Stock assessment of Kingclip (*Genypterus blacodes*) in the Falkland Islands, 2017–2018

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Abstract

The shared Falkland Islands and Argentinean kingclip stock size in 2018 was 16% of the stock size in 1987 and about 43% of the biomass that would provide maximum sustainable yield. With a median intrinsic growth rate of 0.1967, the kingclip population is capable of increasing about 22% per year. Length at capture (41.6 cm) off the Falkland Islands during 2018 was approximately 43 cm below the optimum length at capture (84.8 cm). Overall, there was a statistically significant decrease in age at maturity and size at maturity through time, whereas modal length had a non-significant decrease through the time series. The estimated median biomass of the shared stock for 2017 was 47,527 t and the median MSY was 15,095 t. The median MSY estimated for 2017 was 7,682 t above the average annual kingclip catch from 2013 to 2017 (7,413 t). According to the BSM analysis, kingclip stocks appear to be overfished ($B < B_{MSY}$) and overfishing is currently occurring ($F > F_{MSY}$). This finding is supported by the current low average length at capture compared to the optimum length at capture, by the relatively low intrinsic growth rate estimated, and by the low resilience of the species; indication that the stock is being harvested at a rate that is outpacing growth rates in terms of overall weight or biomass. Considering $B_{current}/B_{MSY}$ = 43%, it's recommended that the present catch limit of the combined kingclip stock examined should be 43% of MSY: 15,095 × 0.43 = 6,491 t. However, further catch restriction may be advised if the kingclip stock continues to show decreasing trends in abundance.

Introduction

Kingclip (*Genypterus blacodes*, Ophidiidae) is a benthic-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 the Chilean fishery, kingclip are caught at sizes between 19 and 154 cm, and at ages up to 14 years for males and 16 years for females (Wiff et al. 2007). However, a maximum age of 39 years has been reported in New Zealand waters (Horn 1993). The main reproductive season in Chilean waters occurs between July and November, with length at maturity at 88–91 cm (Baker et al. 2014) and age at maturity of approximately 6 years (Aguayo et al. 2001). Low growth rates have been reported for the kingclip population of the Chilean austral demersal fishery (González-Olivares et al. 2009). Little biological information of this species from the Southwest Atlantic is available in the literature despite its considerable importance as a trophic component of the Falkland Islands species assemblage. For instance, the range of prey of kingclip comprises rock cod *Patagonotothen* spp., hoki *Macruronus magellanicus*, and benthic isopods (Nyegaard et al. 2004).

In the Southwest Atlantic, approximately two thirds of the kingclip adult population moves out of Falkland Islands waters during summer to spawn, and the biomass has been reported to be minimal in autumn (Arkhipkin et al. 2012). After the spawning season, kingclip appears to undertake seasonal migrations from the Argentine Exclusive Economic Zone into their feeding grounds in the Falkland Islands Conservation Zone, primarily in the north-western area (Falkland Islands Government 2018). The species' migratory behaviour results in Falklands and Argentinean fisheries taking catches from the same population; therefore, both fisheries must be accounted for stock assessment.

Kingclip is a commercially important bycatch in Argentina, where it is known as abadejo (Sánchez et al. 2012; Navarro et al. 2014). In the Falkland Islands, this species is also a valuable bycatch that has contributed < 10% of trawl fishery production in any year, i.e. in the finfish (hoki *M. magellanicus* and hake *Merluccius hubbsi*) and in the Patagonian squid (*Doryteuthis gahi*) fisheries (Falkland Islands Government 2018). Consequently, kingclip catch in the Falkland Islands is approximately 8× less compared with the catch in Argentina.

The inconstancy of kingclip CPUE in this commercial fishery as an index of relative abundance and the limited information on this bycatch species makes it necessary to implement stock assessment methods developed for data-poor fisheries (Zhou et al. 2018); for instance, the Length-Based Bayesian biomass estimation method (LBB) (Froese et al. 2018). The aim of this report is thus to provide metrics that will be useful for the management of this resource, including biological information necessary to implement the required stock assessment approaches.

Methods

Sampling

Genypterus blacodes specimens were collected on board commercial trawler vessels from 1988 to 2017, and on board research vessels from 2000 to 2018 in Falkland Islands fisheries. Total length and total weight were measured to the nearest centimetre and gram, respectively. Sex was identified and maturity stage was determined following Brickle et al. (2005; modified from Nikolsky 1963). All measurements and maturity stage determinations were carried out on board.

Commercial catch data

Total commercial fishery catches from the Falkland Islands and Argentina were examined from 1987 to 2017. Commercial catch data from the Falkland Islands are available at http://www.fig.gov.fk/fisheries/publications/fishery-statistics (Falkland Islands Government 2018), whereas data from Argentina are available at https://www.agroindustria.gob.ar/sitio/areas/pesca_maritima/desembarques/ (Sánchez et al. 2012; Navarro et al. 2014).

Biomass estimation

Optimized Catch-Only Method (OCOM)

The Optimized Catch-Only Method (OCOM) developed for data-poor species uses time series of catches and priors for the intrinsic population growth rate (r) derived from basic life history parameters, and for stock saturation (S) based on catch trends (Zhou et al. 2018). Stock saturation refers to the biomass of the stock at the end of the catch time series relative to the unfished biomass (Zhou et al. 2017). This method applies an optimization of the Graham-Schaefer surplus production model to search the potential parameter space (Schaefer 1954):

$$B_{y+1} = B_y + r \cdot B_y \left(1 - \frac{B_y}{K}\right) - C_y$$

where B_y = biomass at the start of time step y; r = intrinsic growth rate; K = carrying capacity (equal to the initial biomass B_0 for a surplus production model); C_y = known catch during time-step y. Catches per year (C_y) were the total annual catches of both the Falkland Islands and Argentina.

Population intrinsic growth rate (r) was calculated from the generalized empirical relationship (Zhou et al. 2018):

$$r = 2 \cdot F_{MSY}$$

Maximum sustainable yield $F_{MSY} = 0.87 \cdot M$ for teleosts (Zhou et al. 2012), where M is instantaneous natural mortality rate. To avoid potentially negative values being sampled, a lognormal distribution was implemented as follows:

$$r \sim \text{lognormal}\ (\mu_r, \sigma^2{}_r)$$

where mean r (μ_r) = log($2F_{MSY}$), and uncertainty of r (σ_r^2) = $\sigma_M^2 + \sigma_e^2$. Measurement error in M (σ_M^2) = 0.23 and the process error in the relationship between M and F_{MSY} (σ_e^2) = 0.0012; hence, uncertainty of r (σ_r^2) = 0.2312 (Zhou et al. 2018).

Natural mortality M was calculated from several empirical life-history equations (Kenchington 2014; Zhou et al. 2018):

$$M1 = 4.899 \cdot t_{max}^{-0.916}$$

$$M2 = 4.118 \cdot k^{0.73} \cdot L_\infty^{-0.33}$$

$$M3 = 1.82 \cdot k$$

$$M4 = \frac{1.65}{t_{mat}}$$

$$M5 = \frac{4.3}{t_{max}}$$

where t_{max} = maximum age, L_∞ = asymptotic length, k = rate by which L_∞ is approached, and t_{mat} = age at maturity.

Maximum age was taken from the FIFD age-length database, and L_∞ and k were taken from the von Bertalanffy equation used to examine the age-length relationship. The von Bertalanffy equation was implemented using the package 'fishmethods' (Nelson 2017) in R Studio (RStudio Team 2016):

$$L = L_\infty \cdot \left(1 - e^{-k(t - t_0)}\right)$$

where t_0 = theoretical age at zero length.

Age at maturity (t_{mat}) was estimated from females and males combined and collected in the Falkland Islands between 1988 and 2015. The deposition of growth rings in otoliths of 7,600 individuals was examined to determine age. A total of 7,053 otoliths were processed at the Sea Fisheries Institute in Gdynia (Poland), 307 otoliths were processed in the Falkland Islands Fisheries Department (FIFD), and the source of age measurement of 240 otoliths was unknown.

Length at maturity was estimated from individuals collected between 1988 and 2017. Sex was identified and maturity stage was determined, i.e.: I) immature; II) resting; III) early developing; IV) late developing; V) ripe; VI) running; VII) spent; VIII) recovering spent (Brickle et al. 2005, modified from Nikolsky 1963). An additional category (0) referred to juveniles which sex could not be determined. Gonadal maturity of fish is cyclical, for instance fish pass from post-spawning phase VIII to the pre-spawning phase II. In this sense, maturity stages ≤ I are always juveniles, stage II is uncertain, and stages ≥ III are always adults (H. Randhawa, FIFD, *pers. comm.*). Therefore, maturity assignment was simplified to a dichotomous classification of: 0) juvenile (stages ≤ I), or 1) adult (stages ≥ III), omitting stage II. The dichotomous maturity was modelled vs. age on a binomial distribution, and age at maturity was extracted from the logistic function of the binomial model for each year and for all observations pooled. Changes in age and length at maturity, as well as changes in length-frequency were examined through the time series. To examine changes in length-frequency distribution through time, length-frequency modes were calculated for each year with > 100 observations by implementing LOESS (degree = 2, span = 0.75) on weighted length distributions data. Length data from winter (July, August, September) and spring (October, November, December) obtained from commercial vessels were included in the analysis. Summer (January, February, March) and autumn (April, May, June) length data were excluded to avoid any bias in length frequencies given the reduced presence of kingclip in Falkland waters during both seasons due to their migratory pattern (Arkhipkin et al. 2012).

Length-Based Bayesian biomass estimation method (LBB)

Saturation S was derived using the Length-Based Bayesian biomass estimation method (LBB) for evaluating data-poor stocks (Froese et al. 2018):

$$S = \frac{By}{K}$$

where B_y = stock biomass, and K = carrying capacity.

LBB is based on the principle of calculating relative rates of natural mortality (M) over somatic growth (k), i.e. M/k, and fishing mortality (F) over somatic growth (k), i.e. F/k. This approach cancels out absolute values of time and biomass, reducing the data requirements to lengths only. M/k and F/k are used to derive indices of yield per recruit with and without fishing. The ratio of these indices estimates the current exploited biomass relative to unexploited biomass $B_{current}/B_0$. LBB also provided estimates for length at catch (Lc), the ratio of Lc relative to optimum length at catch (Lc/Lc_{opt}), asymptotic length (L_∞), relative fishing mortality (F/M), and the ratio of observed biomass relative to the biomass that would provide maximum sustainable yield (B/B_{MSY}). LBB was run with the Gibbs sampler JAGS (https://sourceforge.net/projects/mcmc-jags/files/JAGS/4.x/) through the package 'R2jags' (Su & Yajima 2015) in R Studio (RStudio Team 2016) following Froese et al. (2018).

Data from winter and spring were weighted to equality by year for finfish grids as there was no pattern of which season was sampled more from year to year. Weighting consisted in assigning a multiplication factor to seasons that had fewer samples, and fractional parts of the multiplication factor were assigned randomly among the samples; the weighting algorithm was thus partly stochastic. Additional restrictions were implemented to include only trawls as fishing gear and only grids that are open to finfish and calamari licences. The resulting database included length measurements that had been sampled randomly in commercial fishing trawlers (i.e. bottom and semi-pelagic trawls) and grids that are open to finfish licences (i.e. A, W), including licences variances during September/October (Fig. 1a). In addition, length data from research cruises (i.e. licence E) conducted every February since the year 2000 were examined apart from commercial data (Fig. 1b).

