Stock Assessment of common hake (*Merluccius hubbsi*) in the Falkland Islands

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Stanley, Falkland Islands

October 2022

SA - 2022 - HAK

Ramos JE, Winter A (2022) Stock assessment of common hake (*Merluccius hubbsi*) in the Falkland Islands. SA–2022–HAK. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 36 p.

Acknowledgements
We thank the captains and crews of the commercial fishing vessels, and the scientific observers of the Falkland Islands Fisheries Department that facilitated and assisted in catch and biological data collection. Daryl Parkyn and Alexander Arkhipkin provided valuable comments that improved this report. Common hake cover picture by Susanne Weitemeyer (Copyright Scandinavian Fishing Year Book).

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Reviewed and approved 24th of October 2022

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Summary

Merluccius hubbsi commercial catches in Falkland Islands licenced fisheries were 59,150.25 t in 2021; the highest annual reported total catch since 1988. Following recommendations of the MacAlister Elliott & Partners external review, Total Allowable Catch (TAC) was calculated according to the ICES category 5 advice rule: 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. The *M. hubbsi* TAC for 2023 is set at 49,366 t.

Two parallel *Doryteuthis gahi* and groundfish trawl surveys were conducted in July 2017 and 2020, around the time when *M. hubbsi* reaches its highest annual presence in Falkland Islands waters. Estimated *M. hubbsi* biomass in July 2017 was 111,093.86 t, and estimated *M. hubbsi* biomass in July 2020 was 355,649.60 t.

The CPUE of common hake in Falkland Islands waters has increased since 2014, with the highest CPUE estimated in 2019.

Introduction

Common hake *Merluccius hubbsi* is a benthopelagic (demersal) species inhabiting the shelf and upper continental slope of the Southwest Atlantic Ocean, from southern Brazil to southern Argentina (Cohen et al. 1990; Arkhipkin et al. 2015). Common hake migrate into west of Falkland Islands waters in February, large numbers are then found to the west and north from March to May. In May, *M. hubbsi* is also found to the south and southeast, and its widest distribution occurs from July to September. Return migration from the southeast occurs in September; individuals are found to the northwest in October, and leave Falkland Islands waters in November (Arkhipkin et al. 2012, 2015). Falkland Islands waters have been identified as a feeding ground for this species (Arkhipkin et al. 2003), where resting/feeding individuals are found from July to November, spawning individuals from December to February, and post-spawning individuals from March to June (Arkhipkin et al. 2015). Common hake feeds on fishes, squids, and macro-zooplankton (Cohen et al. 1990). Females are larger than males, with maximum sizes in the Falkland Islands fishery at 102 cm total length for females and 90 cm total length for males; maximum age has been estimated at 18 years old (Arkhipkin et al. 2015).

Three stocks of *M. hubbsi* are recognized in the Southwest Atlantic (Irusta et al. 2016). The Southern or Patagonian stock migrates between Argentine and Falkland Islands waters where it is fished commercially (Arkhipkin et al. 2015). Falkland Islands fisheries have been reporting hake catches since 1987. However, *M. hubbsi* was not always distinguished from its rarer congeneric *M. australis* (Falkland Islands Government 1989). Hake was a relatively small component of the finfish catch compared to hoki and Southern blue whiting until about 2005, just before rock cod became briefly predominant. Subsequent to the decline of rock cod, *M. hubbsi* became the highest finfish catch species and has annually totalled more finfish catch tonnage in Falkland Islands waters than all other species together since 2018 (Falkland Islands Government 2021).

Methods

ICES Advice Rules

ICES Category 5 Total Allowable Catch

In 2020, common hake was included in the 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, 2018), referencing applicable categories of data availability and quality.

Merluccius hubbsi starts its migration into Falkland Islands waters during February (Arkhipkin et al. 2012); hence its abundance can be highly variable during that month. A biomass index of the February surveys (Ramos & Winter 2022) would therefore be likely to reflect variability in its migratory timing, affecting patterns of common hake abundance during February. Commercially, the Falkland Islands hake fishery contributes a relatively small proportion to the common hake catch in the Southwest Atlantic, compared to the Argentine hake fishery. Therefore, a catch-per-unit-effort (CPUE) index of the Falkland Islands fishery alone cannot be implemented. In addition, stock assessment using a data-poor method (CMSY) produced high margins of uncertainty (Winter & Ramos 2020). For these reasons, calculation of Total Allowable Catch (TAC) for *M. hubbsi* was advised at 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 2018) with respect of the TAC set for the current year (TAC_{2022} = 41,138 t; Winter & Ramos 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 common hake have been read routinely at the National Marine Fisheries Research Institute (MFRI) in Gdynia, Poland. However, common hake age estimates by MFRI have been found to have high variability in the early ages, probably due to uncertainty in the assignment of the first annulus, and therefore these data must be taken with caution (Lee et al. 2020). Otoliths are read once by one person only, preventing the use of age precision or repeatability

[a] It is not explicitly stated in the reference but inferred that 'average' catches signifies the 'mean' of the annual total catches, by weight.

measures, and reader accuracy measures. Moreover, the whole otoliths are read, which may not be appropriate for older common hake which have thick otoliths (D. Parkyn, FIFD *pers. comm.*). Limited reliable data do not allow accurate calculation of annual life history parameters such as L_{Inf}, and prevent implementation of LBI for common hake.

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 common hake catch data were examined from 1987 to 2021 from the Falkland Islands (Falkland Islands Government[b]; Falkland Islands Government 2021), and Argentina (Argentine Government[c]; Sánchez et al. 2012; Navarro et al. 2014, 2019). LOESS (span = 1, degree = 2) was implemented to examine the pattern of the association between Falkland Islands and Argentina commercial annual catches of common hake from 1987 to 2021. Commercial catches and discard of common hake were examined by licence type for 2021 in the Falkland Interim Conservation Zone (FICZ).

CPUE was calculated as the sum of common hake 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. A preliminary analysis of monthly CPUE calculated from bottom trawl finfish (A–, G–, and W–licences) vessels to the west of the FICZ was carried out to detect the months with higher and constant abundance of common hake. This allowed to calculate annual CPUE from finfish vessels with fishing activity across the west of the FICZ from May through September. Monthly CPUE was then recalculated from finfish vessels with fishing activity across the west of the FICZ, for years with low abundance and for years with high abundance. LOESS (span = 0.75, degree = 2) was implemented to examine the patterns of annual and monthly CPUE. CPUE was calculated from A–, G–, and W–licences because these contribute most of the common hake catches. The west portion of the FICZ is defined in this assessment as the area that includes the 'hake box' (from 60 °W to the western limit of the FICZ, and from 51 °S to the northern limit of the FICZ), and directly south of the 'hake box' (from 60 °W to the western limit of the FICZ, and from 51 °S to the southern limit of the

[b] http://www.fig.gov.fk/fisheries/publications/fishery-statistics

[c] https://www.agroindustria.gob.ar/sitio/areas/pesca_maritima/desembarques/

FICZ), which represents the area where common hake are caught in greater abundance most of the year (Arkhipkin et al. 2015).

Survey biomass estimates

Biomass estimates and the spatial distribution of common hake 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). Common hake biomass estimates during the February surveys were presented as an additional comparative proxy for abundance patterns, with the caveat that these would likely reflect variability in its migratory timing.

Biomass estimates, spatial distribution, 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). While two sets of data cannot serve as a time series index, they provide a baseline for the recent biomass of *M. hubbsi* in Falkland Islands waters.

Length and age analyses

Length-age relationship

Given that common hake age data must be taken with caution[d] (Lee et al. 2020), a subset of age data from 2020 deemed reliable (D. Parkyn, FIFD *unpublished data*) were used to calculate the von Bertalanffy growth function parameters L_{Inf}, k, and t_0 (R package 'fishmethods'; Nelson 2019) for females and males separate, using nonlinear least square regression.

[d] High variability and difference between age readers are noted, but inter-annual trends are considered reliable.

Length and age at 50% maturity

Overall and yearly length at 50% maturity (L50) were 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 assignment was simplified to a dichotomous classification of 0) juvenile, including maturity stages I and II, and 1) adult, including maturity stages III to VIII. Common hake L50 was calculated for females and males separate, from individuals sampled randomly and collected by finfish vessels from January through March, months when immature and spawning individuals occur in Falkland Islands waters (Arkhipkin et al. 2015). Common hake length and maturity data were consistently available from 2005 to 2021, and therefore these data were examined. Trends of annual L50 were calculated using LOESS (span = 1, degree = 2), excluding years for which the binomial logistic regression did not converge. Overall and yearly age at 50% maturity (A50) was calculated for females and males separately, by predicting age corresponding to L50 using the von Bertalanffy equation.

Catch at length

Yearly length frequency distributions, from 2005 to 2021, were examined for females and males to describe patterns in length through time. Unsexed individuals were excluded from the analysis. Lengths of individuals sampled randomly and caught by finfish and experimental (E–licence) vessels west of 60 °W in the FICZ during the months found to have higher presence of common hake in the area were used, i.e., June and July. Yearly length frequencies were compared with yearly L50 to assess if the catch is mainly comprised of immature or mature individuals.

Catch at age

A subset of age data from 2020, that have been verified as an accurate control set (D. Parkyn, FIFD *unpublished data*) were used to create an age-length key, from which ages were assigned to length data (R package ‘FSA’; Ogle et al. 2022) of individuals sampled randomly in the FICZ from 2005 to 2021. Catch-at-age proportions were examined as a proxy for fishing pressure at each age class, for females and males separately, and per year. Relative frequencies of immature vs mature age classes (corresponding to lesser vs greater than L50) in the catch were assessed for females and males separately through time. Older age classes with negligible representation in the catch were excluded.

Natural mortality

Annual natural mortality (M) 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 not considered an outlier. 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, calculated as the average of the in-zone catch (t) of the last completed three years (51,894.03 t) limited to a ± 20% cap with respect of the TAC for the current year (TAC_{2022} = 41,138 t; Winter & Ramos 2021) resulted in a TAC for 2023 of 49,365.60 t:

$$TAC\_5_{2023} = \overline{53286.24{,}43245.72{,}59150.25} \mid \pm 20\% = 49{,}365.60 \text{ t}$$

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

Common hake catches in Falkland Islands waters have averaged 13,827 t per year since 1987, representing approximately 5% of the Falkland Islands and Argentine combined annual catch (Fig. 1). Falkland Islands catches were negatively associated with Argentine catches when Argentine catches were > 250,000 t (Fig. 2; Appendix I).

