Stock Assessment of kingclip (*Genypterus blacodes*) in the Falkland Islands

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Summary

The kingclip Total Allowable Catch (TAC) for 2023 is set at 1,675 tonnes (t). Following recommendations of the MacAlister Elliott & Partners external review, this 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, as applicable for a species with landings data but not reliable indices from surveys or catch-per-unit-effort.

Kingclip commercial catches in Falkland Islands licenced fisheries were 1,709 t in 2021; below the average catch over the past 10 years.

CPUE of kingclip in Falkland Islands waters increased from 1990 through 2013, followed by a significant decline from 2014 through 2021.

Length-based indicators suggest that conservation of immature fish, large individuals, mega-spawners, optimal yield, and MSY were of concern or negative through most of the time series. The length and age analyses showed decreasing trends for length at 50% maturity. Comparison of length at 50% maturity and catch at length revealed that kingclip are mainly caught before reaching maturity, which can reduce the stock sustainability.

Introduction

Kingclip (*Genypterus blacodes*, Ophidiidae) is a demersal fish that occurs at 100–700 m depth in temperate waters of the shelf and slope of New Zealand, southern Australia and South America (Nyegaard et al. 2004). In South America, *Genypterus blacodes* occurs in the Southeast Pacific and the Southwest Atlantic; however, no studies have addressed kingclip population connectivity between the Southeast Pacific and Southwest Atlantic. In the Southwest Atlantic, kingclip migrate in austral autumn (April to June) from Argentine waters into Falkland Islands waters, and remains abundant in feeding grounds to the north, northwest, and west of the Falkland Islands during winter (July to September) and spring (October to December) (Falkland Islands Government 2021). In Falkland Islands feeding grounds, kingclip preys upon a range of commercial species including rock cod *Patagonotothen* spp. and hoki *Macruronus magellanicus* (Nyegaard et al. 2004). During summer (January to March), approximately two thirds of the kingclip adult population move out of Falkland Islands waters to spawn (Arkhipkin et al. 2012). Based on the migratory behaviour of kingclip in the region it is assumed that Falklands and Argentine fisheries catch the same stock. This species is a valuable bycatch in both nations' commercial fisheries, with most of the catch historically taken by the Argentine fishery; however, this difference has decreased since 2016 with the decline of Argentine kingclip catches (Argentine Government[a]).

Methods

ICES advice rules

In 2020, kingclip 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, 2018a), referencing applicable categories of data availability and quality; for kingclip, the advice was to calculate Total Allowable Catch (TAC) using the ICES category 5. 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

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

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 kingclip have been read routinely at the National Marine Fisheries Research Institute (MFRI) in Gdynia, Poland. Kingclip age data in the FIFD database require verification but do not appear to suffer from the same bias and low precision compared with other finfish species (Lee et al. 2020); therefore, LBI was implemented.

ICES Category 5 Total Allowable Catch

Kingclip research survey and commercial catch data from Falkland Islands waters are available but may not be appropriate for biomass estimates. Demersal surveys have been conducted every February since 2015 through the north and west of Falkland Interim Conservation Zone (FICZ); however, approximately two thirds of the kingclip adult population carry out a reproductive migration out of Falkland Islands waters at this time of the year (Arkhipkin et al. 2012). A biomass index estimated from the February surveys (Ramos & Winter 2022) would thus be inaccurate. Demersal surveys were also conducted in the same area in July 2017 and in July 2020 but two sets of data are insufficient to serve as a time series index. Since 1987, the Falkland Islands fishery has contributed only a small proportion (~13%) to the kingclip annual production in the Southwest Atlantic (Fig. 1; Appendix I), and a catch-per-unit-effort (CPUE) index for this bycatch species in the Falkland Islands fishery alone cannot be implemented. In addition, stock assessment using data-poor methods (OCOM and CMSY) produced high margins of uncertainty (Ramos & Winter 2019).

For these reasons, calculation of Total Allowable Catch (TAC) for kingclip 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[b] 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} = 1,587 t; Ramos & Winter 2021):

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

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

Commercial catch and CPUE

Catch and CPUE were examined as indices of fishing on this species. 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 kingclip catch data were examined from 1987 through 2021 from the Falkland Islands (Falkland Islands Government[c]; Falkland Islands Government 2021), Argentina (Argentine Government[d]; Sánchez et al. 2012; Navarro et al. 2014, 2019), and Chile SERNAPESCA (1990, 2000, 2011, 2021). LOESS (span = 0.75, degree = 2) was implemented to examine the pattern of the association between Falkland Islands and Argentina commercial annual catches of kingclip from 1987 through 2021. Commercial catches and discard of kingclip were examined by licence type for 2021 throughout the FICZ.

CPUE was estimated as the sum of kingclip 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 and to the north of the FICZ was carried out to detect the months with higher and constant abundance of kingclip. This allowed calculating annual CPUE from finfish vessels with fishing activity along the west and north of the FICZ from April through September. Monthly CPUE was then recalculated from finfish vessels with fishing activity along the west and north of the FICZ from 1990 through 2020, and for 2021. CPUE was calculated from finfish vessels because these contribute most of the kingclip catches. The west and north of the FICZ are defined in this assessment as the area that includes from 60 °W to the western limit of the FICZ, and from 50.5 °S to the northern limit of the FICZ, which represents the area where kingclip are caught in greater abundance most of the year (Arkhipkin et al. 2012).

Survey biomass estimates

July survey data were used to provide a baseline for recent kingclip biomass in Falkland Islands waters, even if they are not yet useable as a time series. Biomass estimates and the spatial distribution of kingclip were examined from the joint surveys (groundfish and

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

Patagonian squid *Doryteuthis gahi* pre-season surveys) carried out in July 2017 (Gras et al. 2017; Winter et al. 2017) and July 2020 (Randhawa et al. 2020; Winter et al. 2020) in Falkland Islands waters. The July surveys were conducted for the primary purpose of assessing common hake *Merluccius hubbsi* (Gras et al. 2017; Randhawa et al. 2020) but may be a good indicator for kingclip abundance because kingclip is present in high numbers in its feeding grounds to the west, northwest, and north in the FICZ during autumn, winter, and spring (Falkland Islands Government 2021). The biomass ratio between the most recent July survey (2020) and the first July survey (2017) were calculated 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.

Biomass estimates, spatial distribution, and biomass ratios were also examined from the February joint surveys (groundfish and Patagonian squid pre-season surveys) carried out in 2010, 2011, and 2015 – 2022 (Ramos & Winter 2022). Kingclip biomass estimates during the February surveys were presented as an additional comparative proxy for abundance patterns, with the caveat that at this time of year survey catches would likely reflect variability in its migratory timing. A trend of the biomass time series from 2010 through 2022 was calculated using LOESS (span = 1, degree = 2).

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 observer length measurements of kingclip were available and reported as random samples (FIFD database codes R and S), i.e., years 2001 to 2021. Total lengths of up to one hundred individuals per trawl were measured to the lowest centimetre. Because finfish trawls are restricted to larger meshes than Patagonian squid trawls, only observer length measurements taken in finfish-licensed fisheries were used, to avoid biasing length-frequency distributions. Skate and *Illex* trawls were also excluded because their different targets could also relate to characteristically different length-frequency distributions of kingclip.

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 by number (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 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, > 0.8, and > 0.3, yellow if 1, 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, < 0.8, 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 for optimal yield was green if the lower and upper 95% quantiles spanned 1, yellow if the lower and upper 95% quantiles spanned 0.9 (the threshold used in ICES 2015) without spanning 1, and red otherwise. Reference criterion ≥ 1 for MSY was scored the same as > 1, except that empirical values ≥ 1 were automatically green.

Length-age relationship

The von Bertalanffy growth function (R package 'fishmethods'; Nelson 2019) was used to fit all kingclip length-at-age data available in the FIFD database. Kingclip age data do not appear to suffer from bias and low precision compared with other finfish species (Lee et al. 2020), although verification is recommended (D. Parkyn, FIFD *pers. comm*). 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) 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 is cyclical as fish pass from pre- to post-spawning phases, and definitive maturity assignments can only be made that stage I is immature, stages II and III can be uncertain, and stages IV+ 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 IV to VIII, omitting stages II and III. Annual L50s were calculated from randomly sampled individuals collected to the west and north of the FICZ under finfish and experimental (E–) licences through the year, and therefore included mature individuals during the spawning season (January-March), from 2001 to 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 2001 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 and the experimental vessels to the west and north in 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.

Catch at age

Age 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 2001 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. The catch at age proportions were examined for the whole range of age classes; taking as reference overall L50, the relative frequencies of immature vs mature age classes 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

Natural mortality rate (M) of kingclip 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 (1,675 t) is a less than 20% increase from the TAC_5_{2022} (1,587 t; Ramos & Winter 2021), and therefore should represent the effective TAC for 2023 without the need of an uncertainty cap:

$$TAC\_5_{2023} = \overline{1701.3, 1619.5, 1704.2} = 1{,}675 \text{ t}$$

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

Kingclip catches in Falkland Islands waters have been on average 2,058 t per year since 1987, representing approximately 13% of the Falkland Islands and Argentina combined annual catch. However, this proportion increased to an average of 28% since 2016 due to the decline of Argentine catches (Fig. 1). Falkland Islands catches and Argentine catches correlated positively when Argentine catches were < 10,000 t; Falkland Islands catches and Argentine catches correlated negatively when Argentine catches were > 10,000 t, with considerable variability when Argentine catches were between 15,000 t and 25,000 t (Fig. 2; Appendix I).

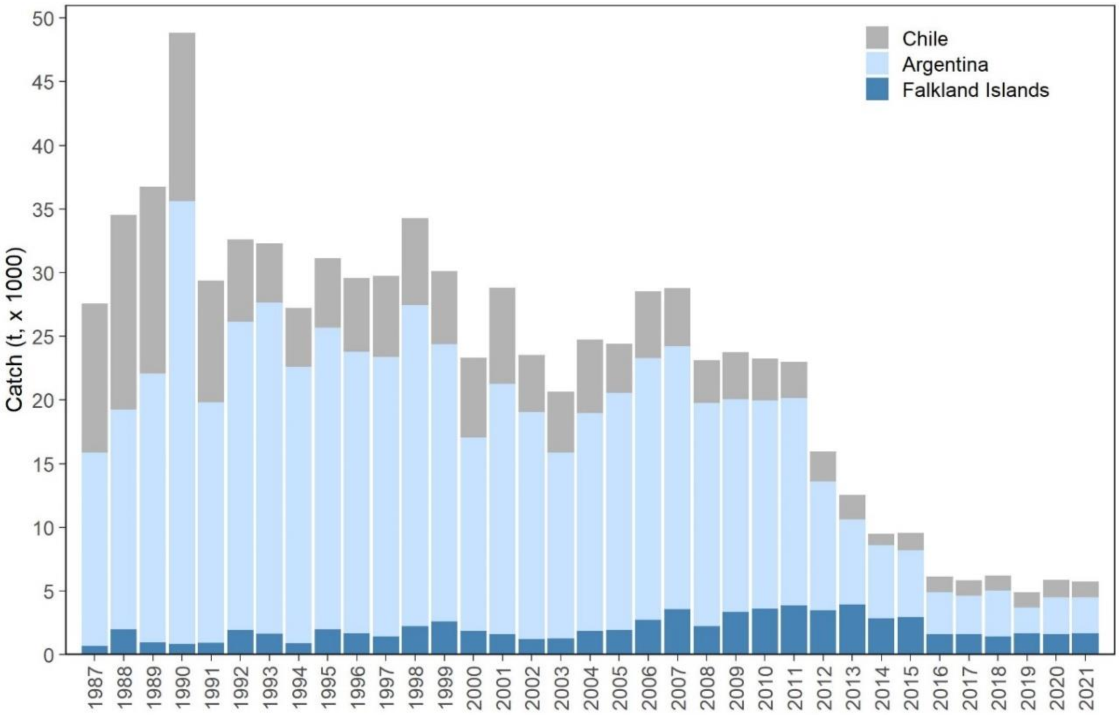

Fig. 1. Annual commercial catch of kingclip in Falkland Islands, Argentine, and Chilean waters. Falkland Islands catch data exclude experimental (E–licence) and out-of-zone (O–licence) licences from 1990; earlier than 1990 these licences were not designated.