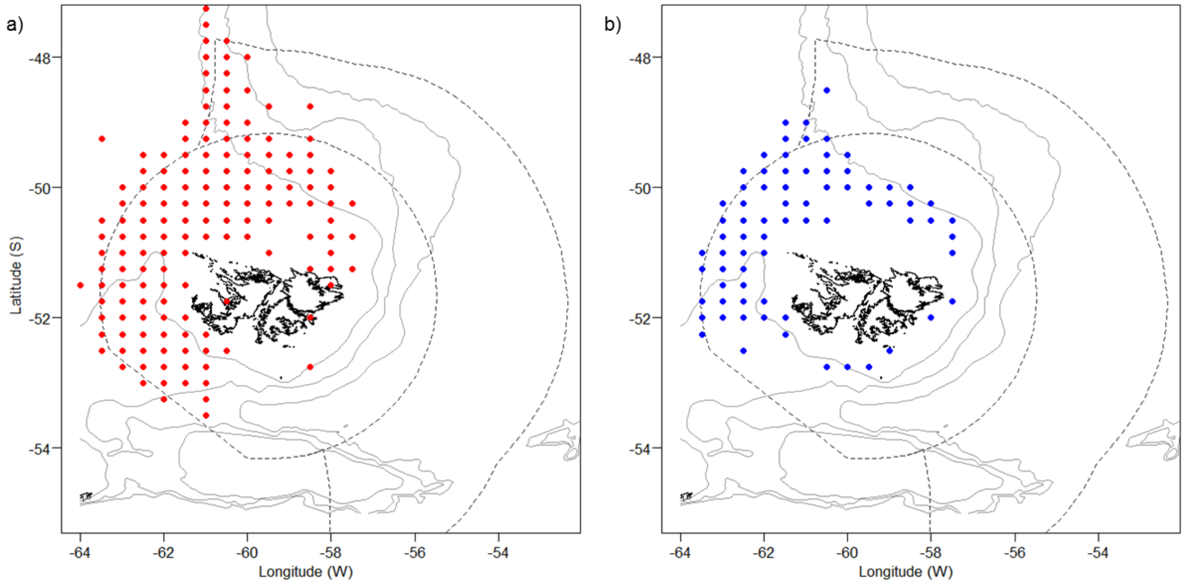

Fig. 1. Source of kingclip catch and sampling data by (a) commercial trawlers under licences A and W in red, and (b) research surveys under licence E in blue around the Falkland Islands.

Time series of annual biomass were calculated by randomly drawing values of growth rate (r) and biomass ratio $B_{current}/B_0$ from their distributions, iterated and optimized 10,000× following Zhou et al. (2018). Medians and 95% confidence intervals were computed for parameters r, K, $B_0 = B_{1987}$, and $B_{current.}$ MSY was also reported and was defined from the Graham-Schaefer production model as indicated in Hilborn & Walters (1992):

$$MSY = \frac{r \cdot K}{4}$$

where r = intrinsic growth rate, and K = carrying capacity.

CMSY

The CMSY method was also implemented to estimate biomass and MSY from catch data and resilience of the species (Froese et al. 2017). Resilience is defined by the spawning stock biomass per recruit that corresponds to replacement fishing mortality (Musick 1999). Monte Carlo simulations were used to detect viable maximum intrinsic rate of population increase (r) and unexploited population size or carrying capacity (K) pairs from probable ranges of these parameters. Kingclip has low resilience according to the classification of

FishBase (Froese & Pauly 2018), which corresponds to a prior r-range of 0.05–0.5 (Froese et al. 2017). The lower and upper bounds of the prior range for carrying capacity (K) were estimated as follows (Froese et al. 2017):

$$K_{low} = \frac{\max(C)}{r_{high}}, K_{high} = \frac{4 \max(C)}{r_{low}}$$

where K_{low} = lower bound of the prior range of K; max*(C)* = maximum catch in the time series; r_{high} = upper bound of the range of r-values that the CMSY method will explore; K_{high} = upper bound of the prior range of K; r_{low} = lower bound of the range of r-values that the CMSY method will explore.

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 only from 1987 (Falkland Islands Government 1989). Taking in consideration an undefined level of fishing pressure on kingclip before 1987, both low (0.01–0.4) and medium (0.2–0.6) prior biomass ranges relative to K (B/K) were examined (Froese et al. 2017). Pairs of r-K were visualized in a scatterplot where CMSY searched for the most probable r. This method relies on the principle that defines r as the maximum rate of increase for the examined population, which should be found among the highest viable r-values. Median biomass levels and 95% confidence intervals were derived from the validated r and K pairs. In addition, a Bayesian state-space implementation of the Graham-Schaefer model (BSM) was used to predict r, K, biomass, MSY, and the ratios B/B_{MSY} and F/F_{MSY} from catch and abundance data following Froese et al (2017).

Results

Commercial catch

The annual mean catch of kingclip in Argentina over the period 1987–2017 was 17,390 t, with a maximum in 1990 of 34,775 t. Catches of kingclip in the Falkland Islands have been on average 2,120 t per year since the start of the Falklands' fisheries management in 1987; catches increased from 1,841 t in 2004 to reach a maximum of 3,977 t in 2013, with a subsequent decrease in 2016–2017 below the long term average (Fig. 2; Appendix I). Annual kingclip catches from Falkland Islands and Argentina had a significant negative correlation ($r = -0.36$, $n = 31$, $p = 0.045$; Appendix II).

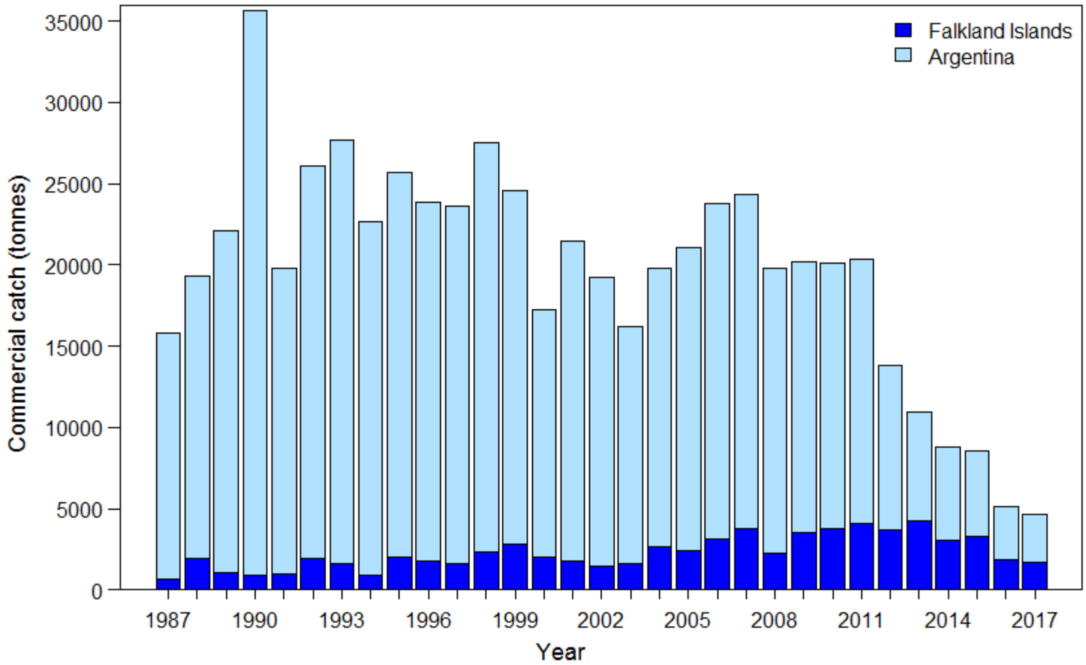

Fig. 2. Commercial catches of kingclip reported in Falkland Islands and Argentinean fisheries from 1987 to 2017.

Age-length relationship

Total length ranged from 21 to 153 cm, whereas age ranged from 1 to 38 years. The age-length relationship (Fig. 3) gave the following values for: L_∞ = 141.04 cm, k = 0.0933, and t_0 = -0.0973 years.

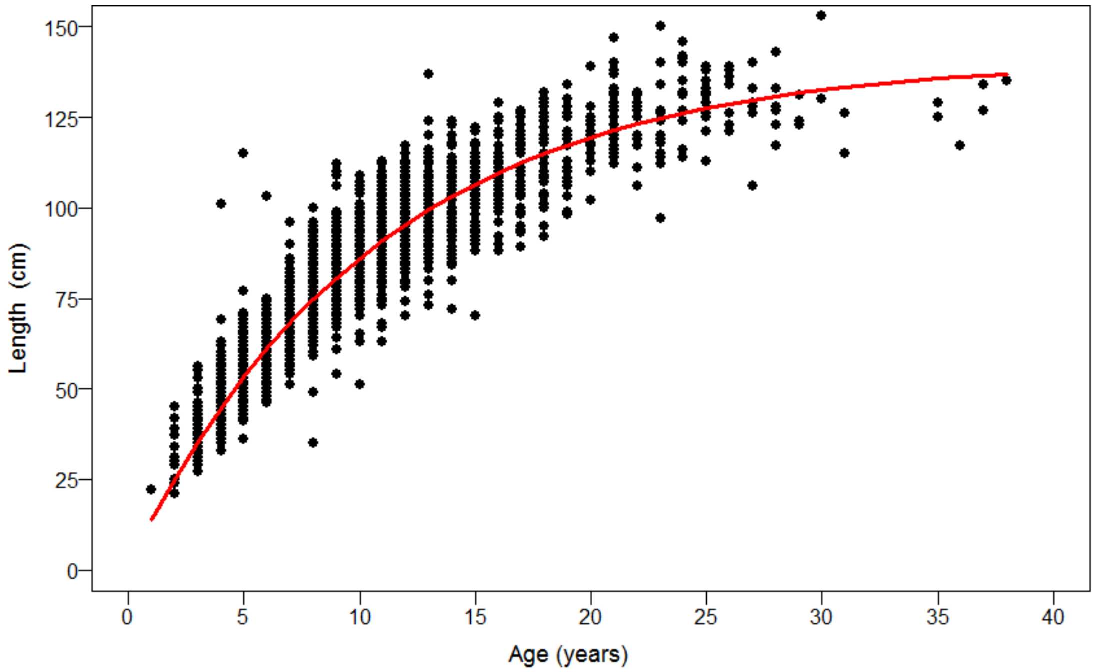

Fig. 3. von Bertalanffy age-length relationship of kingclip from the Falkland Islands.

The range of modal length was 51–87 cm during the period 1990–2017, with a non-significant decreasing linear trend from 62 cm in 1990 to 51 cm in 2018 at an average rate of 0.27 cm per year ($p = 0.16$; Fig. 4). Modal lengths tended to increase over several consecutive years (2003–2008) as a cohort grew, and then decrease again from 2008 to 2009 as the next cohort began to predominate in abundance. The stock was not able to reach large modal lengths again over the subsequent years (see length frequencies per year in Appendix III). The LBB analysis of February survey data showed that average length at capture in 2018 (41.6 cm) was 43 cm below optimum length at capture (84.8 cm).

