Stock Assessment of hoki (*Macruronus magellanicus*) in the Falkland Islands

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Summary

The hoki Total Allowable Catch (TAC) for 2023 is set at 5,637 tonnes (t). Following recommendations of the MacAlister Elliott & Partners external review, this TAC was calculated according to the ICES category 5 framework: three-year average catch limited to an 'uncertainty cap' of ± 20% with respect of the TAC set for the current year, for a species with landings data but not reliable indices from surveys or catch-per-unit-effort.

Hoki commercial catches in Falkland Islands licenced fisheries were 1,883 t in 2021, below the average catch over the past 10 years.

Hoki commercial CPUE in the Falklands Interim Conservation Zone increased significantly from 1990 through 2021. Intra-annually, the highest CPUE of hoki occurred from February through April, with secondary peaks in June and in October.

Length-based indicators suggest that conservation of immature fish was positive for females but negative for males most years, with positive outcomes in recent years. Conservation of large individuals was of concern or negative in recent years for females and males. Conservation of mega-spawners was mostly negative for females and of concern for males. Optimal yield was negative in recent years for females, and mostly positive for males. MSY was negative in recent years for females and of concern for males.

Introduction

Hoki *Macruronus magellanicus* Lönnberg, 1907 (Merlucciidae) is a highly migratory pelagic-demersal fish that inhabits 30–500 m depth (Froese & Pauly 2021). This species occurs in temperate shelf and slope waters of the Southeast Pacific from 29°S (southern Chile) and of the Southwest Atlantic from 33°S to 57°S around Cape Horn, including Argentina and Falkland Islands (Wöhler & Giussi 2001; Schuchert et al. 2010; Froese & Pauly 2021). Hoki is one of the most abundant species on the Patagonian shelf; however, it is not highly abundant in Falkland Islands waters as the Falklands Interim Conservation Zone (FICZ) is located at the edge of its distribution (Falkland Islands Government 2021). Hoki in the Southwest Atlantic and in the Southeast Pacific belong to the same population (McKeown et al. 2015), via migrations around Cape Horn and throughout the channels of Tierra del Fuego (Wöhler & Giussi 2001). Genetic studies also suggest that individuals from the Argentine coast, and from near the west (52°S, 64°W) and southwest (54°18'S, 64°43'W) edge of the FICZ belong to the same population (D'Amato & Carvalho 2005; D'Amato 2006). Therefore, hoki from the Falkland Islands, Argentina and Chile will be considered a single stock for the purpose of this report.

The main spawning aggregations have been encountered in the vicinity of Guamin Island, Chile, between 43°S and 48°S (Payá et al. 2002). Smaller aggregations of spawning fish and juveniles have also been found in the Southwest Atlantic in the Gulf of San Matias and in the Gulf of San Jorge in Argentina (Wöhler & Giussi 2001), and on the shelf edge east of the Falkland Islands (Giussi 1996). Larvae are present on either side of the Magellanic Strait (53°S), near Cape Horn (55°S), and farther north in coastal areas of the Atlantic Ocean (Niklitschek et al. 2014). After winter spawning, part of the hoki population migrates in spring to feeding grounds in the slope areas of the Falkland Current Front (west of the Falkland Islands) (Brickle et al. 2009; Arkhipkin et al. 2012), and in summer it mainly occupies the warmer northern Falkland Islands' shelf (Brickle et al. 2009).

Methods

ICES advice rules

In 2020, hoki was included in a Falkland Islands Government finfish stock assessment and management review conducted by MacAlister Elliott & Partners Ltd, UK (MEP 2020). The MEP report recommended stock assessments for most commercial finfish species to be based on the ICES advice rules (ICES 2012, 2018a), referencing applicable categories of data availability and quality; for hoki, the advice was to calculate Total Allowable Catch (TAC) using the ICES category 5, as a species for which landings data are available, but not reliable indices from surveys or CPUE. Under category 5 the recommended assessment framework is based on the average catches[a] from the last 3 years (MEP 2020), further limited to an 'uncertainty cap' of ± 20% (ICES 2018a) with respect of the TAC set for the current year (TAC_{2022} = 6,478 t; Ramos & Winter 2021):

$$TAC\_5_{2023} = \overline{C_{2019\ to\ 2021}} \mid \pm 20\%$$

MEP (2020) also recommended exploring ancillary stock status information from ICES data limited methods such as length-based indicators. A Length-Based Indicator method (LBI) has been used since 2021 by the Falkland Islands Fisheries Department (FIFD) to provide a suite of indicators for several commercial finfish species based on combinations of catch-at-size distributions, and life-history parameters such as L_{Inf} (asymptotic length; Haddon 2001) and L50 (length at 50% maturity; Cope & Punt 2009). Otolith growth increments of Falkland Islands hoki have been read routinely at the National Marine Fisheries Research Institute (MFRI) in Gdynia, Poland. These otoliths were read at the MFRI once by one person only, preventing the use of age precision or repeatability measures, and reader accuracy measures. Therefore, LBI was implemented for hoki taking into account that the status of hoki age data was advised 'with caution' (Lee et al. 2020) as verification of these ages is in progress.

Commercial catch and CPUE

Commercial fishing around the Falkland Islands was not distinguished from other parts of the Southwest Atlantic prior to 1982 and catch data by species were recorded systematically from 1987 only (Falkland Islands Government 1989). Therefore, total hoki catch data were examined from 1987 to 2021 from the Falkland Islands (Falkland Islands Government[b]; Falkland Islands Government 2021), Argentina (Argentine Government[c]; Sánchez et al. 2012; Navarro et al. 2014, 2019), and Chile (Chilean Government[d]; SERNAPESCA

[a] It is not explicitly stated in the reference but inferred that 'average' catches signifies the 'mean' of the annual total catches, by weight.
[b] http://www.fig.gov.fk/fisheries/publications/fishery-statistics
[c] https://www.agroindustria.gob.ar/sitio/areas/pesca_maritima/desembarques/
[d] http://www.sernapesca.cl/informes/estadisticas

1990, 2000, 2011, 2021). LOESS (span = 0.75, degree = 2) was implemented to examine the pattern of the association between Falkland Islands and Argentine, and between Falkland Islands and Chilean commercial annual catches of hoki from 1987 through 2021. Commercial catches and discard of hoki were examined by licence type for 2021 in the FICZ.

CPUE was calculated as the sum of hoki catches divided by the sum of effort; annual CPUE, monthly CPUE through the time series, and the monthly distribution of the CPUE in the FICZ during 2021 were examined. Annual CPUE was calculated from bottom trawl finfish (G–, and W–licences) vessels with fishing activity in the FICZ from 1990 through 2021. Monthly CPUE was calculated from finfish (G–, and W–licences) vessels with fishing activity in the FICZ from 1990 through 2020, and for 2021. CPUE was calculated from G–, and W–licences because these contributed approximately 75% of the hoki catches from 1990 to 2021. LOESS (span = 0.75, degree = 2) was implemented to examine the patterns of annual and monthly CPUE.

Survey biomass estimates

Biomass estimates and the spatial distribution of hoki were examined from joint surveys (groundfish and Patagonian squid *Doryteuthis gahi* pre-season surveys) carried out in February 2010, 2011, and 2015 – 2022 in Falkland Islands waters (Ramos & Winter 2022). Biomass ratios between the most recent February surveys (2022) and the first February surveys (2010) were estimated as a proxy of the change in biomass over time. Significance of difference and 95% confidence intervals of the change in biomass were computed from the randomized re-samples of the survey biomass estimates (Ramos & Winter 2022). A trend of the biomass time series from 2010 to 2022 was calculated using LOESS (span = 1, degree = 2).

Biomass estimates, the spatial distribution of hoki, and biomass ratios were also examined following Ramos & Winter (2022) from joint surveys (groundfish and Patagonian squid pre-season surveys) carried out during July 2017 (Gras et al. 2017; Winter et al. 2017) and July 2020 (Randhawa et al. 2020; Winter et al. 2020). The July surveys were conducted for the primary purpose of assessing common hake (Gras et al. 2017; Randhawa et al. 2020), and are presented as an additional comparative proxy for abundance patterns, with the caveat that these would likely reflect variability in the migratory timing of hoki.

Length and age analyses

Length Based Indicators

ICES (2015, 2018b) recommends the LBI method which provides a suite of indicators based on combinations of catch-at-size distributions, life-history parameters such as L_{Inf} (asymptotic length; Haddon 2001) and L50 (length at 50% maturity; Cope & Punt 2009). L_{Inf} and L50 parameters were assessed for females and males separately.

LBI method was applied to all years from which hoki pre-anal length and age data were available and reported as random samples (FIFD database codes R and S), i.e., years 1990 to 2021 for length data, and years 2002 to 2019 for age data. Because finfish trawls are restricted to larger meshes than calamari trawls, only observer length measurements taken in finfish (A–, G–, and W–licences), surimi (S–licence), and experimental (E–licence) vessels were used, to avoid biasing length-frequency distributions if proportionally more samples are recorded from one fishery or another in different years. Skate and *Illex* trawls were also excluded because their different targets could also relate to characteristically different length-frequency distributions of hoki.

LBI method indicators were then selected and scored using Tables 2.1.1.4.1 and 2.1.2.2 in ICES (2015) as templates:

1) Length at half the modal catch length should be bigger than L50, for conservation of immature fish (L_C / L50 > 1). Note that length at half the modal catch length may be poorly defined if the catch length-frequency distribution is not smooth and unimodal.
2) Length at cumulative 25th percentile of catch numbers should be bigger than L50, for conservation of immature fish ($L_{25\%}$ / L50 > 1).
3) Mean length of the largest 5% of individuals in the catch should be at least 80% of the asymptotic length, as a benchmark that enough large individuals are in the stock ($L_{max5\%}$ / L_{Inf} > 0.8).
4) 'Mega-spawners' should comprise at least 30% of the catch (thus implicitly represent at least 30% of the stock), as large, old fish disproportionately benefit the resilience of the population (Froese 2004) (P_{mega} > 0.3). Mega-spawners are defined as individuals larger than optimum length (L_{Opt}) + 10%, where L_{Opt} is described as the length at which growth rate is maximum (ICES 2015), or the length at which total biomass of a year-class reaches its maximum value (Froese & Binohlan 2000). $L_{Opt} = 3 \cdot L_{Inf} \cdot (3 + Mk^{-1})^{-1}$ (Beverton 1992), where M is instantaneous natural mortality, k is the rate of curvature of the von

Bertalanffy growth function, and the ratio Mk^{-1} is set in WKLIFE V software (ICES 2015) at the standard constant of 1.5 (Jensen 1996).

5) Mean length of individuals larger than L_C (L_{meanC}) should be approximately equal to L_{Opt}, for optimal yield (L_{meanC} / $L_{Opt} \approx 1$).
6) L_{meanC} should be equal or bigger to the length-based proxy for MSY ($L_{F=M}$), for producing maximum sustainable yield (L_{meanC} / $L_{F=M} \geq 1$). $L_{F=M}$ implements the premise that MSY is attained when fishing mortality equals natural mortality (Froese et al. 2018), and in WKLIFE V software (ICES 2015) is computed as $(3{\cdot}L_C + L_{Inf})/4$.

Margins of variability of the six indicators were estimated by randomly re-sampling 10,000× on the normal distribution each year's fits of L_{Inf} and L50. Indicators were scored against the 'traffic light' scale (ICES 2015) with reference criteria > 1.0 for conservation of immature fish, > 0.8 for conservation of large fish, and > 0.3 for conservation of mega-spawners. The score was green if the lower 95% quantile of the re-sampled iterations was > 1.0, > 0.8, and > 0.3, yellow if 1.0, 0.8, and 0.3 were between the lower and upper 95% quantiles, and red if the upper 95% quantile of the re-sampled iterations was < 1.0, < 0.8, and < 0.3. The use of the margins of variability means that same empirical values of indicators may be scored different colours in different years. Reference criterion ≈ 1.0 for optimal yield was green if the lower and upper 95% quantiles spanned 1.0, yellow if the lower and upper 95% quantiles spanned 0.9 (the threshold used in ICES 2015) without spanning 1.0, and red otherwise. Reference criterion ≥ 1.0 for MSY was scored the same as > 1.0, except that empirical values ≥ 1.0 were automatically green.

Length-age relationship

The von Bertalanffy growth function (R package 'fishmethods'; Nelson 2019) was used to fit hoki length-at-age data available in the FIFD database, from finfish (A–, G–, and W–licences), surimi (S–licence), and experimental (E–licence) vessels. Hoki length and age data were jointly available for years 2002–2019. Growth model parameters (L_{Inf}, k, and t_0) were calculated for females and males using nonlinear least square regression. A likelihood ratio test (R package 'fishmethods'; Nelson 2019) was used to test whether the von Bertalanffy growth function was significantly different between females and males. Variabilities of the growth model parameters were estimated by bootstrapping; residuals of the model fits were randomly re-sampled with replacement, added back to the expected lengths, and re-fit to the von Bertalanffy growth function. The 95% quantiles of 10,000 iterations were retained as confidence intervals. Inter-annual trend of von Bertalanffy L_{Inf} was calculated by LOESS (span = 0.75, degree = 2).

Length and age at 50% maturity

Overall and yearly length at 50% maturity (L50) was calculated as the mid-point of the binomial logistic regression of maturity ogives vs. length (Heino et al. 2002). Sex and maturity were identified following the fish maturity scale by Brickle et al. (2005; modified from Nikolsky 1963): I) immature; II) resting; III) early developing; IV) late developing; V) ripe; VI) running; VII) spent; VIII) recovering spent. Maturity is cyclical as fish pass from post-spawning phase to resting phase, and definitive maturity assignments can only be made that stage I is immature, and stages III+ are always adult (A. Arkhipkin, FIFD, *pers. comm.*). Therefore, maturity assignment was simplified to a dichotomous classification of 0) juvenile, including maturity stage I, and 1) adult, including maturity stages III to VIII, omitting stage II. Annual L50s were calculated from randomly sampled individuals collected throughout the FICZ under finfish (A–, G–, and W–licences), surimi (S–licence), and experimental (E–licence) vessels from 1990 through 2021. Trends of annual L50 were calculated with LOESS (span = 0.75, degree = 2). Overall and yearly age at 50% maturity (A50) was calculated for females and males separately, by predicting age corresponding to L50 using the inversed von Bertalanffy equation.

Catch at length

Yearly length frequency distributions, from 1990 through 2021, were examined for females and males to describe patterns in catch at length through time. Unsexed individuals were excluded from the analysis. Lengths of individuals sampled randomly and caught by finfish (A–, G–, and W–licences), surimi (S–licence), and experimental (E–licence) vessels throughout the FICZ from January through December were included in the analysis. Yearly length frequencies were compared with yearly L50 to assess if the catch was mainly comprised of immature or mature individuals.