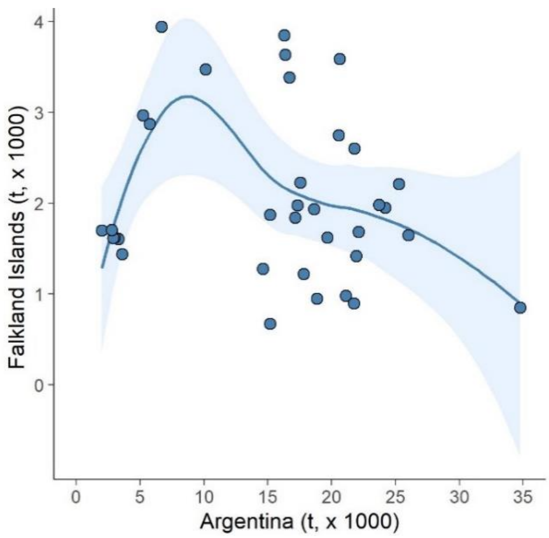

Fig. 2. Falkland Islands vs. Argentina annual commercial catches of kingclip from 1987 to 2021, with LOESS smooth ± 95% confidence intervals (LOESS; span = 0.75, degree = 2).

From 1990 through 2021, approximately 92% of the annual kingclip catch in the FICZ was from finfish licences (A–, G–, and W–licences). During 2021 a total of 1,709 t of kingclip were reported caught in Falkland Islands waters, of which 1,704 t were caught under commercial licences, i.e., excluding the experimental E–licence. Approximately 41% of all

Falkland Islands kingclip catch was under A–licence, 33% was under W–licence, and 25% under G–licence. The three finfish licences (A–, G– and W–licences) together accounted for 99% of the total kingclip catch (Table I). Kingclip discards were 1% of the total kingclip catch in 2021; calamari vessels (C– and X–licences) discarded an average of 39% of their kingclip catch, *Illex* vessels (B–licence) discarded 13%, and finfish vessels discarded 0.7%.

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

Licence	Target species	Catch (t)	Catch (%)	Discard (t)	Proportion discarded (%)
A	Unrestricted finfish	694.827	40.66	6.337	0.91
W	Restricted finfish	562.623	32.93	2.972	0.53
G	Restricted finfish and *Illex*	434.324	25.42	2.446	0.56
C	Calamari 1st season	4.933	0.29	2.447	49.60
E	Experimental	4.632	0.27	0.843	18.20
B	*Illex* squid	4.110	0.24	0.516	12.55
X	Calamari 2nd season	3.347	0.20	0.938	28.03
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		1708.796	100	16.499	0.97

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

The monthly CPUE by finfish licences from 1990 through 2020 ranged from 38 kg/h in January to 72 kg/h in May. Monthly analysis from 1990 through 2020 reveals that CPUE was low at the start of the year and increased from January to reach relatively high and constant values from April through December, although CPUE had a small decline from October through December (Fig. 3; Appendix II). This pattern is consistent with previous studies (Arkhipkin et al. 2012; Falkland Islands Government 2021) that kingclip is more abundant in Falkland Islands waters mainly during autumn and winter. Monthly CPUE in 2021 ranged between 63 kg/h in June to 99 kg/h in November; there was no commercial fishing effort in January and February, and fishing effort was low in December 2021 (Fig. 3; Appendix II). During 2021, kingclip were caught mainly to the west in the FICZ (Appendix III).

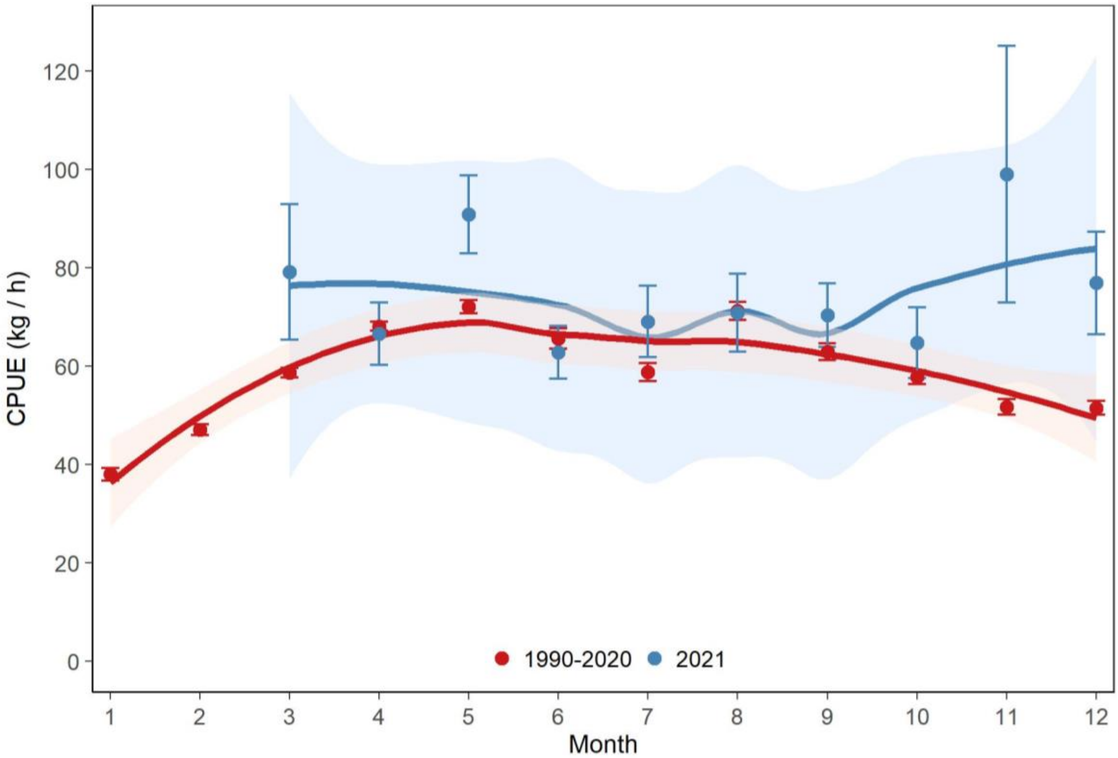

Fig. 3. Monthly CPUE ± 1 standard error of kingclip in Falkland Islands waters from 1990 through 2020 (red), and in 2021 (blue), calculated from finfish (A–, G–, and W–licences) vessels to the west of 60°W and north of 50.5°S in the FICZ, with LOESS smooths ± 95% confidence intervals (LOESS; span = 0.75, degree = 2).

Detection of the months with high and constant CPUE across years (April through September), and the main aggregations of kingclip within Falkland Islands waters (west and north of the FICZ) allowed examining annual CPUE. Kingclip CPUE increased from 1990 (34 kg/h) through 2013 (137 kg/h), followed by a steep decline from 2014 (96 kg/h) through 2021 (79 kg/h; Fig. 4).

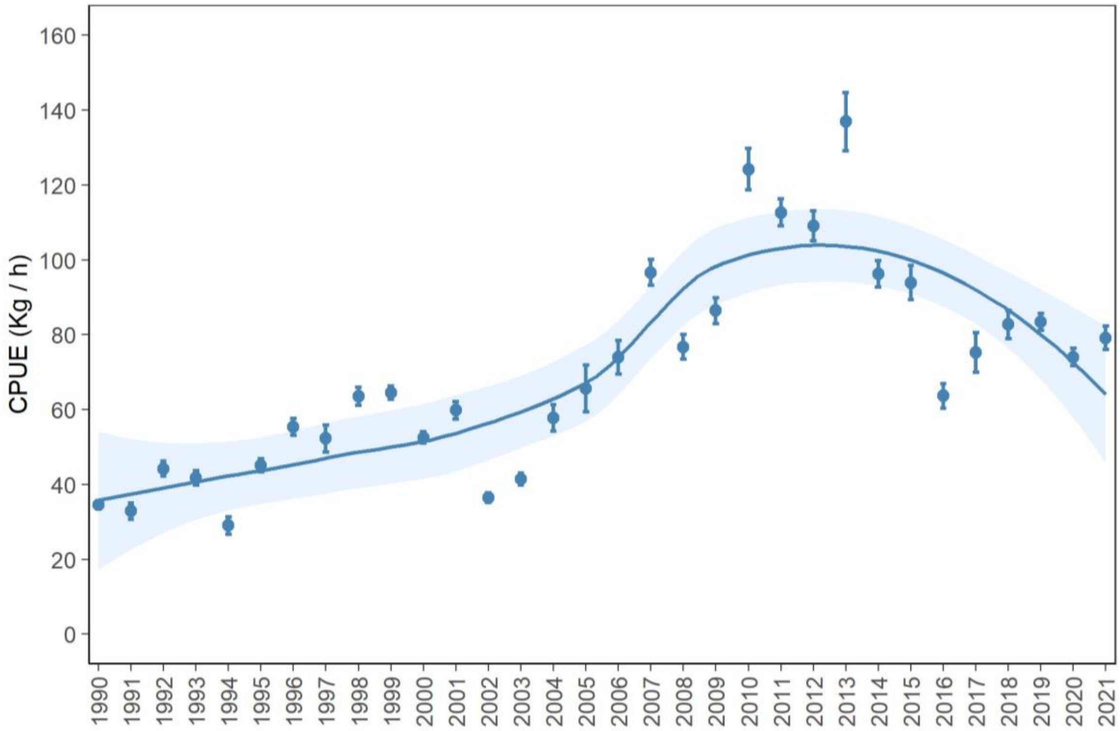

Fig. 4. Yearly CPUE ± 1 standard error of kingclip in Falkland Islands waters from 1990 through 2021, calculated from finfish (A–, G–, and W–licences) vessels to the west of 60°W and to the north of 50.5°S in the FICZ from April through September, with LOESS smooth ± 95% confidence intervals (LOESS; span = 0.75, degree = 2).

Surveys biomass estimates

Winter surveys (July)

The calculated biomass of kingclip in the July 2017 survey (19,820 t) was 31% of the calculated biomass of kingclip in the July 2020 survey (35,114 t; Table II). A total of 9,172 out of 10,000 paired re-samples had higher biomass estimate values in July 2020 than in July 2017 (92%), thus not significant at $p > 0.05$. In July 2017 and 2020, kingclip was mainly aggregated to the west of the FICZ (Appendix IV).

Table II. Winter (July) surveys catch and effort, and biomass estimates (mean ± 95% confidence intervals) of kingclip 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	4087.50	55.24	19820.03 (5228.31 – 35176.65)
	D. gahi[a]	59	54.71	114	70.15	0.62	
	Total	133	70.12	188	4157.65	22.12	
2020	Groundfish[b]	33	7.14	33	1836.44	55.62	35113.90 (19923.35 – 50095.91)
	D. gahi	55	98.57	101	709.09	7.00	
	Total	88	105.71	134	2545.53	18.96	

[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 the analyses as their locations were not relevant to the distribution of kingclip.
[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 surveys) were conducted in 2018 and 2019.

Summer surveys (February)

The biomass estimate of kingclip during the February surveys did not change significantly from 2010 to 2022. The biomass in 2010 (21,274 t) was 21.5% of the biomass in 2022 (43,437 t; Fig. 5; Appendix V). A total of 8,023 out of 10,000 paired re-samples had higher biomass estimate values in February 2010 than in February 2022 (80.2%), therefore not significant at $p > 0.05$. From 2010 to 2022, kingclip was dispersed around the FICZ, except for the southeast (Appendix VI).