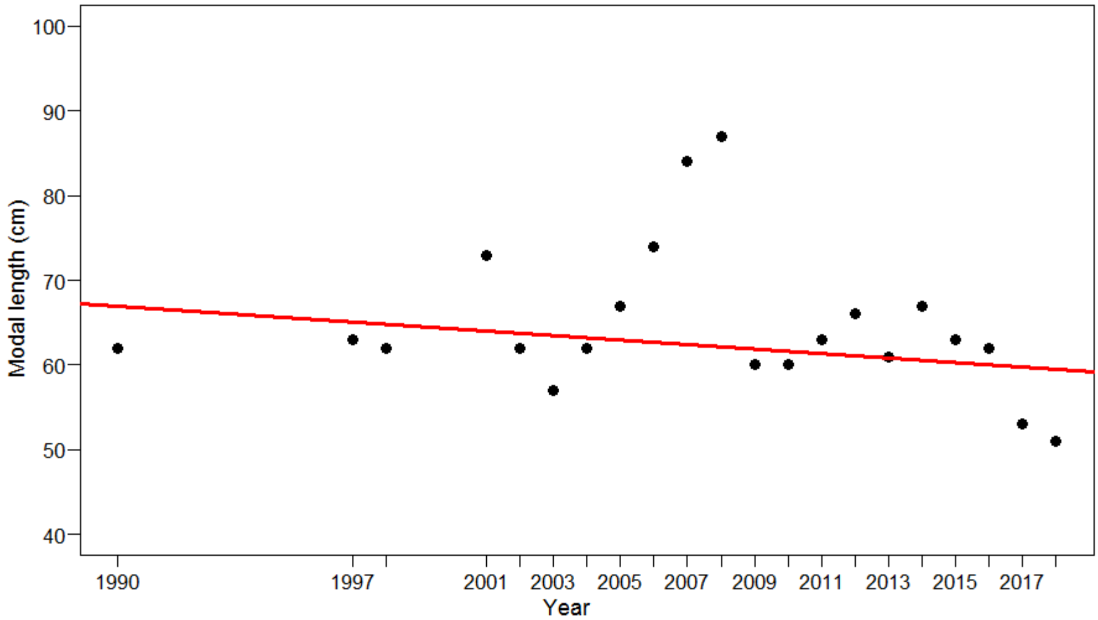

Fig. 4. Annual modes of kingclip lengths in the Falkland Islands. Linear regression of modes vs. year (regression weighted by the inverse RMSD of each year's LOESS function).

Age and length at maturity

A decline in the annual average age at maturity occurred from 10 years in 1988 to 6 years in 2015 ($p < 0.001$) at a rate of 0.11 years per year (Fig. 5a). Similarly, a decline in the annual average length at maturity from 96.6 cm in 1988 to 56 cm in 2018 was observed ($p < 0.001$) at a rate of 1.1 cm per year (Fig. 5b). Annual age and size at maturity curves per year can be consulted in Appendixes IV–V.

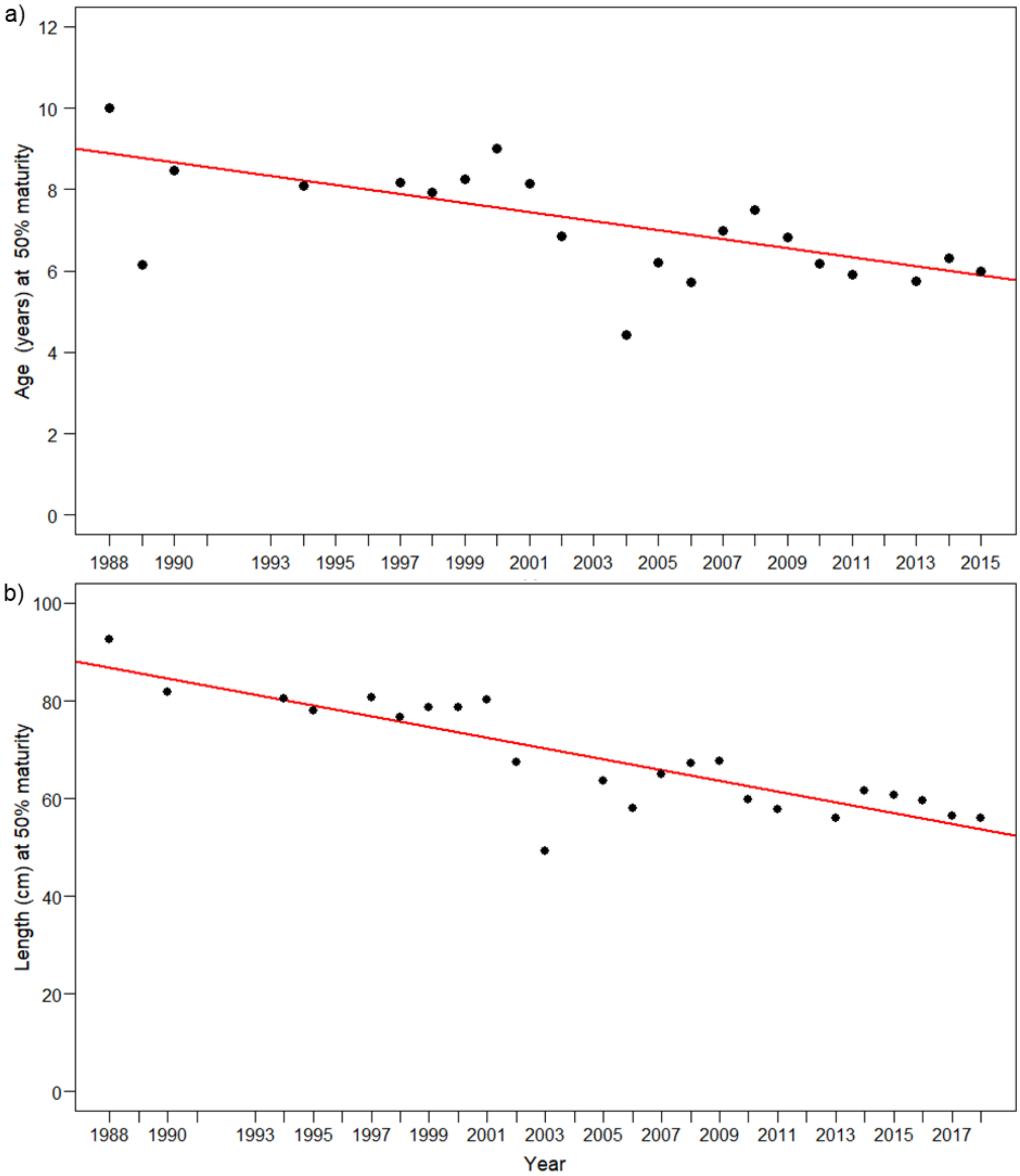

Fig. 5. Linear regression of (a) age and (b) length at 50% maturity of kingclip vs. year (regression weighted by the R^2 of each year's logistic function).

Biomass estimation

The different calculations for empirical life-history mortality provided the following results:

$$M1 = 4.899 \cdot t_{max}^{-0.916} \qquad = 0.1749$$

$$M2 = 4.118 \cdot k^{0.73} \cdot L_{\infty}^{-0.33} \qquad = 0.1484$$

$$M3 = 1.82 \cdot k \qquad = 0.1794$$

$$M4 = \frac{1.65}{t_{mat}} \qquad = 0.2330$$

$$M5 = \frac{4.3}{t_{max}} \qquad = 0.1132$$

where t_{max} = 38 years; k = 0.0933 cm · year^{-1}; L∞ = 141.04 cm; t_{mat} = 7 years.

A total of 25,054 kingclip lengths from commercial data were used for the LBB calculations. High margins of uncertainty and high inter-annual variability in B/B_0 ratios were observed prior to 2005. Therefore, only the smoother trend of the B/B_0 ratio from 2005 to 2017 is presented (Fig. 6a). A total of 13,461 kingclip lengths obtained from research data allowed B/B_0 estimations only from the year 2005 due to limited data in previous years. The inter-annual B/B_0 ratio followed a smoother trend during the same period of time using research data (Fig. 6b; Appendix VI) compared with commercial data. An exploratory comparative analysis for 2017 showed more conservative values using research data (B_{2017}/B_0 = 0.181; B/B_{MSY} = 0.42) compared to commercial data (B_{2017}/B_0 = 0.231; B/B_{MSY} = 0.63). LBB outputs for commercial and research data for the year 2017, and for research data for the year 2018, are indicated in Table I for comparative purposes.

Table I. Summary of LBB parameters for kingclip from the most recent year of commercial and research data. Lc = length at first capture; Lc_{opt} = optimum length at capture; L_{max} = maximum length; L_{∞} = asymptotic length; alpha = steepness of the ogive; F/k = fishing mortality rate relative to somatic growth rate; M/k = natural mortality rate relative to somatic growth rate; F/M = relative fishing mortality; B/B_0 = Current biomass relative to unfished biomass; B/B_{MSY} = ratio of observed biomass to the biomass that would provide maximum sustainable yield. Medians with 95% confidence intervals in parentheses.

	2017		2018
Parameter	Commercial	Research	Research
Lc	43.154 (42.876 – 43.494)	47.292 (46.666 – 47.996)	41.636 (41.351 – 41.915)
Lc/Lc_{opt}	0.48	0.56	0.47
L_{max}	116	136	131
L_{∞}	147.839 (144.904 – 151.202)	149.187 (145.460 – 152.034)	145.215 (142.788 – 147.748)
alpha	47.105 (45.567 – 48.590)	28.263 (27.306 – 29.402)	42.591 (41.598 – 43.785)
F/k	1.712 (1.541 – 1.931)	2.269 (2.029 – 2.531)	2.332 (2.145 – 2.555)
M/k	1.516 (1.390 – 1.650)	1.544 (1.372 – 1.695)	1.471 (1.348 – 1.601)
F/M	1.132 (0.939 – 1.351)	1.487 (1.244 – 1.791)	1.571 (1.364 – 1.847)
B/B_0	0.231 (0.181 – 0.289)	0.181 (0.140 – 0.227)	0.157 (0.129 – 0.191)
B/B_{MSY}	0.63 (0.496 – 0.79)	0.42 (0.347 – 0.505)	0.43 (0.353 – 0.522)