Natural mortality

Natural mortality (M) of hoki was calculated as an indicator to examine vulnerability of the stock. Natural mortality is the component of total mortality that is not caused by fishing, but by causes such as predation, diseases, senility, pollution, amongst other factors. Annual natural mortality refers to the proportion of fish dying during the year expressed as a fraction of the fish alive at the beginning of the year (FAO 1999), and was calculated using equation 1 following Then et al. (2015):

$$\mathrm{M} = 4.899 \times \mathrm{t}_{\mathrm{max}}^{-0.916} \qquad \text{Eqn. 1}$$

where t_{max} = maximum age, taken as the oldest age reported in the FIFD database (20 years; excluding entries considered erroneous due to their vast excess from reliable published values, e.g., Giussi et al. 2016). Then et al. (2015) recommended the use of the t_{max}-based estimator over other estimators based on cross-validation of prediction error, model residual patterns, model parsimony, and biological considerations.

All analyses were performed in RStudio (R Core Team 2021).

Results

ICES advice rules

ICES Category 5 Total Allowable Catch

ICES category 5 TAC for next year 2023 was calculated at 5,636.6 t:

$$TAC\_5_{2023} = \overline{7398 + 7629 + 1883} = 5636.6$$

The 20% cap reduction of the current year TAC_{2022} (6,478 t; Ramos & Winter 2021) is 5,182.4 t. Given that the average catch of the last completed three years did not decrease beyond the 20% cap reduction of the current year TAC_{2022}, TAC for 2023 is set at 5,637 t.

Note that the year jumps from 2021 to 2023. Standard procedure is to inform next year's allowable catch with data up to the last completed year, i.e., the previous year (2021), as licencing advice must be issued while the current year is still in progress.

Commercial catch and CPUE

Hoki catches in Falkland Islands waters have averaged 14,445 t per year since 1987, representing approximately 9% of the Falkland Islands, Argentine, and Chilean combined annual catch (Fig. 1; Appendix I). Falkland Islands and Argentine annual hoki catches were significantly positively associated when Argentine catches were approximately between 30,000 t and 95,000 t. Falkland Islands and Chilean annual hoki catches were significantly positively associated when Chilean catches were < 100,000 t (Fig. 2).

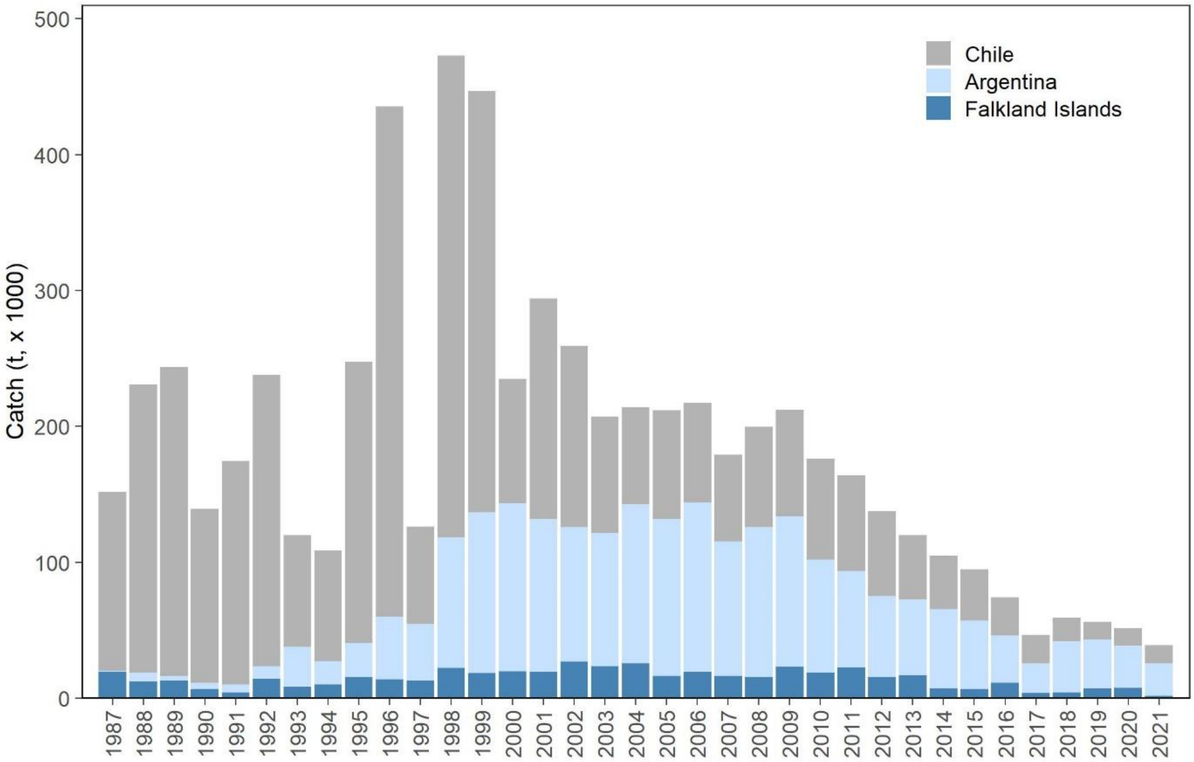


Fig. 1. Annual commercial catch of hoki in Falkland Islands, Argentine and Chilean waters. Falkland Islands commercial catch data exclude experimental (E–licence) and out-of-zone (O–licence) licences since 1990; earlier than 1990 these licences were not designated.

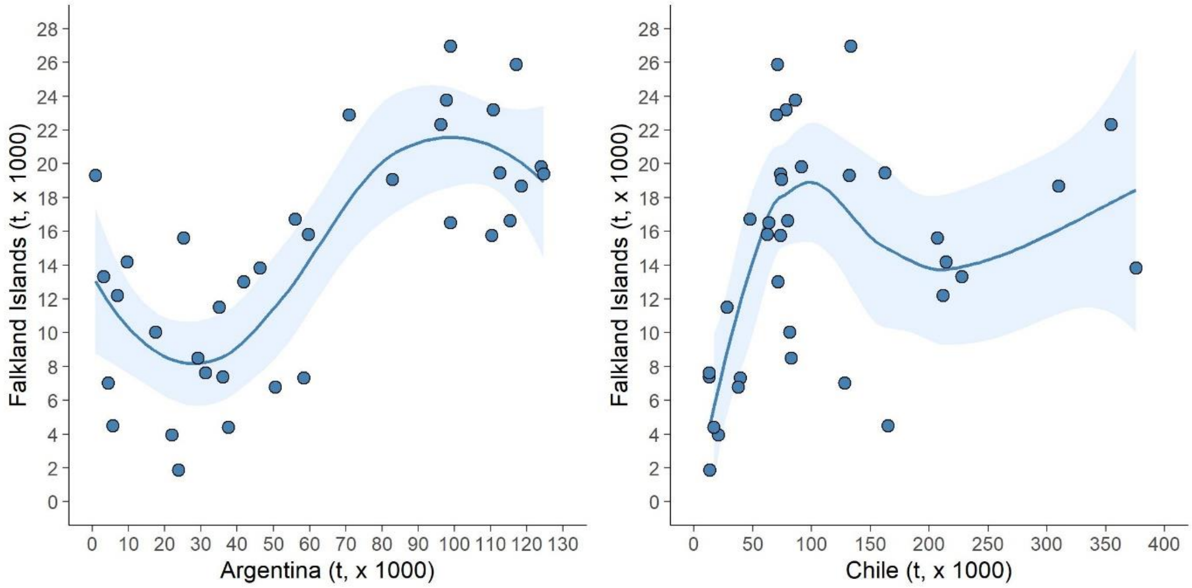


Fig. 2. Falkland Islands vs. Argentina, and Falkland Islands vs. Chile, annual commercial catches of hoki from 1987 to 2021, with LOESS smooth ± 95% confidence intervals (LOESS; span = 0.75, degree = 2).

From 1990 through 2021, approximately 89% of the annual hoki catch in the FICZ was from finfish licences (A–, G–, and W–licences), with most catches contributed by G– and W–licences over the last 5 years, i.e., 95%.

During 2021, a total of 1,914 t of hoki were reported caught in Falkland Islands waters, of which 1,883 t were caught under commercial licences, i.e., excluding the experimental E–licence. Approximately 83% of all Falkland Islands hoki catch was under W–licence, 14% was under G–licence, and 0.7% under A–licence in 2021; the three finfish licences (A–, G–, and W–licences) together accounted for 98% of the total hoki catch (Table I). Reported hoki discards were 0.85% of the total hoki catch in 2021. Finfish licences discarded approximately 0.84% of their total hoki catch, which is nearly 15 t of hoki. Calamari vessels (C– and X–licences) discarded 99.7% of their total hoki catch, which was approximately 600 kg (Table I).

Table I. Catch proportion of hoki by licence type in Falkland Islands waters during 2021.

Licence	Target species	Catch (t)	Catch (%)	Discard (t)	Proportion discarded (%)
W	Restricted finfish	1593.027	83.23	13.943	0.88
G	Restricted finfish and *Illex*	275.465	14.39	1.223	0.44
E	Experimental	31.377	1.64	0.397	1.27
A	Unrestricted finfish	13.721	0.72	0.232	1.69
C	Calamari 1st season	0.516	0.03	0.516	100.00
X	Calamari 2nd season	0.104	0.01	0.102	98.08
B	*Illex* squid	0.000	0.00	0.000	0.00
F[a]	Skates and rays	0.000	0.00	0.000	0.00
L	Toothfish (longline)	0.000	0.00	0.000	0.00
S[a]	Southern blue whiting and hoki	0.000	0.00	0.000	0.00
O	Outside Falkland Islands waters	0.000	0.00	0.000	0.00
Total		1914.21	100.00	16.413	0.85

[a] F and S licenses were not fished during 2021.

Average CPUE ranged from 177 kg/h in 1991 to a maximum of 1,351 kg/h in 2019. CPUE had an increasing trend from 1990 (261 kg/h) to reach the highest CPUE in the time series in 2019; CPUE in 2021 was 1,062 kg/h (Fig. 3). While catches have decreased since the early 2000s (Fig. 1), fishing effort has decreased at a still higher rate, leading to CPUE that is increasing, as well as being more variable in recent years (Fig. 3).

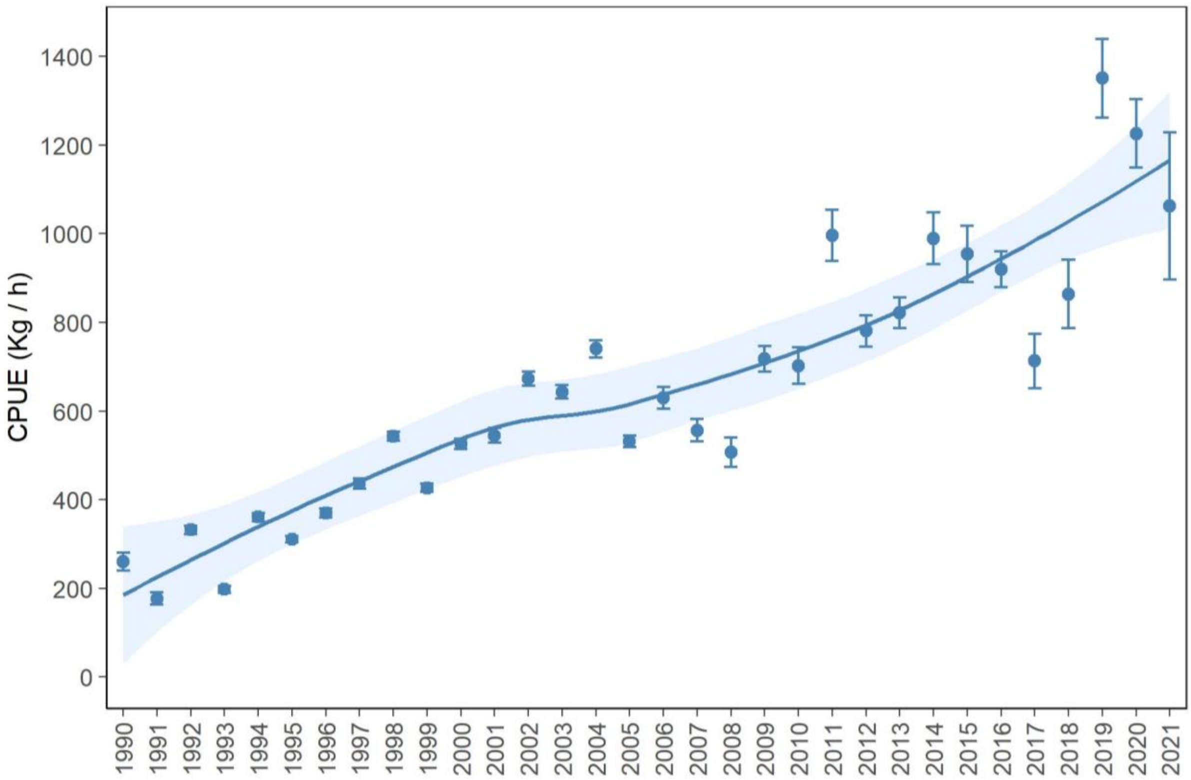


Fig. 3. Yearly CPUE ± 1 standard error of hoki in Falkland Islands waters from 1990 through 2021, calculated from finfish (G–, and W–licences) vessels, with LOESS smooth ± 95% confidence intervals (LOESS; span = 0.75, degree = 2).

The monthly CPUE for 1990-2020 had a declining trend from January through December, with the highest values recorded in February (729 kg/h), March (737 kg/h), and April (684 kg/h). Relatively high abundances in June represent the subadult slope foraging immigration at > 200 m depth, and the adult shelf spawning emigration at < 200 m depth (Laptikhovsky 2007). The year 2021 had a different pattern compared with 1990–2020. There was no fishing effort in January and February 2021, and higher CPUEs were observed towards the end of 2021 due to a combination of low effort in November and one trawler exceptionally targeting hoki in December. Hence, the highest CPUE was recorded in December (3,722 kg/h) and the second highest CPUE in November (2,649 kg/h) (Fig. 4; Appendix II). Hoki were caught mainly to the west and southwest of West Falkland, between 51°S and 53°S, and between 61°W and 63.5°W mainly during the second half of 2021 (Appendix III).

