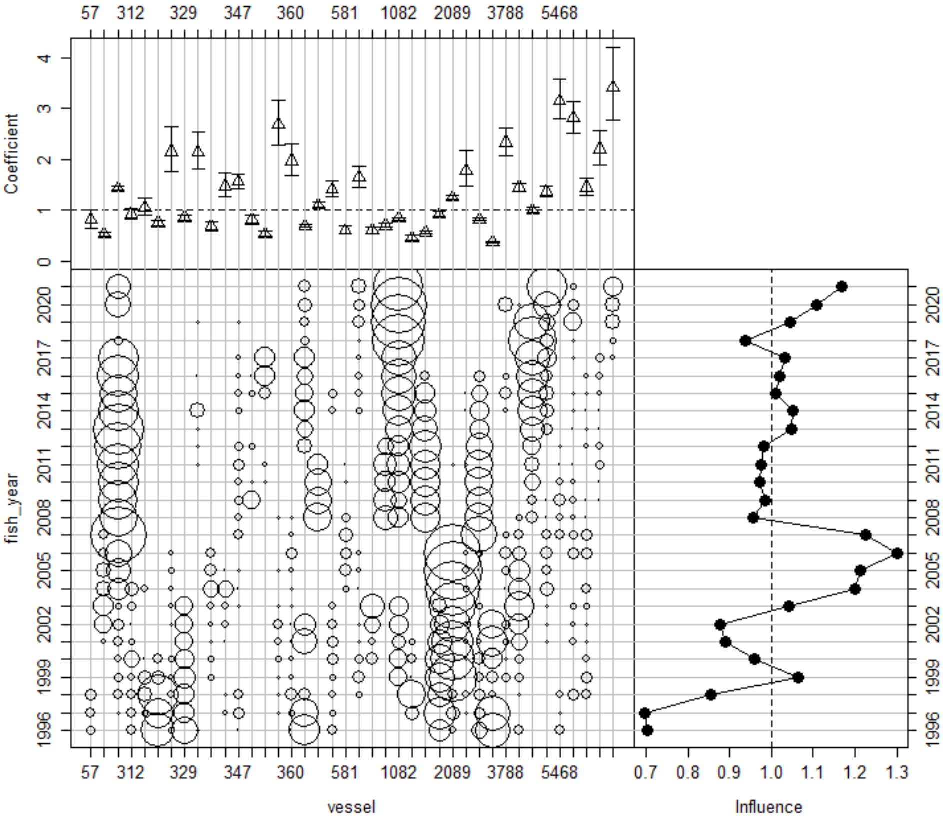

Figure 62: Influence plot for the *vessel* variable from the ENHG lognormal CPUE model.

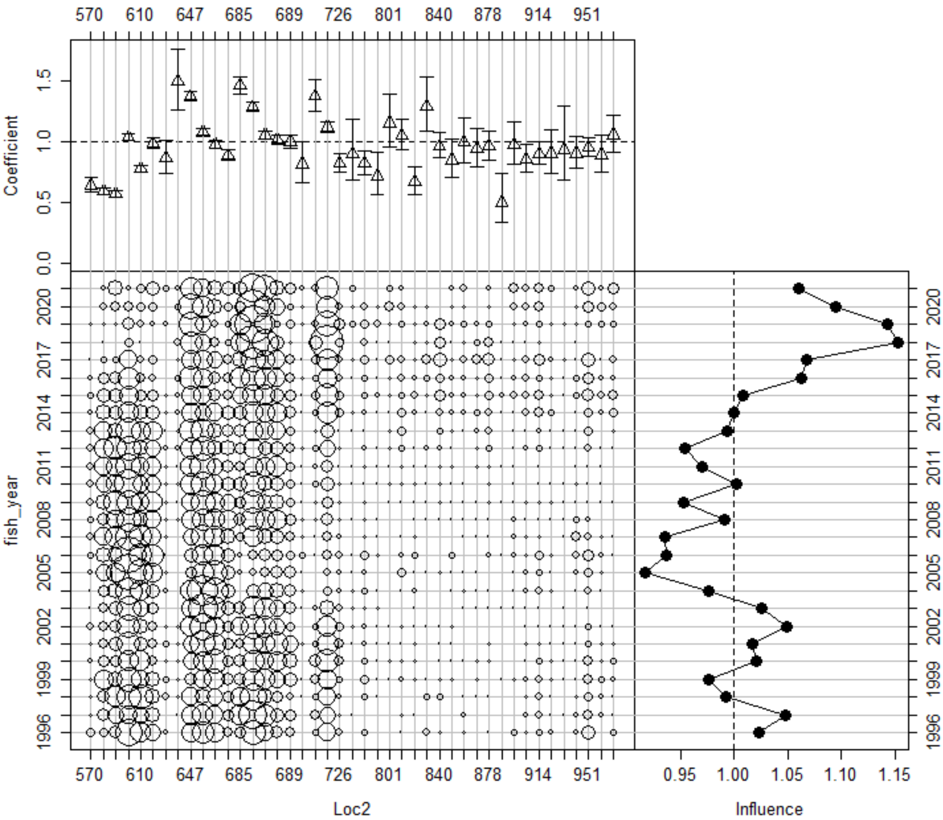

Figure 63: Influence plot for the *Loc2* variable from the ENHG lognormal CPUE model.

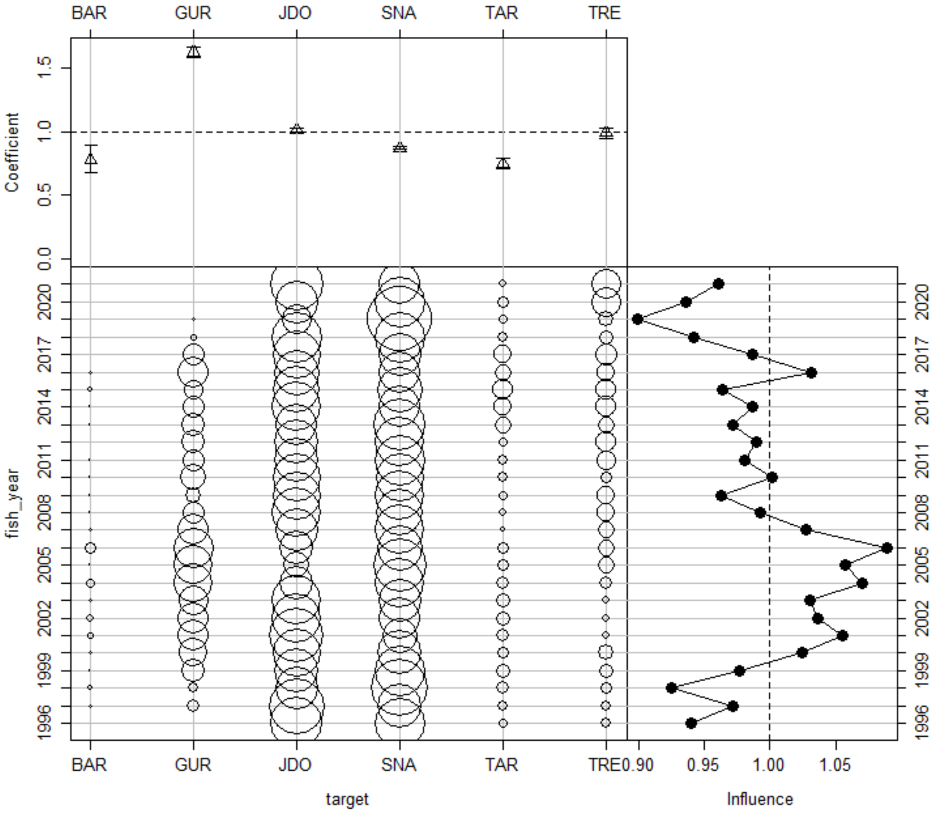

Figure 64: Influence plot for the *target* variable from the ENHG lognormal CPUE model. Species codes are barracouta (BAR), red gurnard (GUR), John dory (JDO), snapper (SNA), tarakihi (TAR), and trevally (TRE).

