

Fisheries New Zealand

Tini a Tangaroa

Chatham Rise hake (*Merluccius australis*) 1989–90 to 2018–19: descriptive analysis of commercial catch effort data and standardised catch and effort data analysis (CPUE)

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EXECUTIVE SUMMARY

McGregor, V. L. (2021). Chatham Rise hake (*Merluccius australis*) 1989–90 to 2018–19: descriptive analysis of commercial catch effort data and standardised catch and effort data analysis (CPUE).

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This report provides a descriptive analysis of the catch and effort data for hake on the Chatham Rise (HAK 4 and part of HAK 1) from 1989–1990 to 2018–2019 and standardised CPUE analyses for the Chatham Rise hake fishery for the same years. The method for reallocation of catches from the Chatham Rise to the west coast South Island was explored with respect to the current data. Updated catch history required for stock assessment is presented, including the method for obtaining it.

Catches in HAK 1 and HAK 4 have been well below TACC since 2005 and 1999, respectively. Chatham Rise catches were mostly from bottom trawl events that targeted hoki or hake. The spawning fishery was identified as Statistical Areas 018, 020, and 404 based on very high catches in these areas within spawning months September–February. These statistical areas were omitted from CPUE analyses to avoid hyper-stability dynamics.

Standardised CPUE indices were produced by fitting GLMs to merged daily processed data from the Chatham Rise fishery. Three final CPUE indices are presented: western Chatham Rise, eastern Chatham Rise, and whole-of Chatham Rise. These indices were very similar from 1995 to 2019 and all presented a general decline followed by an increase from around 2012. The earlier part of the western series had an increasing trend, whereas this was decreasing for the other two series. The eastern and whole-of Chatham Rise indices matched the *Tangaroa* trawl survey abundance index reasonably well.

1. Introduction

Hake are widely distributed throughout the middle depths of the New Zealand Exclusive Economic Zone (EEZ) mostly south of latitude 40° S (Anderson et al., 1998). Adults are mainly distributed in depths from 250 to 800 m although some have been found as deep as 1200 m, juveniles (age 0+) are found in shallower inshore regions under 250 m (Hurst et al. 2000). Hake have been taken almost exclusively by trawl, and predominantly by large demersal trawlers —often as bycatch in fisheries targeting other species such as hoki and southern blue whiting, although target fisheries have also existed (Devine 2009, Ballara 2013, Ballara 2015).

Hake within the New Zealand Economic Exclusion Zone (EEZ) are managed as three separate Fishstocks: the Challenger Plateau and west coast of the South Island (HAK 7); the eastern Chatham Rise (HAK 4); and the remainder of the EEZ (HAK 1), which includes waters around the North Island, east coast of the South Island, and Sub-Antarctic, but excludes the Kermadec area (Figure 1), (Fisheries New Zealand 2020). The Chatham Rise fishery is considered to be all of HAK 4 and part of HAK 1 (Figure 1) (Ballara 2018).



Figure 1: Quota Management Areas (QMAs) HAK 1, 4, 7 and 10, and the Chatham Rise biological stock boundary as defined in Ballara (2018) and used for the catch and effort analyses in this report.

In 2018–19, the Total Allowable Commercial Catch (TACC) for the QMAs were 2272 t in HAK 7, 1800 t in HAK 4, 3701 t in HAK 1, and a nominal 10 t in HAK 10 (Fisheries New Zealand 2020). The TACC for HAK 4 was increased from 1000 t to 3500 t in the 1992 fishing year (fishing year defined as 1 October–30 September and labeled as the later year), after which time the catches increased until they came close to the TACC from 1990–1998. Catches in HAK 4 then declined, falling well below the TACC which was then lowered in 2005 to its current level of 1800 t. The TACC for HAK 1 underwent several smallish increases from its level of 2610 t in 1990 to its current level of 3701 t which was set in 2002. Catches in HAK 1 have been declining since 2009 and now sit at around a quarter of the TACC. Catches in HAK 7 were well below the TACC from 2008–2019, when the TACC was lowered to 2272 t (Fisheries New Zealand 2020).

Dunn (2003) found that area misreporting between the WCSI and the Chatham Rise fisheries occurred from 1994–95 to 2000–01. He estimated that between 16 and 23% (700–1000 t annually) of WCSI landings were misreported as deriving from Chatham Rise, predominantly in June, July, and September. Levels of misreporting before 1994–95 and after 2000–01, and between WCSI and the Sub-Antarctic, were estimated as negligible, and there has been no evidence of significant misreporting since (Ballara 2013).

Fishing year for hake in New Zealand is defined as 1 October –31 September, except for the Chatham Rise fishery, for which it is defined as 1 September –30 August due to the timing of spawning. Spawning occurs on the Chatham Rise during September–January, and sometimes extending out to February. Spawning locations include Statistical Area 404 (north-west of the Chatham Islands) and Mernoo Bank (Colman 1998, Devine 2009, Figure 2).



Figure 2: Chatham Rise fishery areas defined for previous Chatham Rise hake characterisations (Ballara, 2018).

The most recent hake Chatham Rise CPUE was developed using merged daily processed data from HAK 4 (Ballara 2018), and hence did not include the western Chatham Rise. Earlier CPUE analyses for Chatham Rise hake have considered both the western and eastern Chatham Rise fisheries (e.g., Ballara 2013).

A review of the Tangaroa trawl survey series defined hake as "very well estimated" in the core survey

area (O'Driscoll et al. 2011). The relative abundance index and proportions-at-age from this trawl survey series are both used to inform the stock assessment (Horn 2017, Horn & Francis 2010). In comparing CPUE indices to the trawl survey abundance indices, Ballara (2013) found a good match for the eastern Chatham Rise fishery, but not the western Chatham Rise fishery.

Earlier reports that have included descriptive analyses of catch and effort for hake on the Chatham Rise are listed in Table 1.