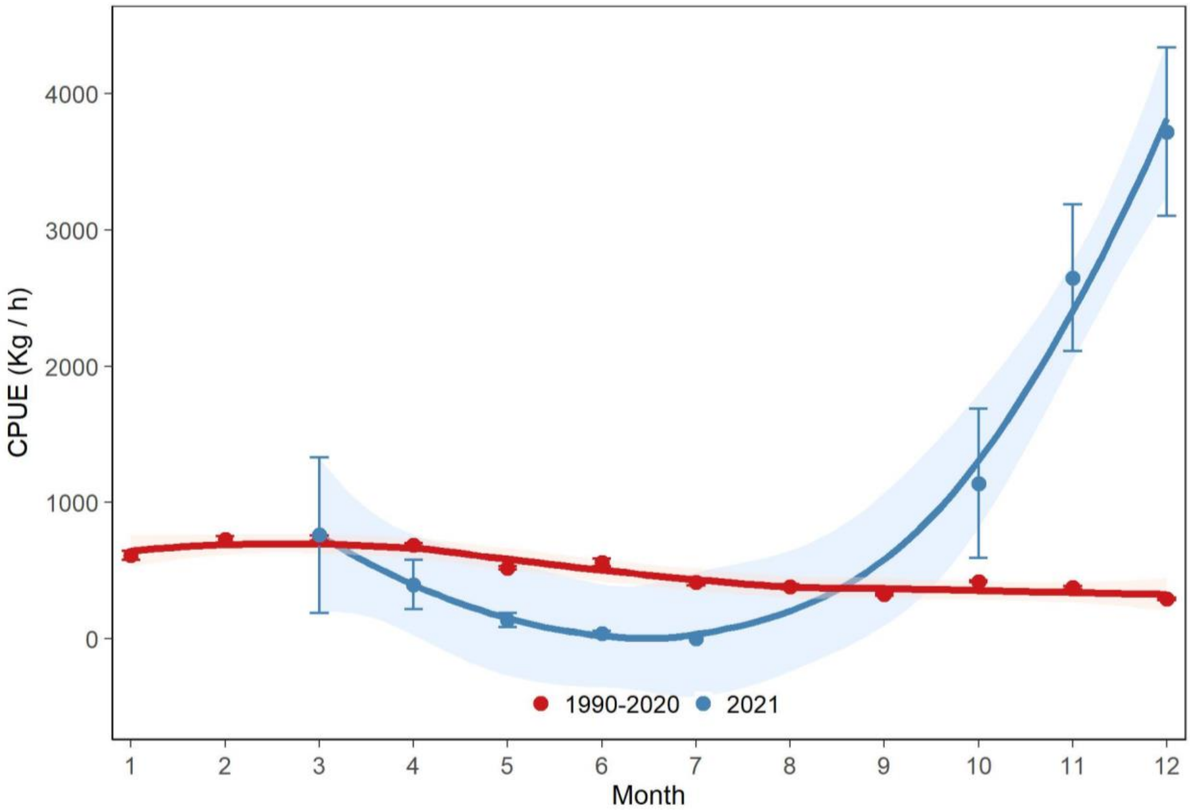


Fig. 4. Monthly CPUE ± 1 standard error of hoki in Falkland Islands waters from 1990 through 2020 (red), and in 2021 (blue), calculated from finfish (G–, and W–licences) vessels, with LOESS smooths ± 95% confidence intervals (LOESS; span = 0.75, degree = 2).

Surveys biomass estimates

Summer surveys (February)

The biomass of hoki during the 2022 February surveys (144,783 t) was 52% of the biomass of the 2010 February surveys (278,980 t; Fig. 5; Table II). A total of 9,770 out of 10,000 paired re-samples had lower biomass estimate values in February 2022 than in February 2010 (97.7%), therefore significant at $p < 0.05$. However, LOESS smooth showed no significant change through the time series, consistent with the overlap of confidence intervals between years. During the February surveys, hoki were dispersed through the FICZ in 2010, 2011, and 2015. From 2016, hoki were mainly aggregated to the southwest edge of the FICZ (Appendix IV).

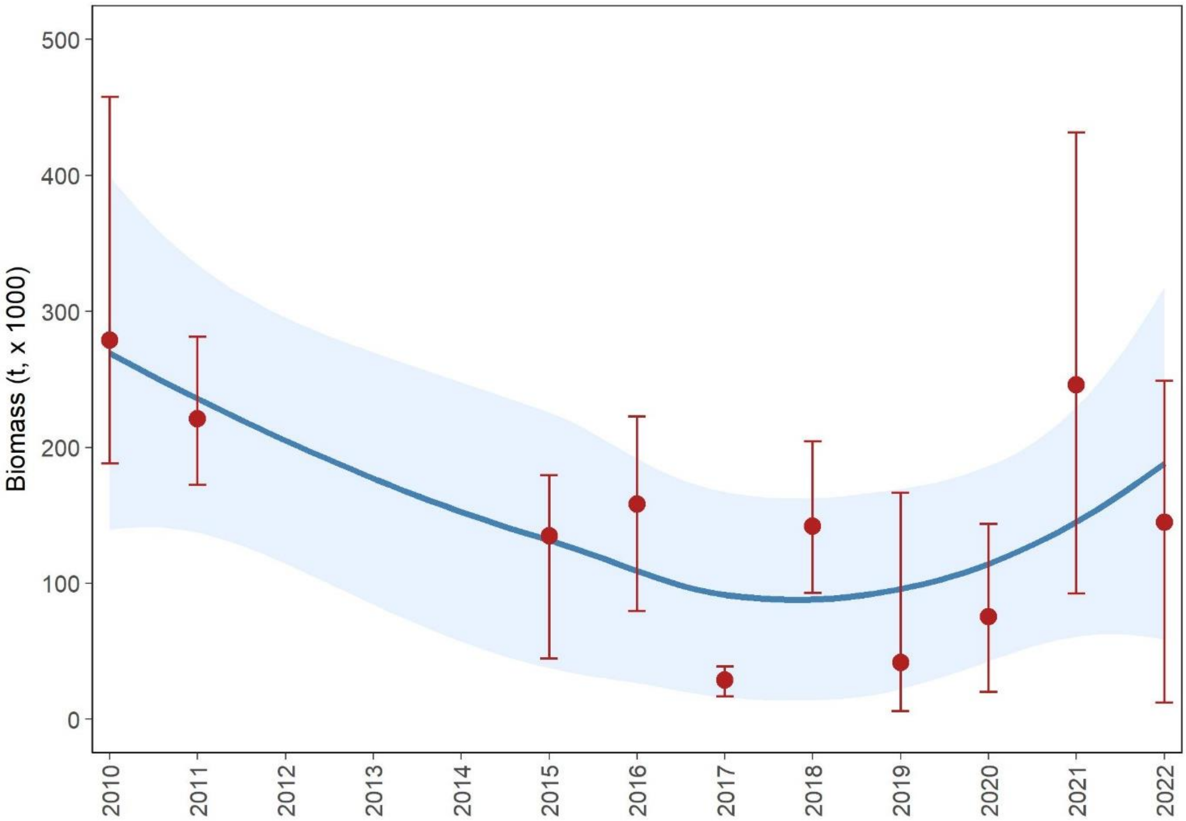


Fig. 5. Hoki biomass estimates (red dots) ± 95% confidence intervals from February surveys in Falkland Islands waters, with LOESS smooths ± 95% confidence intervals (LOESS; span = 1, degree = 2). No parallel February surveys (groundfish and Patagonian squid pre-season surveys) were conducted in 2012, 2013, and 2014.

Table II. Summer (February) surveys catch and effort, and biomass estimates (mean ± 95% confidence intervals) of hoki in Falkland Islands waters.

Year	Survey	Trawls (n)	Swept area (km^2)	Effort (h)	Catch (kg)	CPUE (Kg/h)	Biomass (t)
2010	Groundfish	87	17.04	87.52	49656.01	567.39	278980.21
	D. gahi	55	42.29	109.27	30124.00	275.69	(188264.88–457666.96)
	Total	142	59.34	196.78	79780.01	405.42	
2011	Groundfish	88	17.21	88.00	28405.39	322.79	221132.74
	D. gahi	58	40.04	110.63	27594.30	249.42	(172507.38–281186.26)
	Total	146	57.26	198.63	55999.69	281.92	
2015	Groundfish	89	16.72	90.17	9768.23	108.34	134733.17
	D. gahi	57	46.90	111.50	16596.00	148.84	(44674.67–179592.78)
	Total	146	63.61	201.67	26364.23	130.73	
2016	Groundfish	90	17.64	91.42	21666.57	237.01	158388.16
	D. gahi	56	54.46	107.92	17248.42	159.83	(79371.74–222823.65)
	Total	146	72.10	199.33	38914.99	195.23	
2017	Groundfish	90	18.52	92.00	3206.21	34.85	28882.54
	D. gahi	58	54.09	117.00	488.32	4.17	(16801.50–38817.08)
	Total	148	72.62	209.00	3694.53	17.68	
2018	Groundfish[a]	97	20.47	96.42	29334.90	304.25	141953.50
	D. gahi	59	36.87	100.83	682.10	6.76	(92768.34–204228.49)
	Total	156	57.35	197.25	30017.00	152.18	
2019	Groundfish	79	17.22	79.00	7315.40	92.60	41864.81
	D. gahi	52	72.70	97.05	238.50	2.46	(5779.47–166317.90)
	Total	131	89.93	176.05	7553.90	42.91	
2020	Groundfish[a]	80	17.04	79.95	14323.13	179.15	75402.28
	D. gahi	59	86.80	112.52	59.15	0.53	(20203.23–143531.23)
	Total	139	103.84	192.47	14382.28	74.73	
2021	Groundfish	80	16.43	79.48	30457.98	383.20	245890.30
	D. gahi	55	90.65	111.22	373.83	3.36	(92470.50–431476.19)
	Total	135	107.07	190.70	30831.81	161.68	
2022	Groundfish	42	9.22	41.90	9507.12	226.90	144782.83
	D. gahi	60	86.75	119.08	204.63	1.72	(12362.55–248962.54)
	Total	102	95.97	160.98	9711.75	60.33	

[a]An additional one-day transect of four trawls was taken in shallow inshore waters to sample for juvenile toothfish. These four trawls were not included in analyses as their locations were not relevant to the distribution of hoki. Groundfish February surveys were not conducted in 2012, 2013, and 2014.

Winter surveys (July)

The estimated biomass of hoki in the July 2020 surveys (41,626 t) was 52% of the biomass estimated in the July 2017 survey (80,777 t; Table III). However, a total of 8,829 out of 10,000 paired re-samples had higher biomass estimate values in July 2017 than in July 2020 (88.8%), thus not significant at $p > 0.05$. In July 2017, aggregations of hoki were detected to the southeast and southwest in the FICZ, whereas in July 2020 hoki were mainly aggregated to the southwest (Appendix V). Differences in biomass estimates between February and July surveys are likely due to the migratory pattern of hoki.

Table III. Winter (July) surveys catch and effort, and biomass estimates (mean ± 95% confidence intervals) of hoki in Falkland Islands waters.

Year	Survey	Trawls (n)	Swept area (km^2)	Effort (h)	Catch (kg)	CPUE (kg/h)	Biomass (t)
2017	Groundfish	74	15.41	74.00	6450.40	87.17	80776.89 (26752.75 – 156784.60)
	D. gahi[a]	59	54.71	114.00	108267.50	949.71	
	Total	133	70.12	188.00	114717.90	610.20	
2020	Groundfish[b]	33	7.14	33.02	1721.86	52.15	41626.42 (7468.47 – 64678.23)
	D. gahi	55	98.57	101.25	232.34	2.29	
	Total	88	105.71	134.27	1954.20	14.55	

[a]An additional one-day transect of four trawls was taken in shallow inshore waters to sample for juvenile toothfish. These four trawls were not included in analyses as their locations were not relevant to the distribution of hoki.
[b]Twelve additional trawls were conducted in high seas during the July 2020 survey; these trawls were not included in the analyses.

Length and age analyses

Length Based Indicators

Yearly 'traffic light' length indicators for females and males are summarized in Table IV. Indicator $L_C/L50$, for conservation of immature fish, had positive outcomes (green) most years from 1992 to 2004, and from 2013 to 2021 for females, but was negative (red) most years from 2005 to 2011. Conservation of immature males was negative most years from 1996 to 2018, and was positive only in a few years including 2020 and 2021. Indicator $L_{25\%}/L50$, also for conservation of immature fish, had positive outcomes for females most years. In contrast, conservation of immature males was negative or of concern (yellow) most years, with positive outcomes in recent years, including 2013–2016, and 2020–2021. Indicator $L_{max5\%}/L_{Inf}$, for conservation of large individuals, was of concern most years in the time series for females and for males with negative outcomes for females from 2016 through 2019. Indicator P_{mega}, for the presence of mega-spawners, had no positive outcomes; instead, it was mostly negative for females and of concern for males. Indicator L_{meanC}/L_{Opt}, for optimal yield, was variable for females from 2002 to 2019, with negative outcomes from 2016 through 2019. Indicator L_{meanC}/L_{Opt} was positive most years for males from 2002 through 2019, except for 2006, 2009, and 2017. Indicator $L_{meanC}/L_{F=M}$, for maximum sustainable yield, was mostly positive for females from 2005 to 2016, and negative from 2017 through 2019. Indicator $L_{meanC}/L_{F=M}$ was positive most years for males, except from 2017 through 2019 with outcomes of concern or negative.

Table IV. Hoki indicators by sex and year, with 'traffic light' scoring. L_C) Length at half the modal catch length; L50) Length at 50% maturity; $L_{25\%}$) Length at cumulative 25th percentile of catch; $L_{max5\%}$) Mean length of the largest 5% of individuals in the catch; L_{Inf}) Asymptotic average maximum body size; P_{mega}) Proportion of 'Mega-spawners' in the catch; L_{meanC}) Mean length of individuals larger than LC; L_{Opt}) Optimum length; $L_{F=M}$) Length-based proxy for MSY. Data were not available in some years (blank cells).