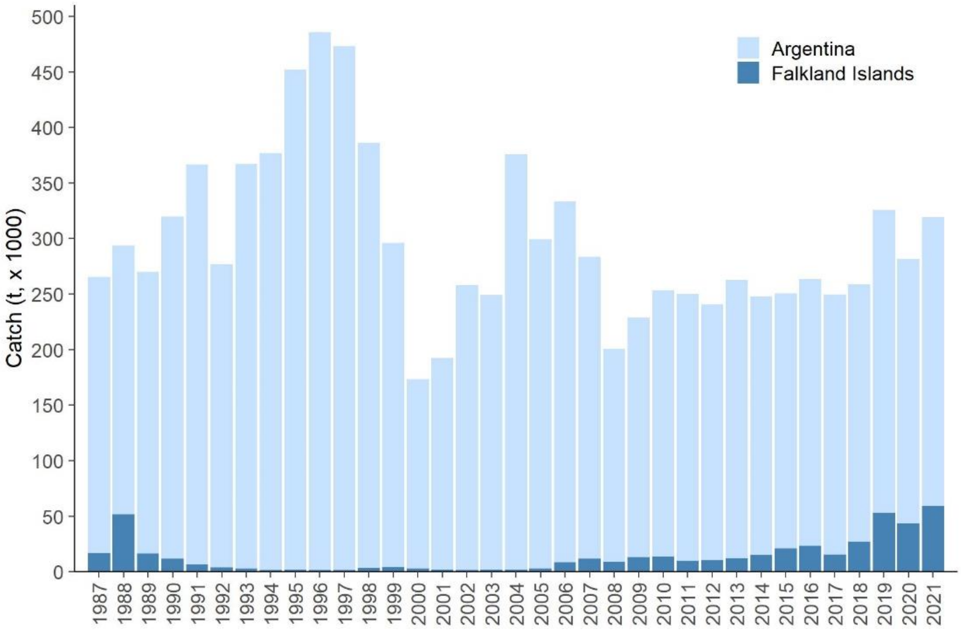

Fig. 1. Annual commercial catches of common hake in Falkland Islands and Argentine waters. Falkland Islands commercial catch data exclude experimental (E–licence) and out-of-zone (O–licence) licences from 1990; earlier than 1990 these licences were not designated.

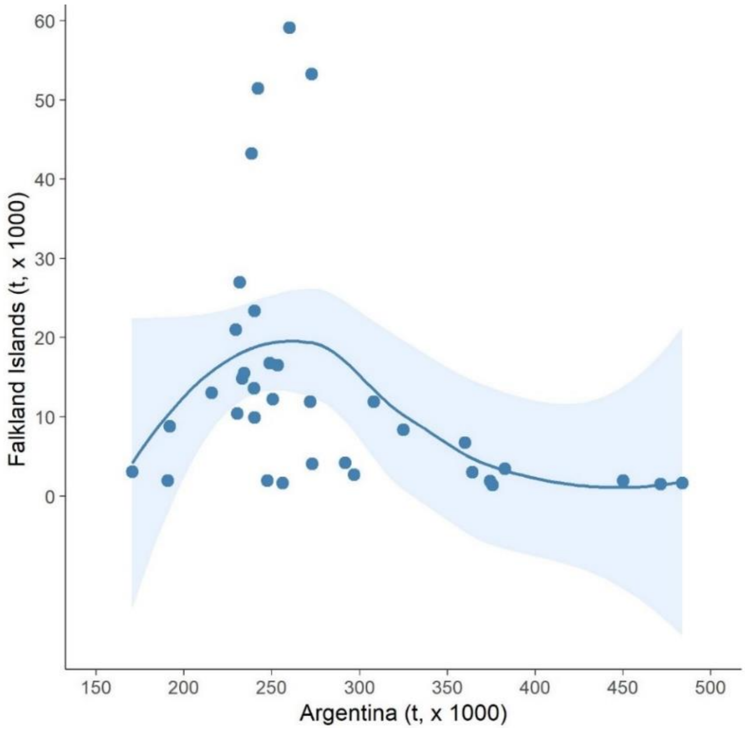

Fig. 2. Falkland Islands vs. Argentina annual commercial catches of common hake from 1987 to 2021, with LOESS smooth ± 95% confidence intervals (LOESS; span = 1, degree = 2).

During 2021, a total of 59,212 t of common hake were reported caught in Falkland Islands waters, of which 59,150 t were reported under commercial licences, i.e., excluding the experimental E–licence (Table I). Finfish vessels accounted for 99% of the total common hake catch. The A–licence targeted this species and accounted for > 50% of the total common hake catch during the year (Table I). Common hake discards were only 0.15% of the total common hake catch in 2021, with most discards made by the B–licence (48%) and the C–licence (15%; Table I).

Table I. Catch proportions of common hake by licence type in Falkland Islands waters during 2021.

Licence	Target species	Catch (t)	Catch (%)	Discard (t)	Proportion discarded (%)
A	Unrestricted finfish	30,504.70	51.52	18.38	0.06
W	Restricted finfish	16,127.35	27.24	2.82	0.02
G	Restricted finfish and *Illex*	12,102.50	20.44	6.59	0.05
X	Calamari 2nd season	281.55	0.48	12.76	4.53
B	*Illex* squid	82.20	0.14	39.77	48.38
E	Experimental	61.36	0.10	0.38	0.63
C	Calamari 1st season	51.94	0.09	7.55	14.53
F[a]	Skates and rays	0.00	0.00	0.00	0.00
L	Toothfish (longline)	0.00	0.00	0.00	0.00
S[a]	Southern blue whiting and hoki	0.00	0.00	0.00	0.00
O	Outside Falkland Islands waters	0.00	0.00	0.00	0.00
Total		59,211.60	100.00	88.25	0.15

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

Common hake CPUEs were relatively constant from 1990 through 2013 (< 550 kg/h), followed by a steep increase from 2014 (669 kg/h) to 2021 (3,026 kg/h). However, the highest CPUE in the time series was reported in 2019 (3,417 kg/h) (Fig. 3).

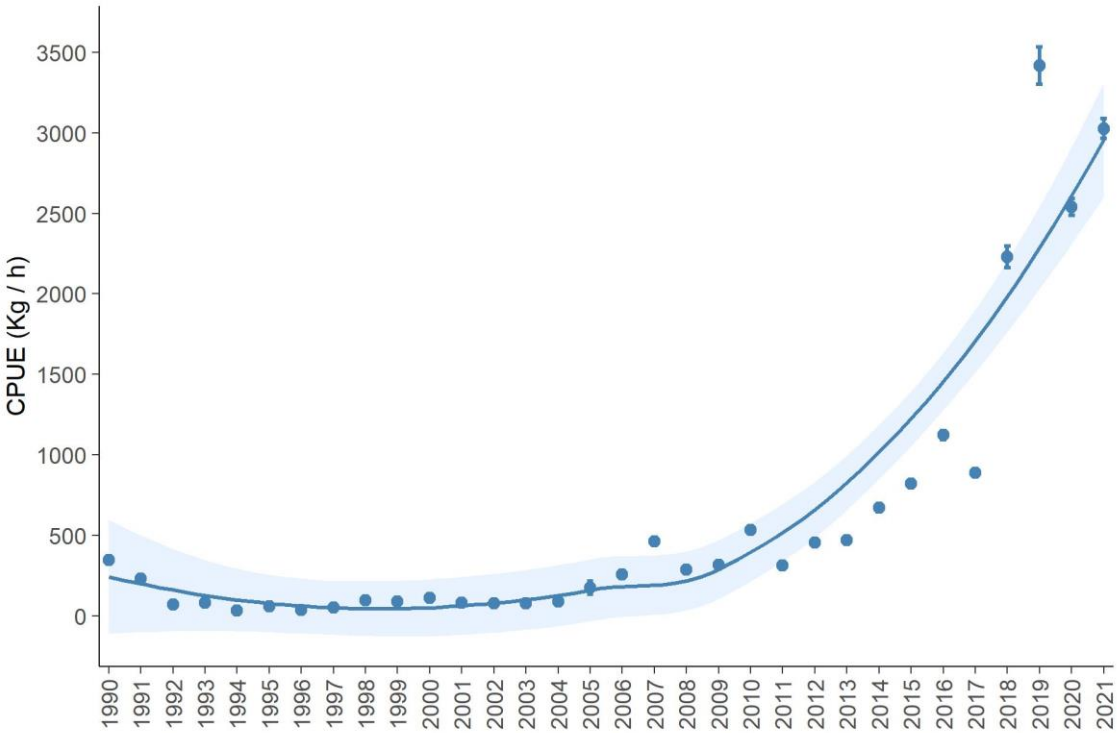

Fig. 3. Yearly CPUE ± 1 standard error of common hake in Falkland Islands waters from 1990 through 2021, calculated from A–, G–, and W–licensed vessels from the west of 60°W in the FICZ (hake box and south of hake box), from May through September, with LOESS smooth ± 95% confidence intervals (LOESS; span = 1, degree = 2).

Monthly CPUE by finfish vessels were examined separately from 1990 to 2013 (a period of time with relatively low and constant annual CPUE), from 2014 to 2020 (a period of time with increasing annual CPUE), and 2021 (previous year), as the CPUE patterns may differ in the years when the CPUE was constant compared with the years when the CPUE increased. The monthly CPUE from 1990 to 2013 ranged from 31 kg/h in November to 364 kg/h in June. CPUE for the period 2014 to 2020 was higher most months compared with 1990 to 2013, with the lowest CPUE in December (14 kg/h) and the highest value in June (1,687 kg/h). CPUE was low at the start of the year and increased from January to reach relatively high values from May through September, then declined from October through December (Fig. 4). This pattern suggests that common hake is more abundant in Falkland Islands waters from mid-autumn to the end of winter. The average monthly CPUE in 2021 had higher values compared with the average monthly CPUE from 1990 to 2013, and from 2014 to 2020. Monthly CPUE in 2021 ranged between 96 kg/h in December to 3,257 kg/h in September; there was no commercial fishing effort in January and February, and fishing effort was low in December 2021. Contrary to previous years, the highest catches were reported in early autumn and late winter, with relatively lower catches in June and July (Fig. 4; Appendix II). During 2021, common hake were caught mainly to the west and northwest of West Falkland under finfish licences (Appendix III).