Table 1: Recent previous Chatham Rise hake reports that included catch and effort descriptive analyses.

Report title	Reference
Descriptive analysis of the fishery for hake (Merluccius australis) in HAK 1, 4 and	Ballara (2018)
7 from 1989-90 to 2016-17, and a catch-per-unit-effort (CPUE) analysis for Sub-	
Antarctic hake	
Descriptive analysis of the fishery for hake (Merluccius australis) in HAK 1, 4 and 7	Ballara (2017)
from 1989–90 to 2014–15, and a catch-per-unit-effort (CPUE) analysis for Chatham	
Rise and WCSI hake	
Descriptive analysis of the fishery for hake (Merluccius australis) in HAK 1, 4 and	Ballara (2015)
7 from 1989–90 to 2012–13, and a catch-per-unit-effort (CPUE) analysis for Sub-	
Antarctic Hake	
Descriptive analysis of the fishery for hake (Merluccius australis) in HAK 1, 4 and 7	Ballara (2013)
from 1989–90 to 2010–11, and a catch-per-unit-effort (CPUE) analysis for Chatham	
Rise and WCSI hake	
Descriptive analysis of the fishery for hake (Merluccius australis) in HAK 1, 4 and	Ballara (2012)
7 from 1989–90 to 2009–10, and a catch-per-unit-effort (CPUE) analysis for Sub-	
Antarctic hake	
Catch-per-unit-effort (CPUE) analysis and descriptive analysis of the fishery for hake	Ballara & Horn (2011)
(Merluccius australis) in HAK 1, 4 and 7 from 1989–90 to 2008–09	
Descriptive Analysis of the fishery for hake (Merluccius Australis) in HAK 1 and 4 from	Devine (2010)
1989–90 to 2007–08, and a catch-per-unit-effort (CPUE) analysis for Sub-Antarctic	
hake	
Descriptive analysis of the commercial catch and effort data for New Zealand hake	Devine (2009)
(Merluccius australis) for the 1989-90 to 2005-06 fishing years	
Catch and effort (CPUE) analysis of hake (Merluccius Australis) for the Chatham Rise	Dunn & Phillips (2006)
from 1989–90 to 2004–05	

This document reports on Specific Objectives 1 and 2 from Project HAK2019-01: Stock assessment of hake in HAK 4.

- Objective 1: To carry out a descriptive analysis of the commercial catch and effort data for hake on the Chatham Rise in preparation for the quantitative stock assessment.
- Objective 2: To complete a standardised catch and effort analyses from the Chatham Rise hake fisheries.

There are two additional components in this report not previously included in similar analyses for hake in New Zealand (Table 1).

- 1. The method for identifying and rescaling catches due to mis-reporting of fishstock (Dunn 2003) was revisited. This method has been routinely applied to commercial catch and effort data for hake descriptive analyses since the work by Dunn (2003), but not reported on, and with no apparent checks on the appropriateness of the method when applied to more recent data.
- 2. The method for updating the catch history was clarified. The updated catch history has previously been reported as part of the stock assessment report (e.g., Horn 2017), with little detail on the

method applied to obtain the catches. In these reports, only catches for the additional year(s) were reported, with no comparison of the new catch history for overlapping years from previous assessments.

2. Data and grooming

Catch-effort, daily processed, and landed data were extracted from the Fisheries New Zealand Enterprise Data Warehouse (EDW) (extract 12649B) and consisted of all fishing and landing events associated with a set of fishing trips that reported a positive catch or landing of hoki, hake, or ling during fishing years 1989–90 to 2018–19. The extract included all fishing recorded on forms listed in Table 2, and included high seas versions of these forms. Catch and effort data for hake from the Fisheries New Zealand observer sampling programme (administered by NIWA in the *cod* database) were also extracted.

 Table 2: Form types from Fisheries New Zealand Enterprise Data Warehouse (EDW) included in data extract 12649B.

Form code	Form description
ERS-trawl	Electronic Reporting System - trawl
TCEPR	Trawl Catch, Effort and Processing Return
TCER	Trawl Catch Effort return
CELR	Catch, Effort and Landing Return
LCER	Lining Catch Effort Return
LTCER	Lining Trip Catch Effort Return
NCELR	Netting Catch Effort Landing Return

TCEPR and TCER forms record tow-by-tow data with the estimated catch (by weight) of the top five species (TCEPRs) or the top eight species (TCERs) in each individual tow. The new ERS-trawl form reports the top five QMS species and top three non-QMS species and consequently should produce data closely comparable to that from the TCEPR and TCER paper forms for deepwater vessels. CELR forms record estimated daily catches for the top five species, which are further stratified by statistical area, method of capture, and target species. Greenweight data associated with landing events are reported on the bottom part of the CELR forms, or on CLR forms for fishing reported on TCEPRs and TCERs. Information on total harvest levels are provided via the Quota Management Area (QMA) (Ballara & O'Driscoll 2019).

The extracted data were groomed and restratified to derive the datasets required for these analyses using a variation of the data processing method developed by Starr (2007) as implemented by Manning et al. (2004), with refinements by Blackwell et al. (2006) and Manning (2007), and further modifications for this study following Ballara & O'Driscoll (2019).

Data from the whole EEZ were groomed for the purpose of defining the catch history and for applying the reallocation method of Dunn (2003). The Chatham Rise data were then selected based on the boundary shown in Figure 1 for the purpose of the descriptive analysis of the catch and effort data and CPUE.

2.1. Reallocation of misreported catches

The reallocation of misreported catches from the Chatham Rise fishery to the WCSI (west coast South Island) fishery followed the method presented by Dunn (2003). The method identifies fishing trips that

may have mis-reported catch from WCSI as catch from the Chatham Rise, then compares catch rates from the potentially mis-reported catches with those that were not mis-reported to determine which ones to reallocate. The comparison of catch rates is done by fitting a mixed-effects generalised linear model (Equation 1) to data from fishing trips with no mis-reported data. The resulting model is then used to predict catch rates for the events that may have been mis-reported. If the observed catches fall outside a defined confidence interval, the difference between the observed catch and the predicted catch is reallocated from being a Chatham Rise catch to be being a WCSI catch. The method only applies to catches recorded on TCEPR forms. Once the reallocation has been applied at the fishing event level, the adjustments are then applied to the landings by QMA.