		Conservation				Optimal yield	MSY
Sex	Year	L_C / L50 >1	$L_{25\%}$ / L50 >1	$L_{max5\%}$ / L_{Inf} >0.8	P_{mega} >0.3	L_{meanC} / L_{Opt} ≈1	L_{meanC} / $L_{F=M}$ ≥1
	1990	1.04	1.04				
	1991	1.02	0.94				
	1992	1.19	1.23				
	1993	1.21	1.17				
	1994	1.27	1.27				
	1995						
	1996	1.07	1.15				
	1997	0.59	0.96				
	1998	1.19	1.23				
	1999	1.16	1.25				
	2000	1.35	1.31				
	2001	1.15	1.06				
	2002	1.21	1.21				
	2003	1.17	1.22	0.77	0.03	0.91	0.95
	2004	1.18	1.14	0.77	0.05	0.93	0.96
F	2005	0.87	1.05	0.81	0.08	0.88	1.08
	2006	0.78	0.83				
	2007	0.74	1.01	0.80	0.10	0.89	1.18
	2008	1.15	1.19	0.81	0.11	0.98	0.99
	2009	0.69	0.87	0.84	0.12	0.84	1.12
	2010	0.78	0.82	0.87	0.15	0.85	1.05
	2011	0.87	0.97	0.88	0.30	0.98	1.14
	2012	0.97	1.06				
	2013	1.12	1.16	0.84	0.21	1.00	1.05
	2014	1.17	1.17	0.75	0.04	0.91	0.94
	2015	1.23	1.28	0.79	0.10	0.95	0.99
	2016	0.96	1.11	0.74	0.02	0.83	1.02
	2017	0.68	0.68	0.62	0.00	0.48	0.72
	2018	1.44	1.14	0.73	0.01	0.89	0.92
	2019	0.97	1.02	0.59	0.00	0.59	0.79

	2020	1.15	1.15
	2021	1.23	1.29

Table IV. *continued…*

		Conservation				Optimal yield	MSY
Sex	Year	L_C / L50 >1	$L_{25\%}$ / L50 >1	$L_{max5\%}$ / L_{Inf} >0.8	P_{mega} >0.3	L_{meanC} / L_{Opt} ≈1	L_{meanC} / $L_{F=M}$ ≥1
	1990	0.99	0.99				
	1991	0.63	0.71				
	1992	1.16	1.16				
	1993	1.14	1.02				
	1994	1.19	1.19				
	1995						
	1996	0.94	1.05				
	1997	0.51	0.71				
	1998	0.76	0.80				
	1999	1.05	1.09				
	2000	1.02	0.98				
	2001	0.78	0.91				
	2002	0.92	0.96				
	2003	1.14	1.14	0.92	0.54	1.16	1.00
	2004	0.77	0.85	0.89	0.22	0.96	1.08
M	2005	0.95	0.99	0.85	0.24	1.02	1.03
	2006	0.74	0.78	0.81	0.16	0.84	1.00
	2007	0.92	0.92	0.82	0.14	1.00	1.06
	2008	0.97	1.01	0.81	0.12	0.99	1.01
	2009	0.66	0.84	0.83	0.09	0.86	1.10
	2010	0.75	0.84	0.87	0.21	0.94	1.12
	2011	0.85	0.90	0.87	0.28	0.99	1.11
	2012	0.90	0.99				
	2013	1.10	1.14	0.86	0.28	1.04	1.02
	2014	0.92	1.06	0.79	0.09	0.93	1.03
	2015	1.12	1.17	0.87	0.24	1.05	1.04
	2016	1.04	1.13	0.82	0.14	0.96	1.01
	2017	0.67	0.67	0.70	0.01	0.59	0.81
	2018	0.82	0.87	0.81	0.03	0.75	0.95
	2019	0.99	0.99	0.71	0.02	0.74	0.87
	2020	1.10	1.05				
	2021	1.17	1.17				

Length-age relationship

The length-age relationship of females and males pooled (n = 7,584) gave the values: L_{Inf} = 50.63 cm, k = 0.1212, and t_0 = -1.7910 years. Length and age of females (n = 4,505) ranged from 11 cm to 48 cm, and from 1 year to 20 years, respectively. The length-age relationship of females gave the values: L_{Inf} = 50.71 cm, k = 0.1259, and t_0 = -1.6708 years. Length and age of males (n = 3,079) ranged from 11 cm to 43 cm and from 1 year to 15 years, respectively. The length-age relationship of males gave the values: L_{Inf} = 44.80 cm, k = 0.1432, and t_0 = -1.7289 years (Appendix VI). Yearly von Bertalanffy parameters are summarized in Appendix VII. Asymptotic lengths (L_{Inf}) were highly uncertain in some years due to low numbers of data, but did not change significantly for females and males over the time series (Fig. 6).

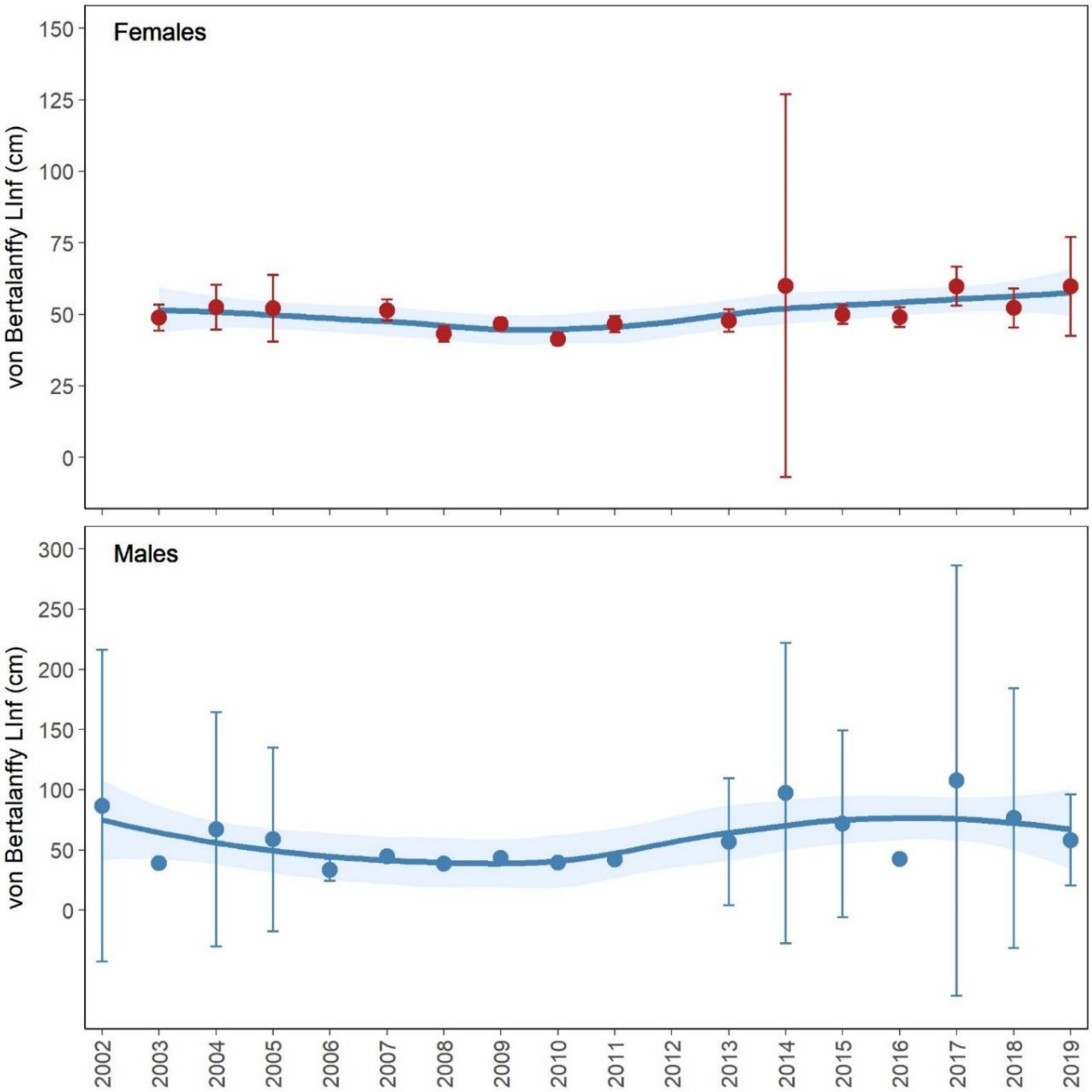


Fig. 6. Asymptotic lengths (L_{Inf}) ± 1 standard error calculated according to the von Bertalanffy growth function for female (red dots) and male (blue dots) hoki caught by finfish (A–, G–, and W–licences), experimental (E–licence), and surimi (S–licence) vessels in the FICZ through the year, from 2002 through 2019, with LOESS smooths ± 95% confidence intervals (LOESS; span = 0.75, degree = 2).

Length and age at 50% maturity

Over the time series 1990–2021, length at 50% maturity (L50) of females was 21.75 ± 0.04 cm pre-anal length (n = 38,915) and age at 50% maturity (A50) was 2.8 years old; L50 of males was 22.83 ± 0.03 cm pre-anal length (n = 40,328) and A50 was 3.3 years old. Therefore, immature individuals are inferred as < 3 years old and mature individuals are inferred as ≥ 3 years old. Annual L50 and A50 of females ranged from 17.4 cm and 2.9 years old in 1996 and 2016, to 28.7 cm and 4.9 years old in 1991, respectively. Annual L50 and A50 of males ranged from 17.8 cm and 1.8 years old in 1996 to 28.3 cm and 5.2 years old in 1991. The L50 fit decreased significantly for females and for males from 1990 through 2021 (Fig. 7; Appendixes VIII–IX).

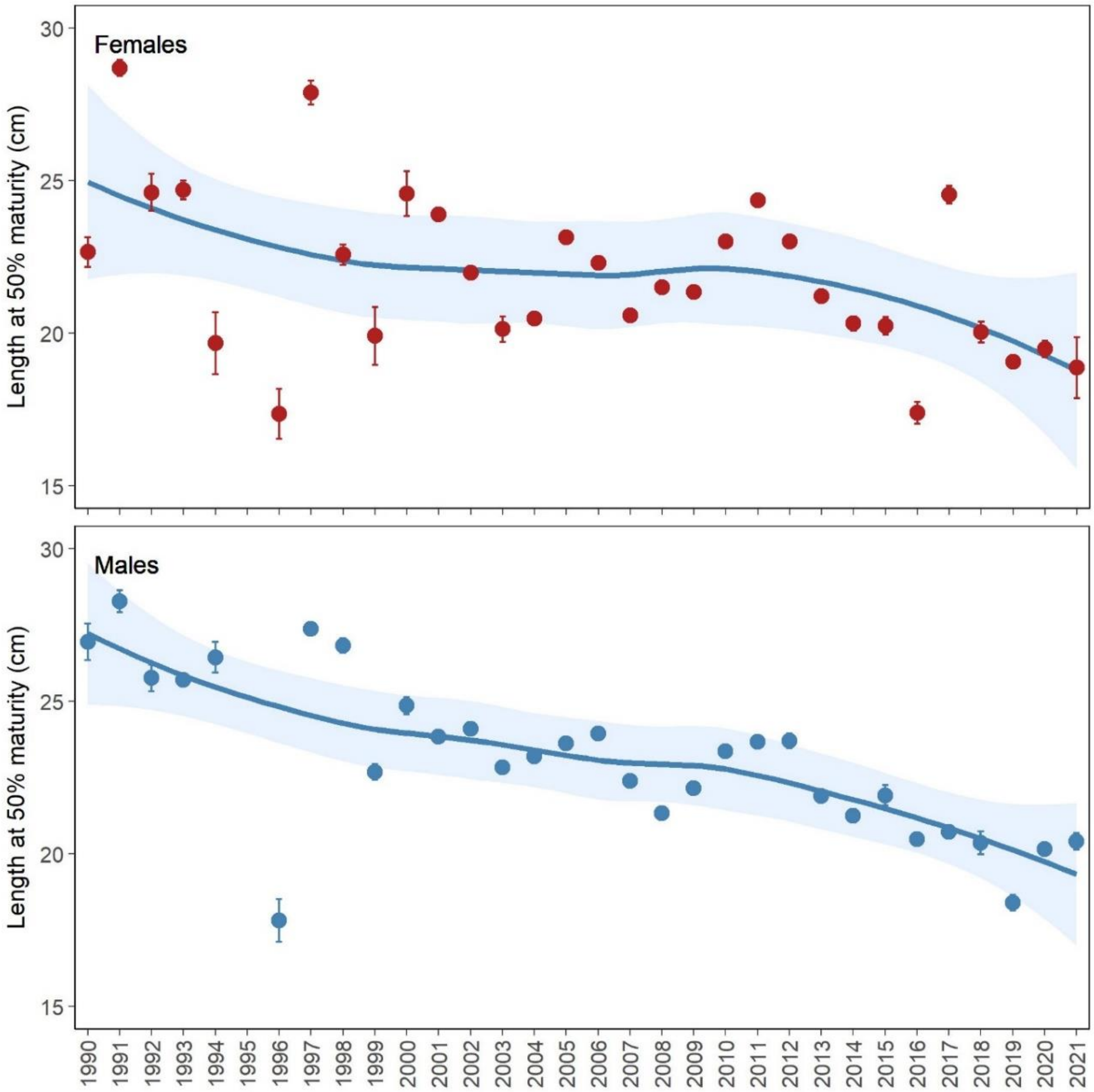


Fig. 7. Lengths at 50% maturity (L50) ± 1 standard error of female (red dots) and male (blue dots) hoki caught by finfish (A–, G–, and W–licences), experimental (E–licence), and surimi (S–licence) vessels in the FICZ throughout each year 1990–2021, with LOESS smooths ± 95% confidence intervals (LOESS; span = 0.75, degree = 2).

Catch at length

Female hoki (n = 129,874; 1990–2021) ranged from 1 cm to 77 cm pre-anal length, and males (n = 91,469; 1990–2021) ranged from 10 cm to 71 cm pre-anal length. Length-groups were not discernible due to size overlap most years. Individuals > 25 cm pre-anal length were more common several years before 2014. Individuals < 25 cm pre-anal length were dominant from 2014 (Fig. 8). The catch was mostly comprised of females and males at sizes ≥ L_{50} in 63% and in 53% of the total number of years assessed (n = 32), respectively (Fig. 8; Appendix X).

