February trawl survey biomasses of fishery species in Falkland Islands waters, 2010–2020

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DESIRE THE RIGHT

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1. Summary

Survey biomass assessments of 10 commercial species: Argentine shortfin squid, banded grenadier, common hake, hoki, kingclip, Patagonian squid, red cod, rock cod, southern blue whiting, and toothfish, were carried out in Falkland Islands waters. The assessments were based on catch data of 1,158 bottom trawls taken during the February groundfish and calamari pre-season surveys from 2010, 2011, and 2015 to 2020.

Comparison of biomass estimates showed that 9 out of the 10 species assessed had lower biomass in February 2020 than in February 2010. The biomass of rock cod in 2020 was 3% of its biomass in 2010; southern blue whiting biomass was 13%, red cod 24%, hoki 29%, toothfish 33%, hake 37%, banded grenadier 46%, the Patagonian squid 47%, and kingclip was 69%. The biomass of the Argentine short-fin squid increased gradually since 2016 to reach 143,952 t in 2020, the second highest biomass estimated in the time series. It is noted, however, that for most of these species Falkland Islands waters represent only part of their range, and for some migratory species February is not a time of peak abundance.

In February 2020, the geographic distribution of the Argentine short-fin squid was to the north of the Falkland Island Conservation Zone (FICZ), and common hake were located to the north-west. Red cod and kingclip occurred around the west. Rock cod, hoki, banded grenadier and toothfish were located mainly to the south-west. Patagonian squid were caught around the FICZ but mainly to the south whereas southern blue whiting occurred only to the south.

Rock cod, common hake, and hoki had statistically significant declining trends in mean length from 2010 to 2020 at rates of 0.47 cm/year, 0.97 cm/year, and 0.62 cm/year, respectively.

2. Introduction

The Falkland Islands shelf is located within the Patagonian large marine ecosystem, one of the most productive areas in the world (Arkhipkin et al. 2012). The Patagonian large marine ecosystem is comprised of a southern temperate ecosystem in the north and a sub-Antarctic ecosystem in the south, divided by a boundary that runs from the south-west to the north-east through the Falkland Islands (Boltovskoy 1999). The temperate ecosystem lies within waters of subtropical origin, transported onto the shelf by the Brazil Current and mixed with temperate shelf waters. Several productive zones are revealed in this ecosystem, mainly due to the existence of tidal mixing oceanographic fronts, as well as seasonal fronts originating from cold fresh water inflows into the Strait of Magellan. The sub-Antarctic ecosystem lies within waters of sub-Antarctic origin transported onto the shelf by the Falkland Current (Peterson & Whitworth 1989). The Falkland Current diverges from the main stream of the Antarctic Circumpolar Current in the Drake Passage and turns northwards. The Falkland Current splits at the continental slope south of the Falkland Islands into a weak branch and a stronger branch that flow around the west and east of the Islands, respectively (Bianchi et al. 1982). These oceanographic features affect the distribution and abundance of marine species; for instance, Argentine short-fin squid *Illex argentinus* and hoki *Macruronus magellanicus* migrate to frontal zones for feeding and back to non-frontal zones for spawning (Agnew 2002). In contrast, migrations of deep water fish such as toothfish *Dissostichus eleginoides* and the ridge scaled rattail *Macrourus carinatus* into the shelf are favoured by intrusions of sub-Antarctic waters (Laptikhovsky et al. 2008a,b; Arkhipkin & Laptikhovsky 2010).

Squid and fish around the Falkland Islands have been targeted by international fishing fleets over decades. However, catch data by species only started to be recorded systematically from the year 1987 (Falkland Islands Government 1989). Maximum catches of 462,487 t of squid and fish were observed in 2015, likely associated to oceanographic changes that favoured migration into Falkland waters, and therefore the abundance of *I. argentinus*. Contrastingly, commercial catches since 2016 have been amongst the lowest in over 34 years of historical catch data (mean 152,099 t; Falkland Islands Government 1989, 2019). Finfish license allocations in the Falkland Islands are set by Total Allowable Effort (TAE) calculated as a function of the catchability of an index species that represents the main target of the fishery. This approach works under the assumption of consistent relationships among catch, effort, and biomass. The first index species for finfish TAE was southern blue whiting (*Micromesistius australis australis*). However, with declining catches of southern blue whiting and increasing catches of rock cod (*Patagonotothen ramsayi*), the licensing index species was switched to rock cod in 2011 (Payá et al. 2010). Catches of rock cod also have decreased since 2010 (Falkland Islands Government 2019) and no other single species has taken a similar consistent level of predominance. Therefore, a mandate to assess each individual commercial stock has been prioritized. An important step to achieve this goal is to assess the abundance and distribution of each commercial species in the FICZ and Falkland Outer Conservation Zone (FOCZ) based on commercial and scientific surveys.