Equation 1:

log(catch) year + poly(net depth, 3) + poly(vessel length, 3) + target + method/(poly(gear width, 3)+ poly(headline height,3)) + statistical area/month

where catch is tonnes/tow year, target, method, statistical area were categorical year was defined as fishing year, i.e., October–September Note: / indicates a nested term

The current analysis produced slight differences in the updated reallocation from the Chatham Rise to WCSI at the QMA level, which were expected due to evolving grooming algorithms applied prior to applying the reallocation method, as well as some assumptions around the reallocation method that were not apparent from the documentation presented by Dunn (2003). Initially, for the purpose of comparison, the current analysis adopted the fishing year definition used by Dunn (2003) of 1 October–30 September. The reallocation at the QMA level using cut-off=0.90 was compared (Figure 3). The only version presented by Dunn (2003) at the QMA level was that with cut-off=0.90, although this was not the final proposed version from the report. The cut-off value determines the confidence interval applied to residuals for trips that may have mis-reported, with 0.9 reallocating catch rates outside the 90% confidence interval, assuming residuals to be normally distribution with $\mu = 0$ and $\sigma = 1$. Note, although the reallocation method has been re-applied for every hake stock assessment carried out since Dunn (2003), there is no mention of the resulting values ever being compared with those presented by Dunn (2003).

At the Chatham Rise fishery level, there remained small differences between the resulting catch histories presented in Dunn (2003) and those updated here. The final proposed version of reallocation in Dunn (2003) used p=0.99. The closest match using the updated analysis appears to be using a cut-off of p=0.975 on the current data (Figure 4).

3. Catch history

The catch history for Chatham Rise hake was updated, and the entire series was compared with the catch history presented for previous Chatham Rise stock assessments (Horn 2017, Horn 2013); slight differences were found. The previous catch histories match each other exactly for overlapping years as only the additional years were updated. In addition to differences resulting from the reallocation method, there were also differences due to the spatial definition of the 'Chatham Rise fishery' and the split between eastern and western Chatham Rise stocks.



Figure 3: Comparison of reallocation method at QMA level using p=0.90. Grey bars = MHR unadjusted landings; blue asterisks = MHR adjusted for reallocation (Dunn 2003); black crosses = MHR adjusted for reallocation (current analysis).



Figure 4: Comparison of catch history by fishing year October–September for the Chatham Rise area (Figure 1) using p=0.99 (left, grey bars) and p=0.75 (right, grey bars). Dunn (2003) p=0.99 (blues asterisks) was the final adjusted catch history presented by Dunn (2003).

The Chatham Rise fishery has been defined as in Figure 1 and this matches that used in Dunn (2003). The previous stock assessments (Horn 2017, Horn 2013) defined the Chatham Rise fishery as a subset of the entire Chatham Rise stock, and with an eastern-western split at 178.1° E longitude (Figure 5). The Chatham Rise catch history presented in Dunn (2003) can be assumed to have used the Chatham Rise fishery was used for the catch history presented in Horn (2017) and used in the stock assessment. Further, previous CPUE analyses (e.g., Ballara (2018)) have split the eastern Chatham Rise to match the HAK 4 boundary (which can be seen in Figure 1), suggesting the eastern/western split has not always been assumed to be at 178.1° E longitude.

In the absence of a documented area definition for the catch history, a process of trial and error revealed a combination of area definition and eastern/western split that produced a catch history that matched those presented for stock assessments previously to the best extent possible.

- 1. The entire Chatham Rise fishery (in Figure 1) was used to apportion the MHR landings (with reallocation applied) to the Chatham Rise hake fishery. This step produced total Chatham Rise landings that are very similar to the previously defined landings (Figure 6, top left).
- 2. The east-west split was produced by selecting data from within the boundary in Figure 5 with a longitude split at 178.1° E.
- 3. The catch from step 1 was split between the eastern and western fisheries using the proportions of east and west catches from step 2. This assigned all of the Chatham Rise fishery landings of step 1 to either the eastern or western Chatham Rise fishery.

It appears a different eastern-western split may have been used for 2009–2016 fishing years, given that the totals for the Chatham Rise catch history of Horn (2017) matched those for these years but the ratio did not (Figure 6 top left and bottom right).



Figure 5: Chatham Rise fishery boundary from Horn (2017). Statistical areas are shown in light grey.

The resulting updated catch history provided to the stock assessment model (Table 3) used the previously reported catch history (Horn, 2013) for fishing years 1990–2008, and the updated catch history for fishing years 2009–2019. The catch history for fishing years 2009–2016 was updated rather than using the previously reported catches of Horn (2017) because of the difference in ratio between eastern and western Chatham Rise stocks for these fishing years which suggested a different eastern/western split compared to the rest of the catch history series.



Figure 6: Previous landings from Horn (2017) (grey bars) and new catch history with reallocation p=0.975 (black crosses) for the Chatham Rise fishery (top left), eastern Chatham Rise fishery (top right), and western Chatham Rise fishery (bottom left). Ratio of western Chatham Rise landings to total Chatham Rise landings from the previous stock assessment (Horn, 2017) (orange dashed line) and the new catch history (black solid line) (bottom right).

Table 3: Updated Chatham Rise hake catch history (tonnes) for fishing years 1990–2019, with catches in fishing years 2009–2019 updated, and catches in fishing years 1990–2008 taken from the previous stock assessments (Horn 2017, Horn 2013). Fishing year defined as September–August.