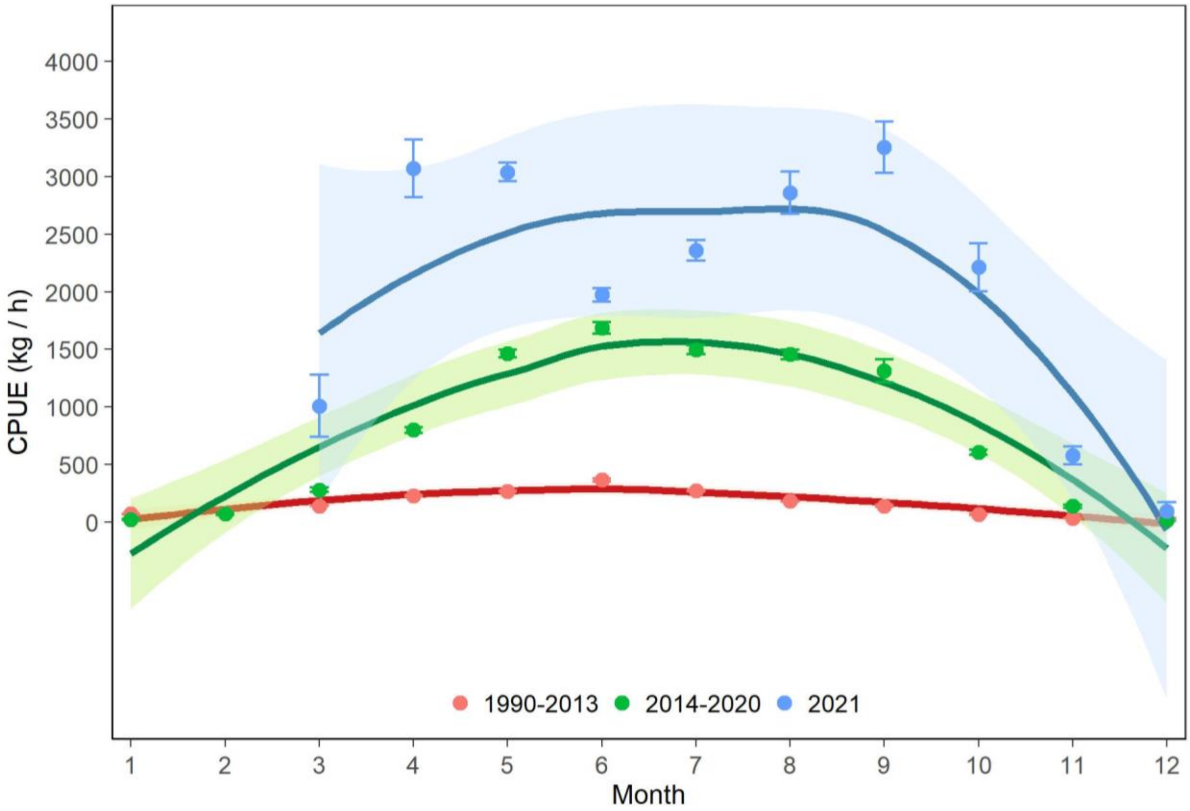

Fig. 4. Monthly CPUE ± 1 standard error of common hake in Falkland Islands waters for 1990–2013 (red), 2014–2020 (green), and 2021 (blue), calculated from finfish (A–, G–, and W–licences) vessels, with LOESS smooths ± 95% confidence intervals (LOESS; span = 1, degree = 2).

Surveys biomass estimates

Summer surveys (February)

The biomass of common hake during the February surveys did not change significantly from 2010 to 2018 but there has been an increasing trend since 2019. The biomass in 2010 (9,124 t) was 21.5% of the biomass in 2022 (42,421 t; Fig. 5; Appendix IV). A total of 10,000 out of 10,000 paired re-samples had higher biomass estimate values in February 2022 than in February 2010 (100%), therefore the difference in biomass between 2022 and 2010 is significant at $p < 0.05$. Common hake was distributed across the north of the FICZ and the main aggregations occurred to the northwest (Appendix V), which is consistent with the migration of this species into Falkland Islands waters from Argentine waters during February.

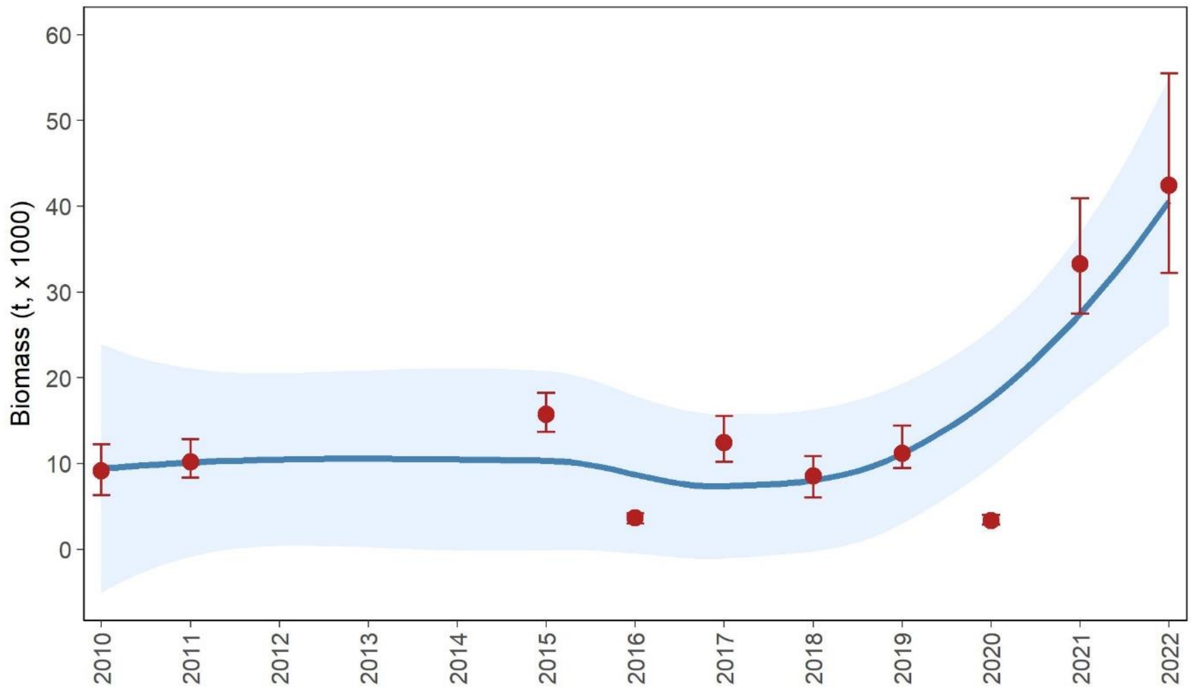

Fig. 5. Common hake biomass estimates (red dots) ± 95% confidence intervals from summer (February) surveys in Falkland Islands waters, with LOESS smooths ± 95% confidence intervals (LOESS; span = 1, degree = 2). Note that no parallel February surveys (groundfish and Patagonian squid pre-season) were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

Winter surveys (July)

The estimated biomass of common hake in the July 2017 survey (111,094 t) was 31% of the July 2020 survey (355,650 t; Table II). A total of 10,000 out of 10,000 paired re-samples had higher biomass estimate values in July 2020 than in July 2017 (100%), thus significant at $p < 0.05$. In July 2017 and 2020, common hake was distributed across the FICZ, with the main aggregations to the north and northwest (Appendix VI).

Table II. Winter (July) surveys catch and effort, and biomass estimates (mean ± 95% confidence intervals) of common hake 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	18323.63	247.62	111093.86 (93300.78 – 146644.89)
	D. gahi[a]	59	54.71	114	8329.50	73.07	
	Total	133	70.12	188	26653.13	141.77	
2020	Groundfish[b]	33	7.14	33	19907.13	602.94	355649.60 (232343.07 – 487272.47)
	D. gahi	55	98.57	101	65744.96	649.33	
	Total	88	105.71	134	85652.09	637.93	

[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 common hake.
[b] Twelve additional trawls were conducted in high seas during the July 2020 survey; these trawls were not included in the analyses.
Note that no parallel July surveys (groundfish and Patagonian squid pre-season) were conducted in 2018 and 2019.

Length and age analyses

Length-age relationship

The length-age relationship of females and males pooled (n = 1,248) gave the values: L_{Inf} = 90.67 cm, k = 0.1287, and t_0 = -1.5185 years. Length and age of females (n = 946) ranged from 20 cm to 82 cm, and from 1 year to 15 years, respectively. The length-age relationship of females gave the values: L_{Inf} = 83.01 cm, k = 0.1783, and t_0 = -0.9459 years. Length and age of males (n = 302) ranged from 19 cm to 56 cm and from 1 year to 11 years, respectively. The length-age relationship of males gave the values: L_{Inf} = 45.93 cm, k = 0.4107, and t_0 = -0.9436 years (Appendix VII).

Length and age at 50% maturity

Over the entire time series, length at 50% maturity (L50) of females was 39 ± 0.06 cm total length (n = 37,042) and age at 50% maturity (A50) was at 2.5 years old. L50 of males was 32 ± 0.08 cm total length (n = 8,137) and A50 was at 1.6 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 33 cm and 1.9 years old in 2020 to 47 cm and 3.7 years old in 2008, respectively. Annual L50 and A50 of males ranged from 18 cm and 1.2 years old in 2013 to 35 cm and 2.6 years old in 2005. The L50 fit did not change significantly for females and males from 2005 through 2021. Limited data prevented estimating L50 in some years, in particular for males (Fig. 6; Appendixes VIII–IX).

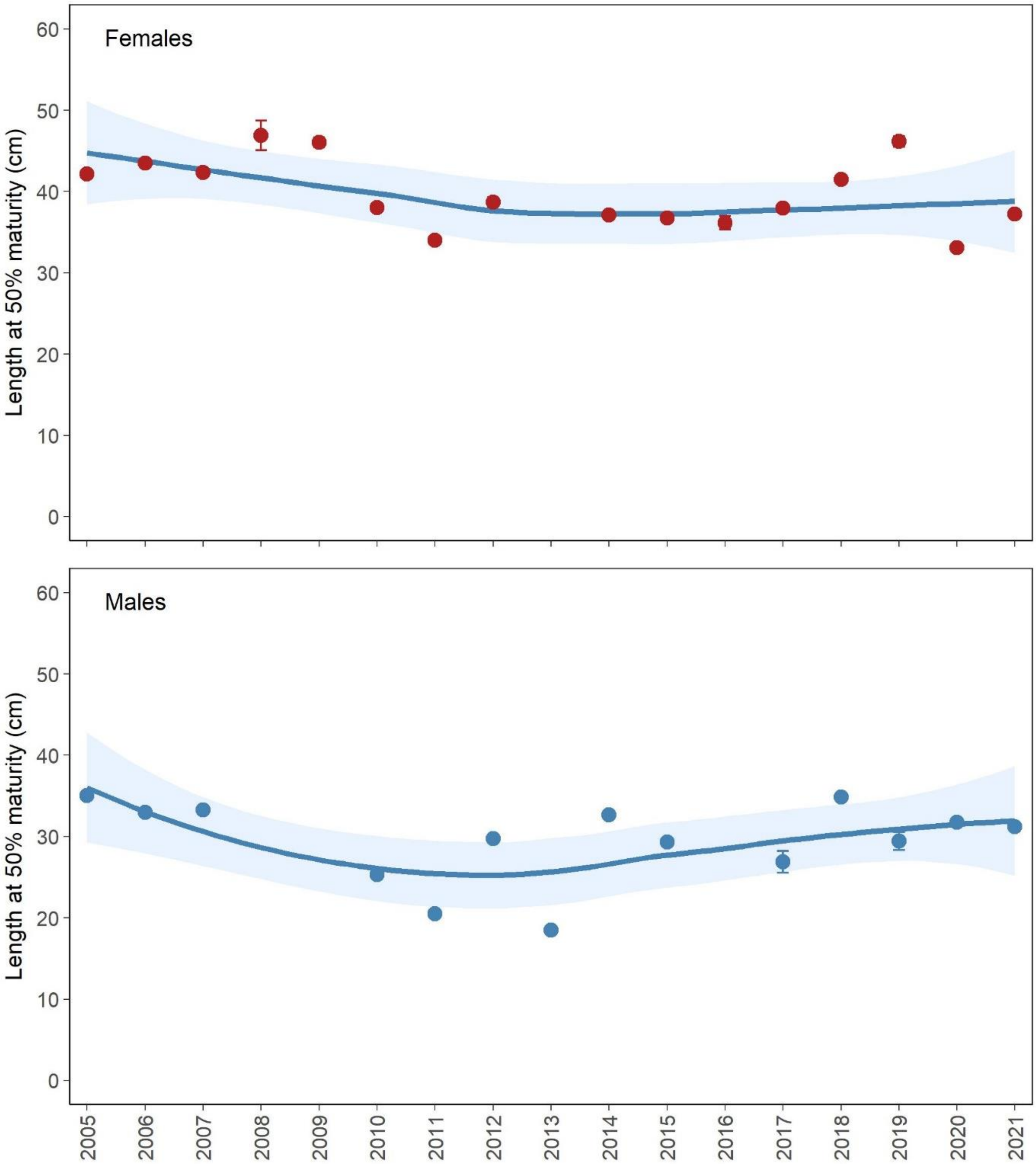

Fig. 6. Lengths at 50% maturity (L50) ± 1 standard error of female (red dots) and male (blue dots) common hake caught by finfish (A–, G–, and W–licences) and experimental (E–licence) vessels in the FICZ from January through March, from 2005 through 2021, with LOESS smooths ± 95% confidence intervals (LOESS; span = 1, degree = 2).