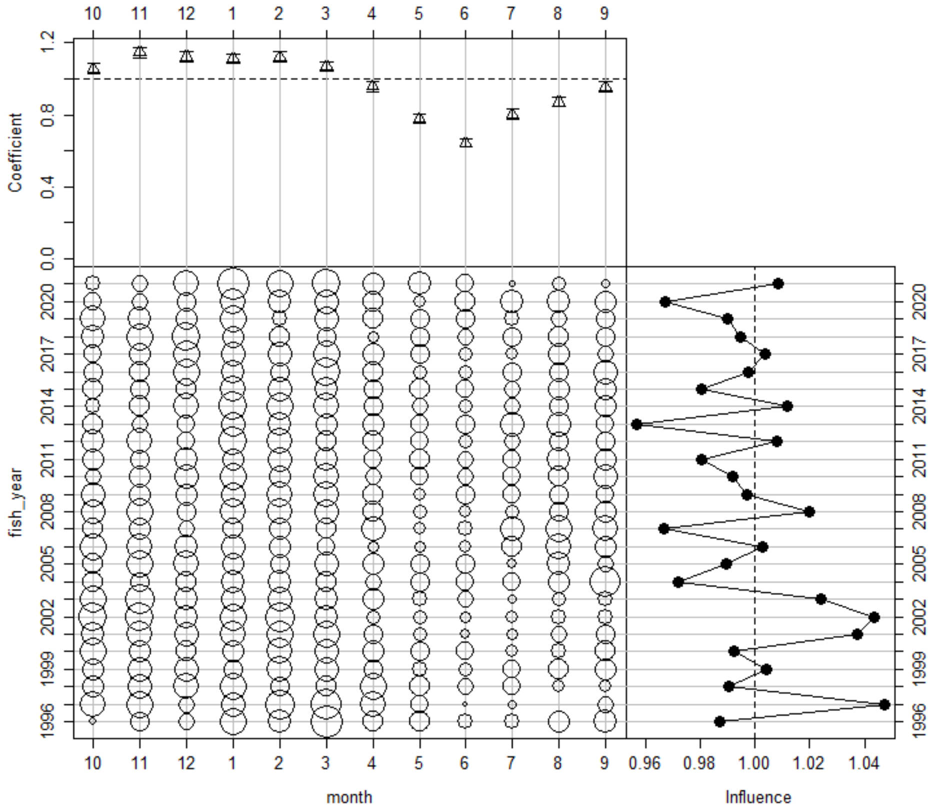

Figure 65: Influence plot for the *month* variable from the ENHG lognormal CPUE model. Month '10' is October.

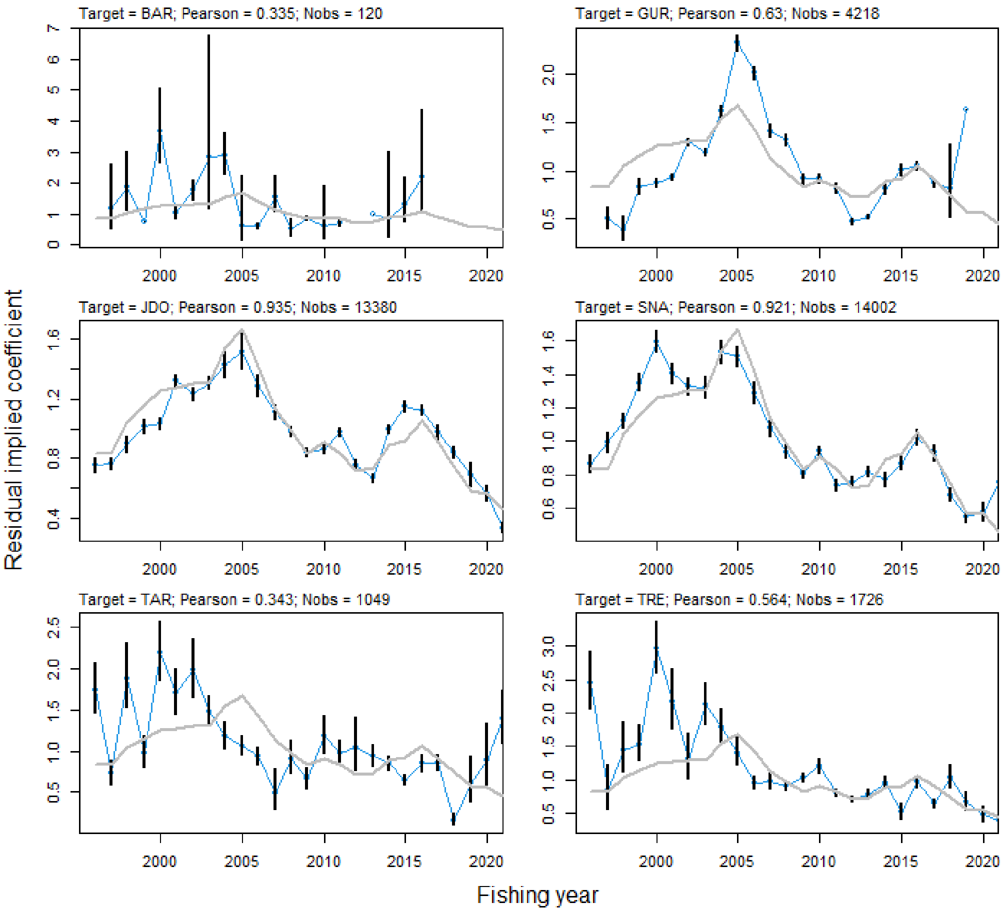

Figure 66: Annual implied residual coefficients (points joined by blue lines) for target species and the ENHG lognormal model, where the confidence intervals are one standard error. The grey line is the standardised index from the lognormal model. Species codes are barracouta (BAR), red gurnard (GUR), John dory (JDO), snapper (SNA), tarakihi (TAR), and trevally (TRE). Nobs: Number of trawls where the species was the target.