Since 2010, the Falkland Islands Fisheries Department (FIFD) has carried out eight trawl surveys over the finfish zone timed to parallel the pre-season surveys for Patagonian squid *Doryteuthis gahi* in February. The original objective of these surveys was to provide a synchronous estimate of rock cod on the entire Falklands fishing grounds (Winter et al. 2010), which has since been expanded to provide information on other commercial species. Studies derived from these surveys have found that the abundance of some demersal resources, e.g. rock cod, southern blue whiting, hoki, kingclip *Genypterus blacodes* and red cod *Salilota australis*, have decreased in some areas around the Falkland Islands (Gras et al. 2018; Ramos & Winter 2019a). This report summarizes catch data from both the groundfish survey in the finfish zone and the calamari pre-season survey in the '*Loligo*' box, to estimate the biomass of key species in Falkland Islands waters since 2010. Previous and current index species (southern blue whiting and rock cod, respectively), species of current commercial value, and species with potential to sustain a fishery are included in this report.

3. Methods

3.1. Trawl stations and biological sampling

Concurrent groundfish and calamari pre-season research cruises were carried out during February 2010–2011, and 2015–2020 on board of chartered fishing trawlers to cover the Falkland Islands fishing zone (Fig. 1). All trawls were bottom trawls; GPS latitude, GPS longitude, net vertical opening, trawl door spread, and trawl speed were recorded on the ship's bridge during the progress of each trawl.

At each trawl station, all species from the catch were sorted by FIFD scientific personnel and the vessel's factory crew. Falkland Islands biomasses were assessed for ten species that represent important commercial targets here and in other nations' fishing zones (Table 1). The total catch of each assessed species was weighed with an electronic balance to the nearest 0.01 kg. Random samples of up to 100 individuals of each species were measured to the lowest 1 cm for finfish and 0.5 cm for squids to produce length-frequency histograms. Dorsal mantle length was measured for Argentine short-fin squid and Patagonian squid. Total length was measured for common hake, kingclip, red cod, rock cod, southern blue whiting and toothfish. Pre-anal length was measured for banded grenadier and hoki. Hereafter, these different length measurements will be referred to as 'length' only.

Characteristics of the trawl nets, trawl performance, and biological sampling during groundfish and calamari pre-season surveys can be consulted in detail in Arkhipkin et al. (2010, 2011, 2019), Brickle & Laptikhovsky (2010), Gras et al. (2015, 2016, 2017, 2018), Winter et al. (2011, 2015, 2016, 2017, 2018, 2019), and Randhawa et al. (in prep).

Mean length was calculated for each species and for each year, and linear regression was implemented to examine changes in mean length through time.

Table I. Species assessed in groundfish and calamari pre-season surveys in Falkland Islands waters during February 2010–2011, and 2015–2020. Distributions from http://www.fao.org/fishery/species/search/en

Common name	Scientific name	Distribution
Argentine short-fin squid	*Illex argentinus*	Southwest Atlantic: Brazil, Uruguay, Argentina, Falkland Islands.
Banded grenadier	*Coelorinchus fasciatus*	Southwest Atlantic: Brazil, Uruguay, Argentina, Falkland Islands. Southern Pacific: Chile, Australia, New Zealand. Southern Indian: Africa, Australia.
Common hake	*Merluccius hubbsi*	Southwest Atlantic: Brazil, Uruguay, Argentina, Falkland Islands.
Hoki	*Macruronus magellanicus*	Southwest Atlantic: Argentina, Falkland Islands. Southeast Pacific: Chile.
Kingclip	*Genypterus blacodes*	Southwest Atlantic: Brazil, Uruguay, Argentina, Falkland Islands. Southern Pacific: Chile, Australia, New Zealand.
Patagonian squid	*Doryteuthis gahi*	Southwest Atlantic: Argentina, Falkland Islands. Southern Pacific: Peru, Chile.
Red cod	*Salilota australis*	Southwest Atlantic: Argentina, Falkland Islands. Southeast Pacific: Chile.
Rock cod	*Patagonotothen ramsayi*	Southwest Atlantic: Argentina, Falkland Islands.
Southern blue whiting	*Micromesistius australis australis*	Southwest Atlantic: Argentina, Falkland Islands. Southeast Pacific: Chile. Southern Ocean: South Georgia, South Shetland, South Orkney Islands.
Toothfish	*Dissostichus eleginoides*	Southwest Atlantic: Argentina, Falkland Islands. Southeast Pacific: Chile. Southwest Pacific: Macquarie Island. Southern Ocean: South Georgia.