Catch at length

Female common hake (n = 59,164) ranged from 16 cm to 95 cm total length, and males (n = 17,965) ranged from 17 cm to 77 cm total length (Appendix X). For females there was an increase in the range of lengths from 2005 to 2012, with larger modal length (60 cm total length) in 2012 compared with previous years, i.e., 45–50 cm total length from 2005 through

2010. Modal length then declined from 60 cm in 2012 to 40 cm total length in 2021. Females were caught at sizes larger than L50 most years, except for 2008, 2018, and 2019 when a considerable proportion of the catch was comprised of individuals that most likely had not reach maturity. For males, modal length was nearly 40–45 cm total length from 2005 through 2011. The range of lengths increased in 2012; modal length then remained at 35 cm total length most years from 2014 through 2021 (Fig. 7). Males were caught at sizes larger than L50 most years; except for 2018 when most of the catch was comprised of individuals that were near L50.

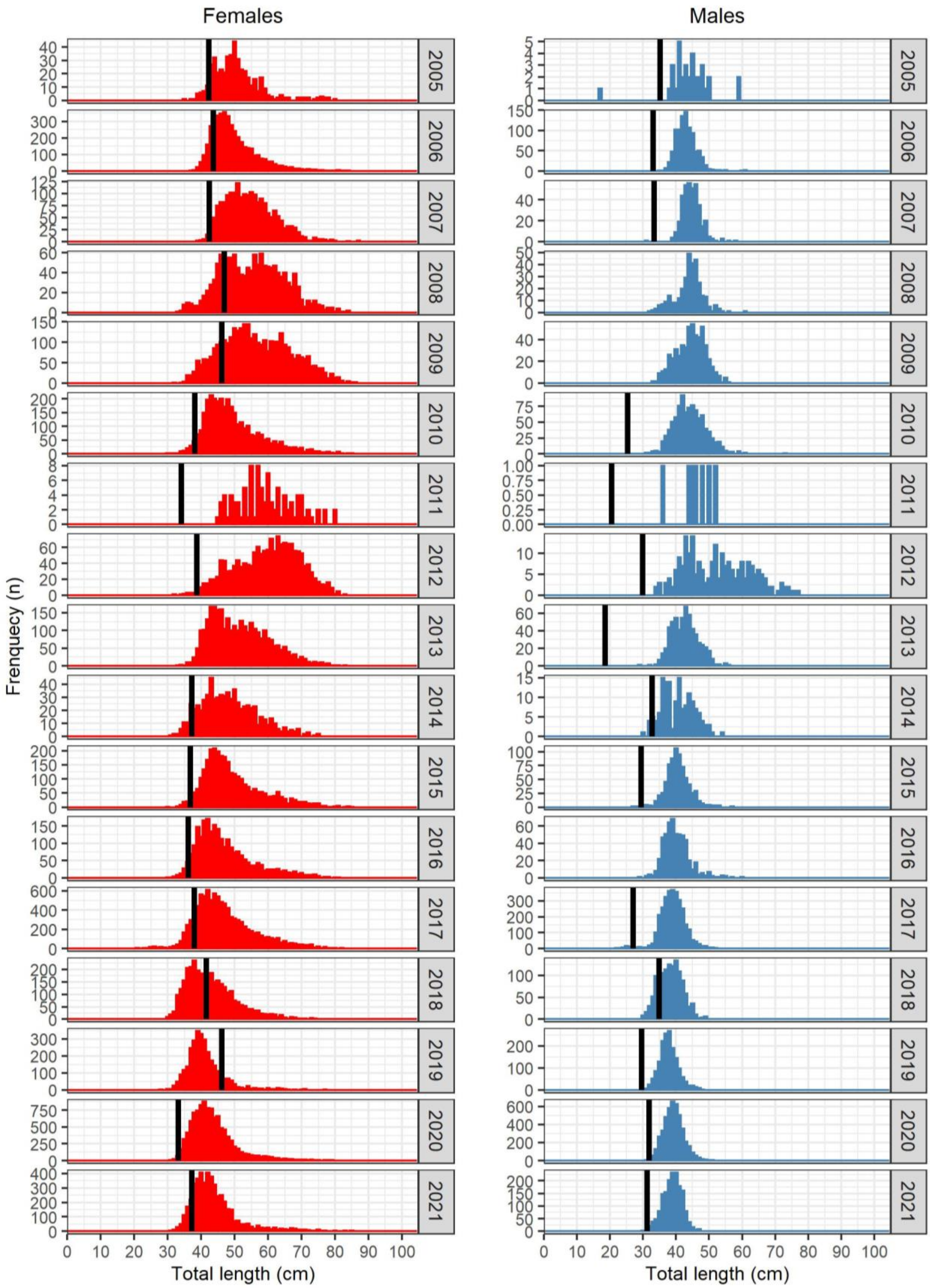

Fig. 7. Length frequency distribution of female and male common hake caught by finfish (A–, and W– licences) and experimental (E– licence) vessels west of 60 °W in the FICZ during June and July from 2005 through 2021. Black solid lines indicate lengths at 50% maturity (L50) from individuals caught from January through March; the binomial model for L50 did not fit the female data in 2013, and the male data in 2008, 2009, and 2016.

Catch at age

Greater proportions of female and male common hake were consistently caught at sizes equivalent to ages 3–8 years old through the time series (Appendixes XI–XII). The proportion of immature individuals (ages 1 and 2) in the annual catch increased since 2014 compared with most years before 2014. The proportion of mature individuals (ages 3–8) in the annual catch had wide ranges and did not show changes through time (Fig. 8).

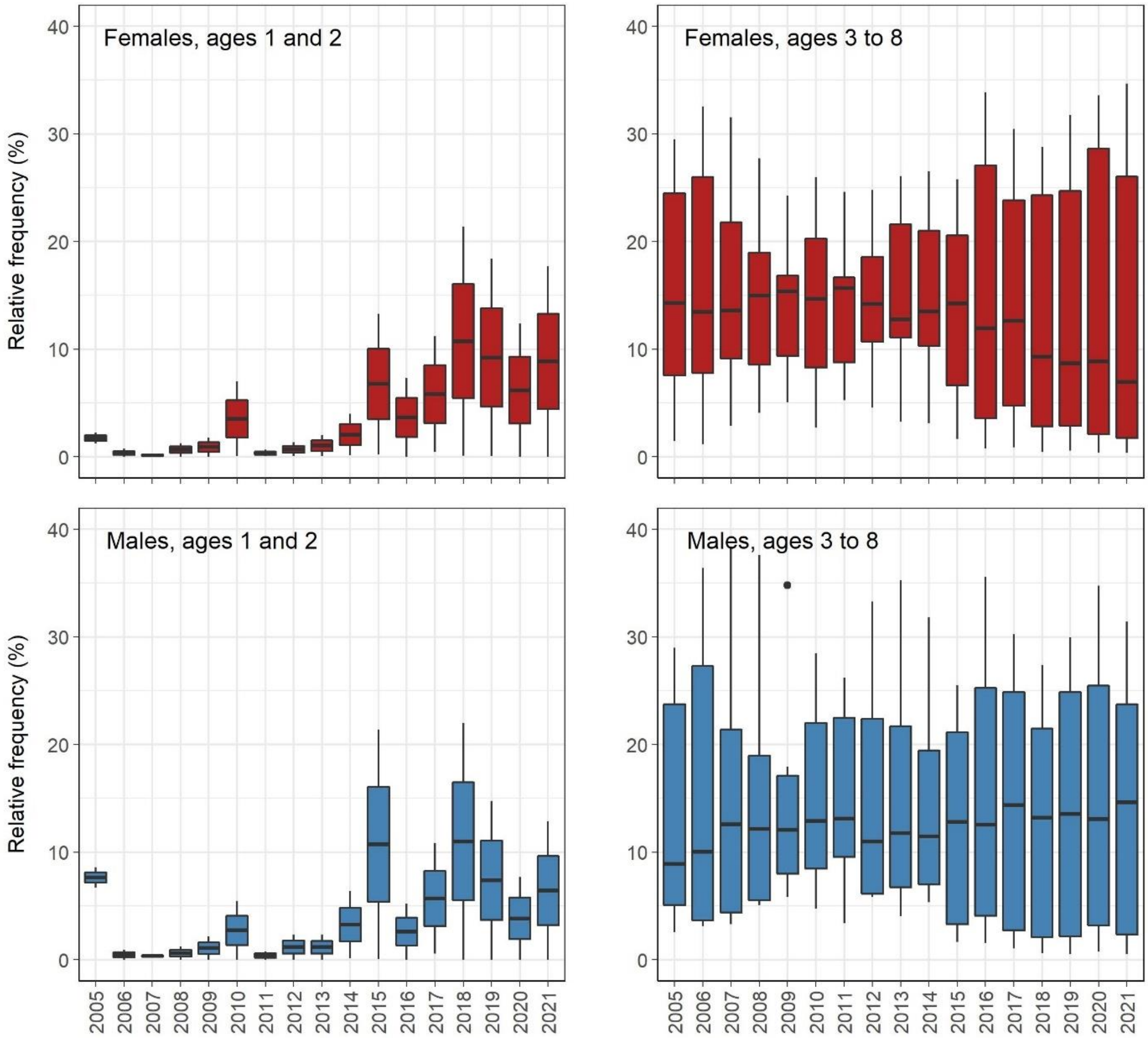

Fig. 8. Catch at age of immature (ages 1 and 2; left panels) and mature (ages 3–8; right panels) female (top panels) and male (bottom panels) common hake caught by finfish (A–, G–, and W–licences) and experimental (E–licence) vessels to the west of 60°W in the FICZ from 2005 through 2021. Common hake ages > 8 were sparse and are not included on the figure.