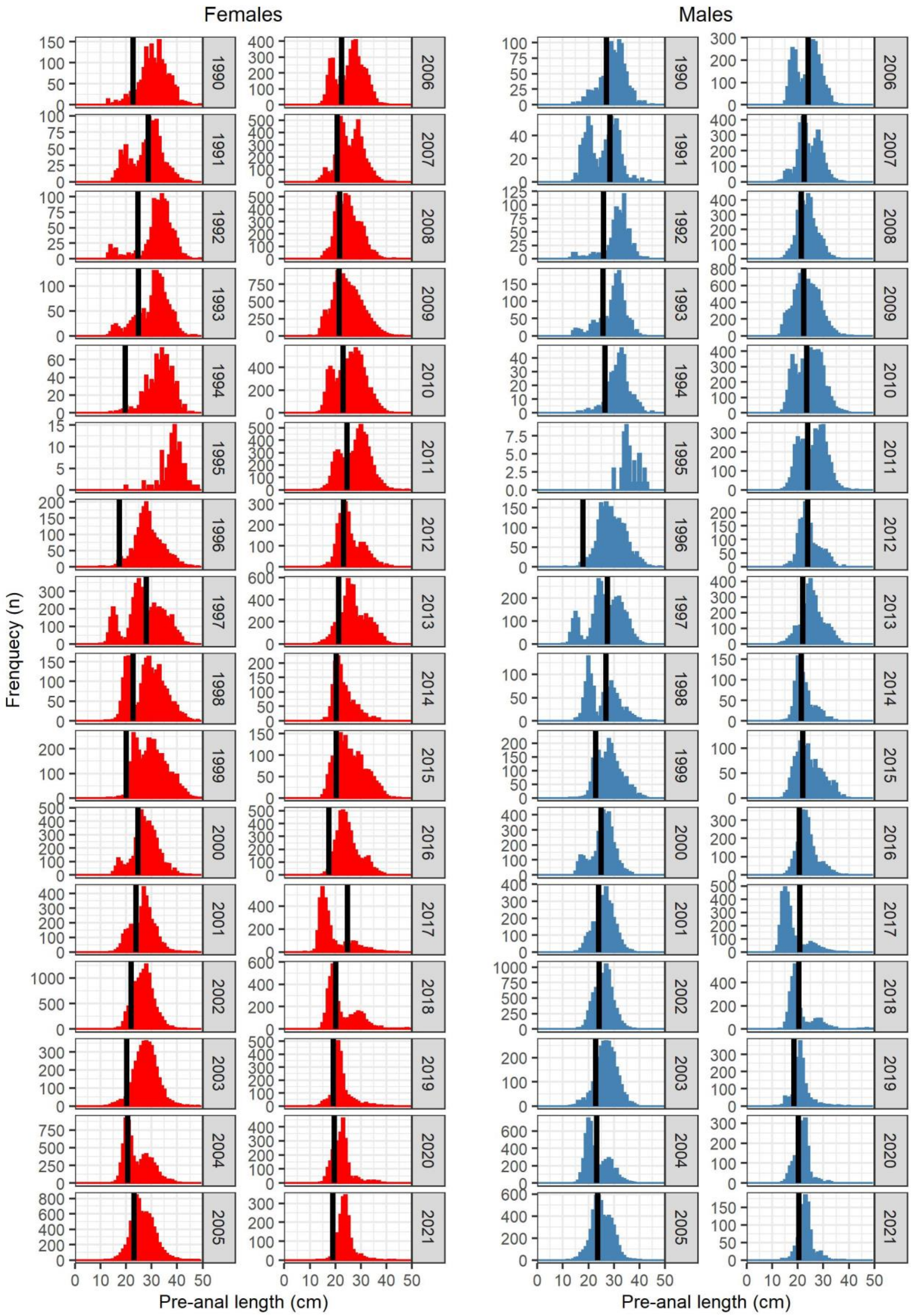


Fig. 8. Length frequency distribution of female and male hoki caught by finfish (A–, G–, and W–licences), experimental (E–licence), and surimi (S–licence) vessels in the FICZ from 1990 through 2021. The black solid lines indicate the length at 50% maturity (L50).

Natural mortality

Equation 1 resulted in a natural mortality (M) calculation of:

$$\mathrm{M} = 4.899 \times \mathrm{t}_{\max}^{-0.916} = 4.899 \times 20^{-0.916} = 0.3150$$

indicating that 31.5% of the stock dies per year not by fishing but due to natural causes such as predation, diseases, senility, amongst others.

Conclusions

Hoki Total Allowable Catch for 2023 was set at 5,637 t, calculated using the ICES category 5 framework, which represents a decrease of 13% of the TAC for 2022 (6,478 t) but an increase compared with the total commercial hoki catch in 2021 (1,883 t).

Most of the hoki catch (98%) in Falkland Islands waters in 2021 was taken between the three finfish licences (A–, G– and W–licences), with the greatest contribution to the catch by W–licence (83%).

Hoki commercial CPUE in the FICZ increased significantly from 1990 (261 kg/h) through 2021 (1,062 kg/h), with the highest CPUE in the time series reported in 2019 (1,351 kg/h). Intra-annually, the highest CPUE of hoki occurred from February through April, with secondary peaks in June and in October.

February surveys biomasses showed no significant change in hoki abundance from 2010 through 2022; however, wide confidence intervals were characteristic each year, likely due to the patterns of geographic distribution of hoki in Falkland Islands waters or due to its migratory timing. The 2017 and 2020 July surveys also revealed overlap in biomass estimates.

Length-based indicators suggest that conservation of immature fish was positive for females but negative for males most years, suggesting that immature males are caught more often; however, positive outcomes occurred in recent years for both females and males. Reasons for the differences between females and males in previous years require further investigation. Conservation of large individuals was of concern or negative in recent years for females and males. Conservation of mega-spawners was mostly negative for females and of concern for males. Optimal yield was negative in recent years for females but mostly positive for males. MSY was negative in recent years for females and of concern for males.

The length and age analyses showed no significant change for L_{Inf} of females and males from 2002 to 2019; however, length at 50% maturity of females and males had a statistically significant decrease from 1990 to 2021.

The multiple analyses used in this study suggest that conservation measures should be implemented for immature, large, and mega-spawner individuals.

References

Arkhipkin A, Brickle P, Laptikhovsky V, Winter A (2012) Dining hall at sea: feeding migrations of nektonic predators to the eastern Patagonian Shelf. Journal of Fish Biology 81: 882–902. https://doi.org/10.1111/j.1095-8649.2012.03359.x

Beverton RJH (1992) Patterns of reproductive strategy parameters in some marine teleost fishes. Journal of Fish Biology 41: 137–160.

Brickle P, Arkhipkin A, Laptikhovsky VV, Stocks AF, Taylor A (2009) Resource partitioning by two large planktivorous fishes *Micromesistius australis* and *Macruronus magellanicus* in the Southwest Atlantic. Estuarine, Coastal and Shelf Science 84: 91–98. https://doi.org/10.1016/j.ecss.2009.06.007

Brickle P, Laptikhovsky V, Arkhipkin A (2005) Reproductive strategy of a primitive temperate notothenioid *Eleginops maclovinus*. Journal of Fish Biology 66, 1044–1059. https://doi.org/10.1111/j.1095-8649.2005.00663.x

Cope JM, Punt AE (2009) Length-based reference points for data-limited situations: Applications and restrictions. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 1: 169–186.

D'Amato ME (2006) Demographic Expansion and Subtle Differentiation in the Long-Tailed Hake *Macruronus magellanicus*: Evidence from Microsatellite Data. Marine Biotechnology 8: 189–201. https://doi.org/10.1007/s10126-005-5075-4

D'Amato ME, Carvahlo GR (2005) Population genetic structure and history of the long-tailed hake, *Macruronus magellanicus*, in the SW Atlantic as revealed by mtDNA RFLP analysis. ICES Journal of Marine Science 62: 247–255.

Falkland Islands Government (1989) Fisheries Department Fisheries Report 87/88, Vol. 1. FIG Stanley, Fisheries Department. 45 p.

Falkland Islands Government (2021) Fisheries Department Fisheries Statistics, Vol. 25. FIG Stanley, Fisheries Department. 98 p.

FAO (1999) FAO Fisheries Technical Paper. No. 382. Rome, FAO. 113 p.

Froese R (2004) Keep it simple: three indicators to deal with overfishing. Fish and Fisheries 5: 86–91.

Froese R, Binohlan C (2000) Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. Journal of Fish Biology 56: 758–773.

Froese R, Pauly D (Eds) (2021) FishBase. World Wide Web electronic publication. Available at: www.fishbase.org

Froese R, Winker H, Coro G, Demirel N, Tsikliras AC, Dimarchopoulou D, Scarcella G, Probst WN, Dureuil M, Pauly D (2018) A new approach for estimating stock status from length frequency data. ICES Journal of Marine Science 75: 2004–2015. https://doi.org/10.1093/icesjms/fsy078

Giussi AR (1996) Estudio de algunos aspectos del ciclo vital de la merluza de cola *Macruronus magellanicus*, Lonnberg, 1907. Tesis Doctoral, Universidad Nacional de Mar del Plata.

Giussi AR, Zavatteri A, DiMarco EJ, Gorini FL, Bernardele JC, Marí NR (2016) Biology and fishery of long tail hake (*Macruronus magellanicus*) in the Southwest Atlantic Ocean. Revista de Investigacion y Desarrollo Pesquero 28: 55–82.

Gras M, Pompert J, Blake A, Busbridge T, Boag T, Huillier JT, Concha F (2017) Report of the 2017 ground fish survey ZDLT1–07–2017. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 68 p.

Haddon M (2001) Modelling and quantitative methods in fisheries. Chapman & Hall/CRC, Boca Raton, Florida. 406 pp.

Heino M, Dieckmann U, Godø OR (2002) Measuring probabilistic reaction norms for age and size at maturation. Evolution 56: 669–678.

ICES (2012) ICES Implementation of Advice for Data limited Stocks in its 2012 Advice. http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2012/ADHOC/DLS%20Guidance%20Report%202012.pdf

ICES (2015) Report of the Fifth Workshop on the Development of Quantitative Assessment Methodologies based on Life-history Traits, Exploitation Characteristics and other Relevant Parameters for Data-limited Stocks (WKLIFE V), 5–9 October 2015, Lisbon, Portugal. ICES CM 2015/ACOM: 56. 157 p.

ICES (2018a) General context of ICES advice. https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2018/2018/Introduction_to_advice_2018.pdf

ICES (2018b) ICES technical guidelines. ICES reference points for stocks in categories 3 and 4. http://www.ices.dk/sites/pub/Publication%20Reports/Guidelines%20and%20Policies/16.04.03.02_Category_3-4_Reference_Points.pdf

Jensen AL (1996) Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Canadian Journal of Fisheries and Aquatic Sciences 53: 820–822.

Laptikhovsky V (2007) Biology, Fishery and Stocks of Hoki, *Macruronus magellanicus* in Falkland Islands Conservation Zone. Scientific Report. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 29 pp.

Lee B, Shcherbich Z, Randhawa H (2020) Towards the development of an ageing strategy for finfish in the Falkland Islands trawl fisheries. Technical Document, FIG Fisheries Department. 23 p.

McKeown NJ, Arkhipkin AI, Shaw PW (2015) Integrating genetic and otolith microchemistry data to understand population structure in the Patagonian Hoki (*Macruronus magellanicus*). Fisheries Research 164: 1–7. https://doi.org/10.1016/j.fishres.2014.10.004

MEP (2020) Annex 3: Review of Finfish Stock Assessments. Report for Falkland Islands Government. MacAlister Elliot & Partners Ltd. 47 p.

Navarro G, Rozycki V, Monsalvo M (2014) Estadísticas de la pesca marina en la Argentina. Evolución de los desembarques 2008-2013. Ministerio de Agricultura, Ganaderia y Pesca de la Nación. Buenos Aires, 144 p.

Navarro G, Rozycki V, Monsalvo M (2019) Estadísticas de la pesca marina en Argentina. Evolución de los desembarques 2012-2016. Secretaria de Gobierno de Agroindustria, 147 p.

Nelson GA (2019) Package ‘fishmethods’: Fishery science methods and models from published literature and contributions from colleagues. R package version 1.11-1.

Niklitschek EJ, Secor DH, Toledo P, Valenzuela X, Cubillos LA, Zuleta A (2014) Nursery systems for Patagonian grenadier off Western Patagonia: large inner sea or narrow continental shelf? ICES Journal of Marine Science 71: 374–390. https://doi.org/10.1093/icesjms/fst129

Nikolsky GV (1963) *The Ecology of Fishes*. New York, USA: Adademic Press. In: Brickle P, Laptikhovsky V, Arkhipkin A (2005) Reproductive strategy of a primitive temperate notothenioid *Eleginops maclovinus*. Journal of Fish Biology 66, 1044–1059. https://doi.org/10.1111/j.1095-8649.2005.00663.x

Payá I, Rubilar P, Pool H, Céspedes R, Reyes H, Ehrhardt N, Adarme L, Hidalgo H (2002) Evaluación de la merluza de cola y merluza tres aletas. Informe Final Proyecto FIP 2000-15, IFOP, 163 p.

R Core Team (2021). RStudio: Integrated Development Environment for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/

Ramos JE, Winter A (2021) Stock assessment of hoki (*Macruronus magellanicus*) in the Falkland Islands. SA–2021–WHI. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 36 p.

Ramos JE, Winter A (2022) February bottom trawl survey biomasses of fishery species in Falkland Islands waters, 2010–2022. SA–2022–05. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 86 pp.

Randhawa HS, Blake A, Trevizan T, Brewin J, Evans D, Kairua T, Büring T (2020) Cruise Report ZDLT1-07-2020: 2020 Hake Demography Survey. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 135 p.

Sánchez R, Navarro G, Rozycki V (2012) Estadísticas de la pesca marina en la Argentina. Evolución de los desembarques 1898-2010. Ministerio de Agricultura, Ganaderia y Pesca de la Nación. Buenos Aires, 528 p.

SERNAPESCA (1990) Anuario Estadístico de Pesca 1990. Ministerio de Economía, Fomento y Reconstrucción. Chile. 191 p.

SERNAPESCA (2000) Anuario Estadístico de Pesca 2000. Ministerio de Economía, Fomento y Reconstrucción. Chile. 194 p.

SERNAPESCA (2011) Anuario Estadístico de Pesca y Acuicultura 2011. Ministerio de Economía, Fomento y Turismo. Chile. 240 p.

SERNAPESCA (2021) Anuario Estadístico de Pesca y Acuicultura 2019. Ministerio de Economía, Fomento y Turismo. Chile. Available at : http ://www.sernapesca.cl/informacion-utilidad/anuarios-estadisticos-de-pesca-y-acuicultura

Schuchert PC, Arkhipkin AI, Koenig AE (2010) Traveling around Cape Horn: Otolith chemistry reveals a mixed stock of Patagonian hoki with separate Atlantic and Pacific spawning grounds. Fisheries Research 102: 80−86. https://doi.org/10.1016/j.fishres.2009.10.012

Winter A, Ramos JE, Shcherbich Z, Tutjavi V, Matošević N (2020) 2020 2nd Season Assessment Survey Falkland calamari (*Doryteuthis gahi*). Technical Document, FIG Fisheries Department. 17 p.

Winter A, Shcherbich Z, Iriarte V, Derbyshire C (2017) *Doryteuthis gahi* Stock Assessment Survey, 2nd Season 2017. Technical Document, FIG Fisheries Department. 25 p.