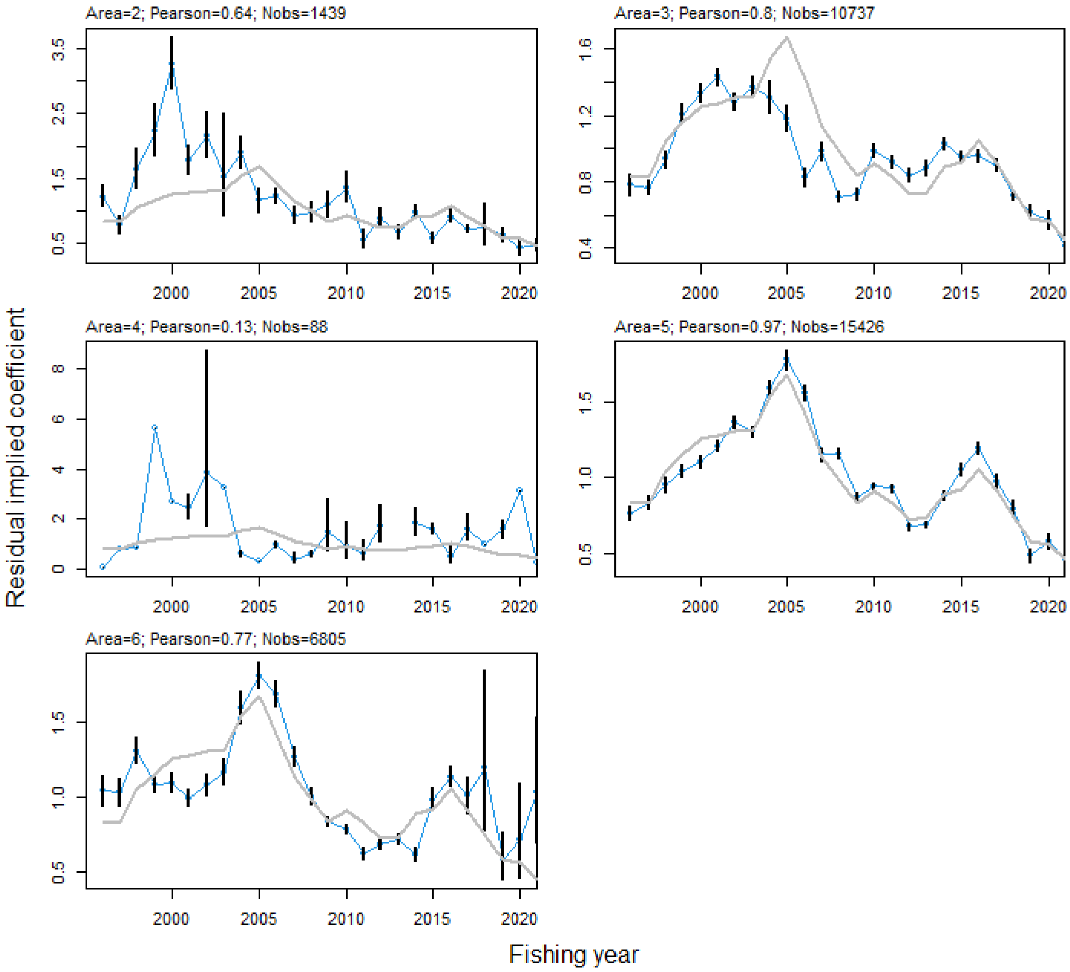

Figure 67: Annual implied residual coefficients (points joined by blue lines) for statistical area ('Area 2' is Statistical Area 002, etc.) and the ENHG lognormal model, where the confidence intervals are one standard error. The grey line is the standardised index from the lognormal model. Nobs: Number of trawls within the area.

APPENDIX 3: WCNI STANDARDISATION DIAGNOSTICS

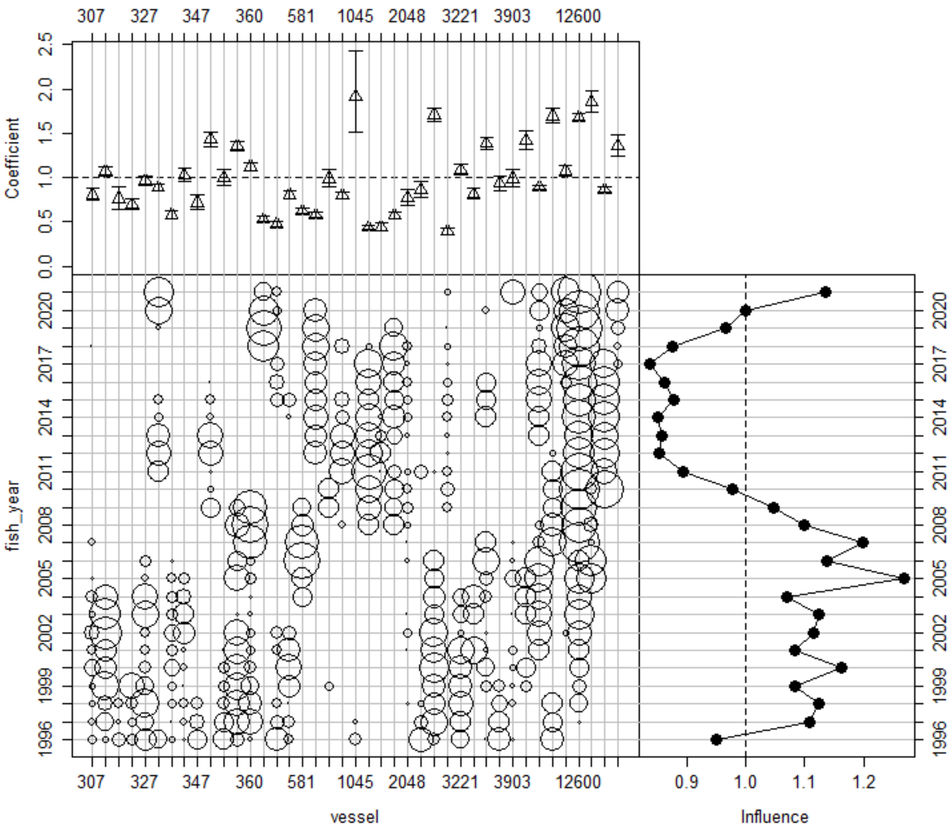

Figure 68: Influence plot for the v*essel* variable from the WCNI lognormal model.

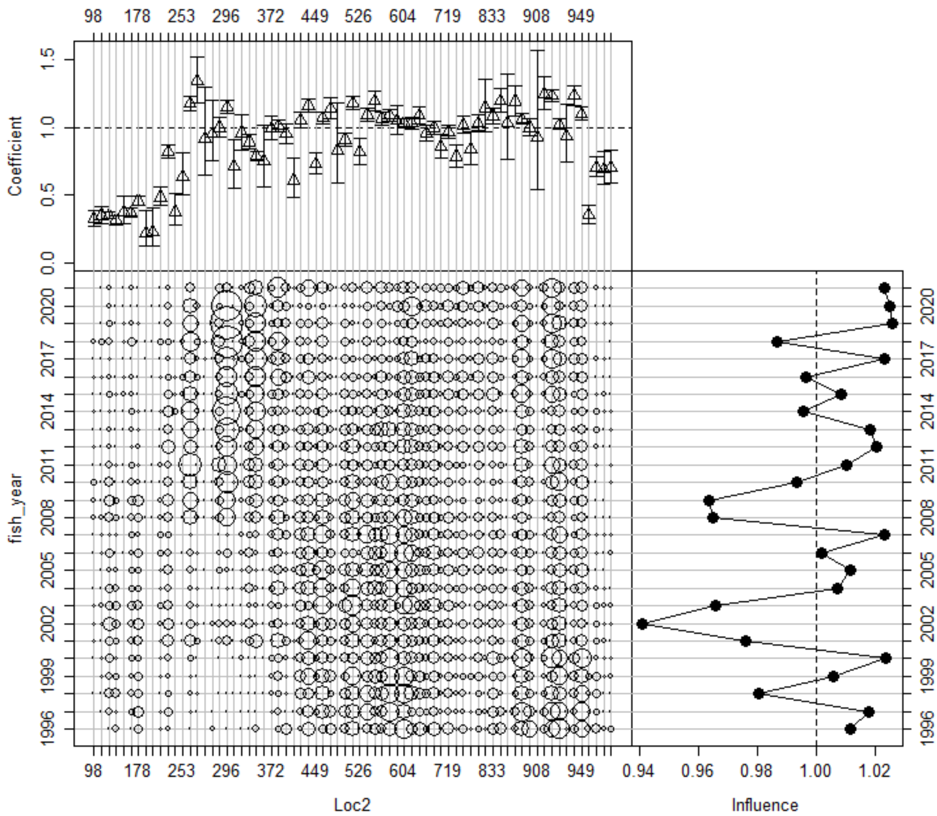

Figure 69: Influence plot for the *Loc2* variable from the WCNI lognormal model.