Natural mortality

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

$$M = 4.899 \times t_{max}^{-0.916} = 4.899 \times 15^{-0.916} = 0.4100$$

indicating that 41% of the stock dies per year not by fishing but due to natural causes such as predation, diseases, senility, amongst others.

Conclusions

TAC_5$_{2023}$ = 49,366 t is the statutory ICES category 5 total allowable catch for *M. hubbsi*, representing an increase of 20% from the TAC in 2022. However, as Falkland Islands finfish licences are currently controlled by a hybrid total allowable catch/total allowable effort (TAE) protocol (Winter 2022), the statutory TAC is used to calculate the TAE for multi-species finfish licensed fisheries rather than directly setting a limit on catch of every species. With the continuing high catches per unit effort of common hake that have been observed in the past few years, annual total catches higher than the statutory TAC are not a breach of licence conditions as long as allocated TAE is not exceeded.

Based on commercial CPUE as a proxy for abundance, common hake in Falkland Islands waters has increased since 2014, with the highest abundance estimated in 2019. February and July surveys biomasses are consistent with the increase in CPUE through time. Intra-annually, the highest CPUE of common hake usually occur from May through September.

Length at 50% maturity did not vary significantly for females (mean L50 = 39 cm) and males (mean L50 = 29 cm), except for a low value in 2013. Length frequencies showed a decrease in modal length from 2012 for females and from 2014 for males, likely due to the removal of large individuals by the fishery and due to the presence of a new cohort.

Females were caught at larger size than mean L50 from 2005 through 2013; however, females were caught at nearly mean L50 the rest of the years. Males were mostly caught at larger sizes than L50. The patterns of L50, and length frequencies throughout the years do not provide evidence of a detrimental effect of the Falkland Islands fishery on the size and length at maturity of common hake. However, fishing pressure should be directed more towards larger and mature individuals that have already reproduced, given that high fishing pressure on smaller (and likely young and immature) individuals can reduce stock sustainability (Vasilakopoulos et al. 2011; Muluye et al. 2016; Ben-Hasan et al. 2021).

Hake age determination carried out at the FIFD is regarded as more reliable than from the MFRI in Gdynia. However, age data from common hake otoliths aged at the FIFD and available in the FIFD database are limited (Females: 144 individuals from 2007 and 459 individuals from 2018; Males: 43 individuals from 2007 and 165 individuals from 2018). Age data of common hake otoliths from other years and aged at the FIFD are currently under revision, and will be entered in the FIFD database at the earliest convenience. A larger base of validated age data is required to implement robust analyses that will provide more accurate results and advice for management.

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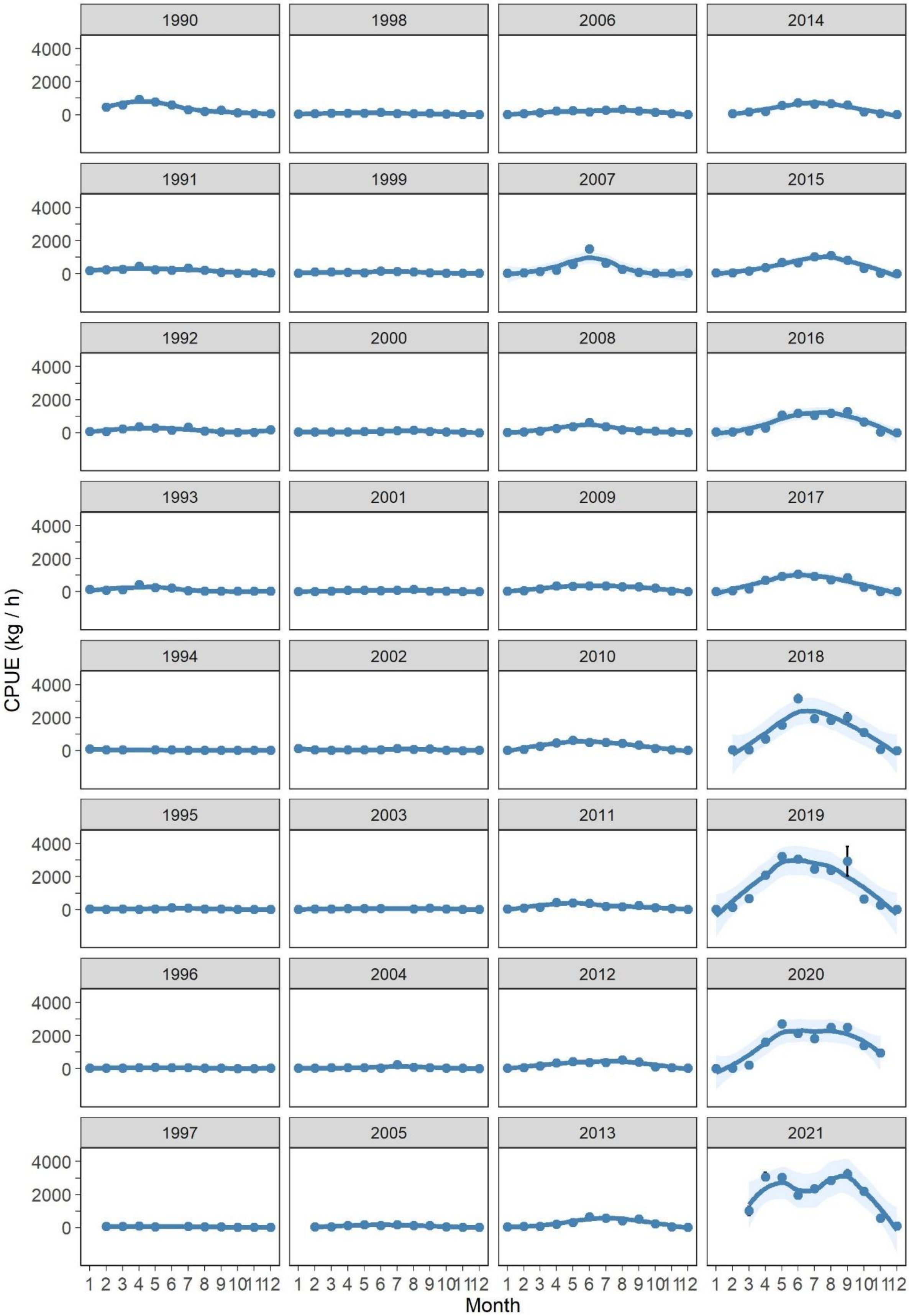
Appendix

Appendix I. Annual commercial catches (t) of common hake reported in Falkland Islands (excluding E–licence from 1990 through 2021; Falkland Islands Government 2021[e]) and Argentina (Argentine Government[f]; Sánchez et al. 2012; Navarro et al. 2014, 2019).

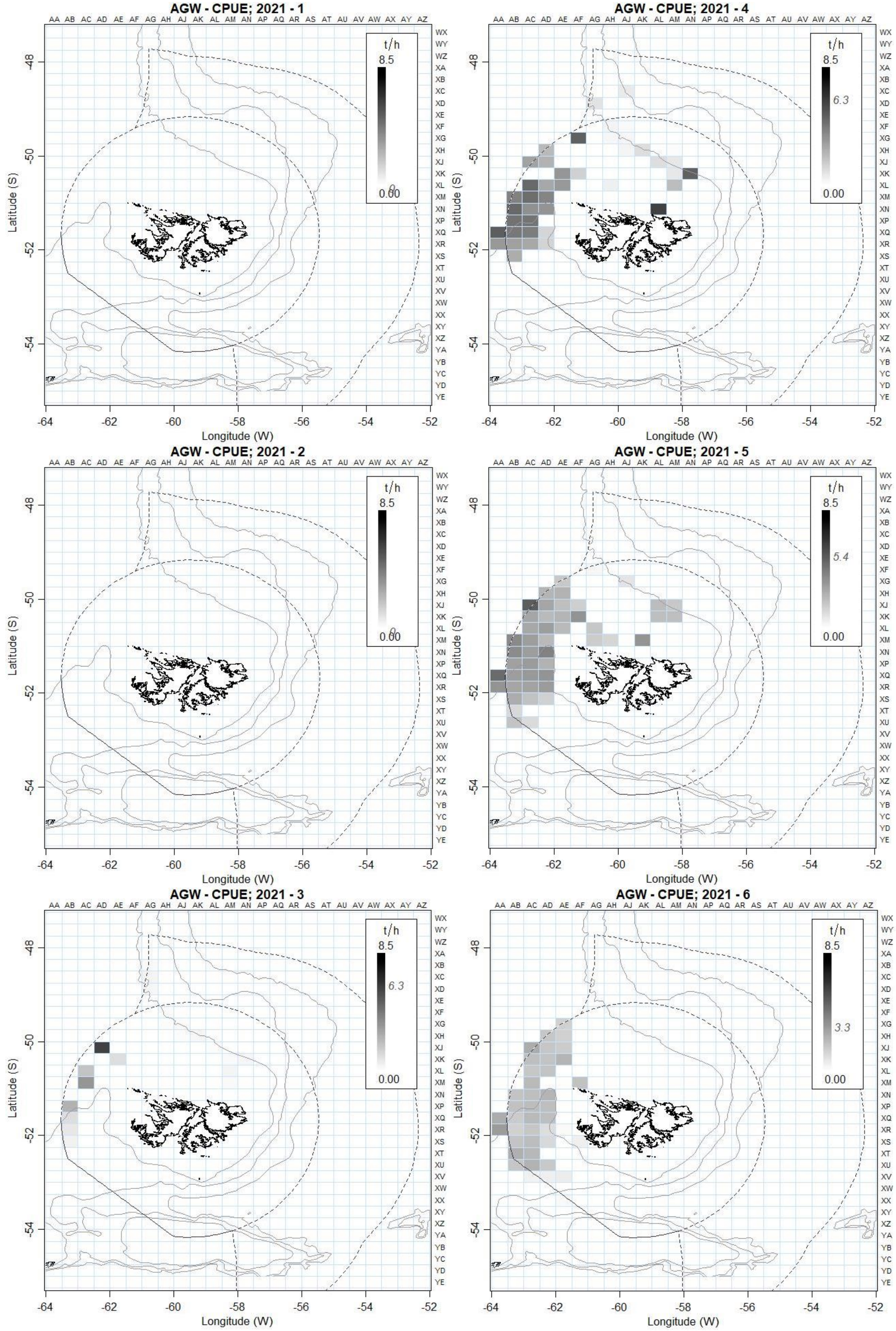
Year	Falkland Islands (t)	Argentina (t)
1987	16781.50	248641.48
1988	51489.39	242057.44
1989	16509.79	253357.50
1990	11901.18	308040.80
1991	6757.93	360026.00
1992	4071.94	272907.00
1993	3034.32	364149.80
1994	1413.68	375532.00
1995	1988.48	449947.10
1996	1628.05	483769.20
1997	1556.21	471393.00
1998	3457.79	382539.40
1999	4210.59	291690.00
2000	3068.55	170435.30
2001	1978.11	190644.10
2002	1678.06	256162.20
2003	1976.56	247343.20
2004	1923.62	374146.60
2005	2734.59	296666.00
2006	8389.12	324886.90
2007	11907.42	271760.90
2008	8797.10	191777.20
2009	13039.02	215638.60
2010	13599.87	239699.00
2011	9921.62	240115.10
2012	10427.64	230153.80
2013	12248.21	250306.10
2014	14860.69	232946.59
2015	21043.38	229318.30
2016	23360.73	240127.04
2017	15556.77	234180.75
2018	26984.96	231655.66
2019	53286.24	272534.80
2020	43245.72	238296.90
2021	59150.25	260078.30