Fishing year	Western	Eastern	Total
1990	309	689	998
1991	409	503	912
1992	718	1 087	1 805
1993	656	1 996	2 652
1994	368	2 912	3 280
1995	597	2 903	3 500
1996	1 353	2 483	3 836
1997	1 475	1 820	3 295
1998	1 424	1 124	2 548
1999	1 169	3 339	4 508
2000	1 155	2 1 3 0	3 285
2001	1 208	1 700	2 908
2002	454	1 058	1 512
2003	497	718	1 215
2004	687	1 983	2 670
2005	2 585	1 4 3 4	4 019
2006	184	255	439
2007	270	683	953
2008	259	901	1 160
2009	1 084	838	1 922
2010	275	134	409
2011	777	165	942
2012	108	101	209
2013	249	117	366
2014	109	96	205
2015	139	83	222
2016	249	209	458
2017	302	124	426
2018	228	173	401
2019	364	93	457

4. Descriptive analysis

4.1. Catches by QMA

Estimated catches, reported landings, and TACC by stock for fishing years 1990–2019 are shown in Table 4, where fishing year is 1 October–30 September. Catches have been below the TACC since the fishing year 2007 in HAK 7, 1999 in HAK 4, and 2005 in HAK 1, and have remained well below TACC in subsequent years.

Table 4: Estimated hake catches, reported landings from QMR records, and TACC (all in tonnes, and rounded to the nearest tonne) for fishing years 1990–2019, where fishing year runs from 1 October–30 September and is labeled by the later calendar year. Estimated catches were scaled to QMR or MHR catch totals and adjusted for misreporting.

	Estimated catch			Reported catch			TACO		
Year	HAK1	HAK4	HAK7	HAK1	HAK4	HAK7	HAK1	HAK4	HAK7
1990	2 1 1 4	763	4 912	2 115	763	4 903	2 610	1 000	3 310
1991	2 594	718	6 151	2 603	743	6 148	2 610	1 000	3 310
1992	2 798	2 013	3 392	3 156	2 013	3 0 2 7	3 500	3 500	6 770
1993	3 387	2 546	7 371	3 525	2 546	7 154	3 501	3 500	6 835
1994	1 768	2 587	2 979	1 803	2 587	2 974	3 501	3 500	6 835
1995	2 401	3 014	10 325	2 572	3 369	8 841	3 632	3 500	6 835
1996	3 740	3 090	9 490	3 956	3 466	8 678	3 632	3 500	6 835
1997	3 170	3 049	6 774	3 534	3 524	6 1 1 8	3 632	3 500	6 835
1998	3 7 3 7	3 307	7 821	3 809	3 523	7 416	3 632	3 500	6 835
1999	3 681	3 0 3 1	8 897	3 845	3 324	8 165	3 632	3 500	6 835
2000	3 831	2 792	6 954	3 899	2 803	6 898	3 632	3 500	6 835
2001	3 391	2 297	8 4 2 0	3 429	2 321	8 360	3 632	3 500	6 835
2002	2 870	1 424	7 519	2 870	1 424	7 519	3 701	3 500	6 835
2003	3 310	811	7 452	3 336	811	7 433	3 701	3 500	6 835
2004	3 466	2 275	7 945	3 466	2 275	7 945	3 701	3 500	6 835
2005	4 795	1 264	7 317	4 795	1 264	7 317	3 701	1 800	6 835
2006	2 743	305	6 906	2 743	305	6 906	3 701	1 800	7 700
2007	2 0 2 5	900	7 668	2 025	900	7 668	3 701	1 800	7 700
2008	2 445	865	2 620	2 445	865	2 620	3 701	1 800	7 700
2009	3 415	856	5 954	3 415	856	5 954	3 701	1 800	7 700
2010	2 156	208	2 352	2 156	208	2 352	3 701	1 800	7 700
2011	1 904	179	3 754	1 904	179	3 754	3 701	1 800	7 700
2012	1 948	161	4 459	1 948	161	4 459	3 701	1 800	7 700
2013	2 079	177	5 434	2 079	177	5 4 3 4	3 701	1 800	7 700
2014	1 883	168	3 642	1 883	168	3 642	3 701	1 800	7 700
2015	1 725	304	6 219	1 725	304	6 219	3 701	1 800	7 700
2016	1 584	274	2 864	1 584	274	2 864	3 701	1 800	7 700
2017	1 175	268	4 701	1 175	268	4 701	3 701	1 800	7 700
2018	1 350	267	3 086	1 350	267	3 086	3 701	1 800	5 064
2019	896	183	1 563	896	183	1 563	3 701	1 800	2 272

4.2. Chatham Rise fishery

Catches from the Chatham Rise fishery were primarily recorded on TCEPR forms, which since 2018 have been replaced by ERS forms (Figure 7). When catches have been high, they have generally occurred during the months September–January (Figure 8), which corresponds with the hake spawning season. In some years, such as 2007–2009, this period has extended out to February. Catches were mostly caught using bottom trawl (BT) (Figure 9), and when targeting hoki or hake, with a small amount from ling target (Figure 10). The spatial distribution of effort by target shows that when hake have been caught on the eastern Chatham Rise, such as near the Chatham Islands or the known spawning ground of statistical area 404, the target has tended to be hake or ling. Hoki target effort has tended to be further west on the Chatham Rise (Figure 11). Catches by statistical area in five-year blocks showed more of the catches were from the western Chatham Rise from 2010 onwards than earlier years, and in particular the spawning ground Statistical Area 404 has had lower catches from 2010 onwards (Figure 12).



Figure 7: Catches from Chatham Rise by form type. Form types are defined in Table 2.



Figure 8: Catches from Chatham Rise by month and fishing year. The small amount of data from 2020 is due to the new fishing year definition which begins 1 September.