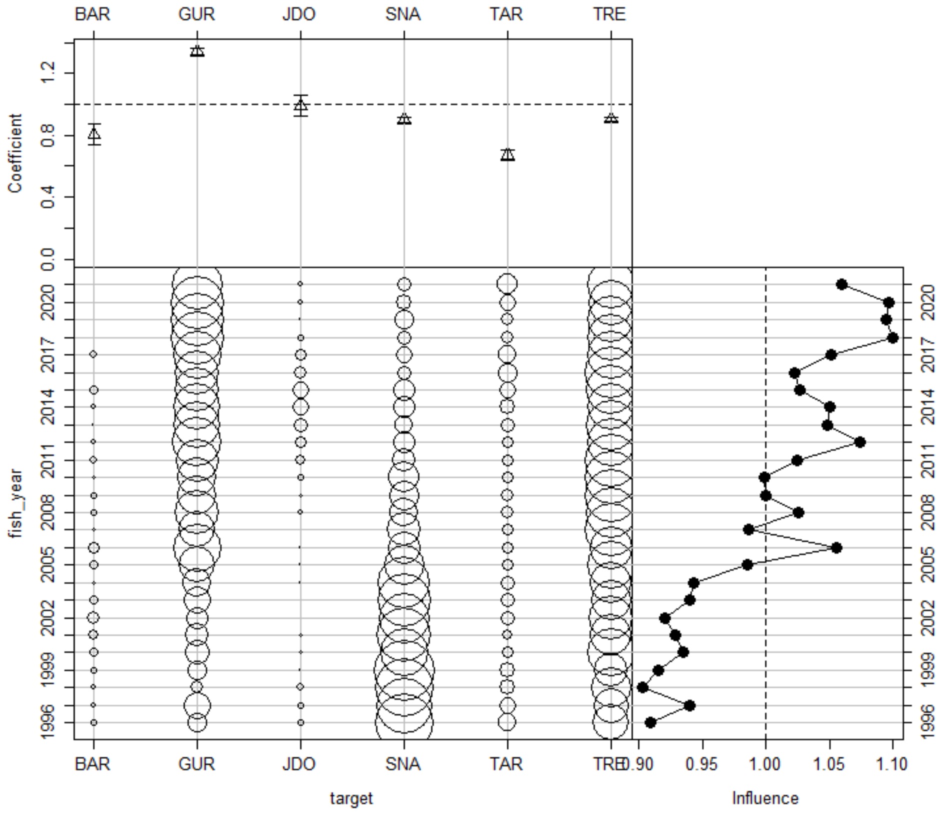

Figure 70: Influence plot for the *target* variable from the WCNI lognormal model. Species codes are barracouta (BAR), red gurnard (GUR), John dory (JDO), snapper (SNA), tarakihi (TAR), and trevally (TRE).

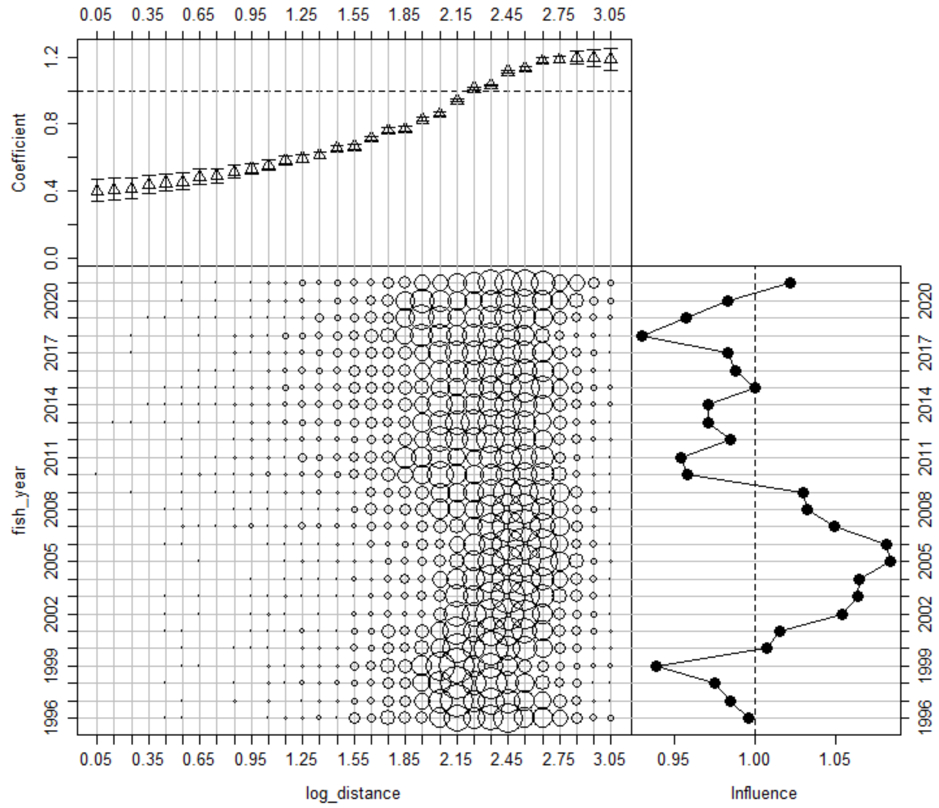

Figure 71: Influence plot for the *distance* variable from the WCNI lognormal model.