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

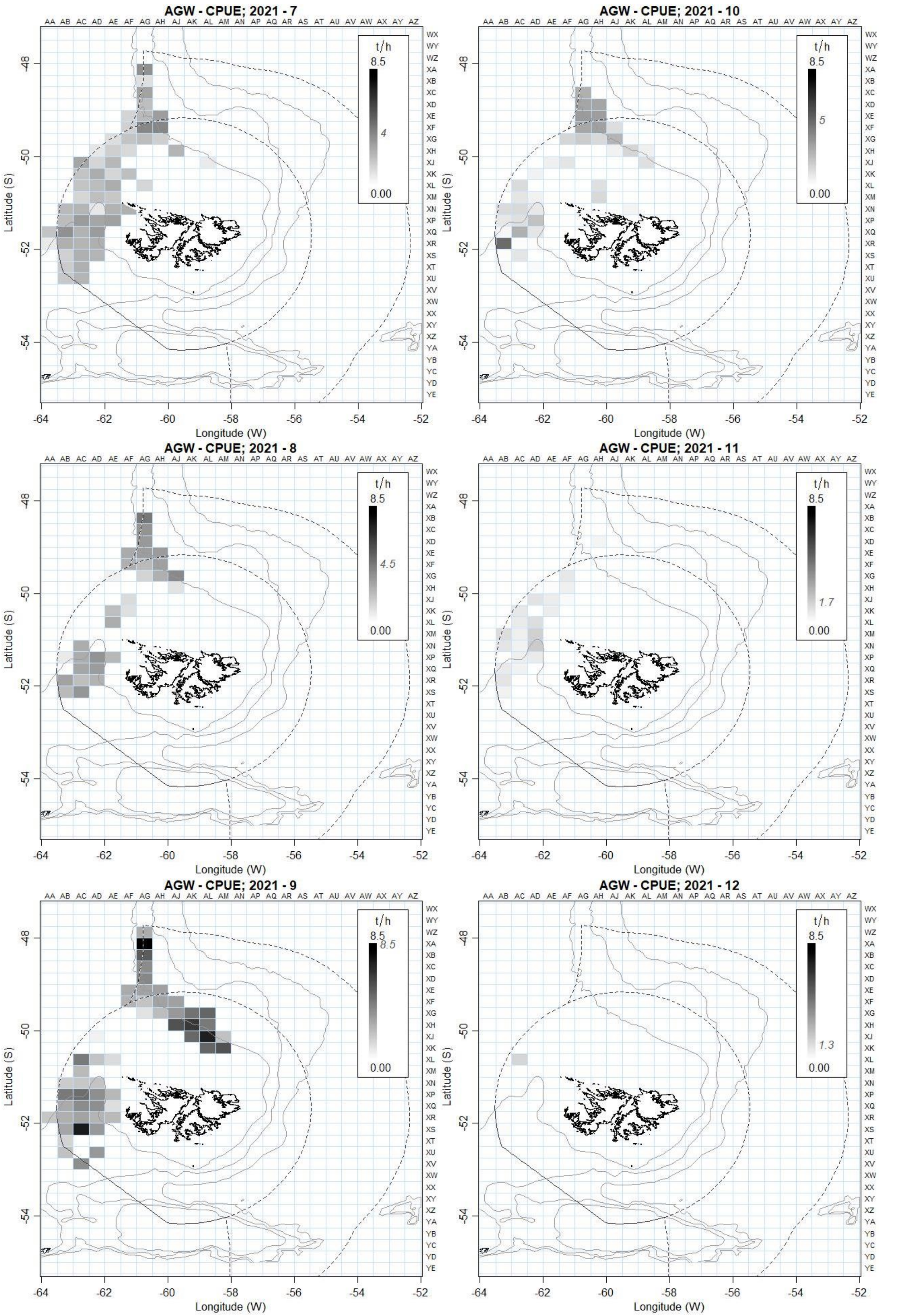
Appendix II. Monthly CPUE of common hake to the west of 60°W in the FICZ from 1990 to 2021, calculated from finfish (A–, G–, and W–licences) vessels, with LOESS smooths ± 95% confidence intervals (LOESS; span = 0.75, degree = 2).



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



Appendix III. *continued…*

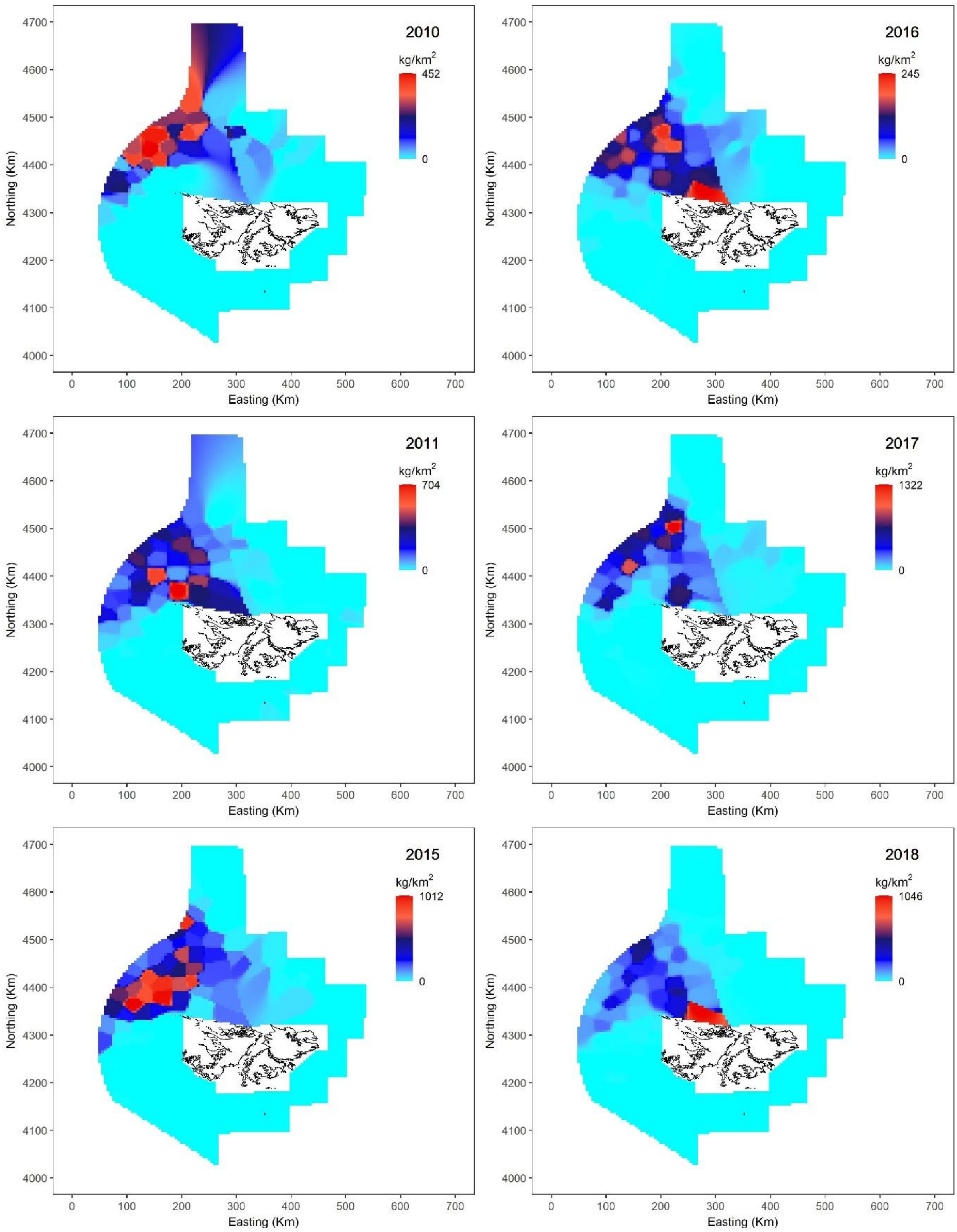


Appendix IV. Summer (February) surveys catch and effort, and biomass estimates (mean ± 95% confidence intervals) of common hake in Falkland Islands waters.