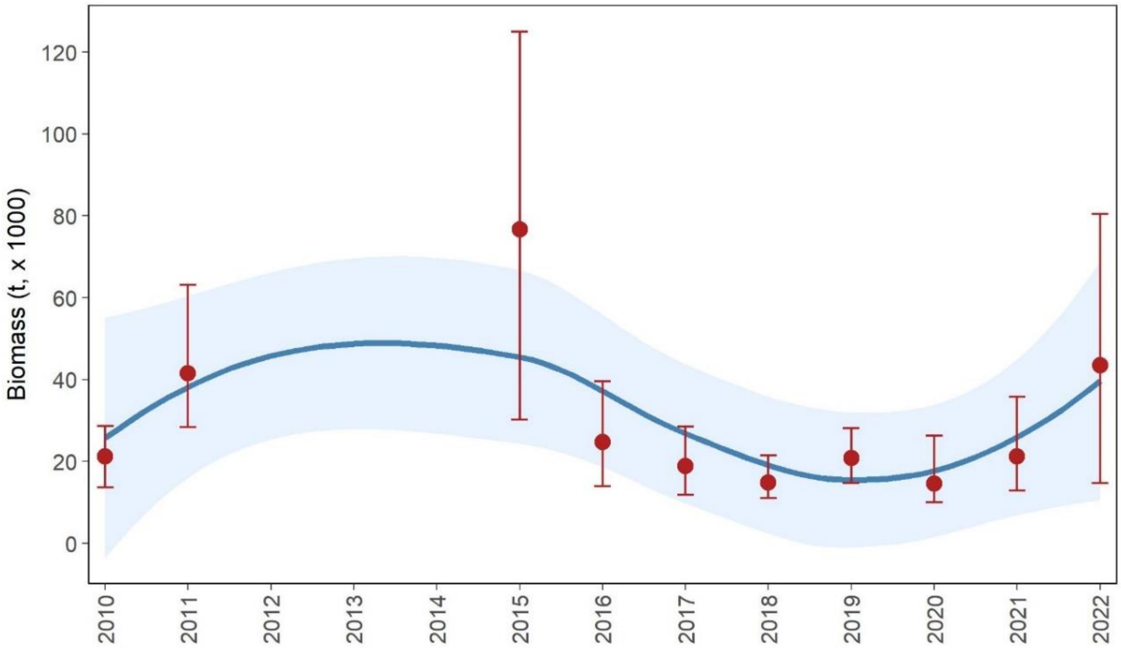

Fig. 5. Kingclip biomass estimates (red dots) ± 95% confidence intervals from February surveys in Falkland Islands waters, with LOESS smooths ± 95% confidence intervals (LOESS; span = 1, degree = 2). No parallel February surveys (groundfish and Patagonian squid pre-season surveys) were conducted in 2012,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

Length and age analyses

Length Based Indicators

Yearly 'traffic light' length indicators for females and males are summarized in Table III. Indicator $L_C/L50$, for conservation of immature fish, had negative outcomes (red) almost every year for females and for males. Indicator $L_{25\%}/L50$, also for conservation of immature fish, was of concern (yellow) or negative most years, with recent years being mainly negative for females and males. Indicator $L_{max5\%}/L_{Inf}$, for the conservation of large individuals, was positive (green) for females early in the time series (2002 and 2004) but the rest of the years was mainly of concern. For males, indicator $L_{max5\%}/L_{Inf}$ was of concern or negative. Indicator P_{mega}, for the presence of mega-spawners, was negative most years for females and males. Indicator L_{meanC}/L_{Opt}, for optimal yield, was of concern or negative before 2015 but positive in 2018 and 2019. For males, indicator L_{meanC}/L_{Opt} was negative most years in the time series. Indicator $L_{meanC}/L_{F=M}$, for maximum sustainable yield, was positive for females some years early in the time series but mainly of concern the following years, and it was negative for males most years.

Table III. Kingclip 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
	2001	0.86	0.98				
	2002	0.80	0.92	0.88	0.13	0.84	1.05
	2003	0.77	0.81	0.76	0.03	0.70	0.91
	2004	0.81	0.94	0.86	0.11	0.84	1.05
	2005	0.85	0.89	0.70	0.01	0.73	0.88
	2006	0.82	0.92	0.78	0.03	0.80	0.96
	2007	1.02	1.07	0.85	0.12	0.98	1.00
	2008	1.14	1.14	0.85	0.21	1.06	0.99
	2009	0.75	0.88	0.83	0.17	0.93	1.12
	2010	0.71	0.81	0.77	0.05	0.78	0.99
F	2011	0.73	0.83	0.74	0.02	0.75	0.96
	2012	0.75	0.87	0.72	0.01	0.74	0.95
	2013	0.85	0.96	0.71	0.01	0.76	0.94
	2014	0.85	0.98	0.72	0.02	0.78	0.98
	2015	0.86	0.97				
	2016	0.85	0.98				
	2017	0.68	0.85				
	2018	0.71	0.82	0.71	0.01	0.66	0.93
	2019	0.78	0.85	0.69	0.01	0.67	0.90
	2020	0.83	0.91				
	2021	0.99	1.01				

Table III. *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
	2001	0.93	0.99				
	2002	0.92	0.99	0.90	0.11	0.87	1.01
	2003	0.82	0.89	0.68	0.00	0.69	0.88
	2004	0.88	0.98	0.83	0.06	0.81	0.98
	2005	0.90	0.95	0.64	0.00	0.74	0.87
	2006	0.88	0.97	0.69	0.01	0.80	0.93
	2007	1.05	1.08	0.77	0.04	0.95	0.96
	2008	1.11	0.95	0.81	0.06	1.00	0.97
	2009	0.75	0.82	0.79	0.06	0.83	1.02
	2010	0.72	0.81	0.73	0.02	0.74	0.93
M	2011	0.78	0.88	0.72	0.02	0.75	0.93
	2012	0.78	0.90	0.75	0.02	0.76	0.96
	2013	0.89	0.95	0.72	0.02	0.79	0.93
	2014	0.80	0.91	0.74	0.02	0.79	0.99
	2015	0.79	0.92				
	2016	0.79	0.87				
	2017	0.62	0.73				
	2018	0.69	0.74	0.71	0.02	0.64	0.87
	2019	0.70	0.76	0.63	0.01	0.62	0.84
	2020	0.79	0.83				
	2021	0.91	0.93				

Length-age relationship

The length-age relationship of females and males pooled (n = 5,706) gave the values: L_{Inf} = 143.66 cm, k = 0.0872, and t_0 = -0.3801 years. Length and age of females (n = 3,339) ranged from 31 cm to 150 cm, and from 2 years to 37 years, respectively. The length-age relationship of females gave the values: L_{Inf} = 146.77 cm, k = 0.0889, and t_0 = -0.1640 years. Length and age of males (n = 2,367) ranged from 21 cm to 141 cm and from 1 year to 35 years, respectively. The length-age relationship of males gave the values: L_{Inf} = 133.22 cm, k = 0.0887, and t_0 = -0.8091 years (Appendix VII). Yearly von Bertalanffy parameters are summarized in Appendix VIII. Asymptotic lengths (L_{Inf}) did not change significantly from 2002 to 2019 (Fig. 6).

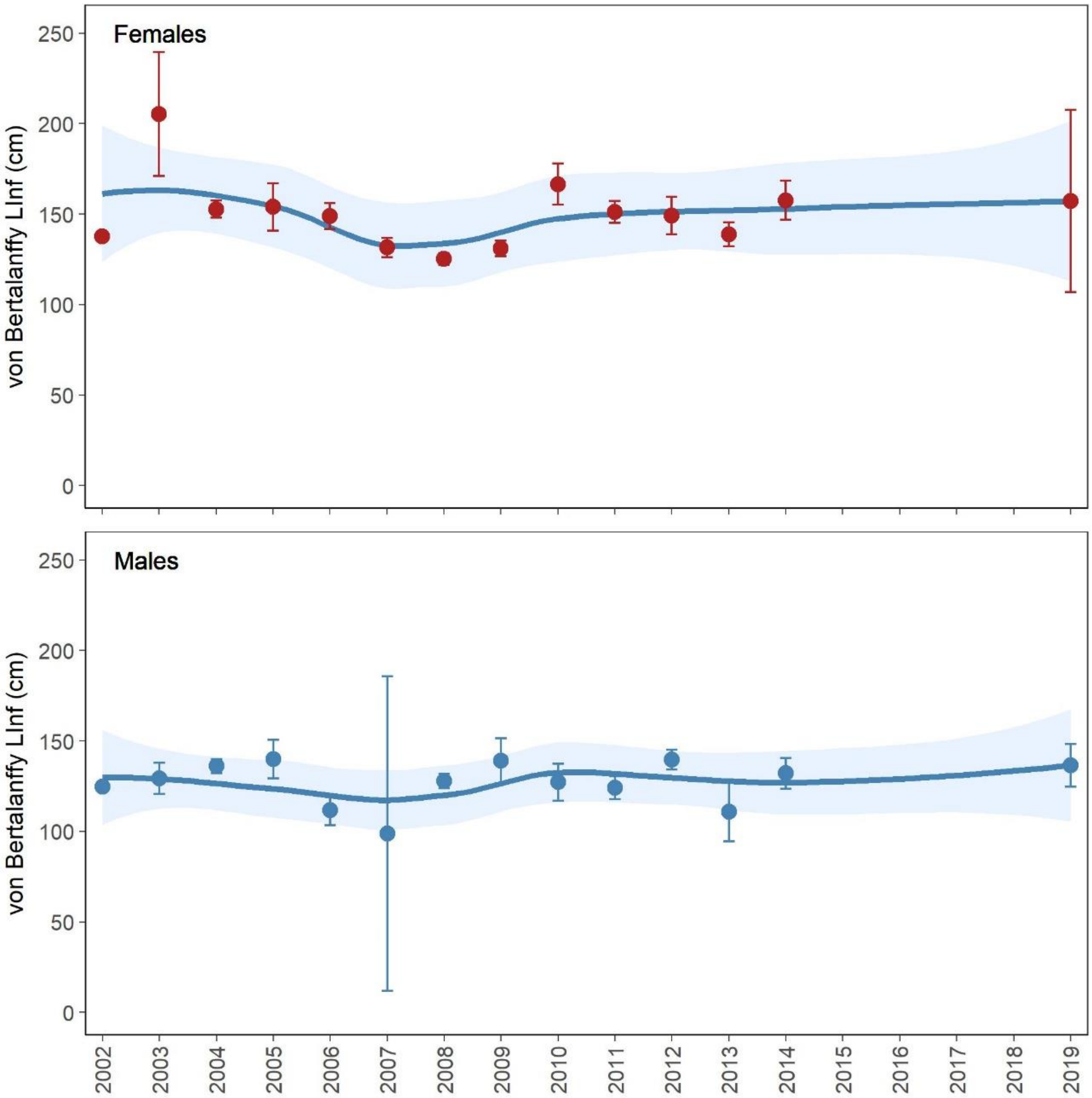

Fig. 6. Asymptotic lengths (L_{Inf}) ± 1 standard error calculated according to the von Bertalanffy growth function for female (red dots) and male (blue dots) kingclip caught by finfish (A–, G–, and W–licences) and experimental (E–licence) vessels in the FICZ from 2002 through 2019, with LOESS smooths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

Length and age at 50% maturity

Over the entire time series, length at 50% maturity (L50) of females was 67.7 ± 0.43 cm total length (n = 3,937) and age at 50% maturity (A50) was 6.8 years old; L50 of males was 66.2 ± 0.25 cm total length (n = 5,024) and A50 was 6.9 years old. Therefore, immature individuals are inferred as < 7 years old and mature individuals are inferred as ≥ 7 years old. Annual L50 and A50 of females ranged from 52.9 cm and 4.9 years old in 2018 to 107.9 cm and 14.8 years old in 2001, respectively. L50 and A50 of males ranged from 61.0 cm and 6.1 years old in 2020 to 83.5 cm and 10.3 years old in 2001. The L50 fit changed significantly for females and males from 2001 through 2021. Limited data prevented estimating L50 for males in 2003 and 2004 (Fig. 7; Appendixes IX–X).