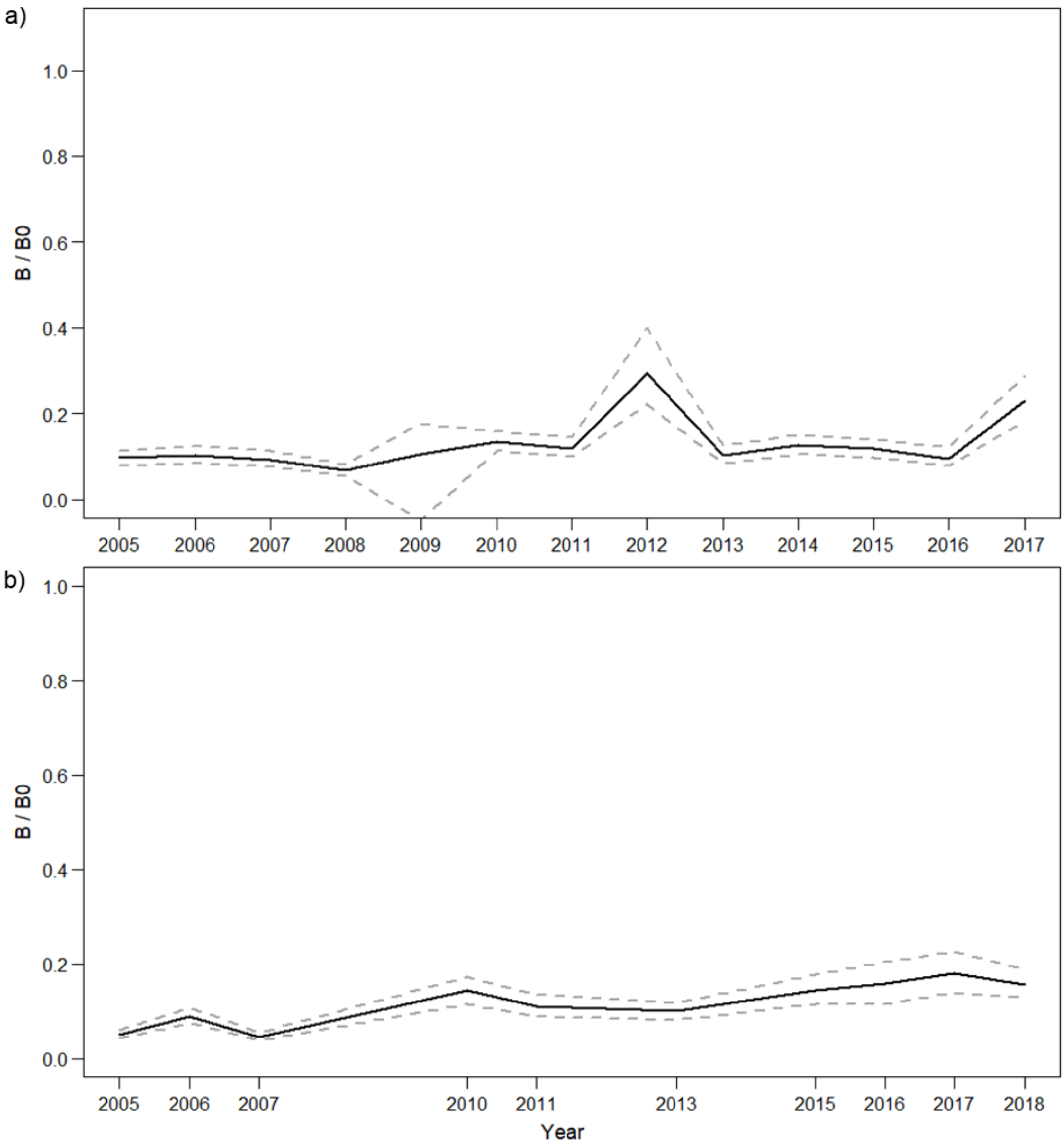

Fig. 6. Time series of $B/B_0 \pm 95\%$ confidence intervals calculated from kingclip lengths from (a) commercial and (b) research data using the LBB model (Froese et al. 2018).

Prior distributions for growth rates r calculated using the different mortality estimates were:

$$r_1 \sim \exp(\text{norm}(\log(\mu_r), \sigma_r)) = \exp(\text{norm}(\log(2 \cdot 0.87 \cdot 0.1749), \text{sqrt}(0.2312)))$$

$$r_2 \sim \exp(\text{norm}(\log(\mu_r), \sigma_r)) = \exp(\text{norm}(\log(2 \cdot 0.87 \cdot 0.1369), \text{sqrt}(0.2312)))$$

$$r_3 \sim \exp(\text{norm}(\log(\mu_r), \sigma_r)) = \exp(\text{norm}(\log(2 \cdot 0.87 \cdot 0.1628), \text{sqrt}(0.2312)))$$

$$r_4 \sim \exp(\text{norm}(\log(\mu_r), \sigma_r)) = \exp(\text{norm}(\log(2 \cdot 0.87 \cdot 0.2330), \text{sqrt}(0.2312)))$$

$$r_5 \sim \exp(\text{norm}(\log(\mu_r), \sigma_r)) = \exp(\text{norm}(\log(2 \cdot 0.87 \cdot 0.1132), \text{sqrt}(0.2312)))$$

whereas the prior distribution for stock saturation S was:

$$S \sim \text{norm}\,(\mu_{B2018/B0}, \sigma_{B2018/B0}) = \text{norm}\,(0.157, 0.02142)$$

Parameters estimated from the OCOM Graham-Schaefer production model based on the different mortality rates are summarized in Table II. Using the most conservative mortality (M = 0.1132), median intrinsic growth rate was 0.1967 which resulted in a 22% increase of the population per year by implementing $e^{0.1967} - 1$. Carrying capacity was approximately 306,972 t (162,432 – 475,211 t; 95% confidence interval). The biomass of kingclip in 2017 was estimated at 47,527 t (23,726 – 80,753 t; 95% confidence interval) and the MSY was 15,095 t (9,034 – 20,159 t; 95% confidence interval). Accordingly, a constant decrease in median biomass was observed from 1987 (308,986 t) to 2017 (47,527 t; Fig. 7).

Table II. OCOM Graham-Schaefer production model parameters and estimates of biomass and MSY for kingclip, 1987 to 2017. M = mortality rate; r = intrinsic growth rate; K = carrying capacity; B_{1987} = biomass in 1987; B_{2017} = biomass in 2017; MSY = maximum sustainable yield. Medians with 95% confidence intervals in parentheses; the most conservative estimates are indicated in bold font.

M	r	K	B_{1987}	B_{2017}	MSY
0.1749	0.3061 (0.1185 – 0.7731)	231751 (113510 – 397898)	231751 (113513 – 397903)	35911 (16551 – 65790)	17734 (11809 – 21939)
0.1369	0.2377 (0.0944 – 0.6165)	273740 (136732 – 439443)	273680 (136712 – 439456)	42534 (20076 – 74925)	16283 (10360 – 21072)
0.1628	0.2827 (0.1114 – 0.7284)	244699 (119284 – 409113)	244675 (119292 – 409122)	37843 (17563 – 68162)	17288 (11386 – 21721)
0.2330	0.4081 (0.1576 – 1.0509)	188515 (87471 –346868)	188542 (87471 – 346851)	29340 (13102 – 56713)	19239 (13664 – 22981)
0.1132	**0.1967** **(0.0760 – 0.4966)**	**306972** **(162432 –475211)**	**306986** **(162505 – 475248)**	**47527** **(23726 – 80753)**	**15095** **(9034 – 20159)**

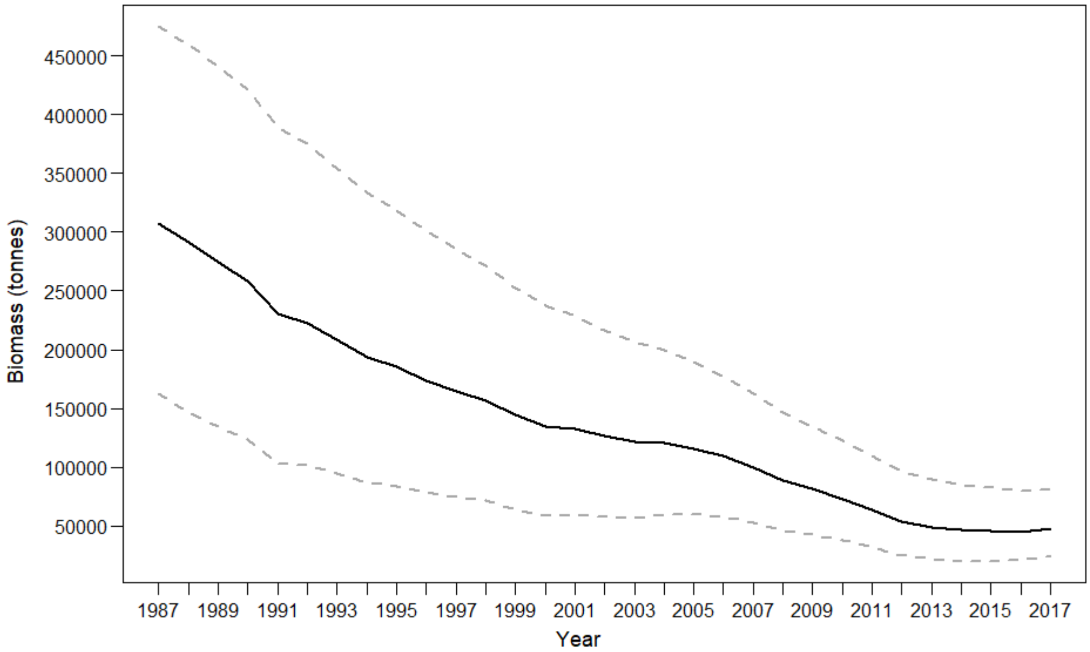

Fig. 7. Median and 95% confidence intervals of annual kingclip biomass estimated from the OCOM Graham-Schaefer production model.

For the CMSY and BSM approaches, the prior range for K was 71,250–2,850,000 t. Biomass and MSY estimates were more conservative when examining prior medium biomass (0.2–0.6) compared to prior low biomass (0.01–0.4) at the beginning of the time series. Parameters estimated from prior low biomass (0.01–0.4) are not presented for brevity. In particular, BSM resulted in more conservative estimates for 2017 (B_{2017} = 42,000 t; MSY = 19,500 t) compared to CMSY (Table III, Fig. 8; Appendix VII), and suggests that kingclip is overfished ($B < B_{MSY}$) and overfishing is currently occurring ($F > F_{MSY}$; Fig. 9).

Table III. CMSY and BSM Graham-Schaefer production model parameters and estimated biomass and MSY for kingclip, 1987 to 2017. r = intrinsic growth rate; K = carrying capacity; B_{1987} = biomass in 1987; B_{2017} = biomass in 2017; MSY = maximum sustainable yield. Medians with 95% confidence intervals in parentheses.

Analysis	r	K	B_{1987}	B_{2017}	MSY
CMSY	0.27 (0.159–0.459)	330000 (156000–699000)	180488 (95218–254582)	104765 (6850–216771)	22300 (14600–34100)
BSM	0.151 (0.063–0.363)	517000 (254000–1053000)	-	42000 (10900–149000)	19500 (12100–31400)

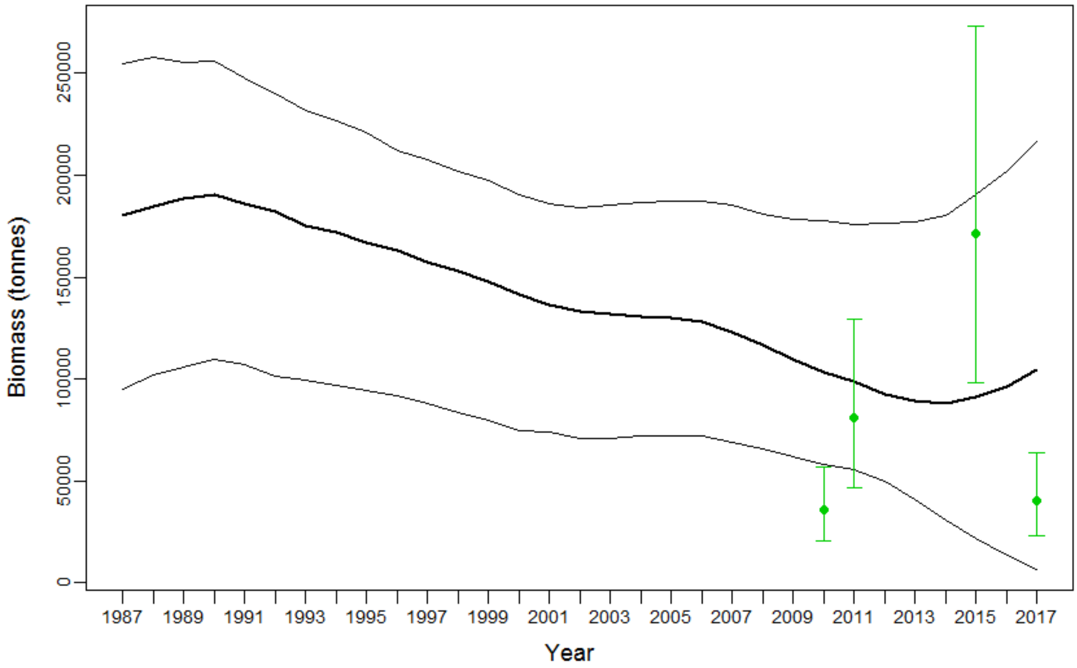

Fig. 8. Median and 95% confidence intervals of annual kingclip biomass estimated from the CMSY (black lines) and BSM Graham-Schaefer production model (green dots and error bars).