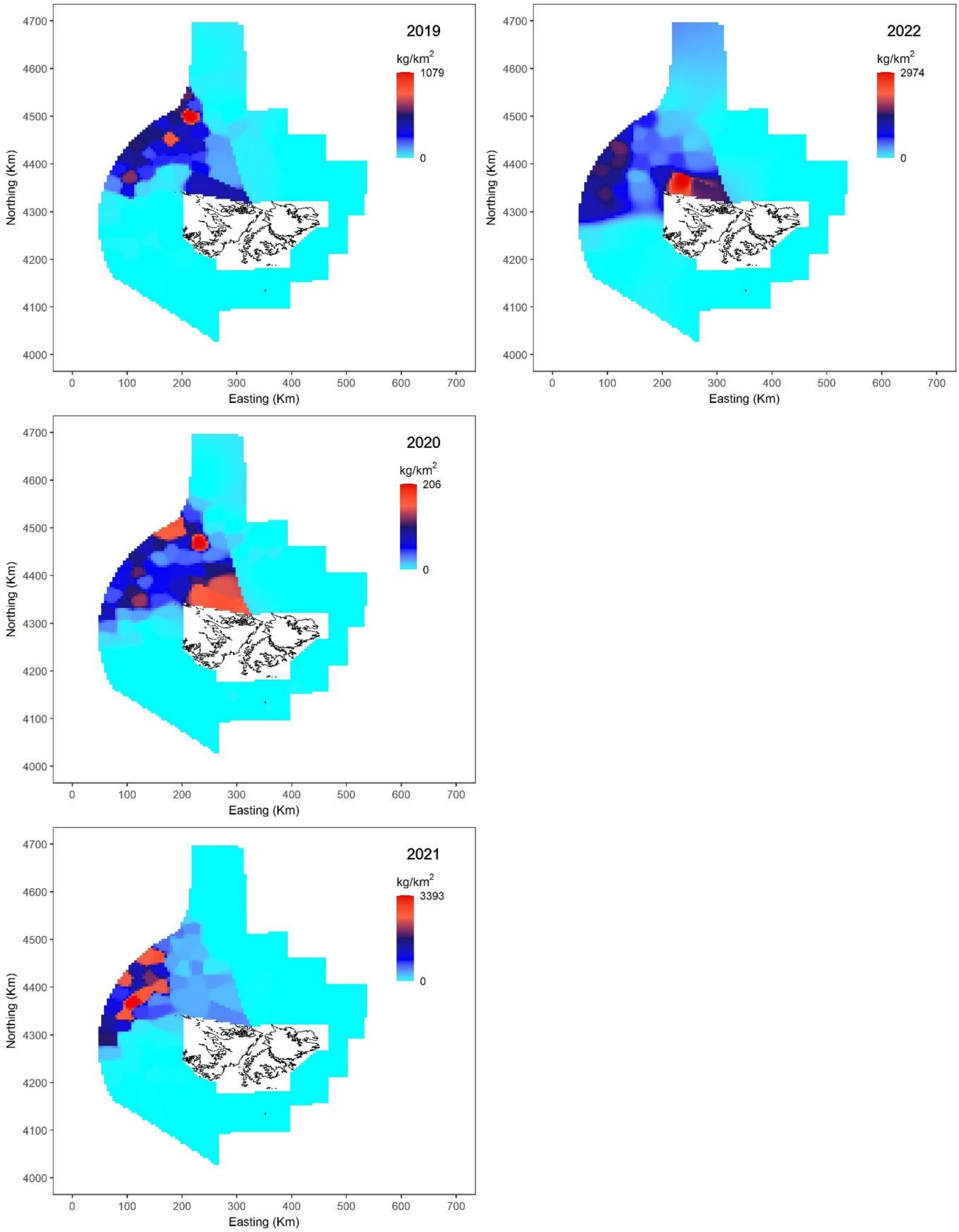
Year	Survey	Trawls (n)	Swept area (km^2)	Effort (h)	Catch (kg)	CPUE (kg/h)	Biomass (t)
2010	Groundfish	87	17.04	87.52	1308.49	14.95	9124.06 (6280.46–12219.25)
	D. gahi	55	42.29	109.27	0.00	0.00	
	Total	142	59.34	196.78	1308.49	6.65	
2011	Groundfish	88	17.21	88.00	1628.12	18.50	10180.26 (8330.32–12809.67)
	D. gahi	58	40.04	110.63	43.50	0.39	
	Total	146	57.26	198.63	1671.62	8.42	
2015	Groundfish	89	16.72	90.17	3165.51	35.11	15758.48 (13700.90–18213.42)
	D. gahi	57	46.90	111.50	0.00	0.00	
	Total	146	63.61	201.67	3165.51	15.70	
2016	Groundfish	90	17.64	91.42	692.94	7.58	3661.91 (2974.25–4175.68)
	D. gahi	56	54.46	107.92	0.00	0.00	
	Total	146	72.10	199.33	692.94	3.48	
2017	Groundfish	90	18.52	92.00	2932.13	31.87	12419.11 (10191.95–15538.58)
	D. gahi	58	54.09	117.00	7.68	0.07	
	Total	148	72.62	209.00	2939.81	14.07	
2018	Groundfish[a]	97	20.47	96.42	1731.75	17.96	8534.38 (6048.05–10877.41)
	D. gahi	59	36.87	100.83	0.00	0.00	
	Total	156	57.35	197.25	1731.75	8.78	
2019	Groundfish	79	17.22	79.00	2750.53	34.82	11151.32 (9483.58–14419.93)
	D. gahi	52	72.70	97.05	3.00	0.03	
	Total	131	89.93	176.05	2753.53	15.64	
2020	Groundfish[a]	80	17.04	79.95	714.12	8.93	3340.09 (2846.51–3971.84)
	D. gahi	59	86.80	112.52	10.71	0.10	
	Total	139	103.84	192.47	724.83	3.77	
2021	Groundfish	80	16.43	79.48	8145.44	102.48	33281.79 (27502.33–40938.52)
	D. gahi	55	90.65	111.22	4.16	0.04	
	Total	135	107.07	190.70	8149.60	42.74	
2022	Groundfish	42	9.22	41.90	5650.24	134.85	42420.98 (32223.84–55471.45)
	D. gahi	60	86.75	119.08	1.17	0.01	
	Total	102	95.97	160.98	5651.41	35.11	

[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 common hake. Note that groundfish February surveys were not conducted in 2012, 2013, and 2014.

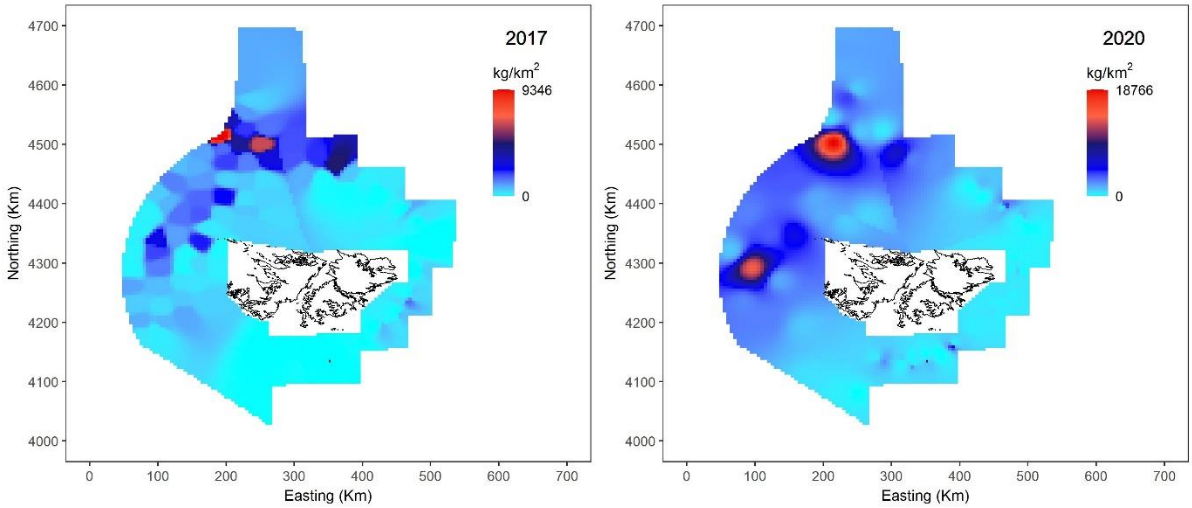
Appendix V. Densities of common hake modelled by inverse distance weighting in the FICZ, during the February 2010–2022 groundfish and Patagonian squid pre-season surveys.



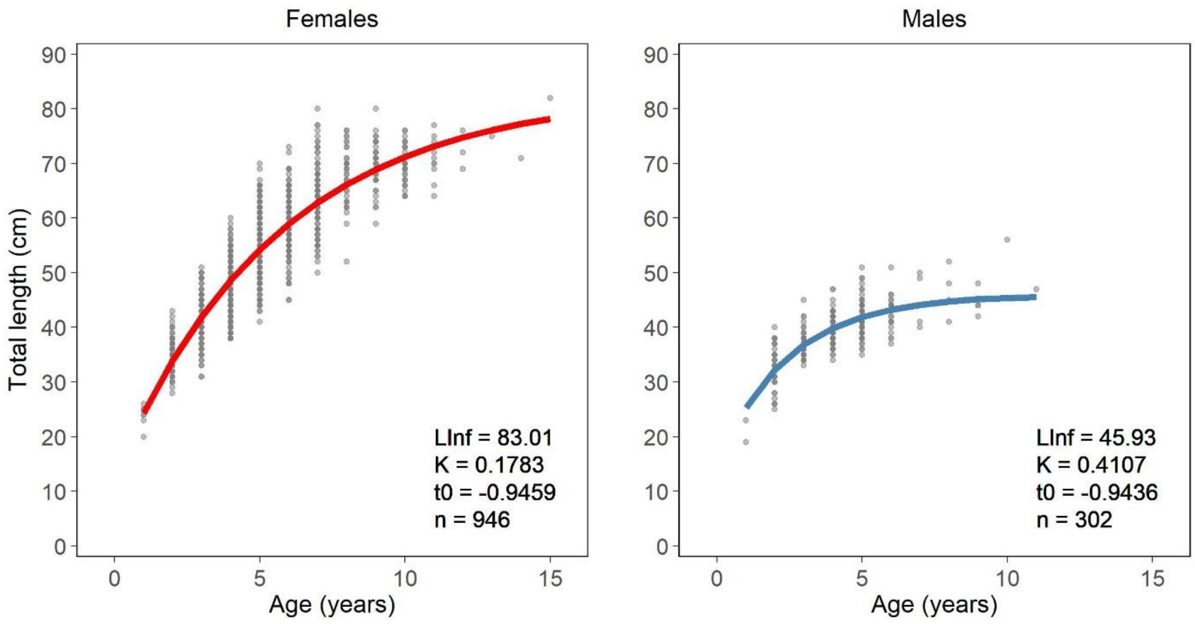
Appendix V. *continued…*



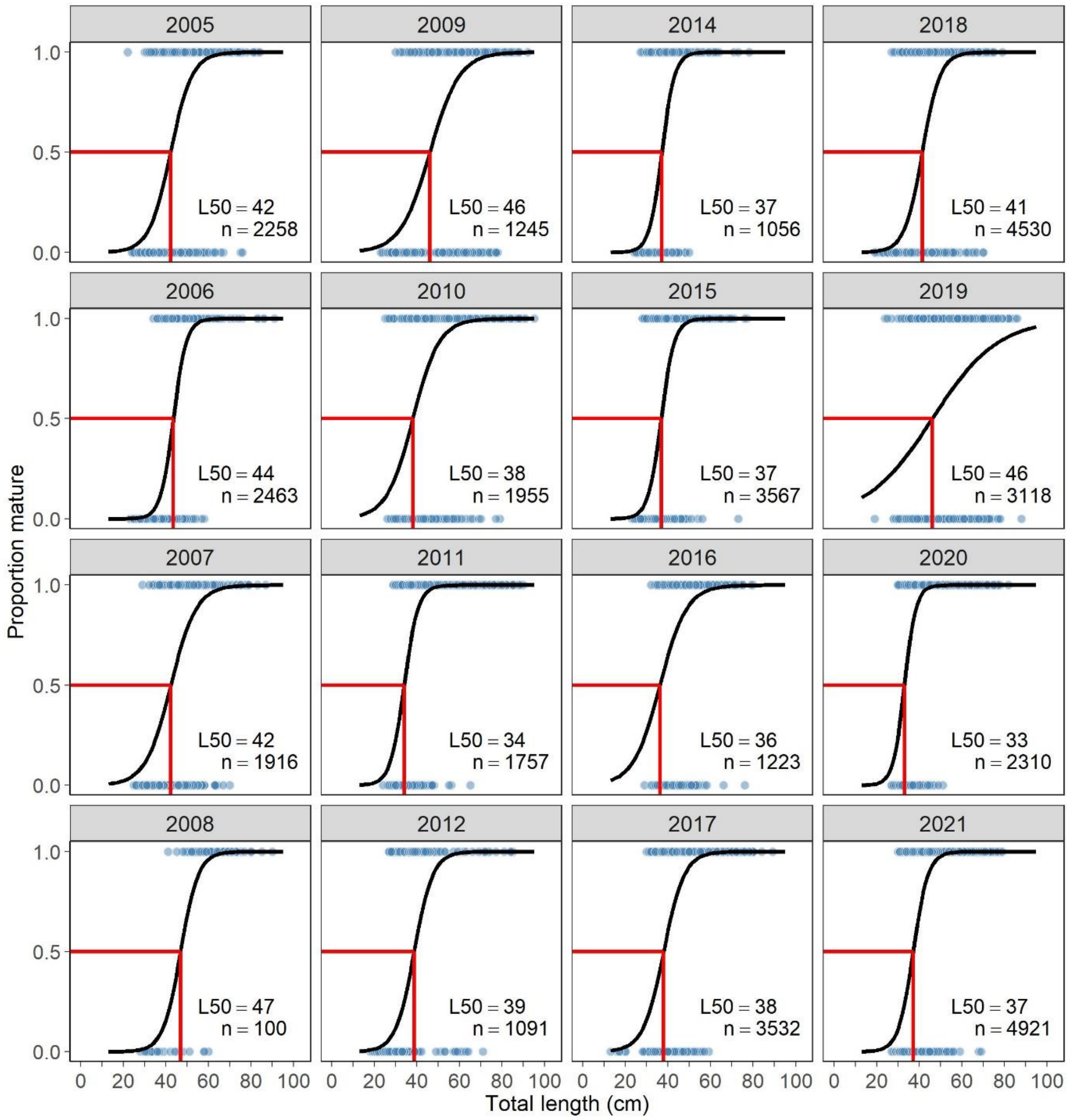
Appendix VI. Densities of common hake modelled by inverse distance weighting in the FICZ, during the July 2017 and July 2020 groundfish and Patagonian squid pre-season surveys.