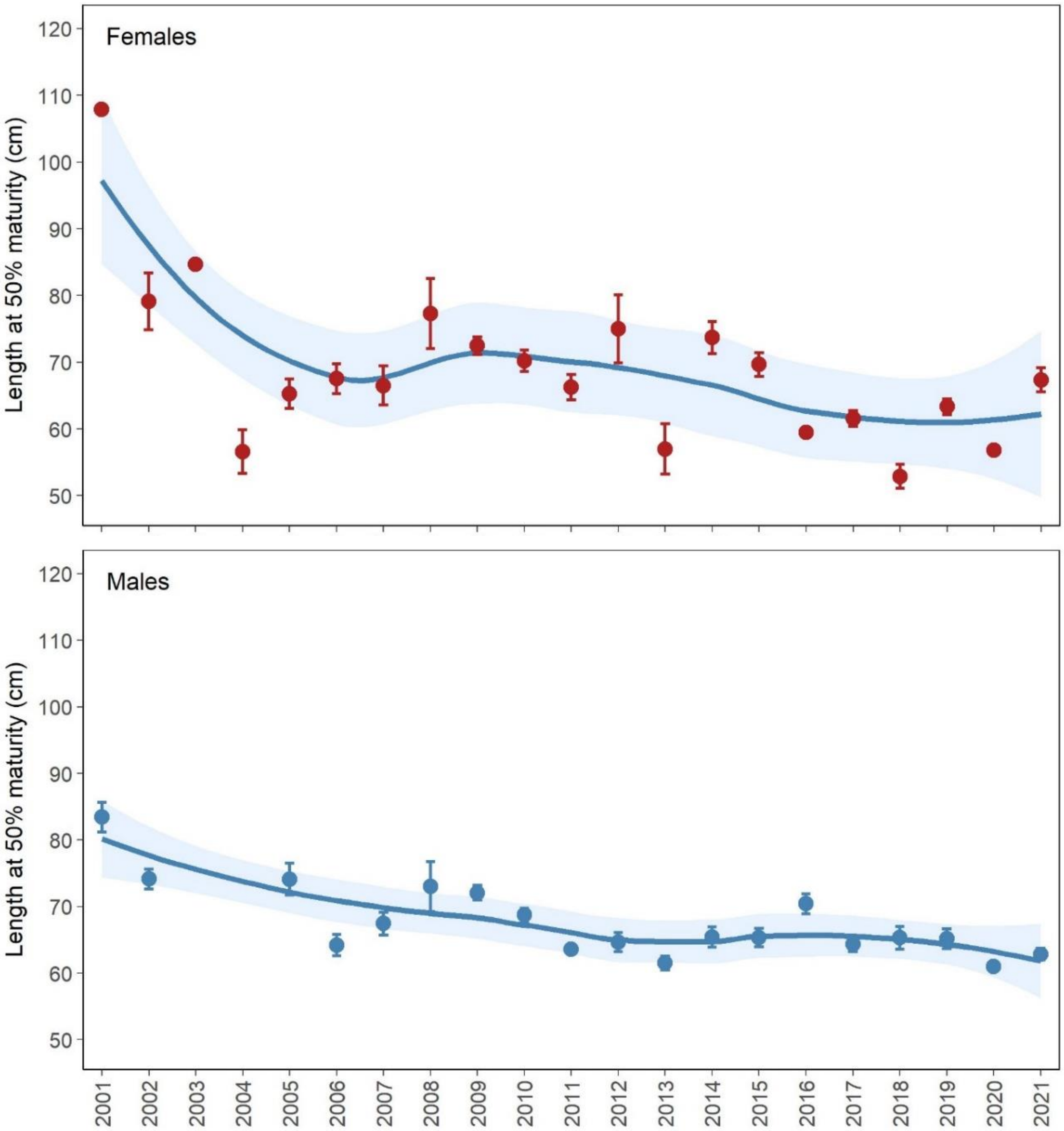

Fig. 7. Lengths at 50% maturity (L50) ± 1 standard error of female (red dots) and male (blue dots) kingclip caught by finfish (A–, G–, and W–licences) and experimental (E–licence) vessels to the west of 60°W and north of 50.5°S in the FICZ through the year, from 2001 through 2021, with LOESS smooths ± 95% confidence intervals (LOESS; span = 0.75, degree = 2).

Catch at length

Female kingclip (n = 50,346; 2001 to 2021) ranged from 10 cm to 153 cm total length, and males (n = 37,412; 2001 to 2021) ranged from 21 cm to 145 cm total length. Length-groups were not discernible due to size overlap most years. There was an increase in modal length of females and males from 2001 through 2007, smaller length-groups were detected and became dominant from about 2008 through 2014, and from 2015 through 2021, probably due to the increase in size of the 5–6 years old cohort (Fig. 8). The catch was mostly comprised of females and males at sizes ≤ L50 in 76% and 85% of the total number of years assessed (n = 21), respectively (Fig. 8; Appendix XI).

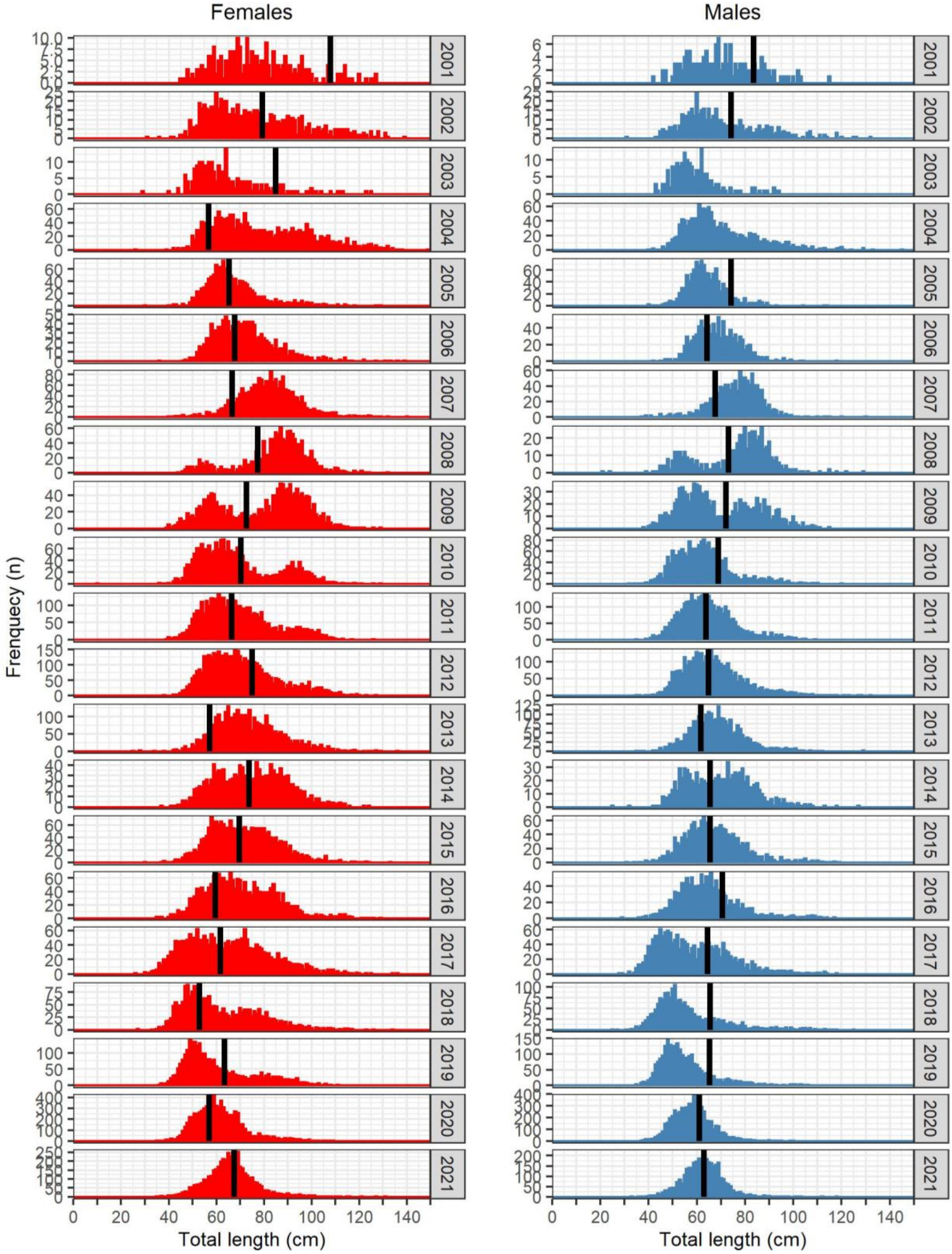

Fig. 8. Length frequency distribution of female and male kingclip caught by finfish (A–, G–, and W–licences) and experimental (E–licence) vessels to the west of 60°W and north of 50.5°S in the FICZ from 2001 through 2021. The black solid lines indicate the length at 50% maturity (L50); the binomial model for L50 did not fit the male data in 2003 and 2004.

Catch at age

Greater proportions of female and male kingclip were consistently caught at sizes equivalent to ages < 15 years old through the time series (Appendixes XII–XIII). Based on the inference that immature individuals are < 7 years old and mature individuals are ≥ 7 years old, the proportions of immature (ages 1 to 6) and mature individuals (ages 7 to 15) in annual catches overlapped from 2001 through 2021, with no evident trends (Fig. 9).

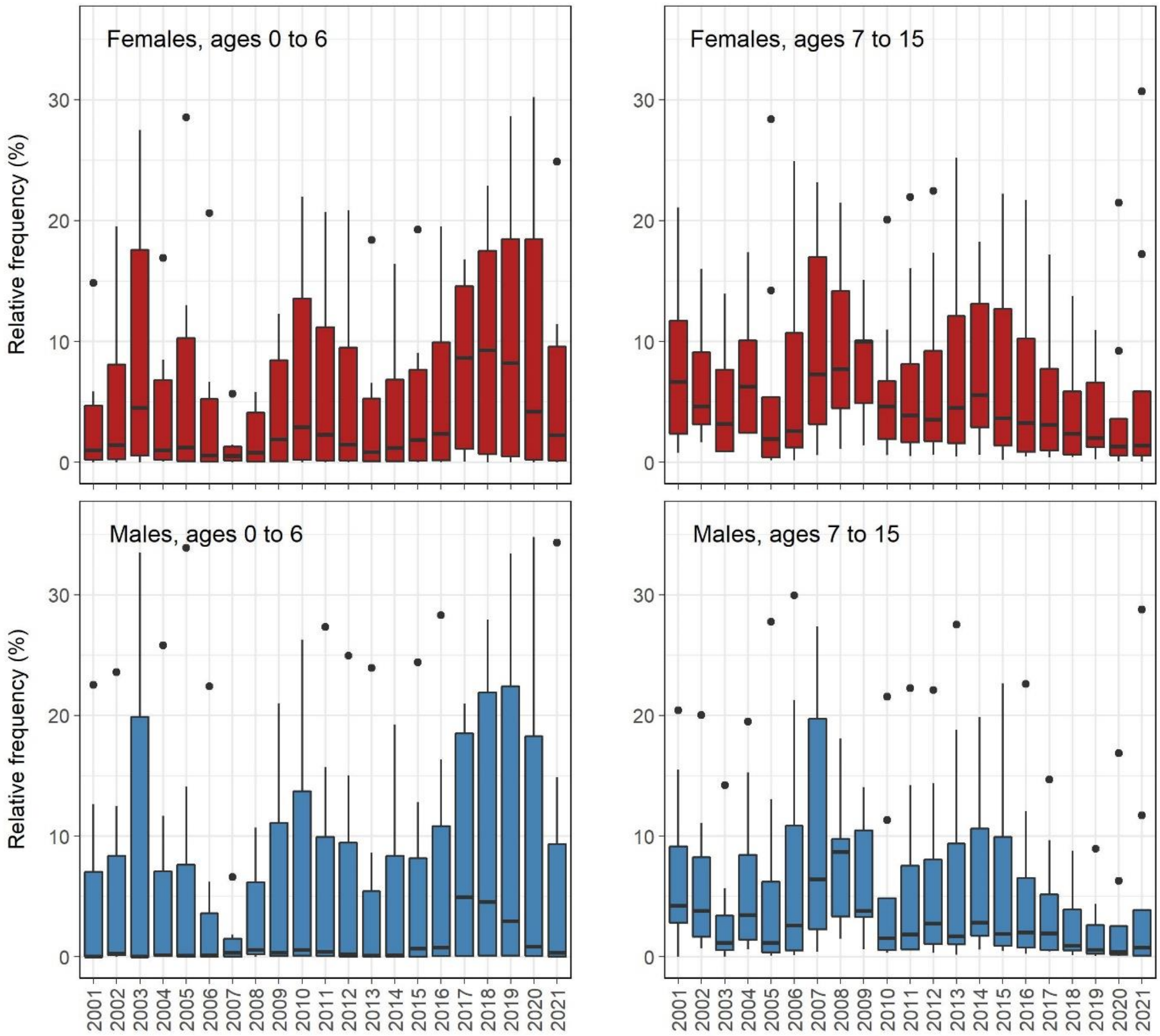

Fig. 9. Catch at age of immature (ages 0 to 6; left panel) and mature (ages 7 to 15; right panel) female (top panels) and male (bottom panels) kingclip caught by finfish (A–, G–, and W–licences) and experimental (E–licence) vessels to the west of 60°W and north of 50.5°S in the FICZ from 2001 through 2021. Kingclip ages >15 were sparse and are not included on the figure.