Wöhler OC, Giussi AR (2001) La Merluza de Cola (*Macruronus magellanicus*) en el Mar Argentino. In: Schuchert PC, Arkhipkin AI, Koenig AE (2010) Traveling around Cape Horn: Otolith chemistry reveals a mixed stock of Patagonian hoki with separate Atlantic and Pacific spawning grounds. Fisheries Research 102: 80−86. https://doi.org/10.1016/j.fishres.2009.10.012

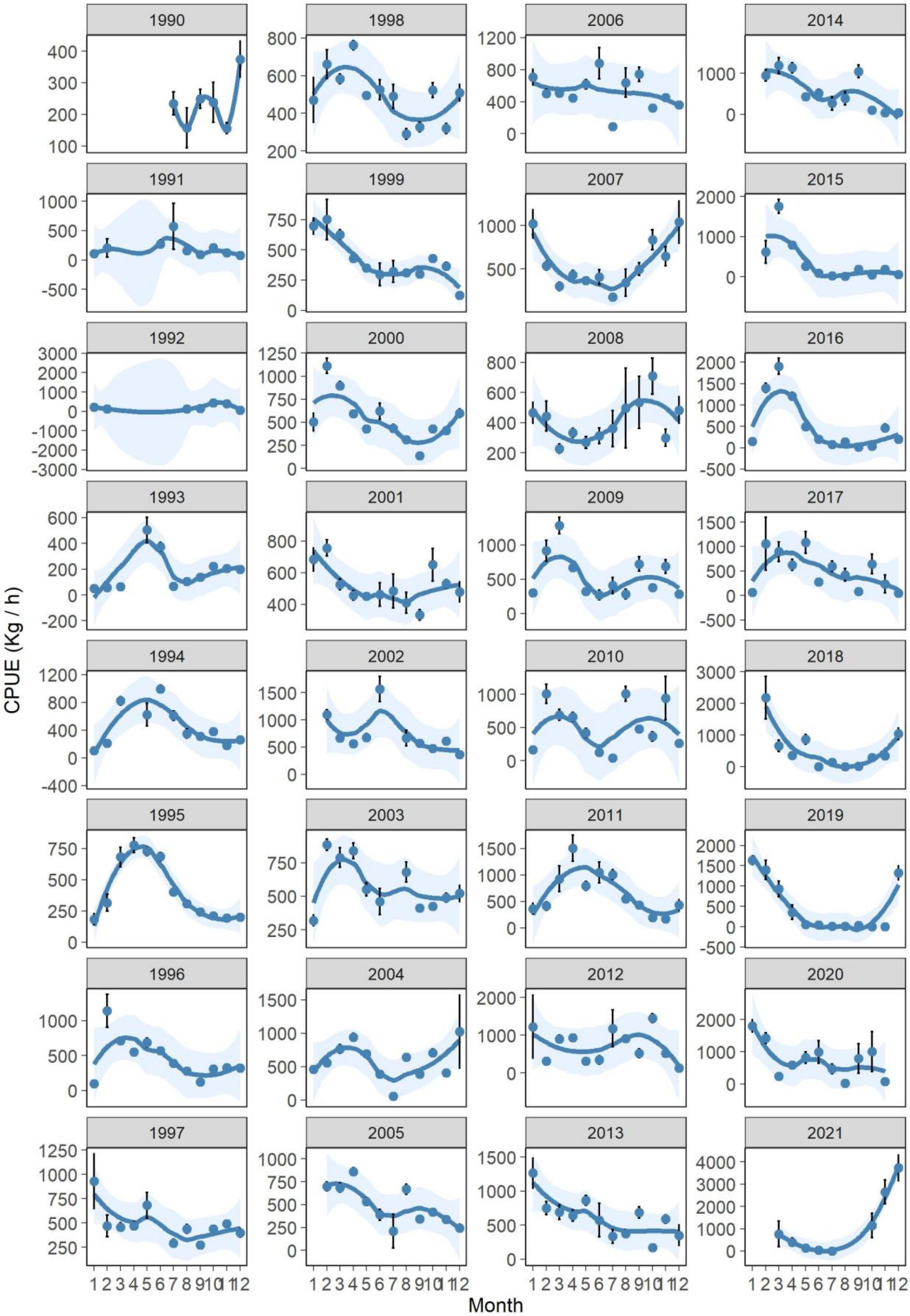
Appendix

Appendix I. Annual commercial catches (t) of hoki reported in Falkland Islands (excluding E–licence; Falkland Islands Government[e], Falkland Islands Government 2021), Argentina (Argentine Government[f]; Sánchez et al. 2012; Navarro et al. 2014, 2019), and Chile (Chilean Government[g]; SERNAPESCA 1990, 2000, 2011, 2021).

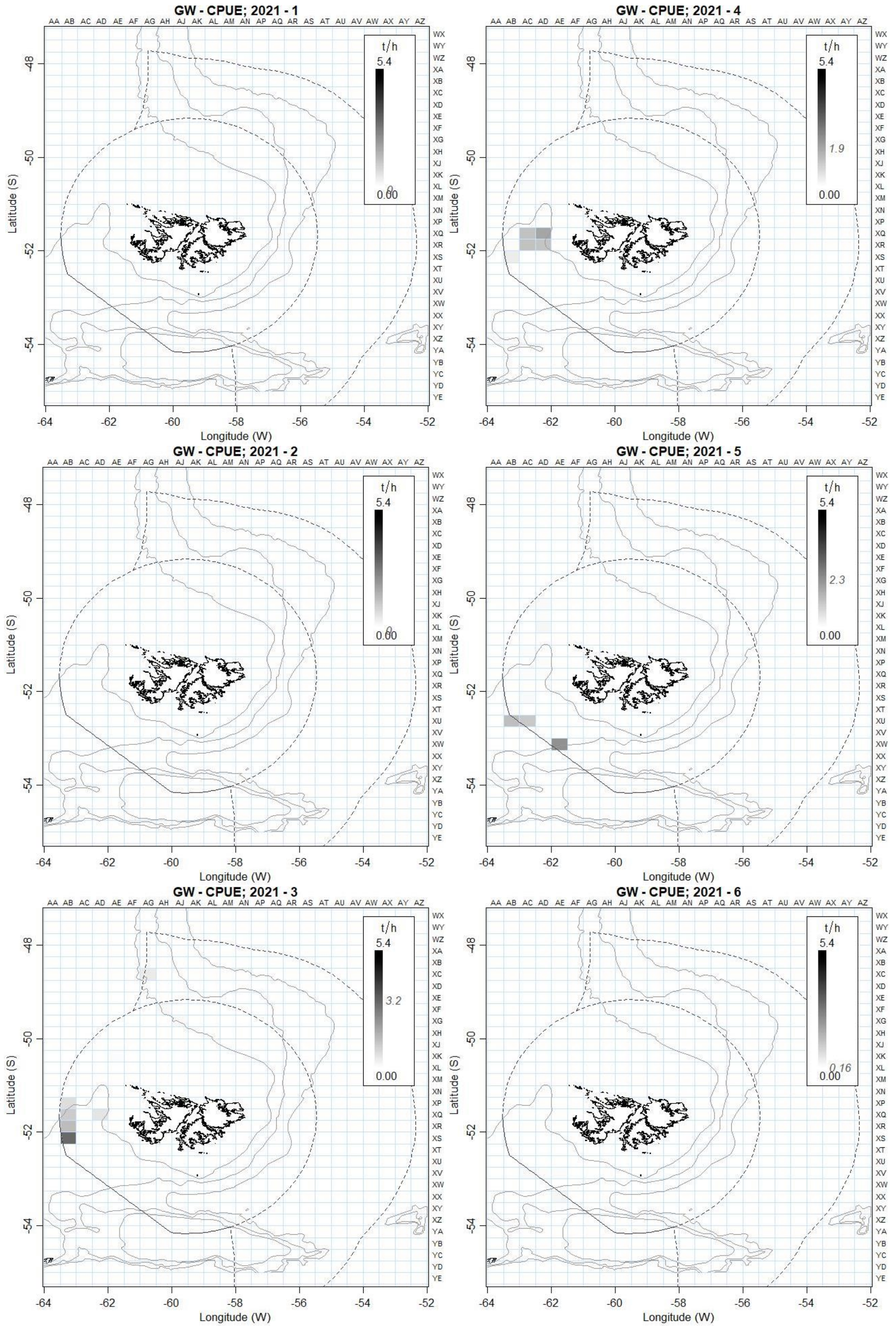
Year	Falkland Islands (t)	Argentina (t)	Chile (t)
1987	19,307	782	131,834
1988	12,209	6,952	211,624
1989	13,313	3,085	227,393
1990	7,031	4,353	128,002
1991	4,499	5,583	164,697
1992	14,195	9,534	214,324
1993	8,516	29,174	82,580
1994	10,055	17,472	81,310
1995	15,606	25,228	206,734
1996	13,849	46,241	375,446
1997	13,020	41,787	71,479
1998	22,334	96,218	354,184
1999	18,692	118,356	309,904
2000	19,846	123,926	91,333
2001	19,471	112,539	162,082
2002	26,975	98,865	133,418
2003	23,764	97,797	85,896
2004	25,898	116,965	71,177
2005	16,646	115,340	79,755
2006	19,425	124,638	73,421
2007	16,524	98,808	63,697
2008	15,765	110,269	73,567
2009	23,219	110,717	78,440
2010	19,074	82,855	74,330
2011	22,906	70,903	70,137
2012	15,815	59,595	62,175
2013	16,716	55,966	47,602
2014	7,336	58,396	39,345
2015	6,782	50,469	37,475
2016	11,509	34,946	28,108
2017	3,974	21,930	20,850
2018	4,408	37,598	17,055
2019	7,398	36,038	13,006
2020	7,629	31,239	12,792
2021	1,883	23,795	13,305

[e] http://www.fig.gov.fk/fisheries/publications/fishery-statistics
[f] https://www.agroindustria.gob.ar/sitio/areas/pesca_maritima/desembarques/
[g] http://www.sernapesca.cl/informes/estadisticas

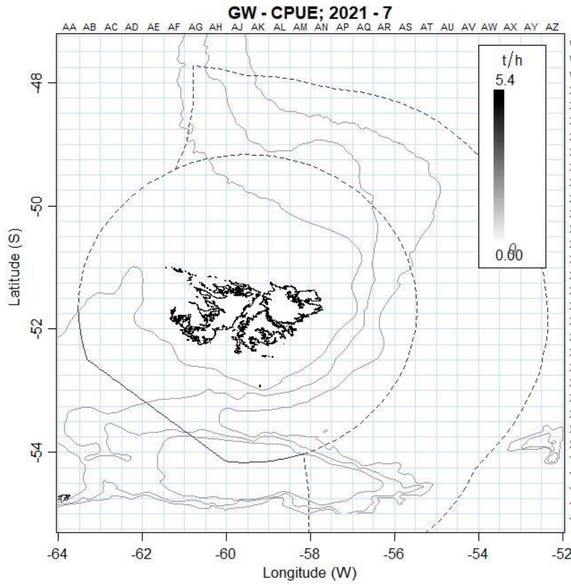
Appendix II. Monthly CPUE of hoki in Falkland Islands waters from 1990 to 2021, calculated from finfish (G–, and W–licences) vessels, with LOESS smooths ± 95% confidence intervals (LOESS; span = 0.75, degree = 2).

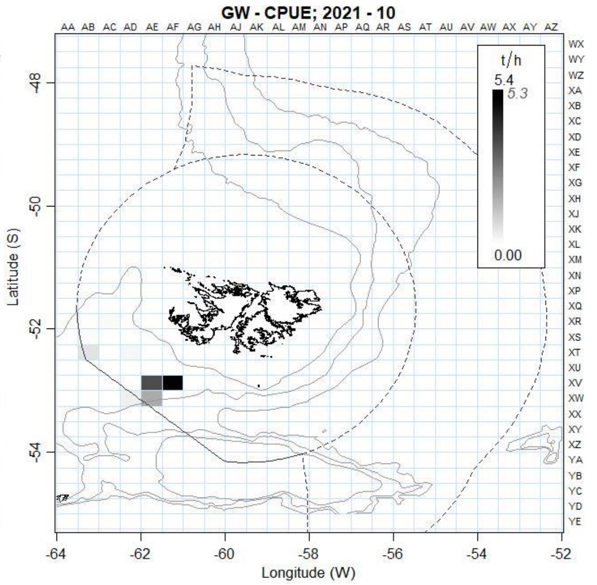


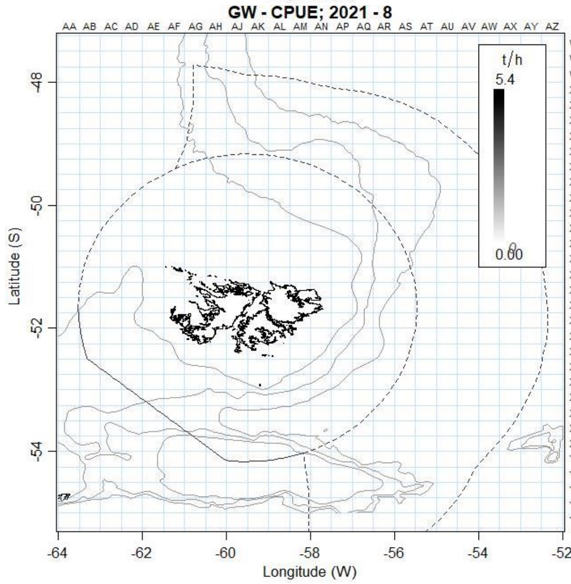
Appendix III. Monthly CPUE of hoki in Falkland Islands waters during 2021, calculated from finfish (G–, and W–licences) vessels. There was no fishing effort during January and February under finfish licences.