Figure 9: Catches from Chatham Rise by fishing method. BPT=bottom trawl - pair; BT=bottom trawl; MW=midwater; MB=mid-bottom trawl (midwater trawl within 5 m of the seabed); PRB=precision bottom trawl; PRM=precision midwater trawl. 'Precision' refers to a trawl system designed to target specific species and fish size, and improve the condition of fish landed (Ballara and O'Driscoll 2019).



Figure 10: Catches from Chatham Rise by target species. WWA = White Warehou; SWA = Silver Warehou; SQU = Arrow Squid; SPE = Sea Pearch; SCI = Scampi; RCO = Red Cod; ORH = Orange Roughy; LIN = Ling; HOK = Hoki; HAK = Hake; BAR = Barracouta.



Figure 11: Effort (number of tows) from Chatham Rise fishing years 1990–2019 merged daily processed data where hake were the predominant target species (top left), hoki were the predominant target species (top right), ling were the predominant target species (bottom left) or the target species was not predominantly hake, hoki, or ling (bottom right).



Figure 12: Catches (kg) from merged daily processed data by statistical area for fishing years (A) 1990–1994; (B) 1995–1999; (C) 2000–2004; (D) 2005–2009; (E) 2010–2014; (F) 2015–2019. Statistical area labels are given in Appendix A.

4.3. Identifying the spawning fishery

Catches on spawning fisheries can retain higher catch rates that may not reflect abundance of the stock (Erisman et al. 2011), and hence should be omitted from CPUE analysis. Ratios of catches from spawning months (considered here to be September–February) to catches from non-spawning months by statistical area were explored to highlight spawning grounds within the fishery based on high catches. The highest catch rates were from Statistical Areas 018, 020, and 404 during spawning months (Figure 13). Statistical Area 018 had large spikes in catches in 2011 and 2013, Statistical Area 020 had large spikes in catches in 2005 and 2009, and catches were consistently high in statistical area 404 up until 2010. Hence, catches from Statistical Areas 018, 020, and 404 were removed from the dataset for the non-spawning fishery for which CPUE models were developed.



Figure 13: Proportion of Chatham Rise catch taken during spawning months and non-spawning months, by fishing year (top left, grey lines), and for each statistical area, by fishing year (blue lines). Fishing year defined as 1 September–31 August; spawning months defined as September–February (solid lines) and non-spawning months March–August (dashed lines). Statistical areas are shown in Figure 5 and Appendix A.

5. CPUE

CPUE models were fitted to daily processed catch and effort data from the non-spawning fishery using GLMs (generalised linear models) with both lognormal and delta-lognormal models explored. Fishing year was forced as a categorical explanatory variable. Additional explanatory variables were selected using a step-wise selection process, with each iteration selecting the variable that explained the largest amount of deviance (r^2), until a lower threshold of 1% in the additional explained deviance was reached. The CPUE analyses were implemented in the R statistical programming language (R Core Team, 2020).

Explanatory variables offered to CPUE models are given in Table 5. There were six variables that were offered to the CPUE model in the previous analyses (Ballara 2018) that were not offered here: *distance* because it correlated with *duration* which was considered more reliable as an explanatory variable; *vessel.experience* was not thought to be reliable so was replaced by fishing fleet, or alternatively *vessel.key*; *longitude* and *latitude* are confounded so statistical area (*statarea*) or sub area (*subarea*) were preferred; *date* and *fishing.day* were replaced because *season* or *fishing.month* were thought to provide a sufficiently fine temporal scale for these data. Interaction terms were explored, in particular spatial:temporal interactions such as *month* and *subarea*.

Fishing fleets were defined using the classifications of Ballara and O'Driscoll (2019) and are as follows:

- BATM: All Ukranian/Russian crewed vessels (regardless of ownership) are referred to as BATMs, which is the specific class of large factory trawler with a meal plant on board.
- FOV: All Korean/Japanese vessels are combined under the term FOV which is defined as all foreign owned vessels excluding BATMs. These vessels do not have a meal plant on board.
- Domestic: All NZ owned vessels except BATMs. The domestic fleet includes vessels that vary in length, presence of meal plants, and on board processing (fillet producing vessels vs ice boats etc.). The domestic category was then further subdivided according to whether meal plants were on board or not.

Table 5: CPUE explanatory variables offered to the models. Continuous variables were offered as 3rd order polynomials. (Continued on next page).

Variable	Туре	Description	Comments
Year	Factor	Fishing year, Sep-Aug	
Vessel.key	Factor	Vessel identifier	
Statarea	Factor	Statistical area	
Subarea	Factor	The 8 subareas shown in Figure 2	Alternative to statarea
Method	Factor	BT, MW, MB	Mostly BT, and alternative fitting to only BT explored
Duration	Continuous	Sum of tow durations from given vessel.day	
Bottom.depth	Continuous	Median of bottom depth from given ves- sel.day	
Effort.depth	Continuous	Median of fishing depth from given ves- sel.day	
Speed	Continuous	Median tow speed from given vessel.day	
Wingspread	Continuous	Median gear windspread from given ves- sel.day	
Target.species	Factor	Most common target species from given vessel.day	
Fmonth	Factor	Most common fishing month from given vessel.day	

Season	Factor	Season: non-spawning Mar-Aug; spawning Sep-Feb	
Fleet ¹	Factor	BATM, FOV, DOM ²	Alternative to vessel.key. Only applicable from 2008
			fishing year onwards
Twin.trawl	Factor		Only applicable from 2008
			fishing year onwards

CPUE models were explored using three spatial subsets of the data: whole-of Chatham Rise used data from the Chatham Rise area defined in Figure 1 and the eastern and western Chatham Rise split this area at longitude 178.1° E as shown in Figure 2.

For each model fitted, a core data set was defined to consistently represent the fishery definition being explored. Selection of core vessels were based on a minimum number of years in the fishery, with a minimum number of fishing days within each of these years. The minimum thresholds were set for each model based on retaining approximately 80% of the catch for that fishery over the entire time series, and with consideration also given to the percentage of catch retained within each fishing year.