Natural mortality

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

$$\mathrm{M} = 4.899 \times \mathrm{t}_{\mathrm{max}}^{-0.916} = 4.899 \times 37^{-0.916} = 0.1793$$

indicating that 17.9% of the stock dies per year not by fishing but due to natural causes such as predation, diseases, senility, amongst others.

Conclusions

Kingclip Total Allowable Catch for 2023 was set at 1,675 t, calculated using the ICES category 5 framework.

Most of the kingclip catch (99%) in Falkland Islands waters in 2021 was taken between the three finfish licences (A–, G– and W–licences), with most of the kingclip catch taken under A–licence (41%).

Kingclip commercial CPUE in the FICZ increased from 1990 through 2013, followed by a significant decline from 2014 through 2021. Intra-annually, the highest CPUE of kingclip occurred from April through December, although CPUE had a small decline from October through December.

February surveys biomasses showed no significant change in kingclip abundance from 2010 through 2022; however, February surveys likely reflect variability in the migratory timing of this species. The 2017 and 2020 July surveys revealed comparable kingclip biomasses.

Length-based indicators suggest that conservation of immature fish, large individuals, mega-spawners, optimal yield, and MSY were of concern or negative most years in the time series (i.e., 2001–2021).

The length and age analyses showed decreasing trends for length at 50% maturity. Comparison of length at 50% maturity and catch at length revealed that kingclip are mainly caught before reaching maturity, which can reduce the stock sustainability (Vasilakopoulos et al. 2011; Muluye et al. 2016; Ben-Hasan et al. 2021).

Natural mortality of kingclip in the FICZ was M = 0.1793; verification of kingclip age data will allow improved estimation of fishing mortality to be able to assess total mortality (natural mortality + fishing mortality) on this stock.

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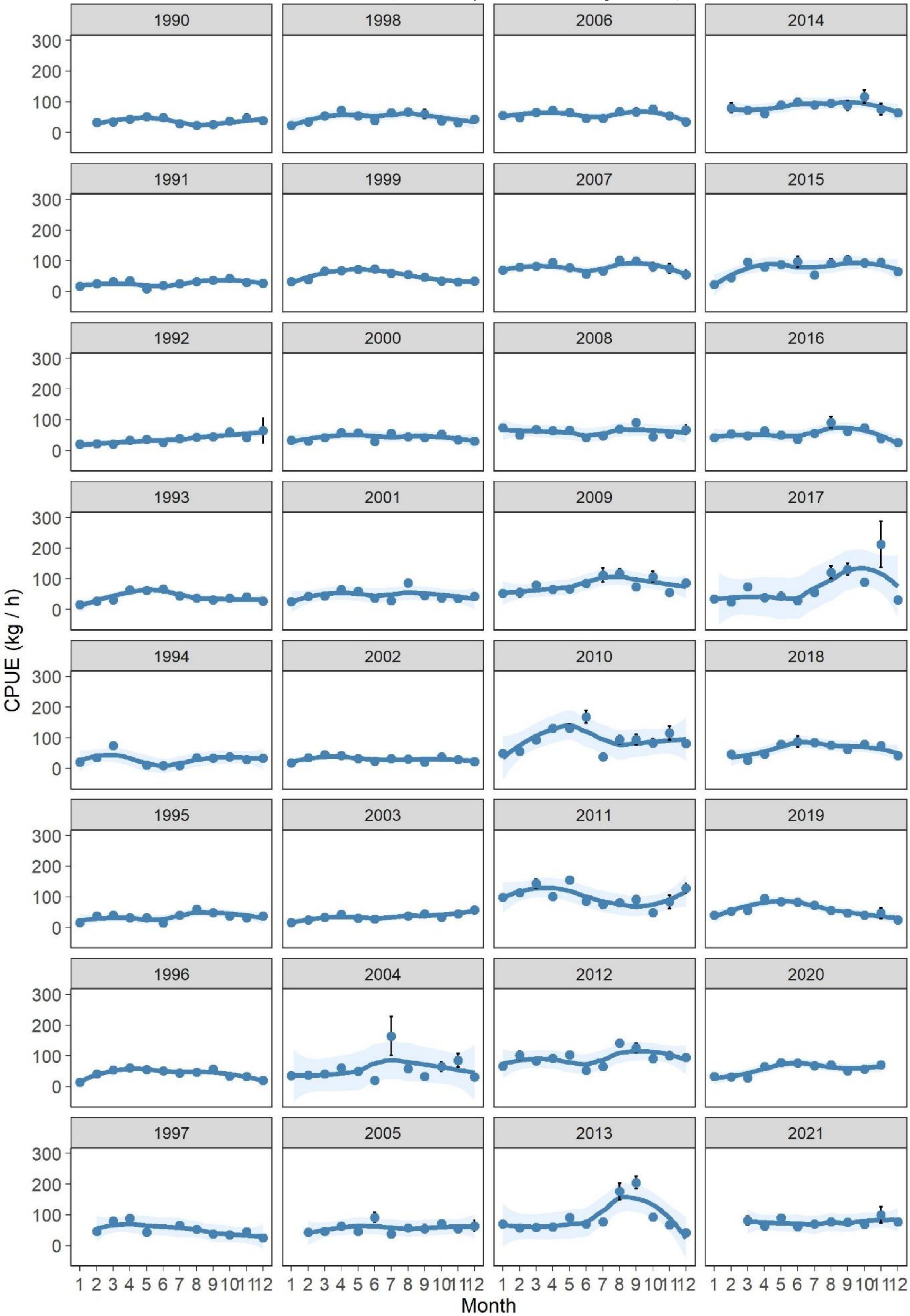
Appendix

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

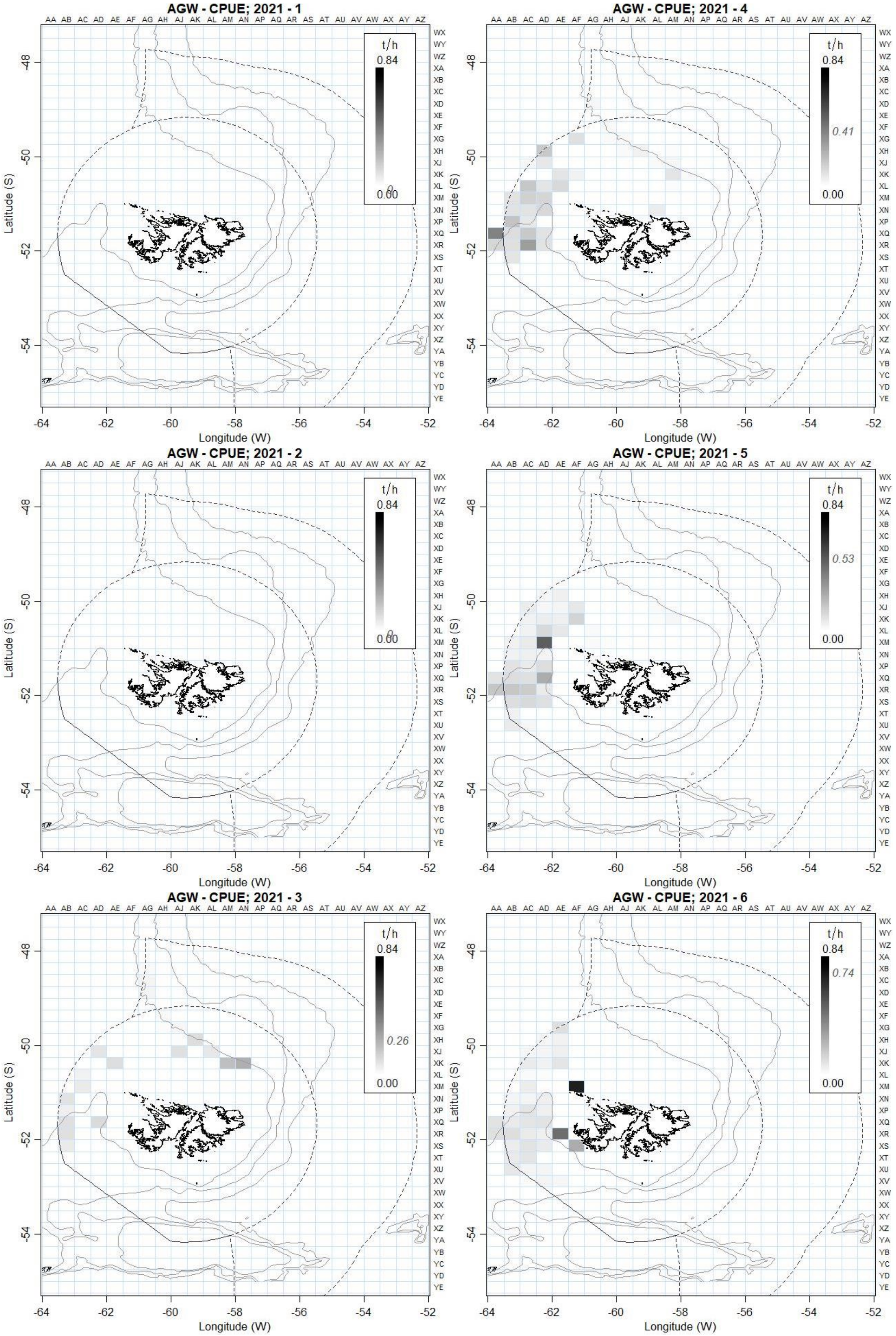
Year	Falkland Islands (t)	Argentina (t)
1987	674.00	15,175.00
1988	1,977.00	17,307.00
1989	979.00	21,091.60
1990	849.90	34,775.00
1991	949.48	18,850.00
1992	1,953.03	24,173.90
1993	1,647.66	26,010.10
1994	899.12	21,725.10
1995	1,985.34	23,711.00
1996	1,686.11	22,094.60
1997	1,421.19	21,939.30
1998	2,215.13	25,245.00
1999	2,602.48	21,792.80
2000	1,875.89	15,183.10
2001	1,625.21	19,666.50
2002	1,223.77	17,817.10
2003	1,276.63	14,604.60
2004	1,840.38	17,124.90
2005	1,935.63	18,627.80
2006	2,751.15	20,558.10
2007	3,591.23	20,609.30
2008	2,227.02	17,558.50
2009	3,387.78	16,693.60
2010	3,635.50	16,358.50
2011	3,853.43	16,276.10
2012	3,475.26	10,113.40
2013	3,943.70	6,697.10
2014	2,873.50	5,750.30
2015	2,968.24	5,238.30
2016	1,606.43	3,298.50
2017	1,623.97	2,999.40
2018	1,438.34	3,609.60
2019	1,701.35	2,004.60
2020	1,619.46	2,889.70
2021	1,704.16	2,782.00

[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 kingclip in Falkland Islands waters from 1990 to 2021, calculated from finfish (A–, G–, and W–licensed) vessels to the west of 60°W and north of 50.5°S in the FICZ, with LOESS smooths ± 95% confidence intervals (LOESS; span = 0.75, degree = 2).