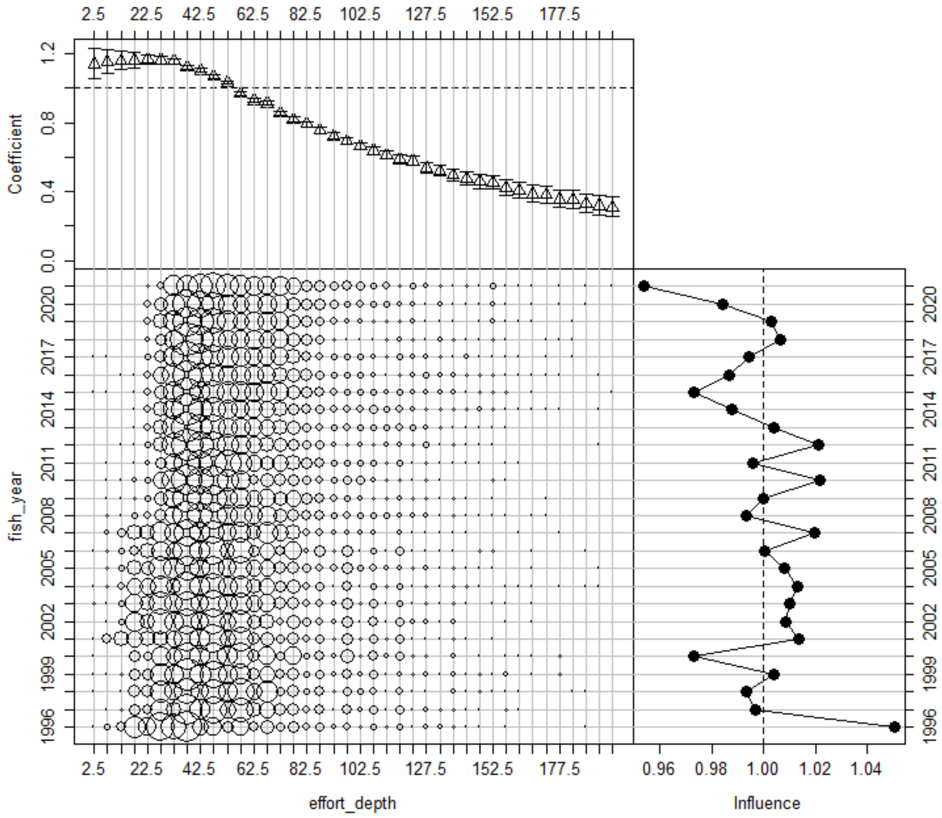

Figure 72: Influence plot for the *depth* (m) variable from the WCNI lognormal model.

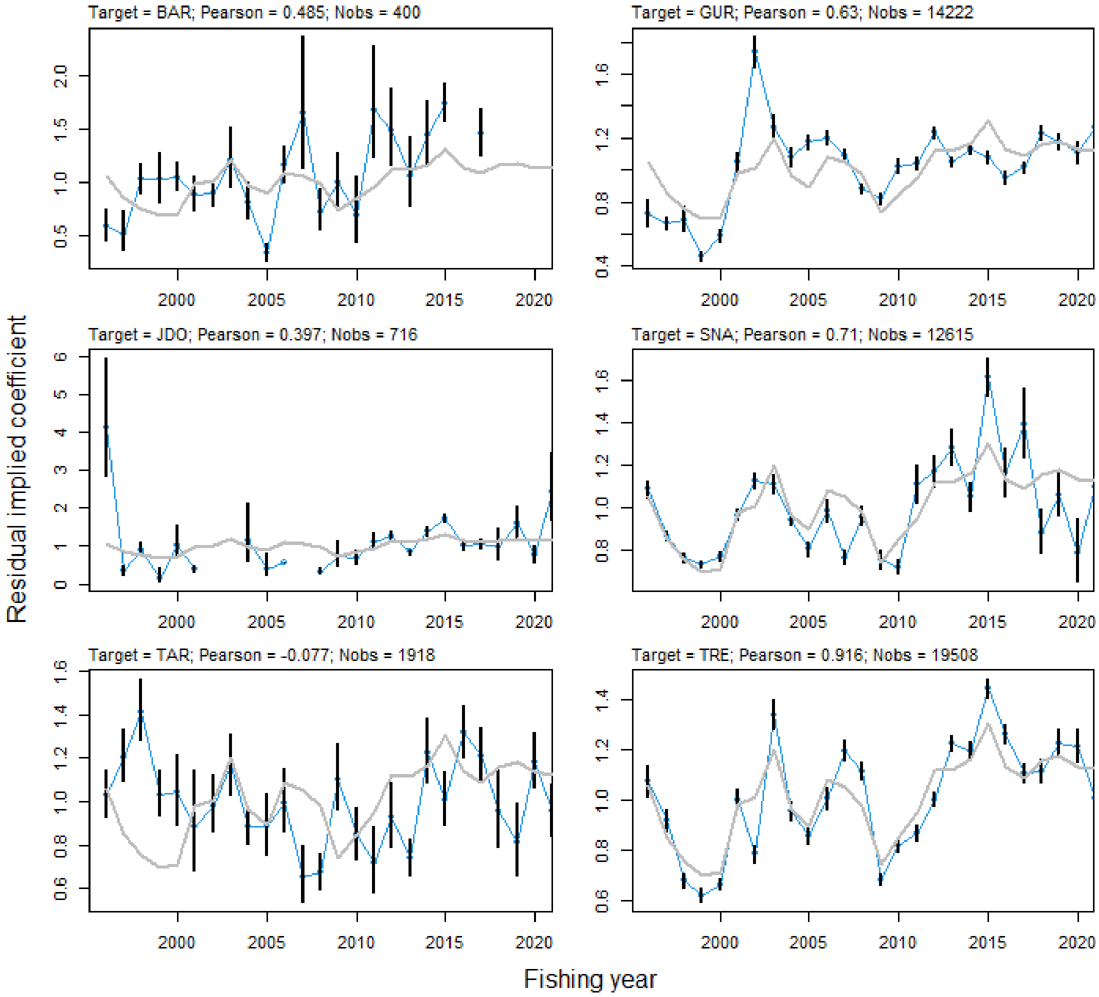

Figure 73: Annual implied residual coefficients (points joined by blue lines) for target species and the WCNI lognormal model, where the confidence intervals are one standard error. The grey line is the standardised index from the lognormal model. Species codes are barracouta (BAR), red gurnard (GUR), John dory (JDO), snapper (SNA), tarakihi (TAR), and trevally (TRE). Nobs: Number of trawls where the species was the target.