A number of CPUE models were explored, including combinations offering fishing fleet rather than *vessel.key*, *subarea* rather than *statarea*, forcing *month:subarea* (or *month:statarea*) interactions, including or excluding spawning areas, and including eastern and/or western Chatham Rise. The models presented in detail are those put forward by the Fisheries New Zealand Deepwater Working Group to be used in the stock assessment. These final CPUE models all used *vessel.key* rather than fishing fleet, and the data were restricted to only bottom trawl (BT) events that targeted hoki or hake, during the non-spawning fishery. For these final CPUE models, spawning areas were assumed to be Statistical Areas 018, 020, and 404, and data from these areas were dropped for non-spawning CPUE.

5.1. Chatham Rise non-spawning CPUE

The Chatham Rise non-spawning CPUE core vessel selection used criteria of at least 3 fishing years for which at least 10 fishing days were recorded, which kept just under 80% of the catch over all years, and over 80% in most years for 1990–2019 (Figure 14).

Variables selected for this CPUE model were *vessel.key*, *statarea*, and *target*, and 53.30% of the null deviance was explained (Table 6). *Vessel.key* pulled down the index in 1990, and up in the last three years (Figure 15).

The vessels with the highest coefficients featured most in this fishery from around 2004 to 2015, and there was also a large amount of effort from vessels with fairly high coefficients in the 1990s that for the most part then dropped out of the fishery (Figure 16). Effort decreased in Statistical Area 019, which had a high coefficient, and in recent years increased in Statistical Area 407, which had a low coefficient (Figure 16). Target species effort was largely hoki, although hake target featured from 2000–2010.

The diagnostics for this model were sound, suggesting the assumptions of normality of errors were reasonable (Figure 17).

¹Ballara pers comm.

²Further subdivided into domestic vessels with or without meal plant



Figure 14: Exploration of core vessel selection criteria for whole-of Chatham Rise non-spawning fishery. Horizontal lines represent target level of catch to be retained by core vessels.

Table 6: Explanatory variables for whole Chatham Rise non-spawning CPUE model, (lognormal model).



Figure 15: Fitted CPUE model of Chatham Rise, non-spawning fishery, showing the year effects of adding each explanatory variable.



Figure 16: Influence plots for CPUE model of Chatham Rise, non-spawning fishery, for each explanatory variable.



Figure 17: Diagnostics for Chatham Rise non-spawning CPUE model.

The binomial component of the delta-lognormal model selected variables *statarea*, *vessel.key*, *duration*, and *bottom.depth*, and explained 28.22% of the null deviance (Table 7). The resulting index was fairly flat, and hence the delta-lognormal model produced a very similar index to the lognormal model (Figure 18). The diagnostics for the binomial model were sound (Figure 19).

Table 7:	Explanatory	variables for	Chatham	Rise	non-spawning	CPUE	model,	(binomial	component	of
delta-log	normal model	l) .								

Variable	r^2
fishing year	4.03
statarea	18.24
vessel.key	22.67
poly(duration, 3)	25.73
poly(depth.bottom, 3)	28.22



Figure 18: Chatham Rise non-spawning delta-lognormal CPUE (dark blue line), binomial index (light blue line), and lognormal model index (dark blue dashed line).



Figure 19: Diagnostics for Chatham Rise non-spawning binomial model.

5.2. Eastern non-spawning CPUE

The eastern Chatham Rise non-spawning CPUE core vessel selection used criteria of at least 3 fishing years for which at least 8 fishing days were recorded, which kept 80% of the catch over all years, and in most years 1990–2019 (Figure 20).

Variables selected for this CPUE model were *vessel.key*, *statarea*, and *target*, and 58.89% of the null deviance was explained (Table 8). Both *vessel.key* and *statarea* pulled down the index in 1990, but the rest of the series remained similar to the unstandardised index (Figure 21).

The vessels with the highest coefficients generally only featured in this fishery from fishing year 2000 onwards, and most of these vessels did not feature in the most recent few years (Figure 22). Effort by statistical area was more consistent over time. Target species effort was largely hoki, although hake target featured from 2000 to 2010, which reduced the standardised CPUE slightly in these years, most notably in 2004 (Figures 22 and 21).

The diagnostics for this model were sound, suggesting the assumptions of normality of errors were reasonable (Figure 23).

Table 8: Explanatory variables for eastern Chatham Rise non-spawning CPUE model, (lognormal model).

Variable	r^2
fishing year	8.9
vessel.key	41.86
statarea	55.90
target	58.89

The binomial component of the delta-lognormal model selected variables *statarea*, *duration*, *vessel.key*, and *bottom.depth* and explained 28.79% of the null deviance (Table 9). The resulting index was reasonably flat, and hence the delta-lognormal model produced a very similar index to the lognormal model (Figure 24). The diagnostics for the binomial model were sound (Figure 25).



Figure 20: Exploration of core vessel selection criteria for eastern Chatham Rise non-spawning fishery. Horizontal lines represent target level of catch to be retained by core vessels.



Figure 21: Fitted CPUE model of eastern Chatham Rise, non-spawning fishery, showing the year effects of adding each explanatory variable.



Figure 22: Influence plots for CPUE model of eastern Chatham Rise, non-spawning fishery, for each explanatory variable.



Figure 23: Diagnostics for eastern Chatham Rise non-spawning CPUE model.

 Table 9: Explanatory variables for eastern Chatham Rise non-spawning CPUE model, (binomial component of delta-lognormal model).

Variable	r^2
fishing year	6.89
statarea	16.23
poly(duration, 3)	22.04
vessel.key	26.67
poly(depth.bottom, 3)	28.79



Figure 24: Eastern Chatham Rise non-spawning delta-lognormal CPUE (dark blue line), binomial index (light blue line) and lognormal model index (dark blue dashed line).