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



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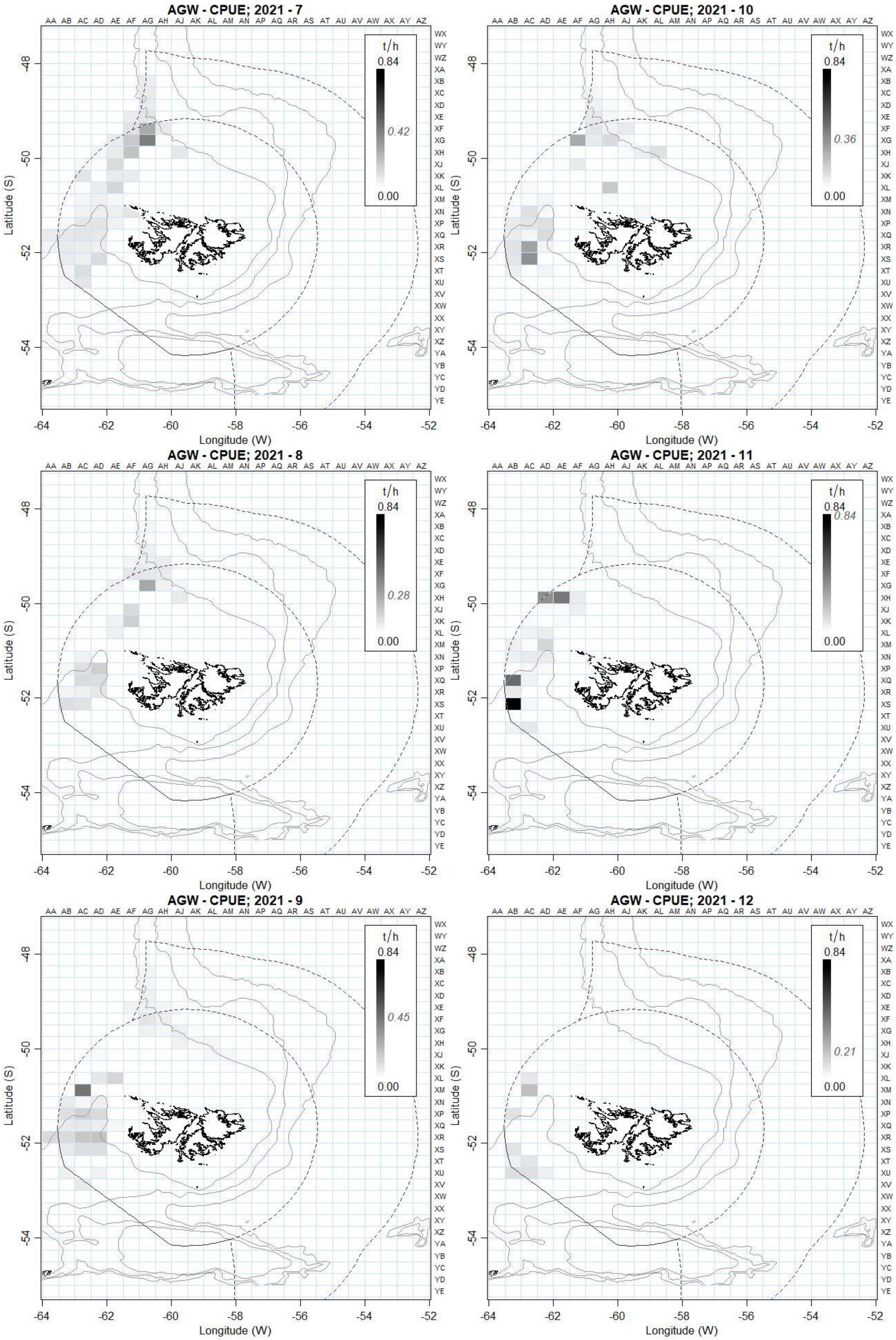
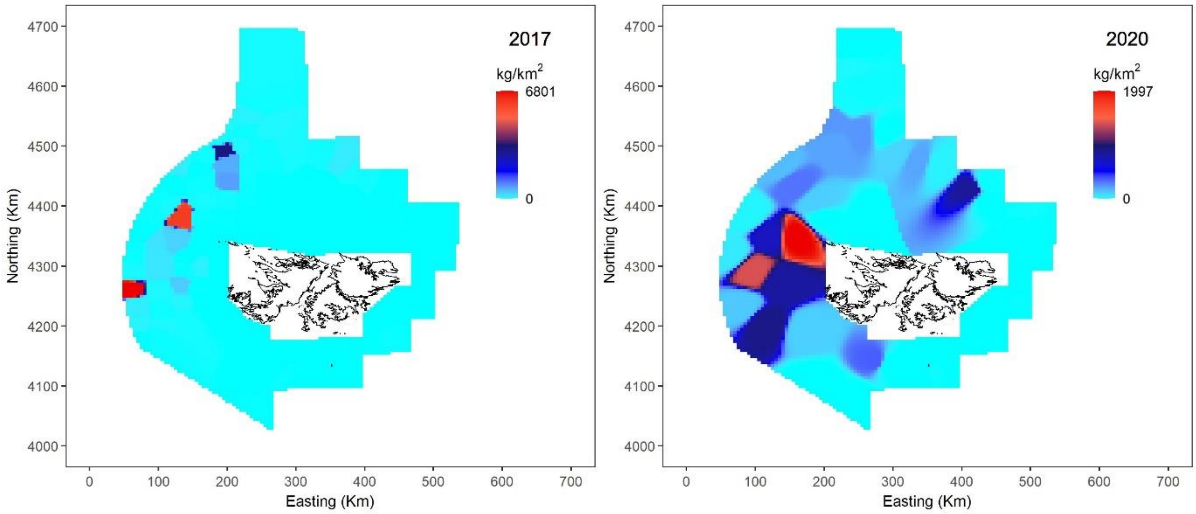


Appendix IV. Densities of kingclip modelled by inverse distance weighting in the FICZ, during the July 2017 and July 2020 groundfish and Patagonian squid pre-season surveys.

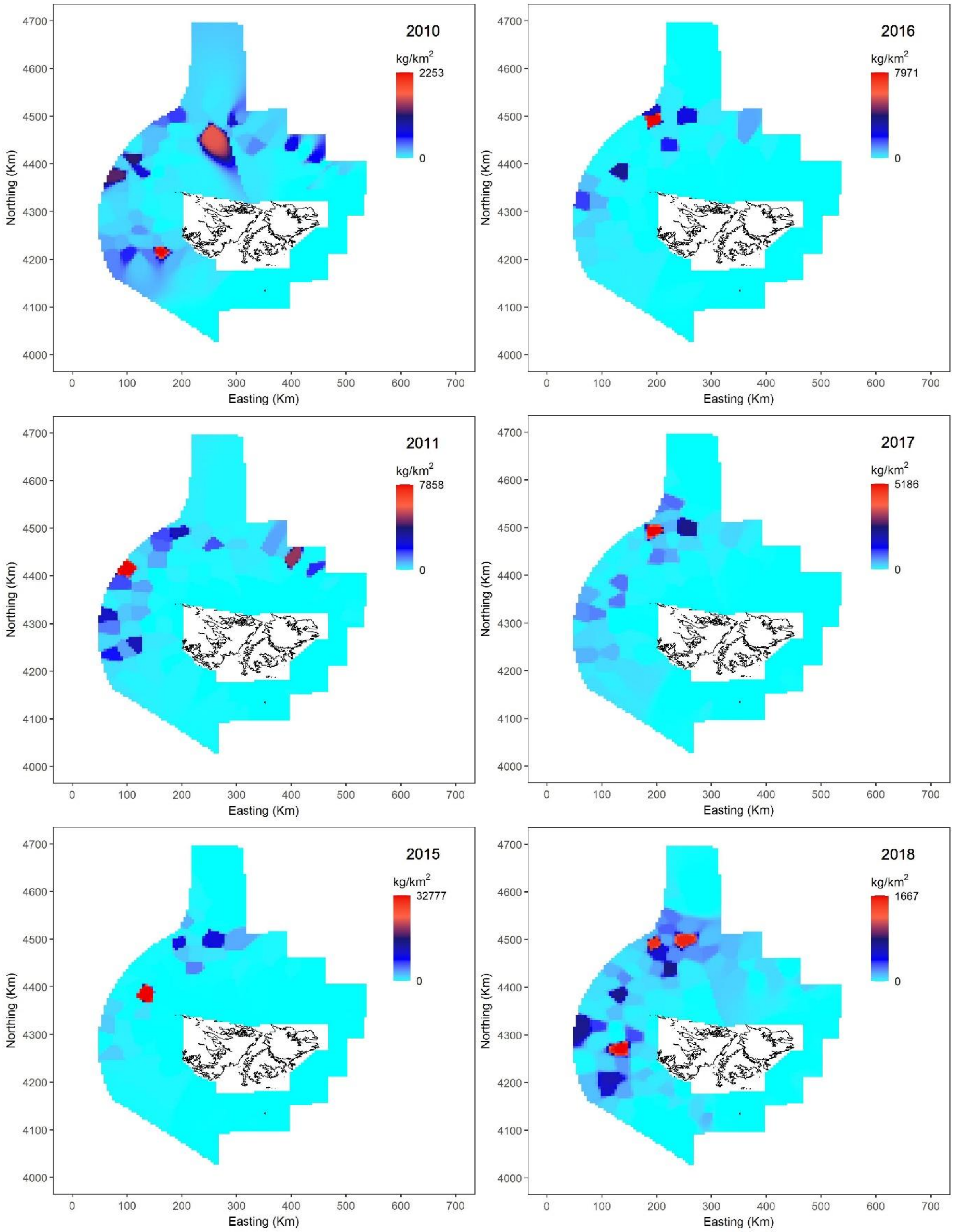


Appendix V. Summer (February) surveys catch and effort, and biomass estimates (mean ± 95% confidence intervals) of kingclip in Falkland Islands waters.

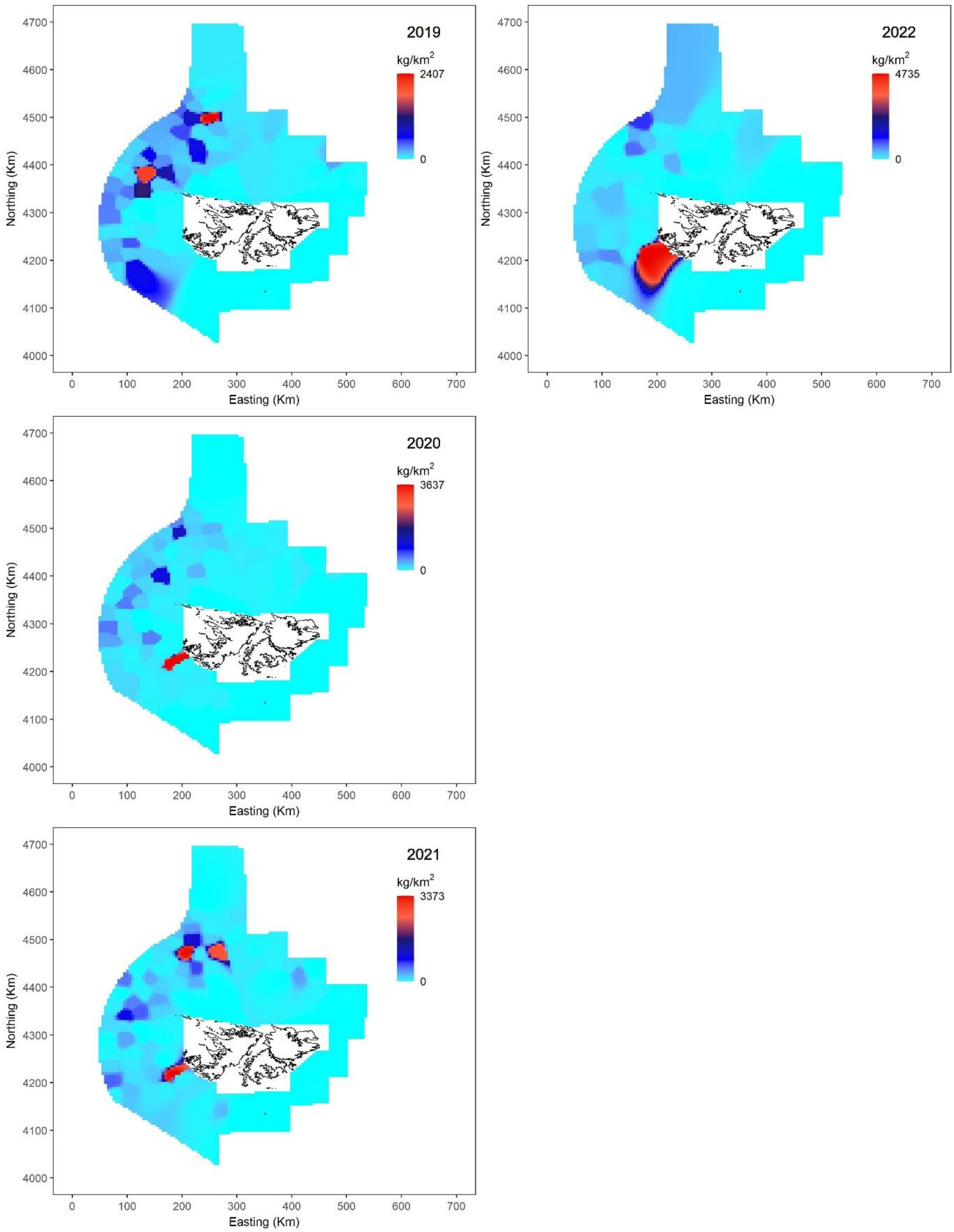
Year	Survey	Trawls (n)	Swept area (km^2)	Effort (h)	Catch (kg)	CPUE (kg/h)	Biomass (t)
2010	Groundfish	87	17.04	87.52	3064.02	35.01	21274.04
	D. gahi	55	42.29	109.27	173.80	1.59	(13705.30–28607.34)
	Total	142	59.34	196.78	3237.82	16.45	
2011	Groundfish	88	17.21	88.00	8420.48	95.69	41485.02
	D. gahi	58	40.04	110.63	168.60	1.52	(28424.85–63121.38)
	Total	146	57.26	198.63	8589.08	43.24	
2015	Groundfish	89	16.72	90.17	14635.03	162.31	76722.26
	D. gahi	57	46.90	111.50	97.19	0.87	(30150.81–124958.88)
	Total	146	63.61	201.67	14732.22	73.05	
2016	Groundfish	90	17.64	91.42	5401.57	59.09	24782.64
	D. gahi	56	54.46	107.92	46.03	0.43	(13955.05–39613.42)
	Total	146	72.10	199.33	5447.60	27.33	
2017	Groundfish	90	18.52	92.00	4156.34	45.18	18831.90
	D. gahi	58	54.09	117.00	103.47	0.88	(11873.32–28544.00)
	Total	148	72.62	209.00	4259.81	20.38	
2018	Groundfish[a]	97	20.47	96.42	3350.93	34.75	14788.92
	D. gahi	59	36.87	100.83	235.05	2.33	(11069.78–21527.00)
	Total	156	57.35	197.25	3585.98	18.18	
2019	Groundfish	79	17.22	79.00	4051.22	51.28	20869.45
	D. gahi	52	72.70	97.05	367.00	3.78	(14764.62–28127.04)
	Total	131	89.93	176.05	4418.22	25.10	
2020	Groundfish[a]	80	17.04	79.95	3398.10	42.50	14531.98
	D. gahi	59	86.80	112.52	226.95	2.02	(10052.06–26304.43)
	Total	139	103.84	192.47	3625.06	18.83	
2021	Groundfish	80	16.43	79.48	4348.60	54.71	21216.07
	D. gahi	55	90.65	111.22	438.51	3.94	(12901.88–35823.59)
	Total	135	107.07	190.70	4787.11	25.10	
2022	Groundfish	42	9.22	41.90	2678.92	63.94	43437.30
	D. gahi	60	86.75	119.08	111.20	0.93	(14738.11–80447.75)
	Total	102	95.97	160.98	2790.12	17.33	