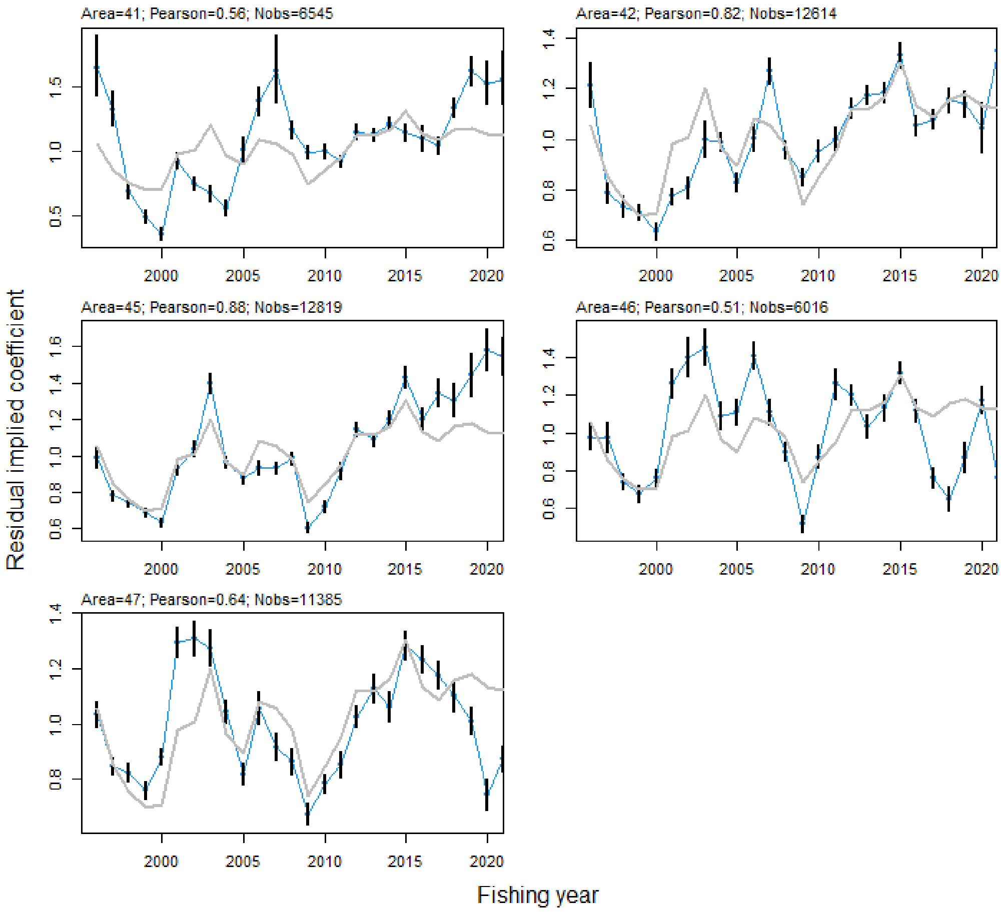

Figure 74: Annual implied residual coefficients (points joined by blue lines) for statistical area ('Area 41' is Statistical Area 041, etc.) and the WCNI lognormal model, where the confidence intervals are one standard error. The grey line is the standardised index from the lognormal model. Nobs: Number of trawls within the area.

APPENDIX 4: TABULATION OF STANDARDISED CPUE INDICES

Table 13: 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
1996	1.207	0.039	0.331	0.621
1997	1.174	0.039	0.276	0.490
1998	1.542	0.036	0.315	0.748
1999	1.226	0.030	0.373	0.726
2000	1.202	0.032	0.385	0.740
2001	1.367	0.026	0.611	1.559
2002	1.144	0.026	0.521	1.043
2003	1.247	0.024	0.496	1.063
2004	1.069	0.022	0.595	1.165
2005	0.938	0.021	0.711	1.329
2006	0.833	0.025	0.623	0.970
2007	0.804	0.027	0.680	1.064
2008	0.843	0.024	0.734	1.261
2009	0.937	0.023	0.703	1.308
2010	0.943	0.024	0.699	1.305
2011	1.011	0.026	0.626	1.193
2012	0.776	0.026	0.583	0.821
2013	0.723	0.029	0.571	0.742
2014	0.762	0.027	0.520	0.688
2015	0.810	0.029	0.570	0.830
2016	1.087	0.033	0.559	1.085
2017	1.059	0.031	0.646	1.301
2018	0.937	0.036	0.603	1.044
2019	0.940	0.034	0.561	0.953
2020	0.868	0.031	0.655	1.096
2021	1.033	0.033	0.669	1.338

Table 14: East Northland and Hauraki Gulf 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
1996	0.880	0.044	0.129	0.304
1997	0.873	0.040	0.105	0.245
1998	1.102	0.042	0.130	0.384
1999	1.216	0.034	0.172	0.564
2000	1.322	0.031	0.209	0.745
2001	1.341	0.028	0.273	0.990
2002	1.371	0.026	0.390	1.452
2003	1.374	0.031	0.425	1.587
2004	1.623	0.034	0.293	1.285
2005	1.763	0.032	0.484	2.324
2006	1.492	0.032	0.477	1.939
2007	1.190	0.029	0.567	1.844
2008	1.034	0.024	0.545	1.539
2009	0.877	0.024	0.467	1.115
2010	0.959	0.024	0.459	1.196
2011	0.873	0.025	0.502	1.194
2012	0.759	0.029	0.323	0.663
2013	0.777	0.027	0.353	0.742
2014	0.934	0.027	0.380	0.963
2015	0.971	0.028	0.370	0.974
2016	1.108	0.028	0.479	1.445
2017	0.955	0.030	0.458	1.189
2018	0.782	0.044	0.626	1.342
2019	0.607	0.049	0.393	0.646
2020	0.590	0.056	0.209	0.332
2021	0.476	0.063	0.191	0.245

Table 15: 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
1996	1.058	0.033	0.736	0.898
1997	0.853	0.026	0.710	0.700
1998	0.759	0.024	0.757	0.660
1999	0.699	0.026	0.759	0.609
2000	0.712	0.026	0.804	0.652
2001	0.981	0.024	0.879	0.971
2002	1.013	0.026	0.897	1.022
2003	1.204	0.027	0.904	1.222
2004	0.966	0.024	0.882	0.960
2005	0.897	0.024	0.863	0.875
2006	1.085	0.030	0.882	1.080
2007	1.056	0.028	0.899	1.067
2008	0.980	0.023	0.903	0.994
2009	0.743	0.024	0.859	0.722
2010	0.852	0.025	0.920	0.879
2011	0.954	0.026	0.856	0.924
2012	1.125	0.023	0.940	1.183
2013	1.121	0.021	0.962	1.203
2014	1.168	0.022	0.959	1.249
2015	1.309	0.021	0.970	1.413
2016	1.136	0.022	0.956	1.212
2017	1.090	0.023	0.952	1.158
2018	1.161	0.026	0.930	1.209
2019	1.180	0.030	0.908	1.204
2020	1.136	0.028	0.905	1.156
2021	1.126	0.031	0.899	1.139

APPENDIX 5: TABULATION OF TRAWL SURVEYS

Table 16: Estimates of red gurnard recruited biomass (t) from *Kaharoa* trawl surveys within GUR 1, where red gurnard is assumed to recruit at 30 cm total length. For the west coast North Island trawl survey, core strata are north of New Plymouth. Year is calendar year.

Year	Trip code	Biomass (t)	CV(%)
Bay of Plenty			
1983	KAH8303	229	31
1985	KAH8506	27	17
1990	KAH9004	234	11
1992	KAH9202	166	10
1996	KAH9601	185	16
1999	KAH9902	180	17
2020	KAH2001	130	14
2021	KAH2101	85	10
Hauraki Gulf			
1984	KAH8421	208	21
1985	KAH8517	33	57
1986	KAH8613	124	32
1988	KAH8810	329	25
1989	KAH8917	58	39
1990	KAH9016	64	17
1992	KAH9212	169	7
1993	KAH9311	85	18
1994	KAH9411	98	21
1997	KAH9720	107	22
2000	KAH0012	15	52
2019	KAH1907	120	34
2020	KAH2006	96	12
West coast North Island (core strata)			
1989	KAH8918	758	13
1991	KAH9111	1 435	18
1994	KAH9410	1 662	28
1996	KAH9615	1 090	11
1999	KAH9915	610	13
2018	KAH1806	551	14
2019	KAH1906	758	13
2020	KAH2005	824	13