Figure 25: Diagnostics for eastern Chatham Rise non-spawning binomial model.

5.3. Western non-spawning CPUE

The western Chatham Rise non-spawning CPUE core vessel selection used the criteria of at least 3 fishing years for which at least 5 fishing days were recorded, which kept close to 75% of the catch over all years 1990–2019, and greater than 80% in years 1995–2015 and 2019 (Figure 26).

Variables selected for this CPUE model were *vessel.key*, *statarea*, *target*, and *depth.bottom* and 47.83% of the null deviance was explained (Table 10). *Vessel.key* pulled down the index in the first few years and up at the end of the series, and *statarea* pulled the index down around the middle of the series (early- to mid-2000s) (Figure 27).

There were some fairly large concentrations of effort from vessels with high coefficients in the early 1990s (Figure 28), which resulted in bringing the standardised CPUE down for these years. Effort decreased in Statistical Area 019, which had a high coefficient, and in recent years increased in Statistical Area 407, which had a low coefficient (Figure 28). The decrease in the standardised index in the mid-2000s from statarea seems to be from high effort in Statistical Areas 021 and 401, both of which had high coefficients (Figure 27 and 28). Target species effort was largely hoki, although hake target featured from 2000–2010 (Figure 29). Bottom depth had negative coefficients for depths less than 500 m and greater than 700 m, and the effort has concentrated within the 500–700 m depth range in the recent part of the mid-2000s (Figure 29).

The diagnostics for this model were sound, suggesting the assumptions of normality of errors were reasonable (Figure 30).



Figure 26: Exploration of core vessel selection criteria for western Chatham Rise non-spawning fishery. Horizontal lines represent target level of catch to be retained by core vessels.

Table 10: Explanatory variables for western Chatham Rise non-spawning CPUE model, (lognormal model).

r^2
5.78
32.17
43.18
46.73
47.83





The binomial component of the delta-lognormal model selected variables *statarea*, *vessel.key*, *duration*, and *bottom.depth* and explained 32.93% of the null deviance (Table 11). The resulting index was reasonably flat, and hence the delta-lognormal model produced a very similar index to the lognormal model (Figure 31). The diagnostics for the binomial model were sound (Figure 32).

Table 11: Explanatory variables for western Chatham Rise non-spawning CPUE	model, (binomial compo-
nent of delta-lognormal model).	

Variable	r^2
fishing year	4.52
statarea	24.18
vessel.key	27.95
poly(duration, 3)	30.70
poly(depth.bottom, 3)	32.93



Figure 28: Influence plots for CPUE model of western Chatham Rise, non-spawning fishery, for explanatory variables *vessel.key* and *statarea*.



Figure 29: Influence plots for CPUE model of western Chatham Rise, non-spawning fishery, for explanatory variables *target* and *bottom.depth*.



Figure 30: Diagnostics for western Chatham Rise non-spawning CPUE model.



Figure 31: Western Chatham Rise non-spawning delta-lognormal CPUE (dark blue line), binomial index (light blue line), and lognormal model index (dark blue dashed line).



Figure 32: Diagnostics for western Chatham Rise non-spawning binomial model.

5.4. Comparison of final CPUE indices

The CPUE indices were very similar from 1995 onwards (Figure 33). Before 1995 the eastern Chatham Rise CPUE and the previous CPUE which modeled data from HAK 4 (i.e., also the eastern Chatham Rise) declined from a high initial value whereas the western Chatham Rise CPUE index began a lot lower. The trawl survey core biomass estimates matched the early decline of the eastern Chatham Rise CPUE.



Figure 33: Comparison of final CPUE models, the previous Chatham Rise hake CPUE (Ballara 2018), and the trawl survey core biomass estimates.

6. Discussion

Hake on the Chatham Rise were taken mostly by bottom trawling, as stated in previous analyses (see Ballara 2018). They were predominantly caught when targeting hoki in the recent years, where as other targets such as hake, ling, and southern blue whiting featured a little more in earlier analyses (e.g., Ballara (2015), Devine (2009)).

Spatial plots of catches showed that, in the most recent 10 years, catches have been more from the western Chatham Rise fishery rather than the eastern Chatham Rise fishery that had previously been dominant. In particular, statistical area 404, the known spawning ground for hake, has seen much lower catches (and effort) in these more recent years. Because the effort has also been reduced in statistical area 404, it is difficult to determine whether the fishery is not focusing on this area because the fish are not there, or for other reasons relating to fishery behaviour.

Identifying spawning aggregations can be important when standardising CPUE to avoid presenting an index with hyper-stability (Erisman et al. 2011). Statistical area 404 has stood out as a spawning fishery, and CPUE analyses have explored treating this area separately (e.g., Devine (2010)). The most recent CPUE analysis for the Chatham Rise hake fishery noted the effect of statistical area 404 on the CPUE, but included it in the standardised index based on the rationale that the resulting index matched the trawl survey index fairly well (Ballara 2018). Statistical areas 018 and 020 that were identified here as likely spawning grounds, based on high peaks in catches during spawning months in some years, have also received mention in relation to spawning in Ballara (2018), but not in relation to the CPUE standardisation. The eastern Chatham Rise CPUE index was used as a sensitivity for the stock assessment (Holmes 2021).

The dynamics of the eastern and western Chatham Rise hake fisheries seem rather different to each other, in particular with respect to the earlier part of the CPUE index, and this could be of importance when assessing this stock. The spatial dynamics of this fishery are likely confounded with the multi-species fishery dynamics. Because hake have often been caught as by-catch in the hoki fishery, the dynamics of the hake fishery are likely to be affected by the dynamics of the hoki fishery, and, as such, it is difficult to assess these fisheries appropriately in isolation.