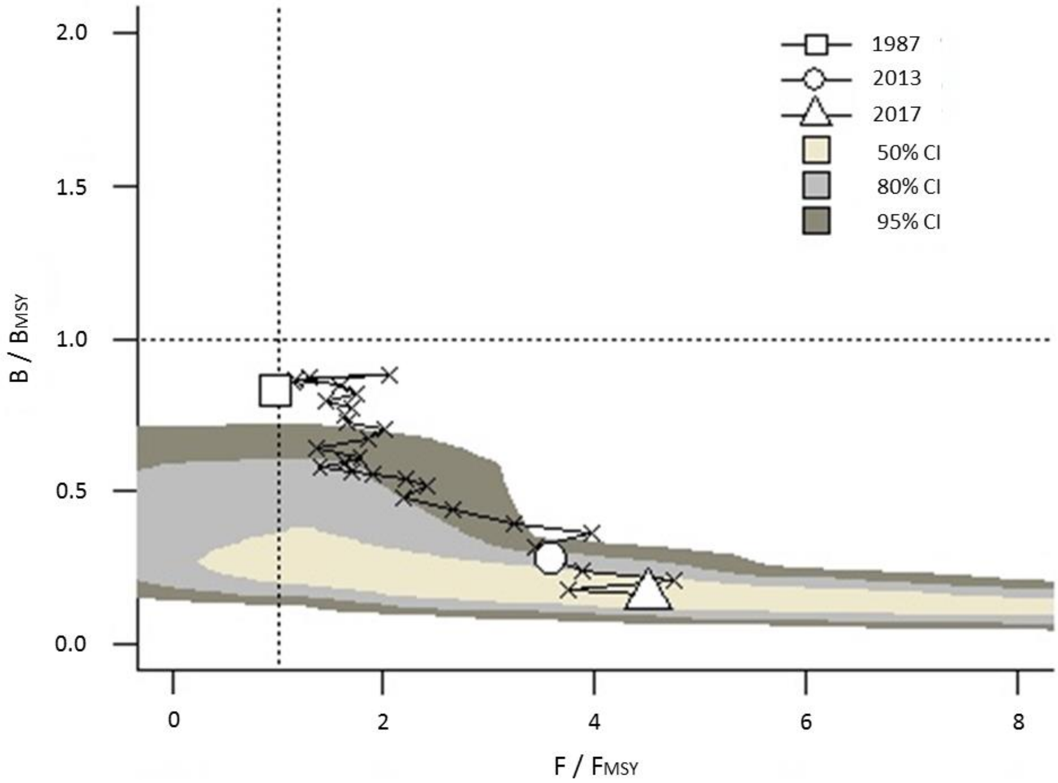

Fig. 9. Trajectory of relative stock size (B/B_{MSY}) vs. relative exploitation (F/F_{MSY}) implementing the BSM analysis on kingclip in the Falkland Islands from 1987 to 2017.

Conclusions

The LBB analysis using research data suggests that the shared Falkland Islands-Argentinean stock size in 2018 was 16% of the unexploited stock size (B_{2018}/B_0 = 0.16) and approximately 43% of the biomass that would provide maximum sustainable yield (B_{2018}/B_{MSY} = 0.43). The different approaches implemented in this study provided fairly similar median estimates of MSY (15,095 – 22,300 t), although median biomass estimates for the year 2017 had a wider range (29,340 – 104,765 t). From all the approaches implemented, the OCOM Graham-Schaefer production model based on the most conservative estimate of mortality (0.1132) provided also the most conservative estimate of median MSY (15,095 t; Table II). The median MSY estimated for 2017 was thus 7,682 t above the average annual kingclip catch from 2013 to 2017 (7,413 t). However, the BSM approach suggests that kingclip is overfished ($B < B_{MSY}$) and overfishing is currently occurring ($F > F_{MSY}$). This finding is supported by the current low average length at capture compared to the optimum length at capture, by the relatively low intrinsic growth rate estimated in this study (0.19) compared to the literature (0.31; Froese & Pauly 2018), and by the low resilience of the species (Froese & Pauly 2018); indication that the stock is being harvested at a rate that is outpacing growth rates in terms of overall weight or biomass.

Although previous studies suggest that stocks can yield sustainable harvests at levels considered overfished (Hilborn 2010), and despite the fact that kingclip is not the primary target in any Falkland Islands fishery, the various metrics of the kingclip stock indicate a need for precautionary management. Froese et al. (2011) proposed 0.5 B_{MSY} as a limit reference point for closing target fisheries, a threshold that would be triggered according to the current LBB estimate. Therefore, it is suggested that with $B_{current}/B_{MSY}$ = 43%, the present catch limit of the combined kingclip stock examined should be 43% of MSY: 15,095 × 0.43 = 6,491 t. Most of the kingclip catch occurred in the northwest and west, and during August (grids XEAG, XDAG, XPAD, XQAD, XGAJ, XFAH), September (grids XEAG, XDAG, XPAD, and XLAD), and October (XLAD, XRAD, and XQAB), with maximum mean monthly catches in September (Appendix VIII). Further spatial or temporal catch restrictions may be advised if the kingclip stock continues to show decreasing abundance trends.

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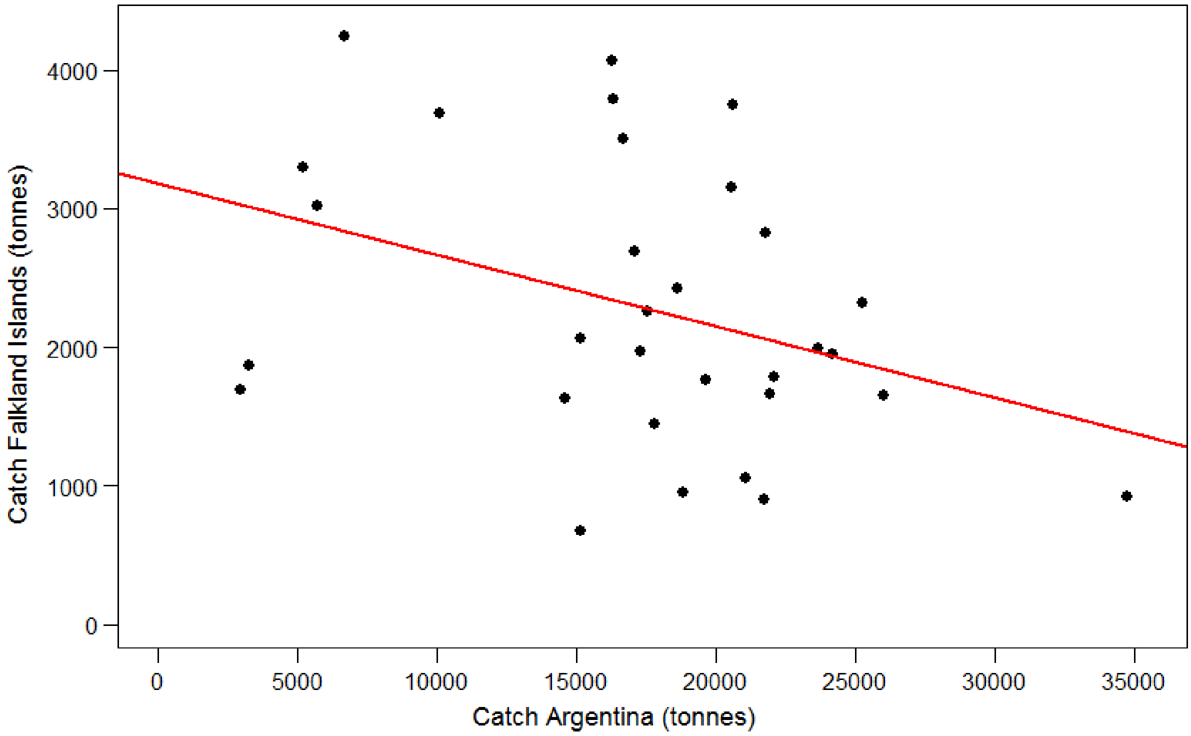
Appendices

Appendix I.

Historical commercial catch (t) of kingclip in Argentinean and Falkland Islands waters.