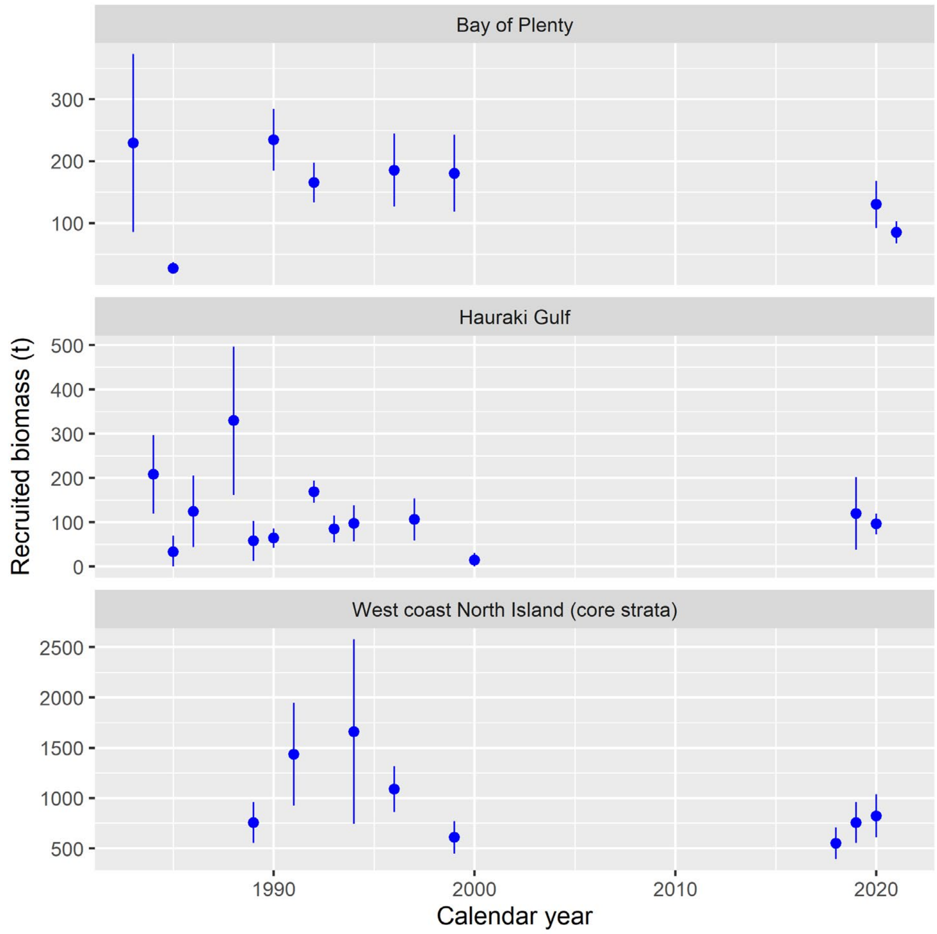

Figure 75: Estimates of recruited (length ≥ 30 cm) red gurnard biomass (t) from *Kaharoa* trawl surveys. Error bars are ± two standard deviations.

APPENDIX 6: TABULATION OF CATCH BY AREA

Table 17: Catch by fishing area in GUR 1.

Fishing year	Bay of Plenty	East Northland and Hauraki Gulf	West coast North Island
1990	129.2	269.4	224.9
1991	276.9	349.0	320.4
1992	342.3	470.0	345.7
1993	332.0	409.7	694.0
1994	292.3	280.4	542.3
1995	237.1	179.8	533.7
1996	185.5	170.5	659.7
1997	184.6	184.4	581.3
1998	235.8	196.8	526.2
1999	213.7	185.9	480.2
2000	238.0	231.1	460.2
2001	215.8	272.5	747.0
2002	230.7	246.0	574.3
2003	244.0	187.5	767.6
2004	267.5	213.8	659.1
2005	287.4	340.3	637.4
2006	232.2	276.5	484.8
2007	173.0	308.7	506.5
2008	193.3	204.4	612.6
2009	185.3	184.6	530.4
2010	203.7	195.0	530.6
2011	223.6	156.3	562.4
2012	147.4	134.7	593.7
2013	182.6	149.1	708.9
2014	171.6	160.0	606.1
2015	156.8	152.1	662.7
2016	177.5	146.3	483.1
2017	200.4	131.7	466.2
2018	171.2	94.3	397.1
2019	178.2	91.0	374.4
2020	171.7	77.9	410.8
2021	151.8	84.7	544.0

APPENDIX 7: SUPPORTING PLOTS FOR STOCK STRUCTURE ANALYSES

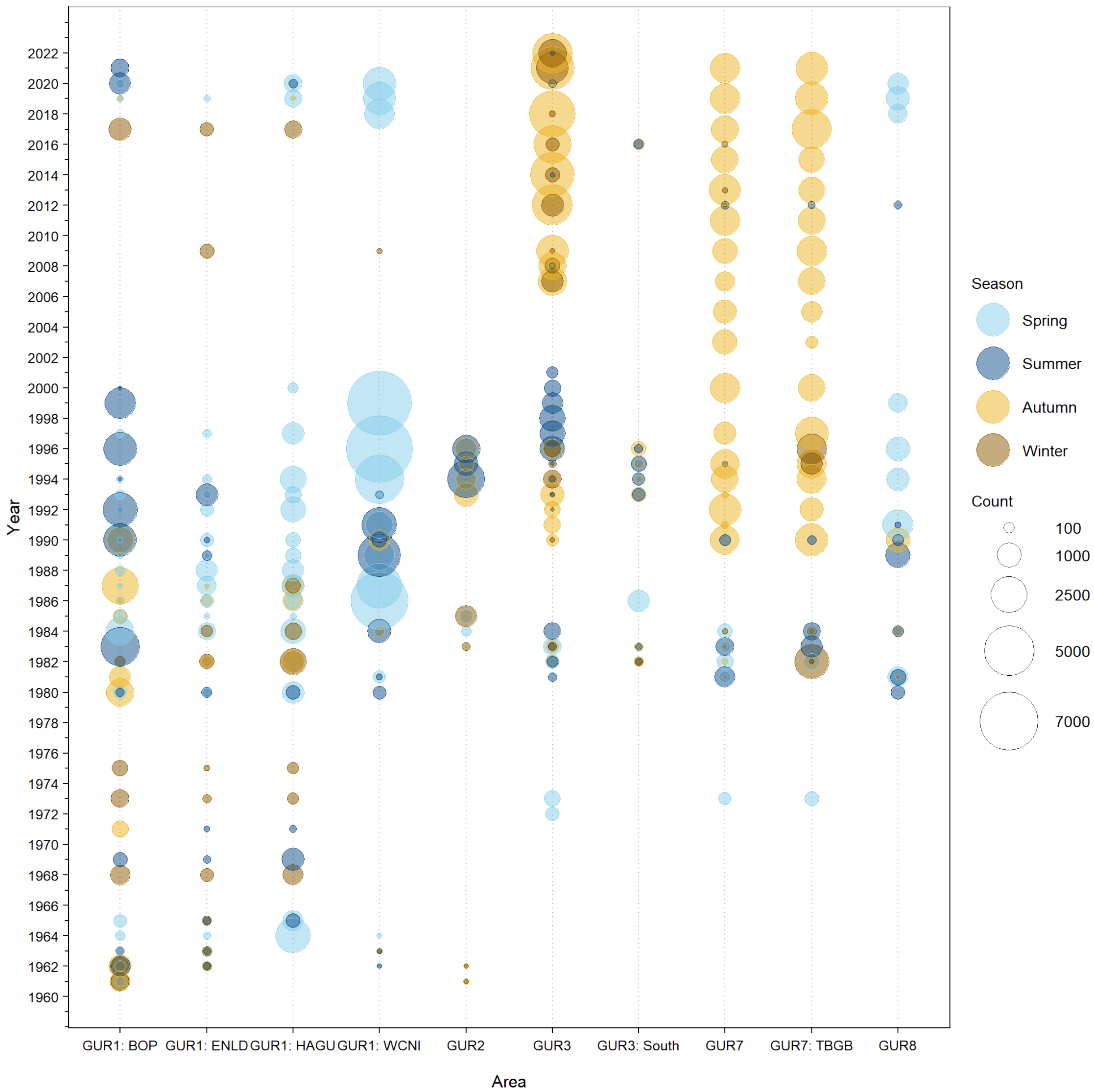

Figure 76: Summary of data availability for red gurnard from trawl surveys by area and season. Circles indicate numbers of records with length available.