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Appendix A: Statistical areas

Fisheries statistical areas



Appendix B: Final CPUE indices

					Who	le of Chatham Rise					Easter	Eastern of Chatham Rise				Western of Chatham Rise		
year	index	lower.CI	upper.CI	se	cv	DeltaLogNormal	index	lower.CI	upper.CI	se	cv	DeltaLogNormal	index	lower.CI	upper.CI	se	cv	DeltaLogNormal
1990	1.28	1.07	1.53	0.09	0.09	1.23	2.26	1.37	3.75	0.25	0.26	2.37	0.93	0.75	1.15	0.11	0.11	0.89
1991	1.56	1.37	1.76	0.06	0.06	1.56	2.5	1.99	3.14	0.11	0.11	2.61	1.04	0.87	1.24	0.09	0.09	1
1992	1.32	1.2	1.47	0.05	0.05	1.26	1.57	1.3	1.9	0.1	0.1	1.4	0.95	0.83	1.1	0.07	0.07	0.9
1993	1.17	1.05	1.31	0.06	0.06	1.1	1.47	1.19	1.81	0.1	0.1	1.47	0.89	0.77	1.03	0.07	0.07	0.78
1994	1.31	1.15	1.5	0.07	0.07	1.29	1.94	1.51	2.5	0.13	0.13	1.93	1.04	0.88	1.24	0.09	0.09	1.01
1995	1.31	1.19	1.43	0.05	0.05	1.31	1.2	1.03	1.39	0.07	0.08	1.16	1.34	1.17	1.52	0.07	0.07	1.31
1996	1.28	1.16	1.4	0.05	0.05	1.26	1.1	0.9	1.35	0.1	0.1	1.03	1.41	1.25	1.59	0.06	0.06	1.35
1997	1.5	1.39	1.62	0.04	0.04	1.49	1.49	1.27	1.74	0.08	0.08	1.46	1.54	1.4	1.7	0.05	0.05	1.51
1998	1.2	1.12	1.28	0.03	0.03	1.19	1.16	1.01	1.33	0.07	0.07	1.13	1.28	1.17	1.4	0.04	0.04	1.25
1999	1.06	0.99	1.14	0.03	0.03	1.07	0.9	0.8	1.01	0.06	0.06	0.89	1.28	1.16	1.4	0.05	0.05	1.29
2000	1.29	1.2	1.39	0.04	0.04	1.32	1.17	1.03	1.34	0.07	0.07	1.16	1.37	1.24	1.52	0.05	0.05	1.4
2001	1.24	1.16	1.33	0.03	0.03	1.27	1.06	0.93	1.2	0.06	0.06	1.06	1.34	1.22	1.46	0.04	0.04	1.36
2002	1.02	0.94	1.1	0.04	0.04	1.05	0.82	0.7	0.96	0.08	0.08	0.84	1.11	1	1.23	0.05	0.05	1.13
2003	1.01	0.93	1.09	0.04	0.04	1.02	0.92	0.79	1.07	0.08	0.08	0.93	1.06	0.96	1.18	0.05	0.05	1.06
2004	1.04	0.95	1.13	0.04	0.04	1.06	0.97	0.84	1.11	0.07	0.07	0.94	0.98	0.85	1.13	0.07	0.07	0.99
2005	0.77	0.69	0.86	0.06	0.06	0.78	0.65	0.54	0.79	0.09	0.09	0.59	0.95	0.8	1.12	0.08	0.08	0.96
2006	1.02	0.9	1.15	0.06	0.06	1.03	0.89	0.71	1.13	0.12	0.12	0.88	1.12	0.95	1.31	0.08	0.08	1.12
2007	1.11	1	1.23	0.05	0.05	1.14	1.27	1.09	1.48	0.08	0.08	1.25	0.97	0.83	1.14	0.08	0.08	0.99
2008	0.9	0.81	0.99	0.05	0.05	0.94	0.91	0.78	1.07	0.08	0.08	0.93	0.96	0.82	1.12	0.08	0.08	0.98
2009	0.77	0.69	0.87	0.06	0.06	0.8	0.7	0.57	0.87	0.11	0.11	0.71	0.85	0.73	0.99	0.08	0.08	0.87
2010	0.77	0.69	0.86	0.06	0.06	0.8	0.64	0.51	0.8	0.11	0.11	0.67	0.79	0.68	0.91	0.07	0.07	0.81
2011	0.63	0.57	0.69	0.05	0.05	0.65	0.57	0.49	0.67	0.08	0.08	0.56	0.7	0.61	0.81	0.07	0.07	0.72
2012	0.59	0.52	0.67	0.06	0.06	0.6	0.48	0.39	0.6	0.11	0.11	0.46	0.71	0.6	0.85	0.09	0.09	0.72
2013	0.55	0.48	0.62	0.06	0.07	0.57	0.53	0.42	0.67	0.12	0.12	0.53	0.62	0.51	0.75	0.09	0.09	0.64
2014	0.71	0.62	0.81	0.07	0.07	0.74	0.8	0.65	0.97	0.1	0.1	0.81	0.63	0.51	0.77	0.1	0.1	0.66
2015	0.67	0.6	0.76	0.06	0.06	0.7	0.6	0.48	0.73	0.11	0.11	0.62	0.72	0.61	0.85	0.08	0.08	0.74
2016	0.86	0.77	0.97	0.06	0.06	0.83	0.86	0.7	1.06	0.11	0.11	0.9	0.9	0.76	1.06	0.09	0.09	0.92
2017	1.11	0.99	1.25	0.06	0.06	1.11	1.13	0.92	1.4	0.11	0.11	1.18	1.14	0.98	1.34	0.08	0.08	1.18
2018	1.08	0.98	1.18	0.05	0.05	1.03	1.12	0.97	1.3	0.07	0.07	1.17	1.13	0.98	1.31	0.07	0.07	1.17
2019	0.99	0.89	1.1	0.05	0.05	0.93	0.93	0.77	1.12	0.09	0.1	0.97	1.09	0.95	1.25	0.07	0.07	1.13