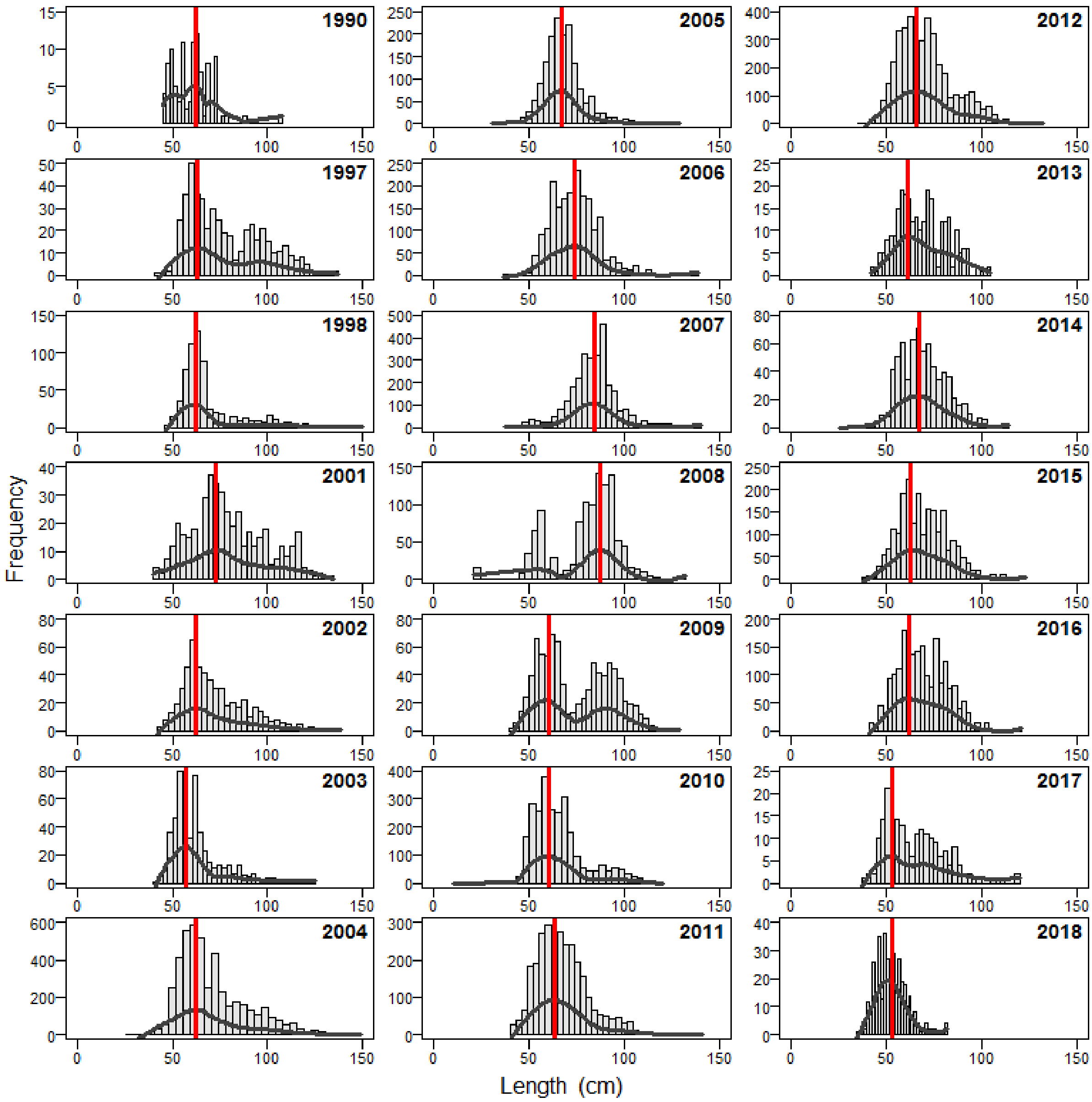
Year	Argentina	Falkland Islands	Total
1987	15175	748	15923
1988	17307	1944	19251
1989	21092	976	22068
1990	34775	850	35625
1991	18850	949	19799
1992	24174	1952	26126
1993	26010	1643	27653
1994	21725	899	22624
1995	23711	1985	25696
1996	22095	1682	23777
1997	21939	1392	23331
1998	25245	2217	27462
1999	21793	2602	24395
2000	15183	1875	17058
2001	19667	1625	21292
2002	17817	1224	19041
2003	14605	1274	15879
2004	17125	1841	18966
2005	18628	1936	20564
2006	20588	2821	23409
2007	20609	3592	24201
2008	17559	2227	19786
2009	16694	3390	20084
2010	16357	3639	19996
2011	16276	3867	20143
2012	10112	3510	13622
2013	6694	3977	10671
2014	5750	2881	8631
2015	5238	2983	8221
2016	3298	1612	4910
2017	3000	1632	4632
2018	3278	1445	4723

Appendix II.



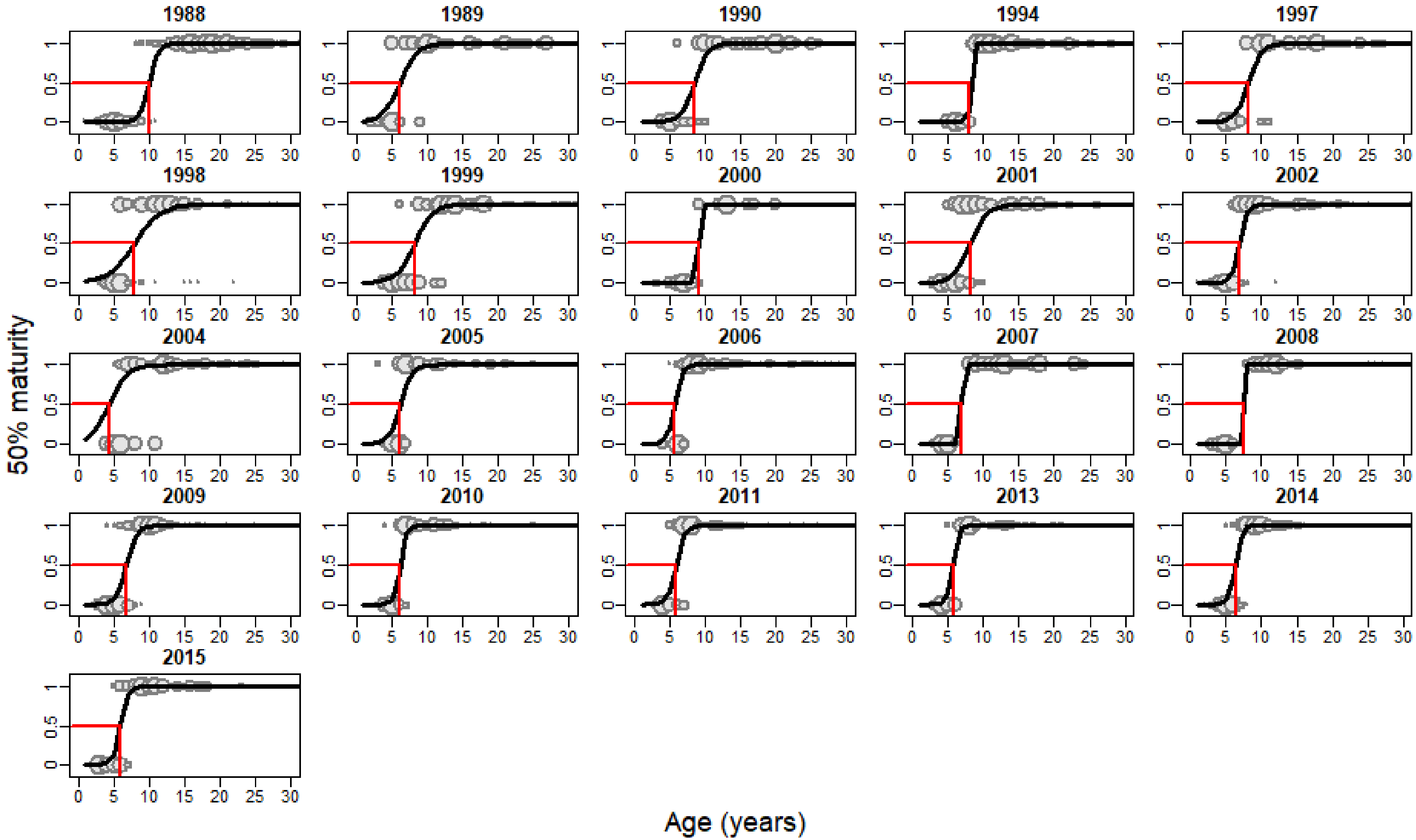
Association between Falkland Islands and Argentine kingclip annual catches from 1987 to 2017. There was a negative and significant Pearson's correlation between annual catches from the Falkland Islands and Argentina ($r = -0.36$, $n = 31$, $p = 0.045$).

Appendix III.



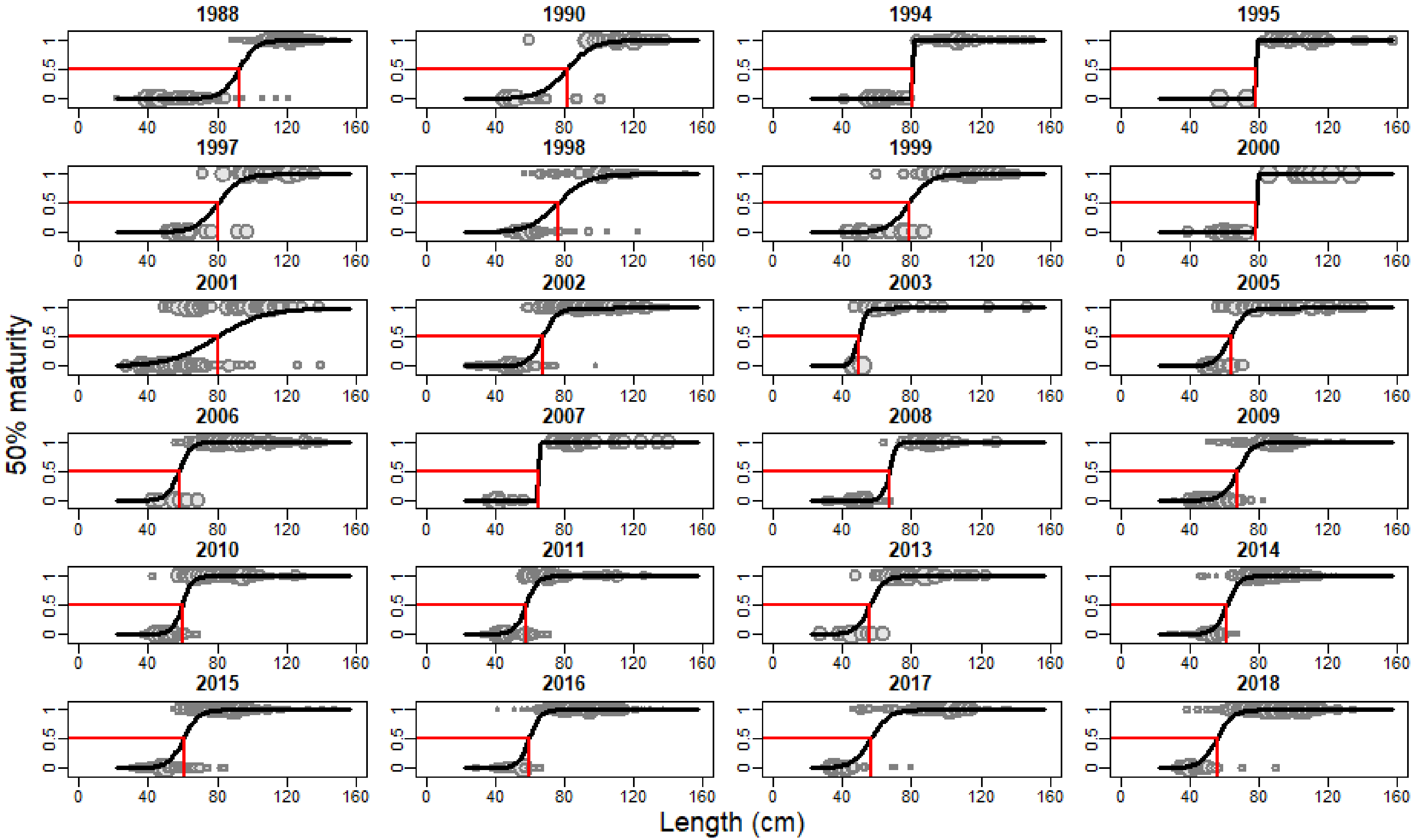
Annual modes of kingclip lengths in the Falkland Islands from 1990 to 2018. The modes (vertical red lines) are calculated from LOESS smooths over the length distributions to mitigate sampling fluctuations. $n_{1990} = 101$; $n_{1997} = 485$; $n_{1998} = 637$; $n_{2001} = 447$; $n_{2002} = 539$; $n_{2003} = 546$; $n_{2004} = 4612$; $n_{2005} = 1589$; $n_{2006} = 1970$; $n_{2007} = 2889$; $n_{2008} = 1128$; $n_{2009} = 872$; $n_{2010} = 2637$; $n_{2011} = 2882$; $n_{2012} = 3972$; $n_{2013} = 270$; $n_{2014} = 694$; $n_{2015} = 2152$; $n_{2016} = 2012$; $n_{2017} = 195$; $n_{2018} = 362$.

Appendix IV.