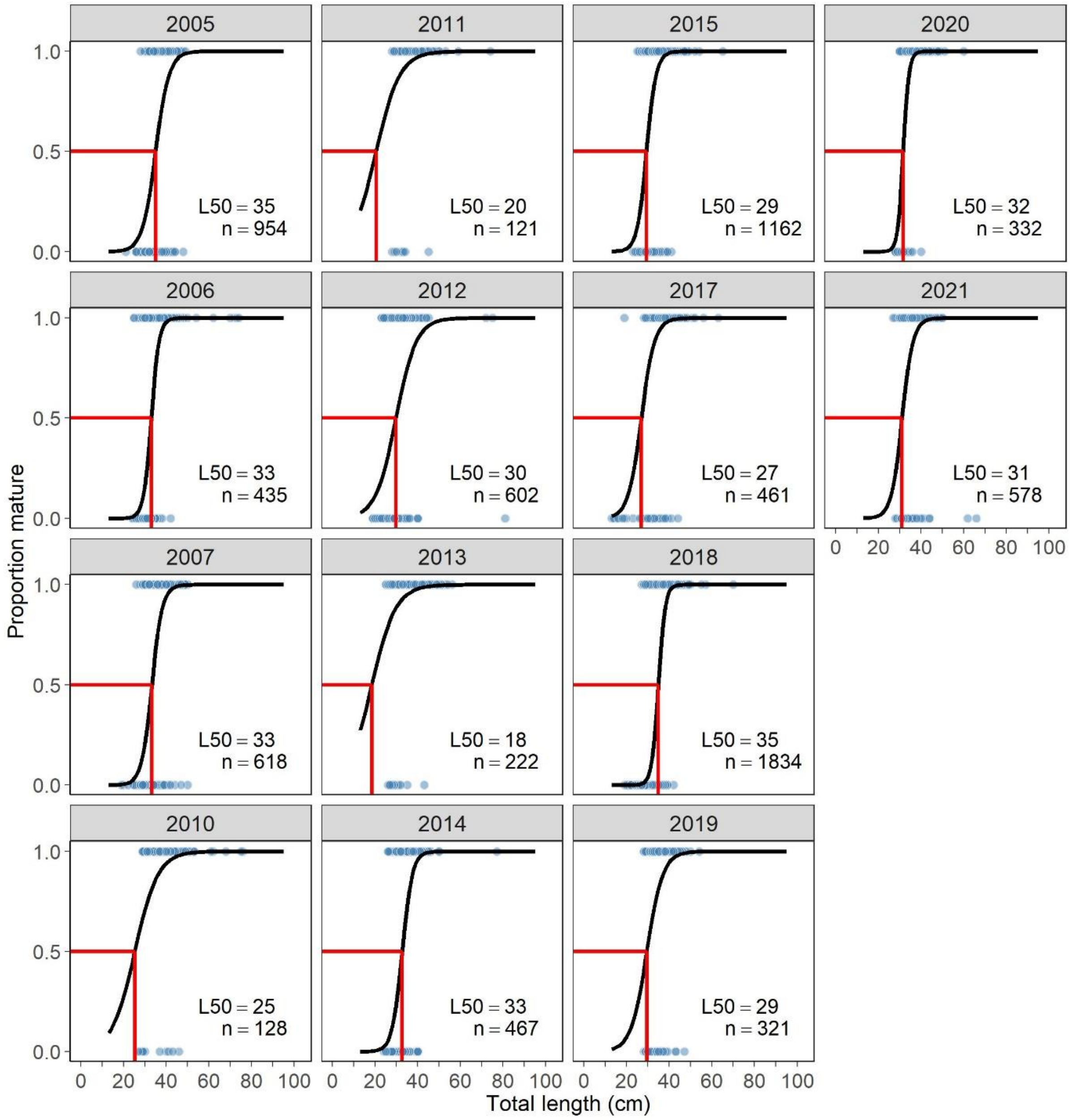
Appendix VII. von Bertalanffy age-length relationship of female and male common hake from the 2020 verified data subset, collected in the FICZ. Ages were determined by FIFD staff.



Appendix VIII. Binomial logistic regressions of juvenile (0) or adult (1) maturity ogives vs. length for female common hake sampled randomly in finfish (A–, G–, and W–licences) and experimental (E–licence) vessels in the FICZ. Red lines indicate the intercept for length at 50% adulthood, corresponding to Fig. 6.



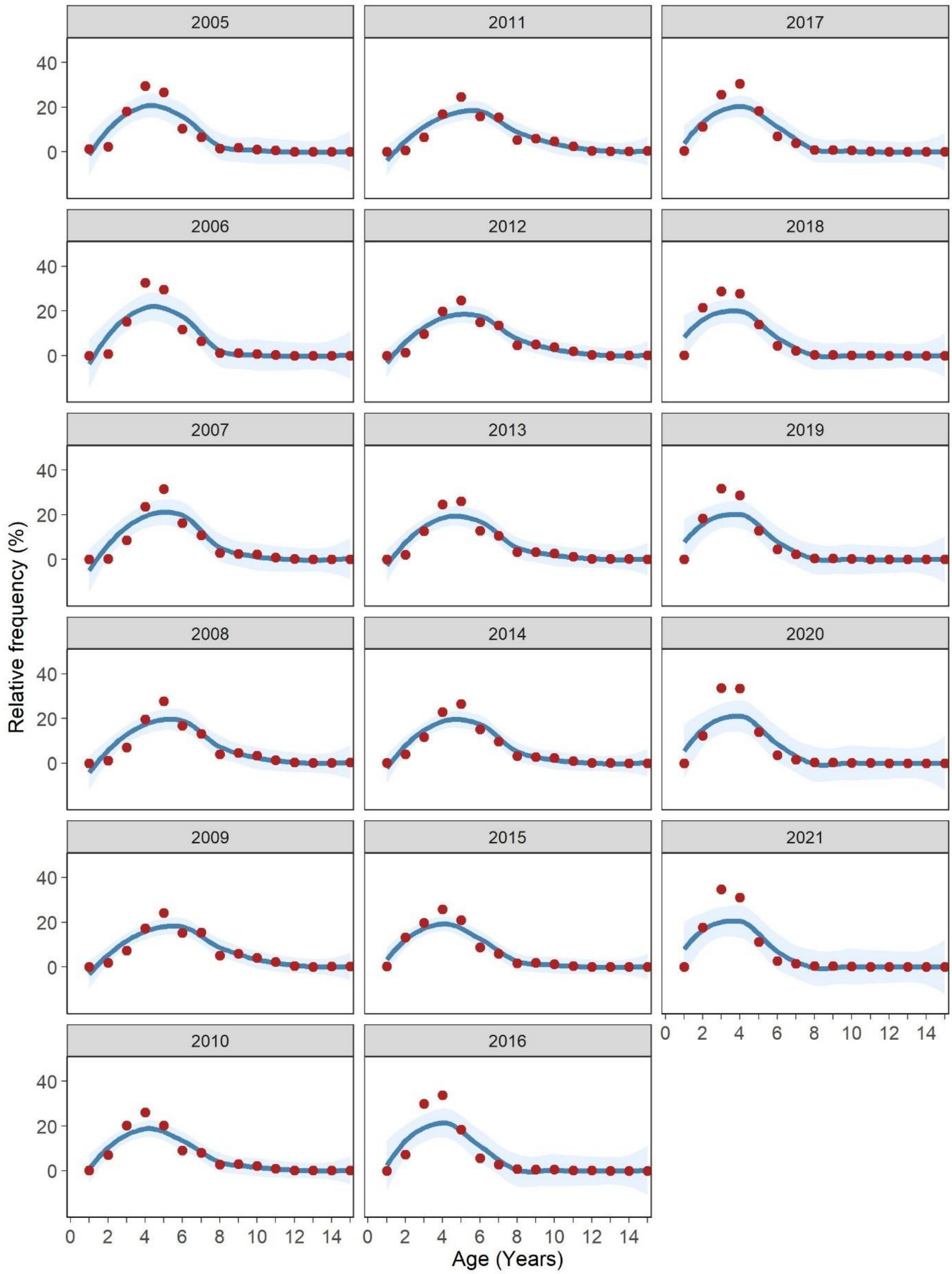
Appendix IX. Binomial logistic regressions of juvenile (0) or adult (1) maturity ogives vs. length for male common hake sampled randomly in finfish (A–, G–, and W–licences) and experimental (E–licence) vessels in the FICZ. Red lines indicate the intercept for length at 50% adulthood, corresponding to Fig. 6.



Appendix X. Number of common hake random-sampled for length frequency distributions, from finfish (A–, G–, and W–licence) and experimental (E–licence) catches during June and July west of 60°W in the FICZ.

Year	Females (n)	Males (n)
2005	457	34
2006	4,359	935
2007	1,993	377
2008	1,368	323
2009	3,496	550
2010	3,336	950
2011	97	7
2012	1,609	227
2013	3,064	597
2014	702	149
2015	3,058	740
2016	2,443	543
2017	9,957	3,134
2018	3,359	1,250
2019	3,034	1,634
2020	10,671	4,596
2021	4,815	1,657

Appendix XI. Catch-at-age of female common hake west of 60°W in the FICZ by finfish (A–, G–, and W–licences) and experimental (E–licence) vessels, with LOESS smooths ± 95% confidence intervals (LOESS; span = 0.75, degree = 2).



Appendix XII. Catch-at-age of male common hake west of 60°W in the FICZ by finfish (A–, G–, and W–licences) and experimental (E–licence) vessels, with LOESS smooths ± 95% confidence intervals (LOESS; span = 0.75, degree = 2).