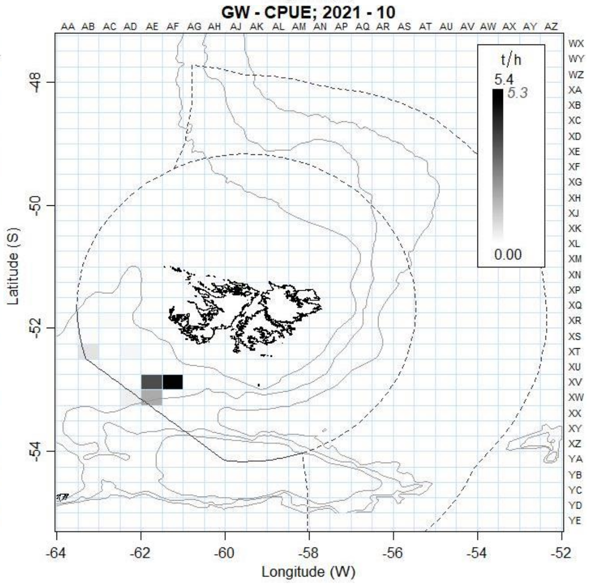


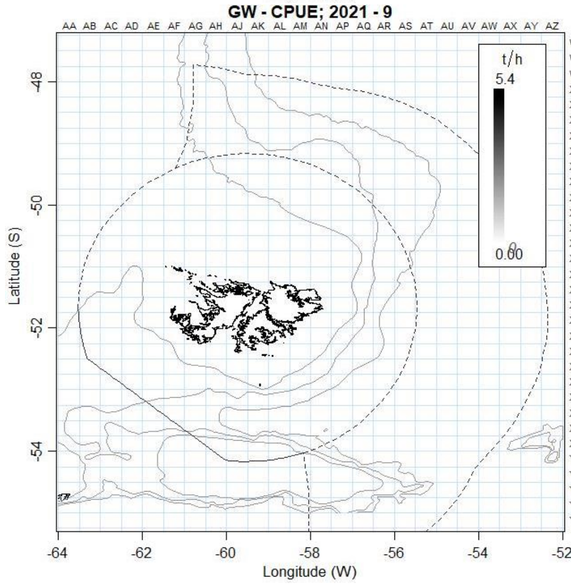
Appendix III. *continued…*

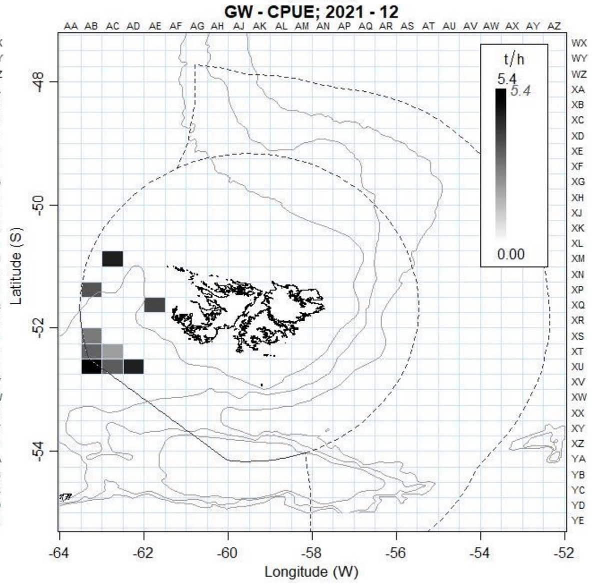




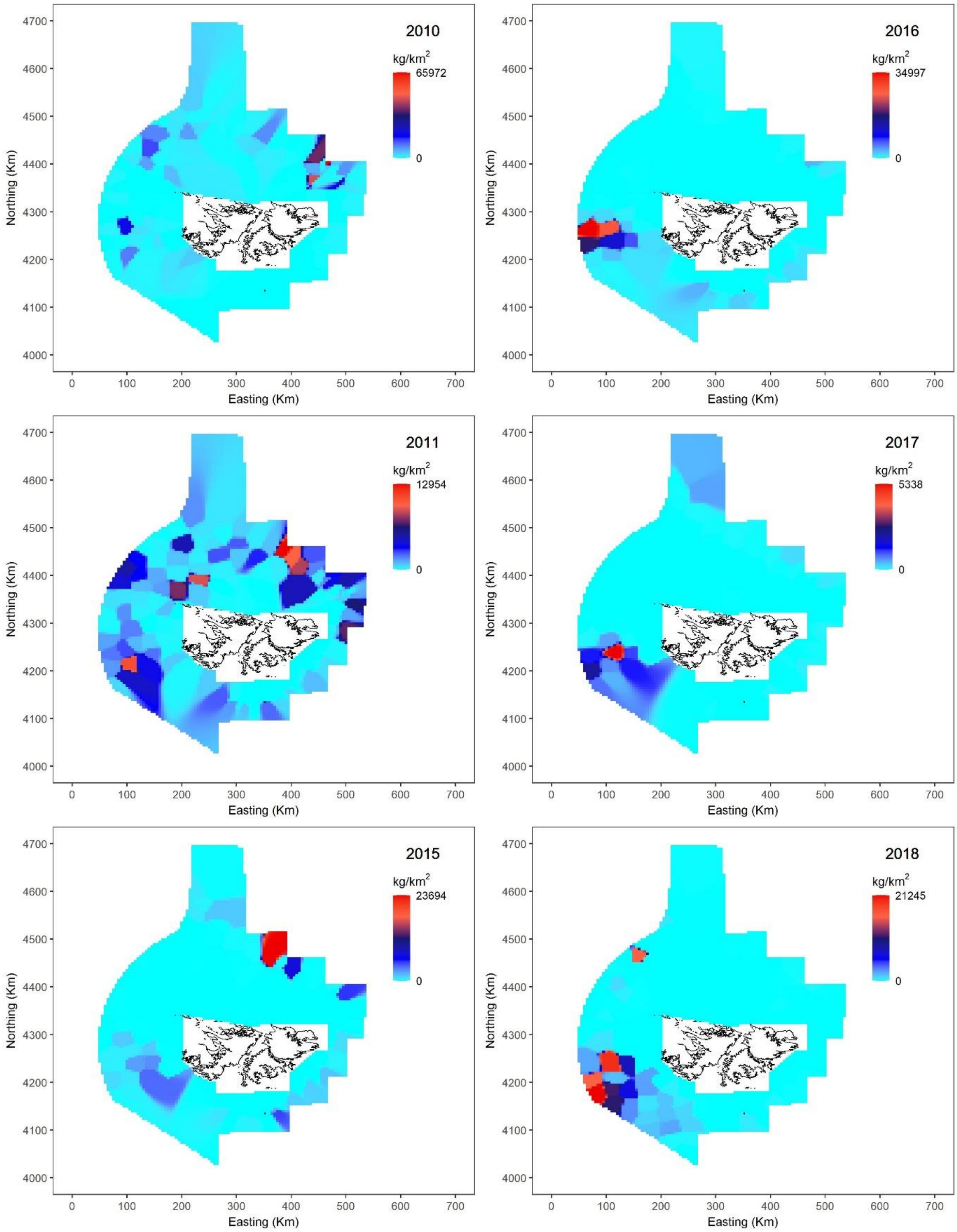




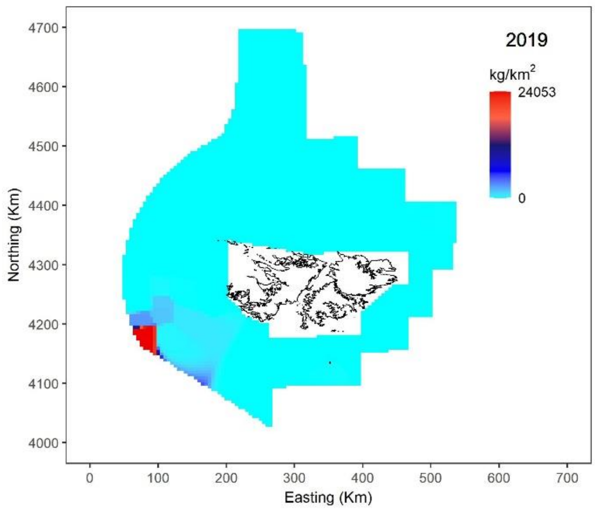


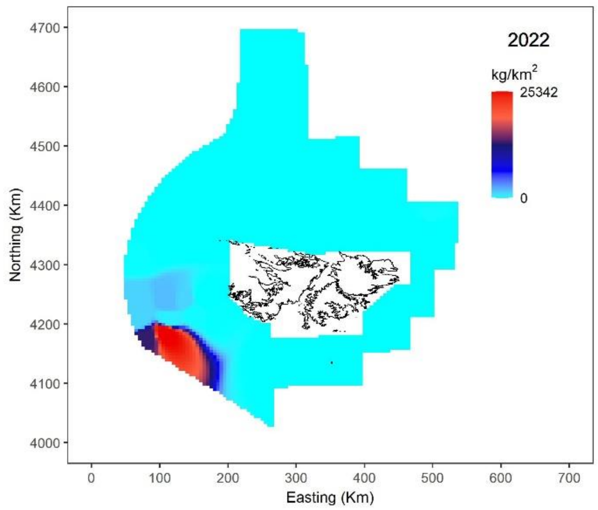


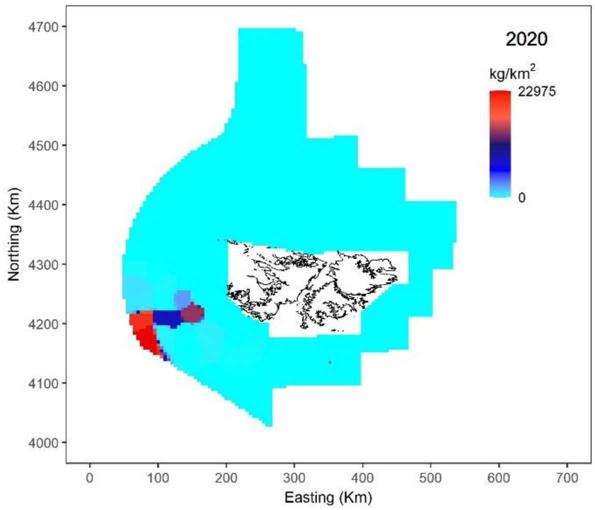
Appendix IV. Densities of hoki modelled by inverse distance weighting in the FICZ, during the February 2010–2022 groundfish and Patagonian squid pre-season surveys.

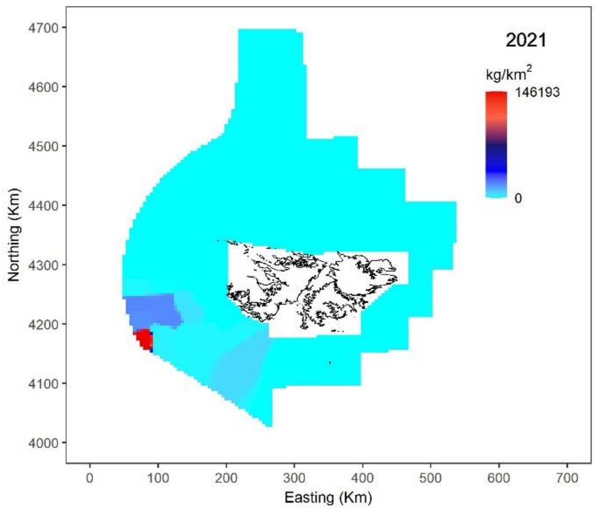


Appendix IV. *continued…*

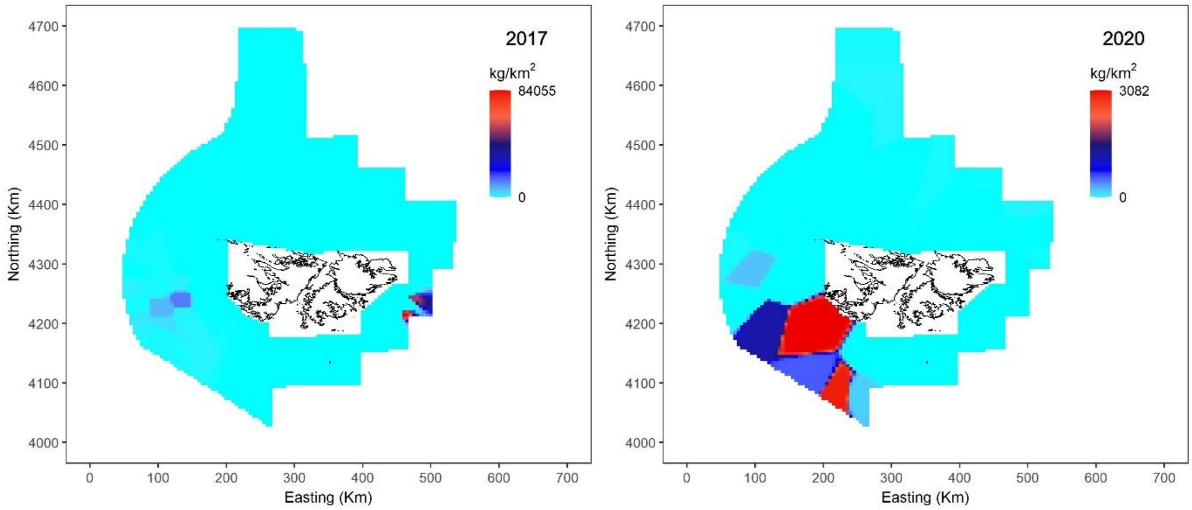




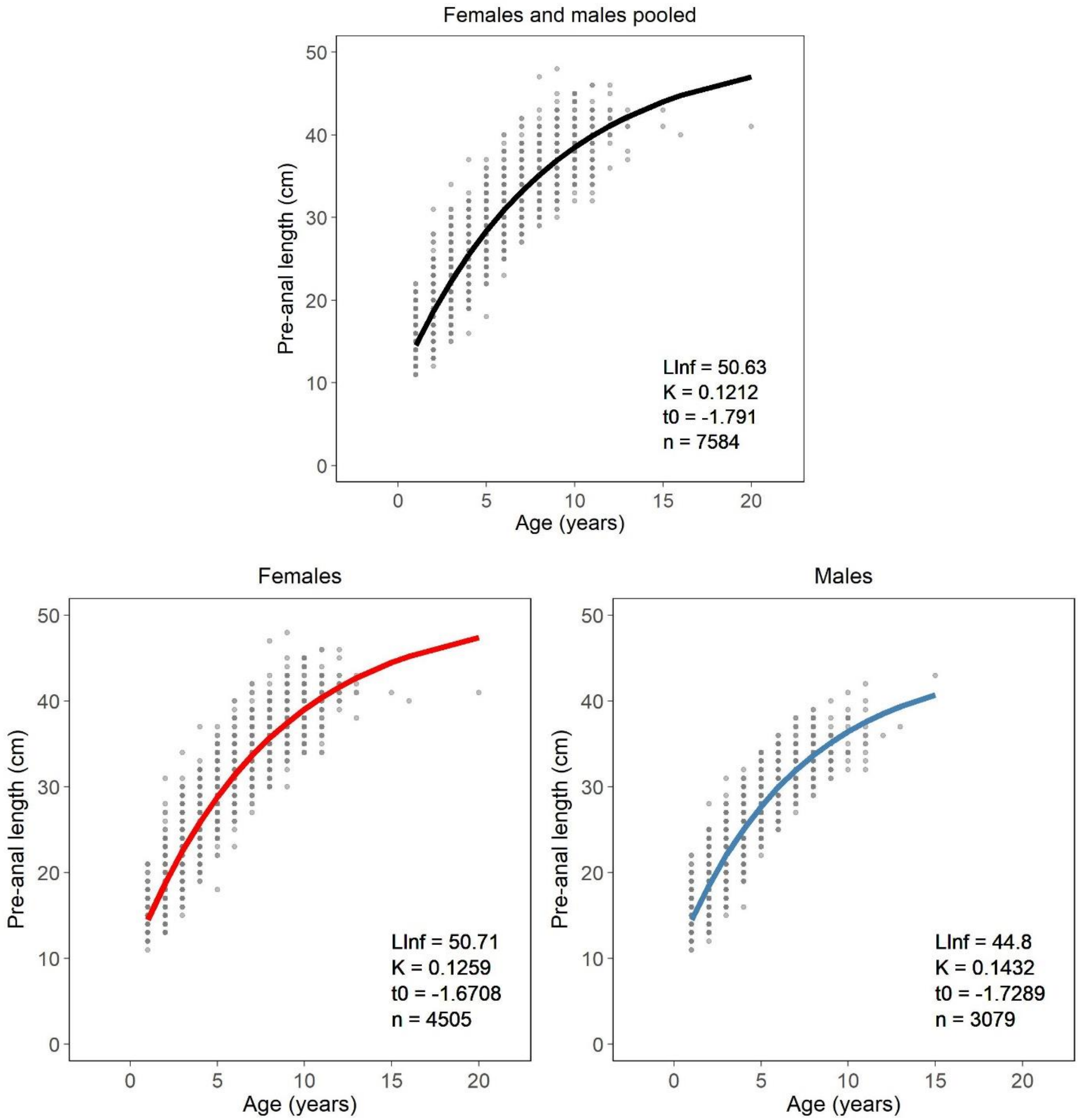




Appendix V. Densities of hoki modelled by inverse distance weighting in the FICZ, during the July 2017 and July 2020 groundfish and Patagonian squid pre-season surveys.