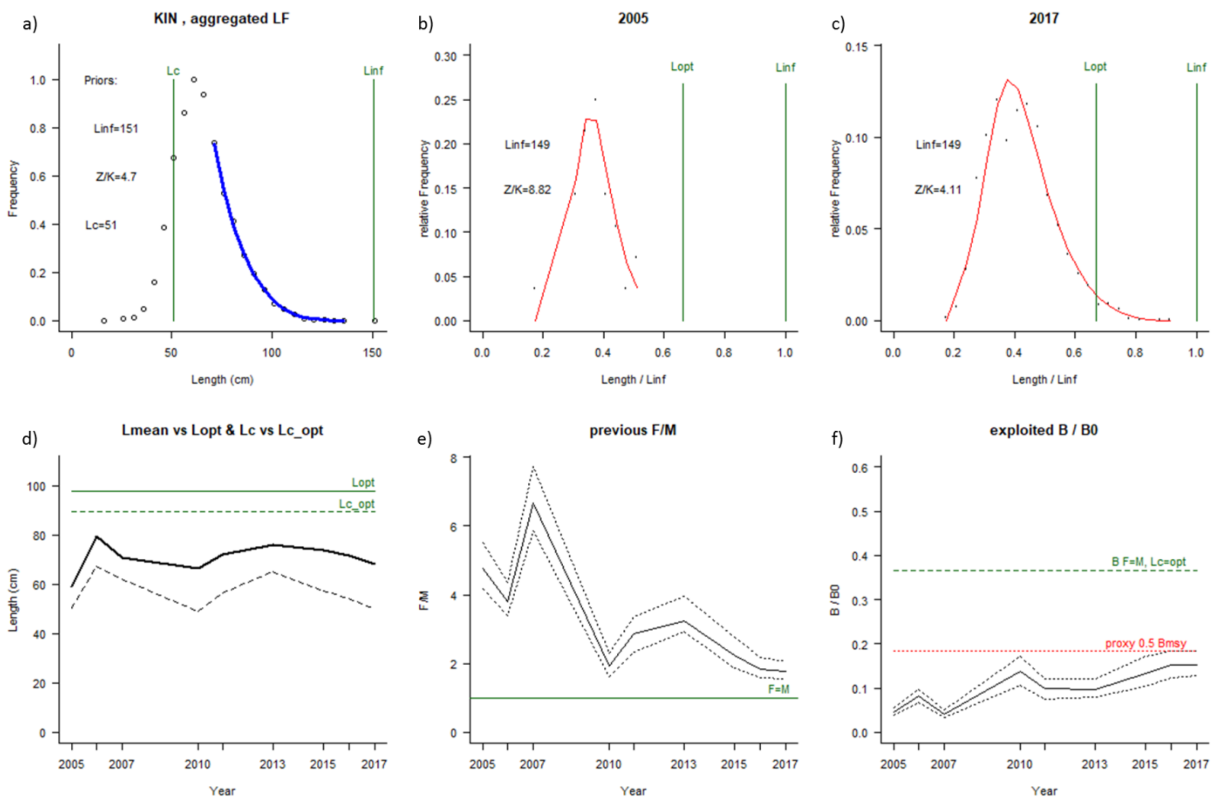
Annual ages at 50% maturity of kingclip in the Falkland Islands from 1988 to 2015. Logistic regressions were made for age vs. juvenile (0: maturity stages 0 and I) and adult (1: maturity stages III+).

Appendix V.



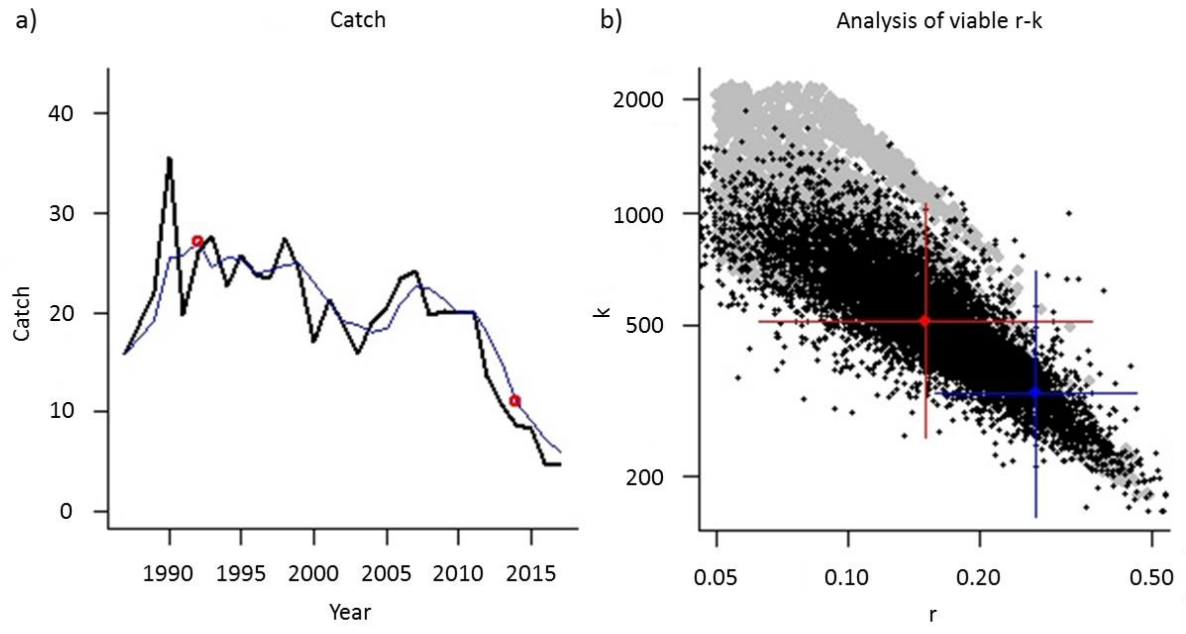
Annual lengths at 50% maturity of kingclip in the Falkland Islands from 1988 to 2018. Logistic regressions were made for length vs. juvenile (0: maturity stages 0 and I) and adult (1: maturity stages III+).

Appendix VI.



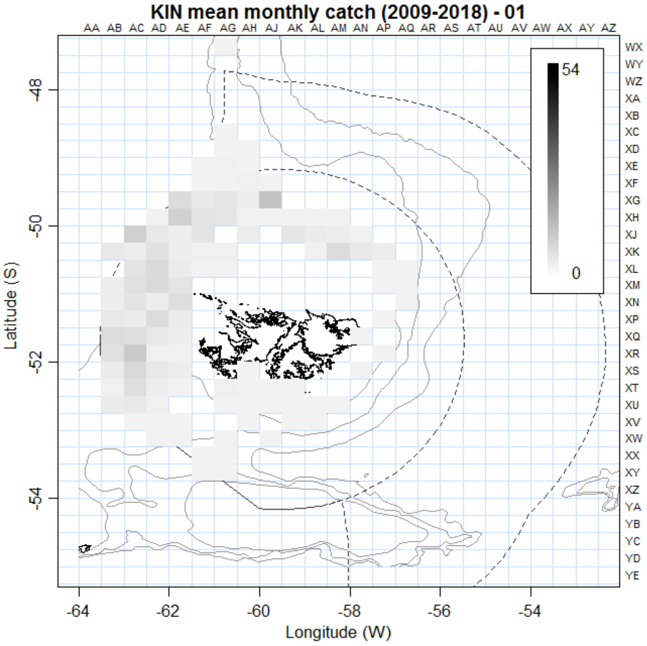
Length-Based Bayesian biomass estimation method (LBB) implemented on kingclip research data from the Falkland Islands from 2000 to 2017. (a) Accumulated length frequency data used to estimate priors for Lc, L_{inf} and Z/k. (b) Length frequency data for the first year in the time series. (c) Length frequency data for the last year in the time series. The red curves provide estimates of Z/k, M/k, F/k, Lc, and L_{inf}. L_{opt} is calculated from L_{inf} and M/k. (d) L_{mean} (bold black curve) relative to L_{opt}, and Lc (dashed black curve) relative to Lc_{opt}. (e) Relative fishing pressure F/M (black curve) and approximate 95% confidence limits (dotted curves), with indication of the reference level where F = M (green horizontal line). (f) Relative biomass B/B_0 (black curve) and approximate 95% confidence limits (dotted black curves), with indication of a proxy for B_{MSY} (green dashed line) and a proxy for B_{PA} or 0.5 B_{MSY} (red dotted line).

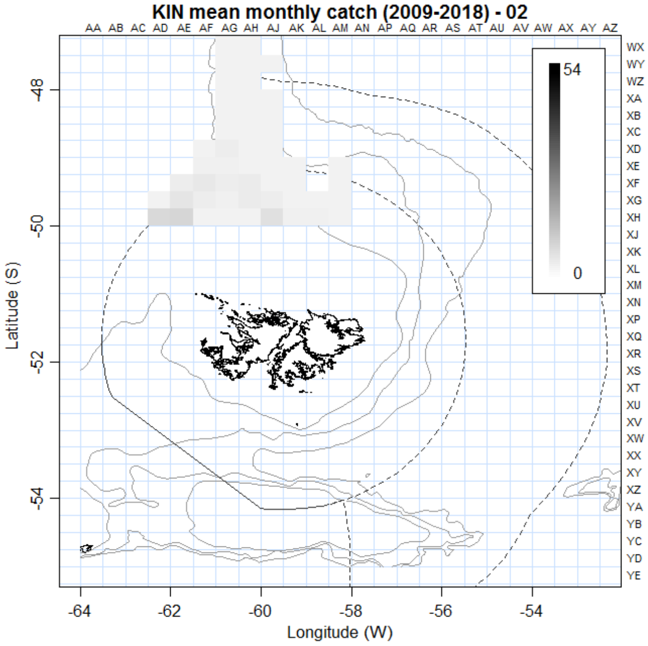
Appendix VII.

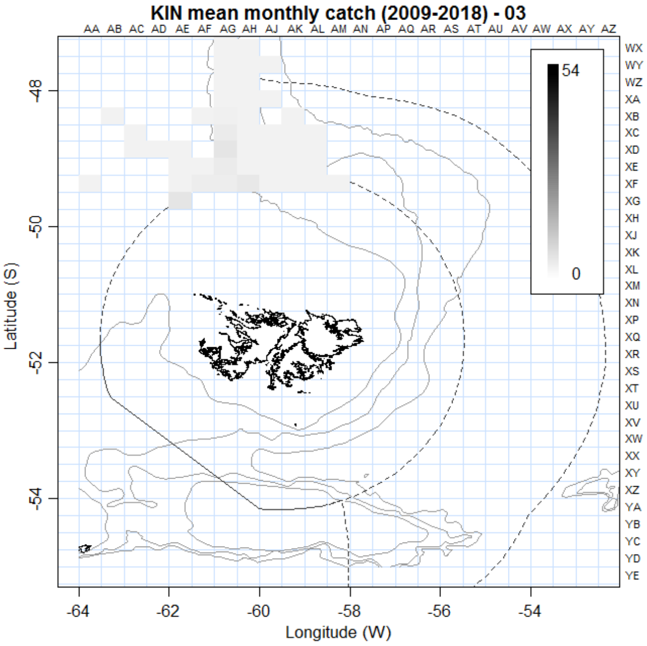


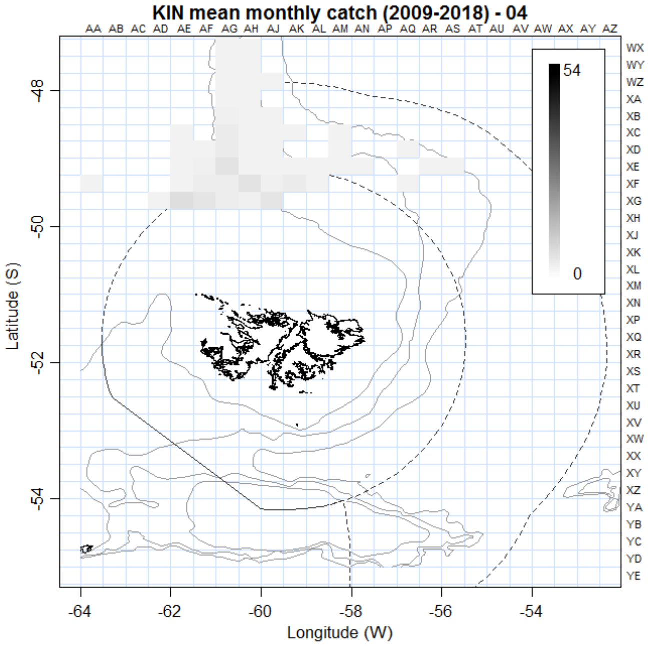
CMSY and BSM analyses on kingclip in the Falkland Islands from 1987 to 2017. (a) Time series of catches (black) and three-years moving average (blue); the highest and lowest catches are indicated by red dots. (b) Probable r-K pairs (grey dots) and most probable r-K pair with approximate 95% confidence limits (blue cross) found by CMSY; probable r-K pairs (black dots) and most probable r-K pair with 95% confidence limits (red cross) found by the BSM model.