[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 the analyses as their locations were not relevant to the distribution of kingclip. Groundfish February surveys were not conducted in 2012, 2013, and 2014.

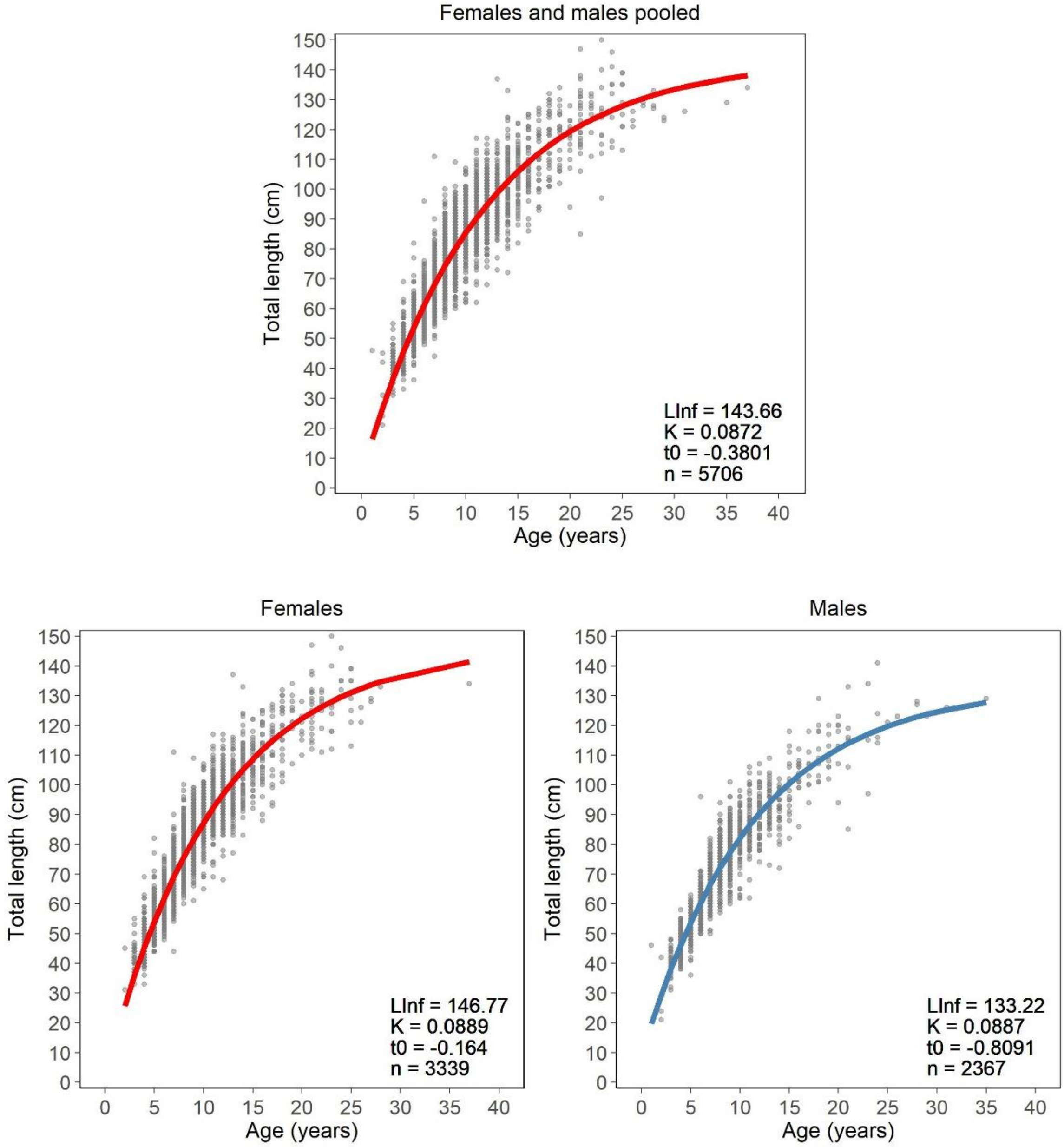
Appendix VI. Densities of kingclip modelled by inverse distance weighting in the FICZ, during the February 2010–2022 groundfish and Patagonian squid pre-season surveys.



Appendix VI. *continued…*



Appendix VII. von Bertalanffy age-length relationship of female and male kingclip collected in the FICZ. Age was determined by MFRI (n = 5,683) and FIFD (n = 23) staff.

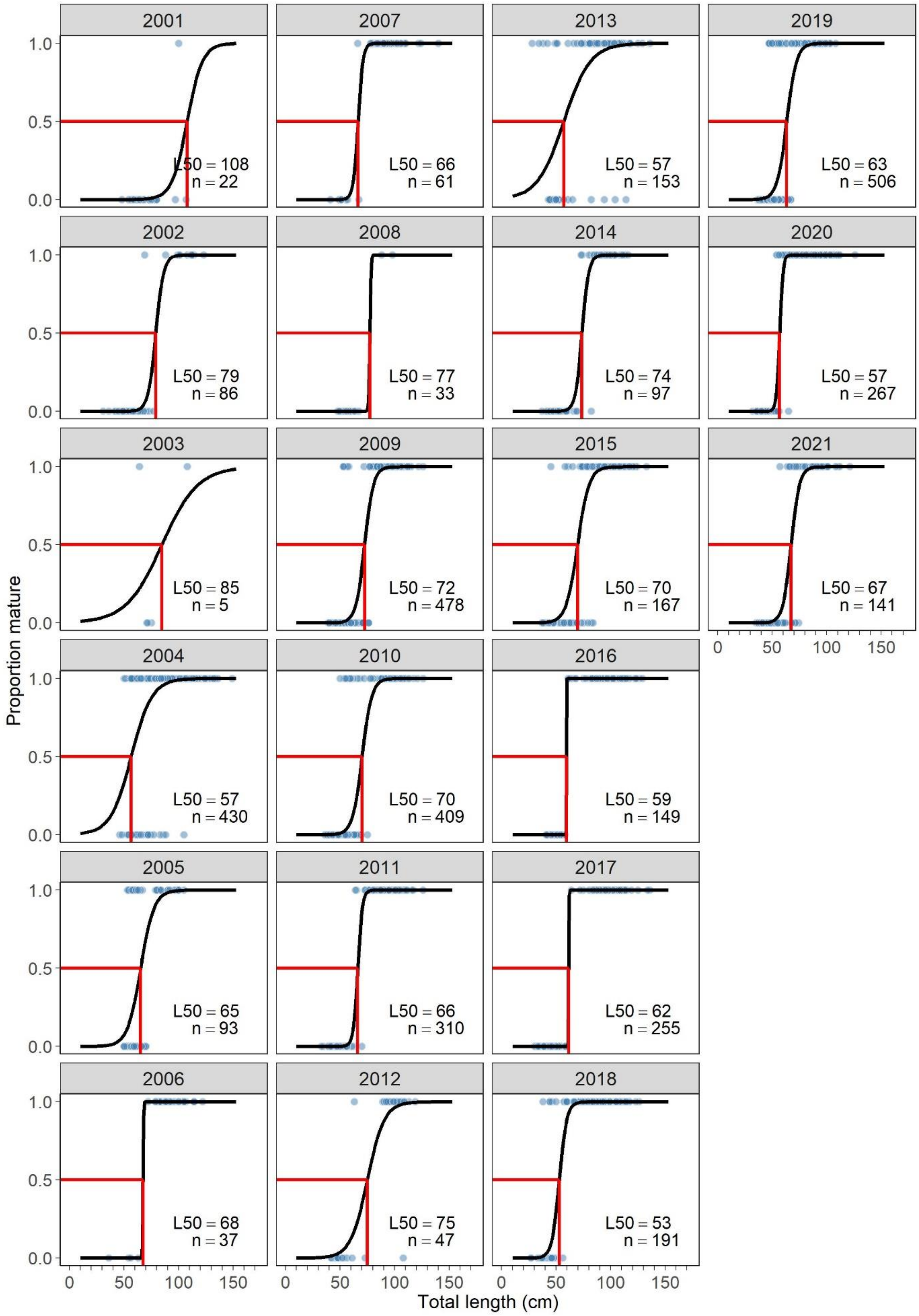


Appendix VIII. Kingclip von Bertalanffy length-at-age parameters for curvature (k), age of fish at length zero (t_0), and asymptotic length (L_{Inf}), by year and sex, with 95% confidence intervals. Data were not available in some years.