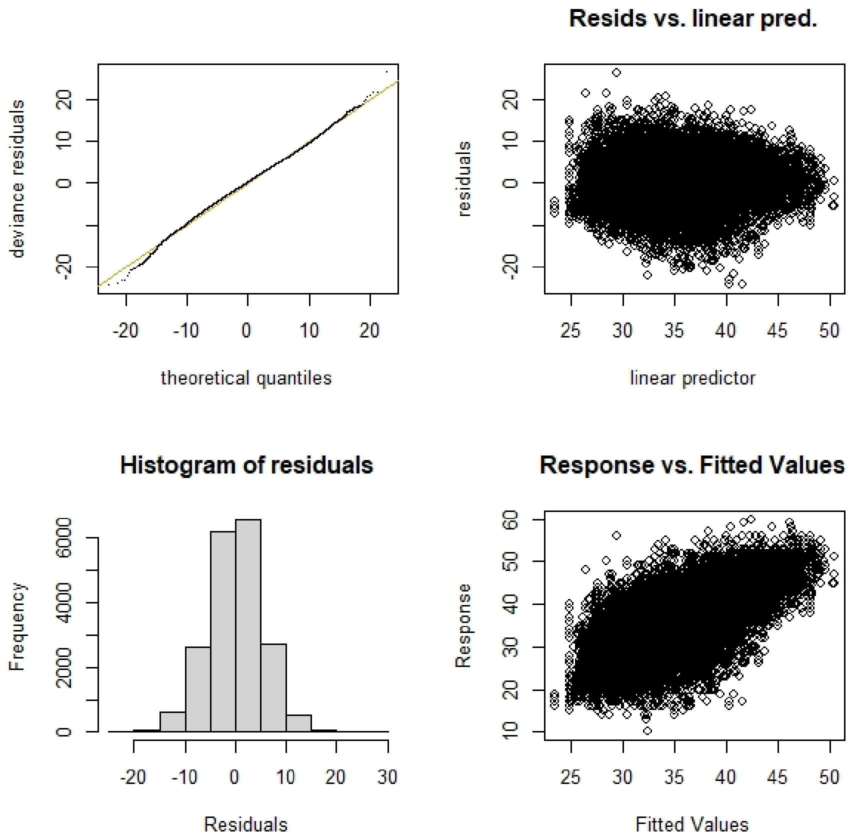

Figure 77: Residuals from the selected model examining mean length of female red gurnard.

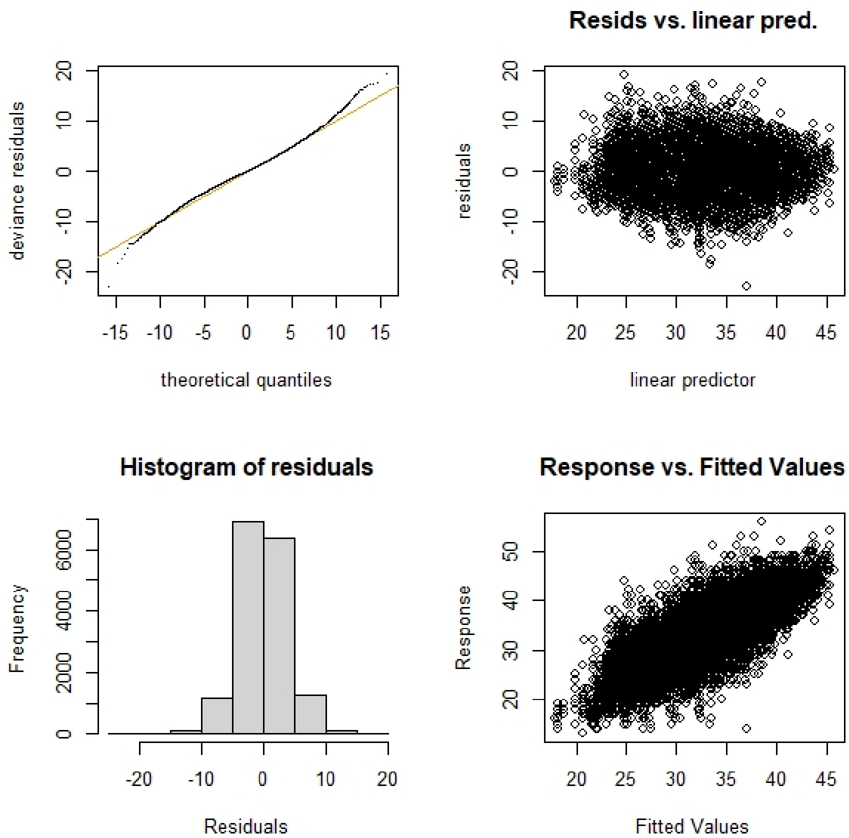

Figure 78: Residuals from the selected model examining mean length of male red gurnard.

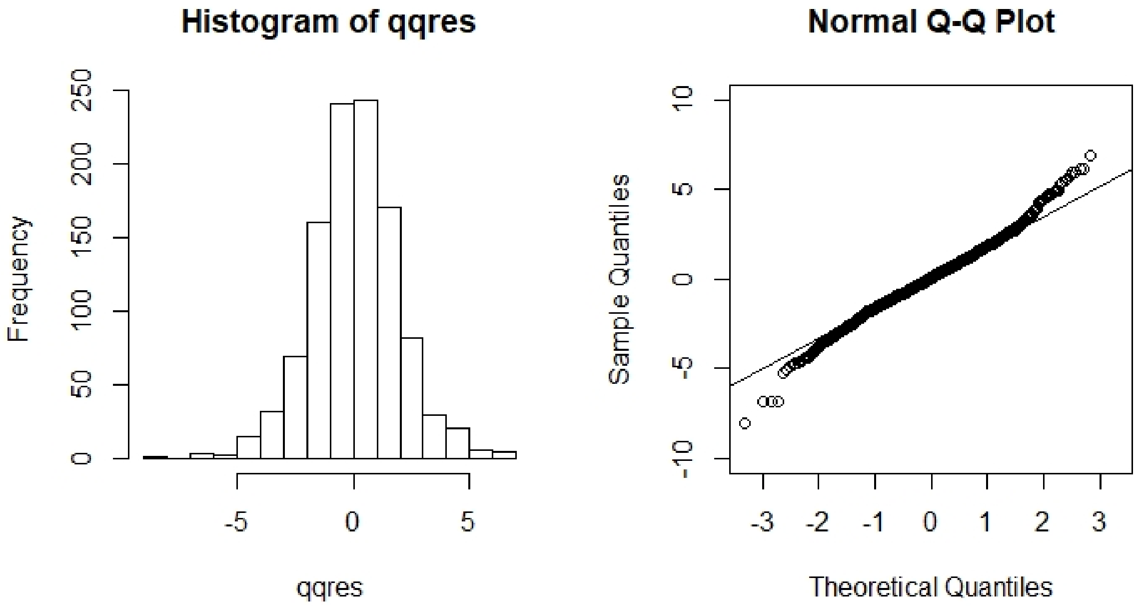

Figure 79: Residuals from the selected model examining sex ratio or red gurnard in GUR 3.