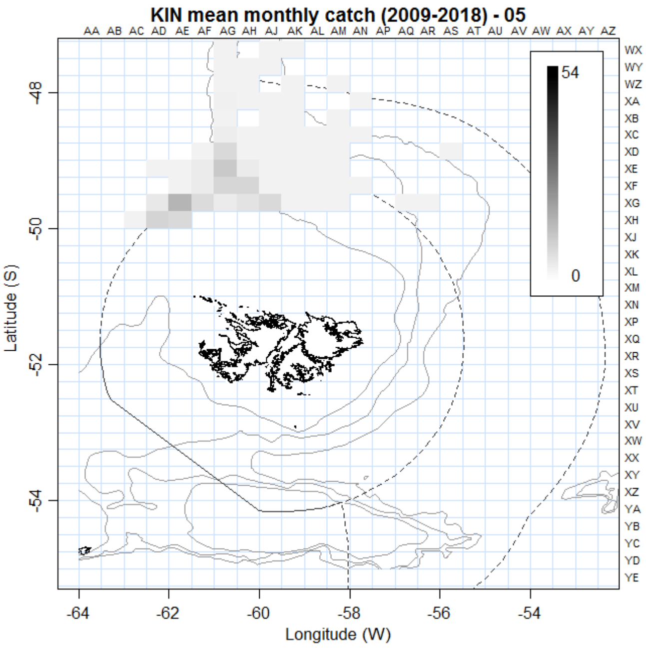
Appendix VIII.

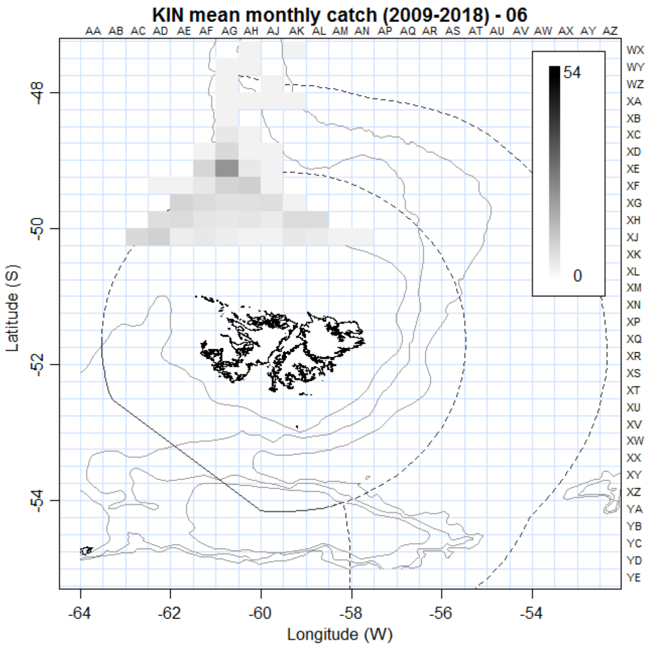









KIN mean monthly catch (2009-2018) - 05
Latitude (S)
Longitude (W)
54
0


KIN mean monthly catch (2009-2018) - 06
Latitude (S)
Longitude (W)
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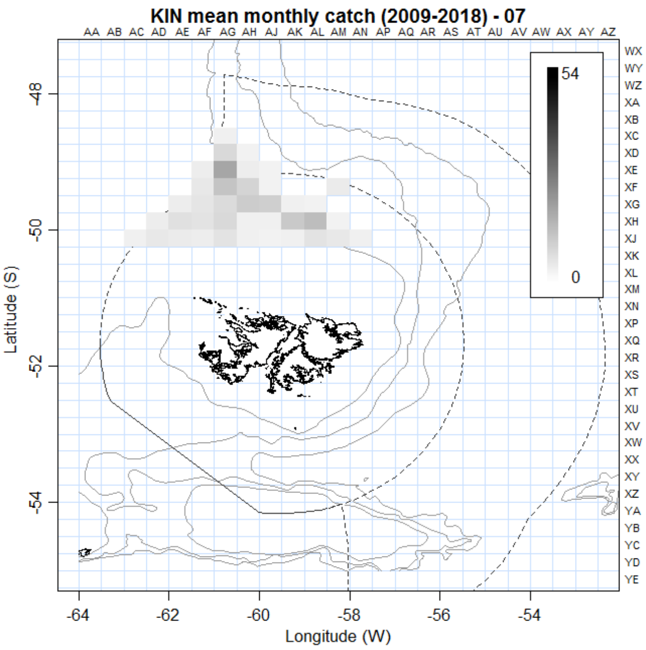
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Latitude (S)
Longitude (W)
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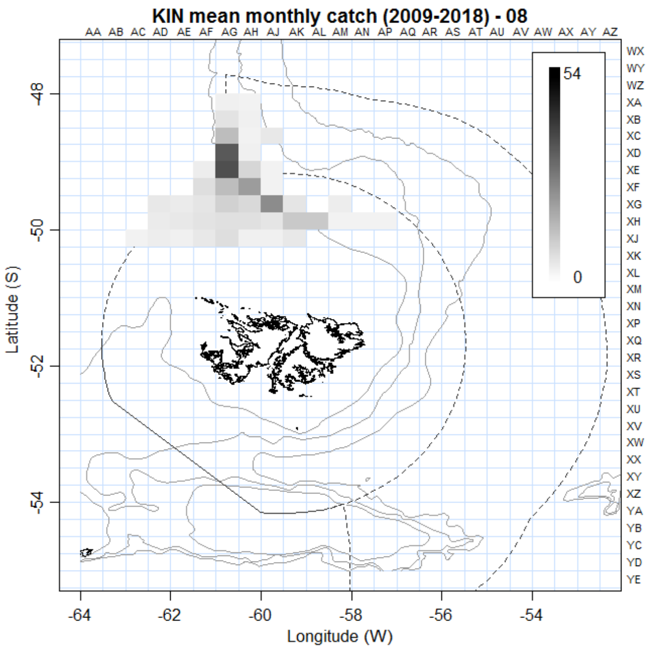
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Latitude (S)
Longitude (W)
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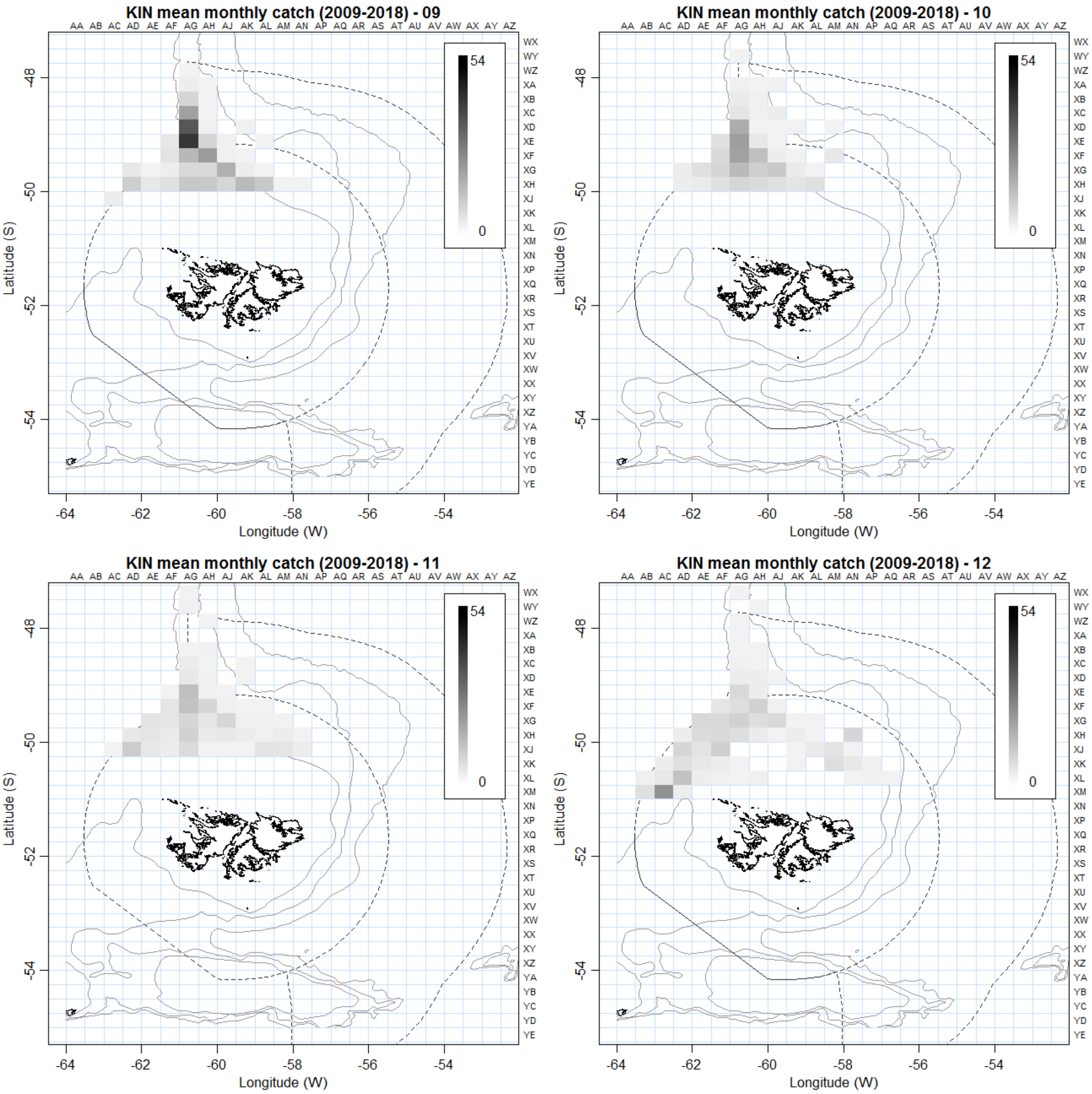

Mean monthly catch of kingclip around the Falkland Islands from 2009 to 2018. The scale indicates catch in tonnes.