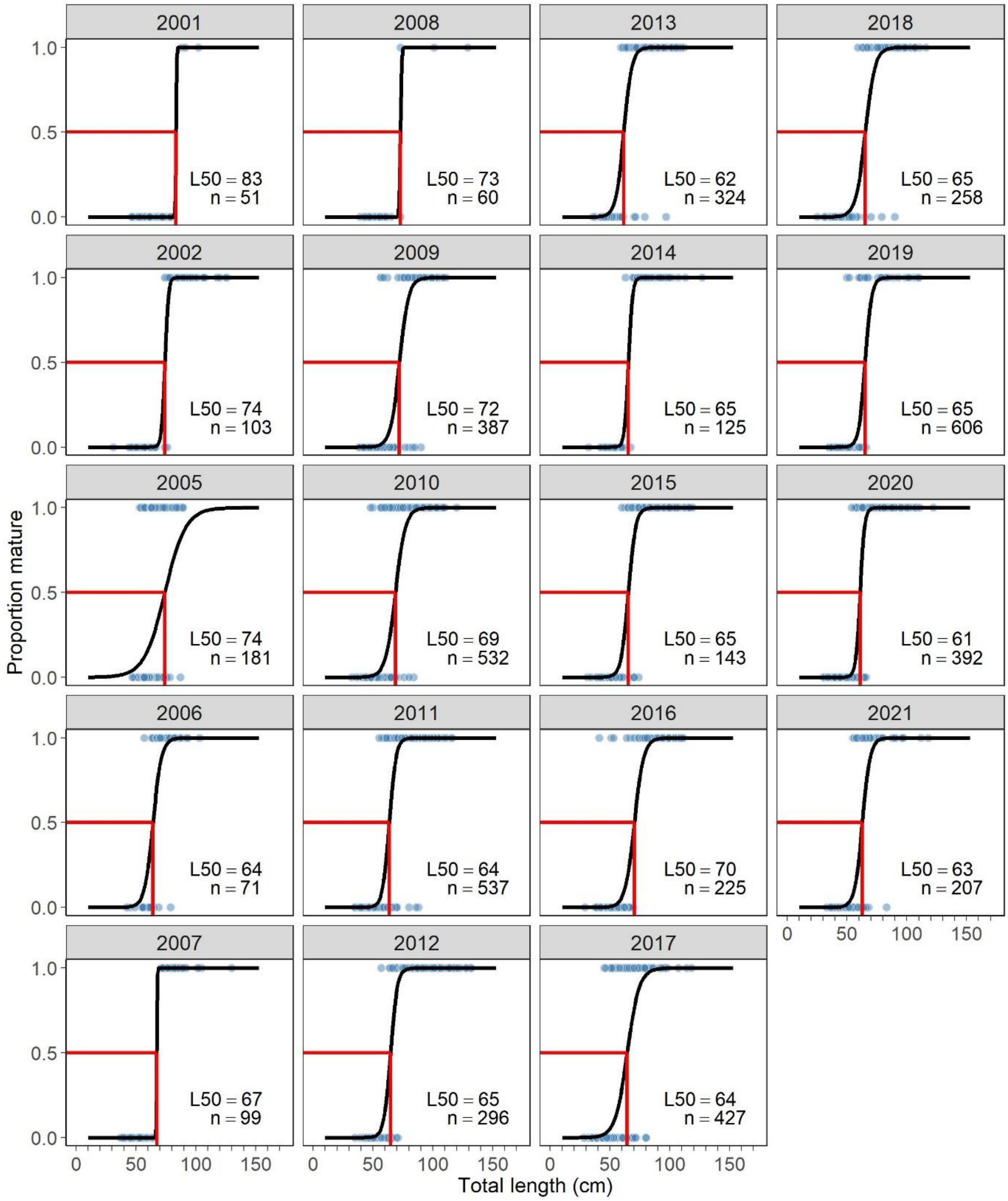
Sex	Year	n	K	t_0 (years)	L_{Inf} (cm)
	2002	396	0.119 (0.108 - 0.132)	0.738 (0.398 - 1.043)	137.7 (133.2 - 143.1)
	2003	36	0.056 (0.031 - 0.082)	-0.361 (-1.708 - 0.575)	205.4 (169.2 - 295.3)
	2004	261	0.093 (0.079 - 0.109)	0.595 (0.026 - 1.089)	152.8 (144.7 - 163.3)
	2005	72	0.088 (0.060 - 0.118)	-0.110 (-1.085 - 0.647)	154.0 (135.9 - 186.7)
	2006	148	0.085 (0.067 - 0.104)	-0.128 (-0.943 - 0.522)	148.9 (137.4 - 165.6)
	2007	63	0.092 (0.071 - 0.115)	-0.230 (-1.452 - 0.734)	131.5 (122.5 - 143.4)
F	2008	285	0.115 (0.099 - 0.133)	0.227 (-0.294 - 0.692)	125.2 (119.5 - 132.3)
	2009	359	0.108 (0.091 - 0.127)	-0.596 (-1.120 - -0.144)	131.0 (123.6 - 140.8)
	2010	213	0.072 (0.055 - 0.089)	-0.185 (-0.824 - 0.340)	166.5 (149.9 - 194.1)
	2011	289	0.089 (0.074 - 0.103)	0.340 (-0.091 - 0.707)	151.2 (141.1 - 164.8)
	2012	169	0.091 (0.065 - 0.118)	0.062 (-0.897 - 0.812)	149.2 (133.6 – 175.0)
	2013	147	0.101 (0.077 - 0.125)	0.387 (-0.422 - 1.054)	138.8 (128.4 - 154.4)
	2014	526	0.083 (0.062 - 0.104)	0.112 (-0.528 - 0.629)	157.6 (141.5 - 184.1)
	2018	67	0.069 (0.009 - 0.210)	-1.526 (-3.785 - 0.653)	155.0 (94.6 - 790.1)
	2019	308	0.070 (0.035 - 0.105)	-1.044 (-2.434 - -0.084)	157.3 (129.4 - 237.7)

Sex	Year	n	K	t_0 (years)	L_{Inf} (cm)
	2002	258	0.135 (0.118 - 0.153)	0.946 (0.527 - 1.305)	124.8 (119.9 - 130.7)
	2003	7	0.133 (0.081 - 0.182)	1.114 (-0.207 - 1.934)	129.3 (116.7 - 150.6)
	2004	214	0.098 (0.083 - 0.113)	-0.071 (-0.671 - 0.457)	136.1 (129.5 - 144.3)
	2005	61	0.094 (0.065 - 0.124)	-0.345 (-1.499 - 0.478)	140.0 (125.6 - 166.9)
	2006	113	0.151 (0.098 - 0.212)	0.893 (-0.268 - 1.742)	111.9 (99.8 - 133.1)
	2007	24	0.153 (0.033 - 0.323)	0.734 (-3.230 - 2.390)	98.9 (81.7 - 213.9)
M	2008	165	0.094 (0.081 - 0.109)	-0.730 (-1.296 - -0.242)	127.9 (120.9 - 136.6)
	2009	228	0.083 (0.057 - 0.110)	-1.001 (-1.868 - -0.328)	139.2 (122.7 - 170.6)
	2010	178	0.099 (0.069 - 0.130)	-0.302 (-1.088 - 0.312)	127.2 (113.0 - 152.4)
	2011	244	0.095 (0.075 - 0.116)	-0.924 (-1.559 - -0.364)	124.1 (113.7 - 138.1)
	2012	99	0.075 (0.061 - 0.091)	-1.691 (-2.610 - -0.948)	139.7 (130.3 - 151.5)
	2013	117	0.114 (0.059 - 0.167)	-0.568 (-2.201 - 0.423)	111.0 (96.0 - 151.9)
	2014	326	0.098 (0.072 - 0.124)	-0.378 (-1.123 - 0.212)	132.2 (119.6 - 152.8)
	2018	59	0.069 (0.008 - 0.188)	-2.083 (-4.698 - 0.044)	141.7 (89.9 - 712.6)
	2019	271	0.066 (0.045 - 0.087)	-2.238 (-3.409 - -1.359)	136.5 (121.3 - 166.5)

Appendix IX. Binomial logistic regressions of juvenile (0) or adult (1) maturity ogives vs. length for female kingclip. Red lines indicate the intercept for length at 50% adulthood, corresponding to Fig. 7.



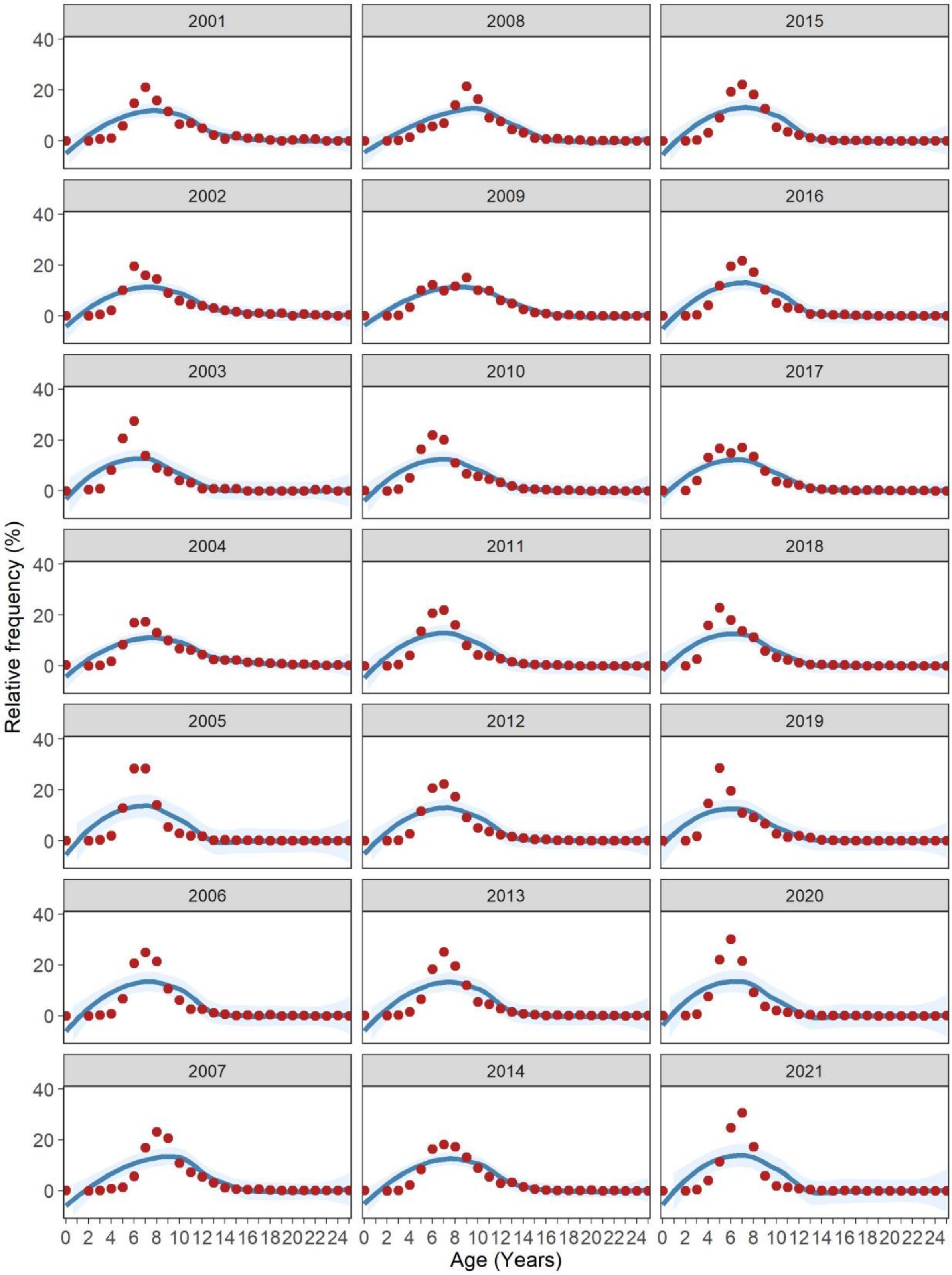
Appendix X. Binomial logistic regressions of juvenile (0) or adult (1) maturity ogive vs. length for male kingclip. Red lines indicate the intercept for length at 50% adulthood, corresponding to Fig. 7. Note the gap in 2003 and 2004 when the model did not fit due to limited data.



Appendix XI. Number of kingclip individuals sampled for length frequency distributions, corresponding to individuals caught randomly by finfish (A–, G–, and W–licences) and experimental (E–licence) vessels through the year to the west of 60°W and north of 50.5°S in the FICZ from 2001 to 2021.

Year	Females (n)	Males (n)
2001	256	142
2002	737	436
2003	222	176
2004	2,053	1,423
2005	1,300	1,184
2006	1,237	1,008
2007	1,990	1,085
2008	1,284	554
2009	1,718	1,033
2010	2,149	1,905
2011	3,851	3,361
2012	4,580	3,308
2013	3,471	2,426
2014	1,415	895
2015	2,191	1,561
2016	2,083	1,276
2017	2,245	1,738
2018	2,263	1,826
2019	2,791	2,457
2020	7,805	6,154
2021	4,705	3,464

Appendix XII. Catch at age of female kingclip by finfish (A–, G–, and W–licences) and experimental (E–licence) vessels to the west of 60°W and north of 50.5°S in the FICZ, with LOESS smooths ± 95% confidence intervals (LOESS; span = 0.75, degree = 2).



Appendix XIII. Catch at age of male kingclip by finfish (A–, G–, and W–licences) and experimental (E–licence) vessels to the west of 60°W and north of 50.5°S in the FICZ, with LOESS smooths ± 95% confidence intervals (LOESS; span = 0.75, degree = 2).