Appendix VI. von Bertalanffy age-length relationship of female and male hoki collected in finfish (A–, G–, and W–licences), experimental (E–licence), and surimi (S–licence) vessels in the FICZ. Age was determined by MFRI (n = 7,510) and FIFD (n = 74) staff.

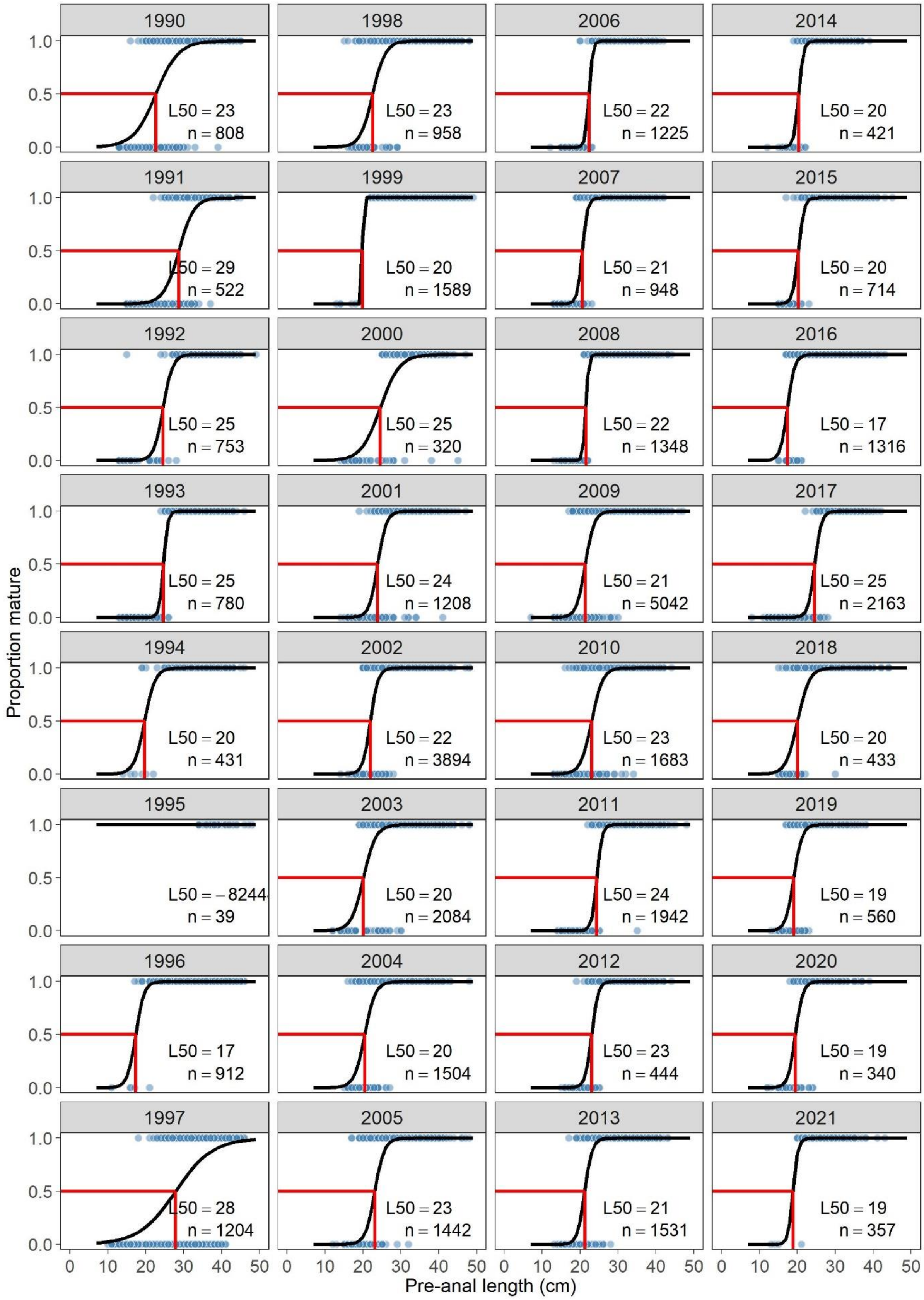


Appendix VII. Hoki von Bertalanffy length-at-age parameters for curvature (k), age of fish at length zero (t_0), and asymptotic length (L_{Inf}), by year and sex, with 95% confidence intervals. Hoki were collected in finfish (A–, G–, and W–licences), experimental (E–licence), and surimi (S–licence) vessels in the FICZ.

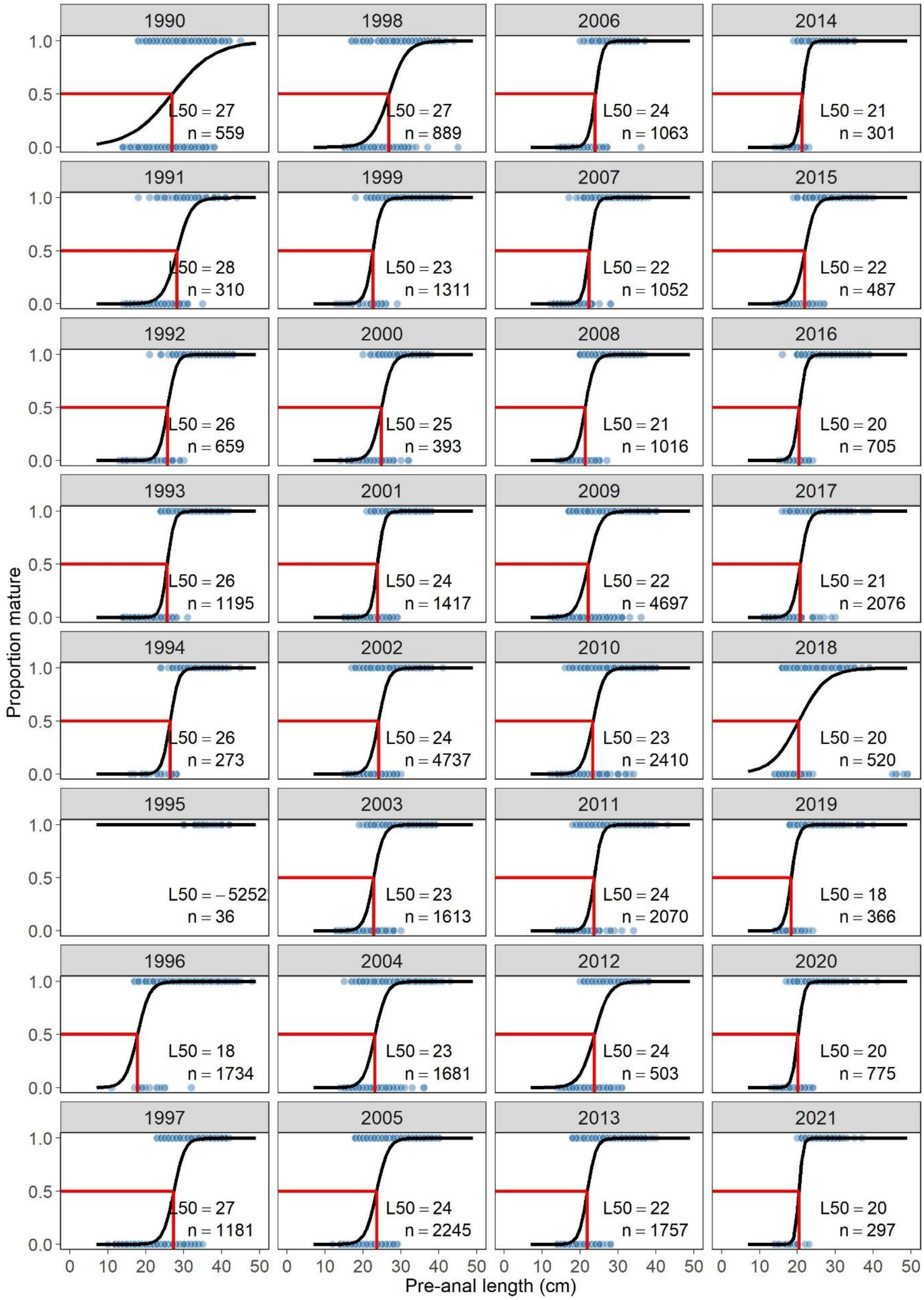
	Year	N	K		t_0 (years)		L_{Inf} (cm)	
	2002	144	0.126	(0.077 - 0.176)	-2.079	(-3.411 - -1.180)	48.9	(43.6 - 60.5)
	2003	201	0.102	(0.055 - 0.154)	-2.852	(-4.016 - -2.002)	52.4	(44.0 - 73.3)
	2004	189	0.117	(0.052 - 0.186)	-2.164	(-4.208 - -0.934)	52.1	(44.3 - 77.8)
	2005	124	0.036	(0.005 - 0.101)	-3.309	(-4.398 - -1.991)	110.4	(56.2 - 629.7)
	2006	380	0.099	(0.071 - 0.130)	-3.008	(-3.850 - -2.327)	51.5	(46.0 - 60.8)
	2007	358	0.196	(0.136 - 0.260)	-0.900	(-1.643 - -0.372)	43.1	(39.4 - 49.9)
	2008	339	0.153	(0.124 - 0.183)	-0.983	(-1.408 - -0.612)	46.7	(43.6 - 50.9)
	2009	227	0.183	(0.137 - 0.232)	-0.964	(-1.550 - -0.517)	41.5	(38.3 - 46.5)
F	2010	149	0.180	(0.128 - 0.234)	-1.002	(-1.700 - -0.512)	46.6	(42.7 - 53.4)
	2011	226	0.149	(0.098 - 0.203)	-1.618	(-2.486 - -0.997)	47.8	(42.8 - 57.7)
	2013	140	0.092	(0.019 - 0.174)	-2.281	(-3.888 - -1.281)	60.0	(43.8 - 184.8)
	2014	273	0.149	(0.108 - 0.191)	-0.784	(-1.375 - -0.328)	49.9	(45.3 - 57.8)
	2015	304	0.151	(0.107 - 0.197)	-1.005	(-1.601 - -0.539)	49.1	(44.1 - 57.5)
	2016	259	0.087	(0.058 - 0.116)	-1.784	(-2.317 - -1.369)	59.9	(51.4 - 76.9)
	2017	183	0.119	(0.076 - 0.163)	-1.654	(-2.521 - -1.041)	52.3	(46.0 - 65.6)
	2018	175	0.096	(0.045 - 0.148)	-1.868	(-2.872 - -1.204)	59.8	(48.1 - 97.0)
	2019	144	0.126	(0.077 - 0.176)	-2.079	(-3.411 - -1.180)	48.9	(43.6 - 60.5)

	Year	N	K		t_0 (years)		L_{Inf} (cm)	
	2002	157	0.035	(0.005 - 0.124)	-5.535	(-7.514 - -2.837)	86.7	(43.4 - 492.5)
	2003	104	0.215	(0.132 - 0.300)	-0.985	(-2.530 - -0.046)	39.0	(36.1 - 44.9)
	2004	163	0.058	(0.008 - 0.142)	-4.415	(-6.556 - -2.626)	67.0	(43.0 - 333.2)
	2005	23	0.098	(0.012 - 0.382)	-1.744	(-4.374 - 0.490)	58.7	(35.1 - 283.1)
	2006	79	0.307	(0.113 - 0.510)	-0.941	(-3.061 - -0.059)	33.4	(29.8 - 47.2)
	2007	242	0.134	(0.084 - 0.183)	-2.198	(-3.143 - -1.538)	44.8	(39.7 - 55.6)
	2008	235	0.215	(0.128 - 0.311)	-1.107	(-2.149 - -0.407)	38.5	(34.5 - 47.0)
	2009	250	0.154	(0.111 - 0.200)	-1.292	(-1.968 - -0.765)	43.2	(39.2 - 49.9)
M	2010	166	0.177	(0.114 - 0.249)	-1.354	(-2.291 - -0.671)	39.5	(35.4 - 47.3)
	2011	86	0.175	(0.110 - 0.248)	-1.693	(-2.739 - -0.978)	41.8	(37.3 - 50.5)
	2013	122	0.007	(0.004 - 0.125)	-4.891	(-5.255 - -2.382)	413.6	(45.6 - 644.3)
	2014	133	0.099	(0.024 - 0.180)	-2.299	(-3.878 - -1.330)	56.7	(42.8 - 149.0)
	2015	99	0.039	(0.006 - 0.157)	-3.811	(-4.995 - -1.883)	97.3	(42.5 - 495.9)
	2016	228	0.072	(0.017 - 0.135)	-1.961	(-3.171 - -1.093)	71.7	(50.5 - 220.1)
	2017	222	0.175	(0.120 - 0.232)	-1.050	(-1.702 - -0.555)	42.6	(38.3 - 50.5)
	2018	217	0.045	(0.007 - 0.102)	-1.791	(-2.333 - -1.223)	107.5	(60.4 - 567.5)
	2019	131	0.055	(0.009 - 0.117)	-2.837	(-4.318 - -1.674)	76.5	(49.6 - 338.6)

Appendix VIII. Binomial logistic regressions of juvenile (0) or adult (1) maturity ogives vs. length for female hoki sampled randomly in finfish (A–, G–, and W–licences), experimental (E–licence), and surimi (S–licence) vessels in the FICZ. Red lines indicate the intercept for length at 50% adulthood, corresponding to Fig. 7.



Appendix IX. Binomial logistic regressions of juvenile (0) or adult (1) maturity ogive vs. length for male hoki sampled randomly in finfish (A–, G–, and W–licences), experimental (E–licence), and surimi (S–licence) vessels in the FICZ. Red lines indicate the intercept for length at 50% adulthood, corresponding to Fig. 7.



Appendix X. Number of hoki individuals sampled for length frequency distributions, corresponding to individuals caught randomly in finfish (A–, G–, and W–licences), experimental (E–licence), and surimi (S–licence) vessels through the year in the FICZ from 1990 to 2021.

Year	Females (n)	Males (n)
1990	1,663	1,084
1991	1,103	666
1992	1,026	808
1993	1,388	1,490
1994	751	376
1995	99	45
1996	1,914	2,011
1997	4,857	3,430
1998	2,361	1,144
1999	3,578	2,318
2000	4,847	3,835
2001	3,471	2,932
2002	11,626	8,650
2003	3,857	2,683
2004	7,162	5,193
2005	8,131	5,295
2006	4,478	2,921
2007	5,497	3,712
2008	5,610	3,846
2009	12,150	9,105
2010	7,917	5,637
2011	6,095	4,147
2012	2,565	1,697
2013	5,703	3,387
2014	1,538	950
2015	1,955	1,315
2016	4,529	2,565
2017	3,359	2,922
2018	3,880	2,867
2019	2,353	1,681
2020	2,664	1,800
2021	1,747	957