3.2. Biomass estimations

Station and catch data were recorded during the surveys, checked and uploaded to the FIFD database, from which the data were later retrieved for analyses. Stations were excluded where trawls failed due to broken net or due to net full of medusae that prevented catching finfish or squids (Appendix I).

Biomass densities per species at each trawl station were calculated as the species catch weight divided by the trawl station area (net horizontal opening × distance covered). For calamari pre-season surveys, trawl width was derived from the distance between trawl doors (Seafish 2010). For groundfish surveys, the triangulation method that derives trawl width from the distance between trawl doors is unsuitable because the geometry of the net is different. Since 2016, groundfish survey trawl width has instead been measured directly from Marport sensors fitted to the extremities of the survey vessel's trawl net wings. Trawl widths of groundfish surveys earlier than 2016 were calculated using a linear function of either trawl net vertical opening or door distance (Gras 2016).

Yearly trawl biomass densities were extrapolated to the survey area combining the finfish zone (122,493.7 km^2) and '*Loligo*' Box (31,296.9 km^2), partitioned into grids of 5 km^2. Position coordinates of trawls were converted to WGS 84 projection in UTM sector 21, and extrapolation was calculated using inverse distance weighting. The basic inverse distance weighting algorithm assigns a value *u* to any grid location *x* that is the weighted average of a known scattered set of points x_i according to the inverse of the *i* points' distances from the grid location *x*:

$$u(\mathrm{x}) = \begin{cases} \dfrac{\sum_{i=1}^{N} w_i(\mathrm{x}) u_i}{\sum_{i=1}^{N} w_i(\mathrm{x})}, & \text{if } d(\mathrm{x}, \mathrm{x_i}) \neq 0 \\ u_i, & \text{if } d(\mathrm{x}, \mathrm{x_i}) = 0 \end{cases}$$

where

$$w_i(\mathrm{x}) = \frac{1}{d(\mathrm{x}, \mathrm{x_i})^p}$$

The power parameter *p* (a positive real number) adjusts the weight of points x_i as a function of distance; higher values of *p* put higher influence on the points x_i closest to a given interpolated point *x*. For this survey analysis, an empirical approach to selecting *p* was used of running the inverse distance weighting algorithm with *p* values from 1 to 25 by 0.25, and for each *p* calculating the aggregate of log proportional differences between the empirical values of density at every trawl and the interpolation at every trawl from all other trawls. The lowest aggregate of log proportional differences corresponded to the best *p* value. Because some points may be more clustered than others, an isolation parameter was assigned attributing more weight to points x_i in proportion to being further away from any other point x_i. Isolation parameters (s) per yearly survey were calculated as the standardized mean of distances between each point x_i and all other points x_j:

$$s(\mathrm{x_i}) = \overline{d(\mathrm{x_i}, \mathrm{x_j})}$$

giving a revised inverse distance weighting factor as:

$$w_i(\mathrm{x}) = \left(\frac{s(\mathrm{x_i})}{d(\mathrm{x}, \mathrm{x_i})}\right)^p$$

A further adjustment was made to the calculation of distance. The distance $d(x, x_i)$ is inherently calculated as Euclidean (straight-line) distance. However, the survey area surrounds the Falkland Islands and between two remote points a fish or ship would have to travel a real distance longer than straight-line; circumnavigating the landmass. Therefore, an axial loop was drawn through the survey area (Fig. 1), and $d(x, x_i)$ was defined as the longer of either the Euclidean distance between x and x_i, or the distance on the axial loop between its two points respectively closest to x and x_i (Winter 2019).

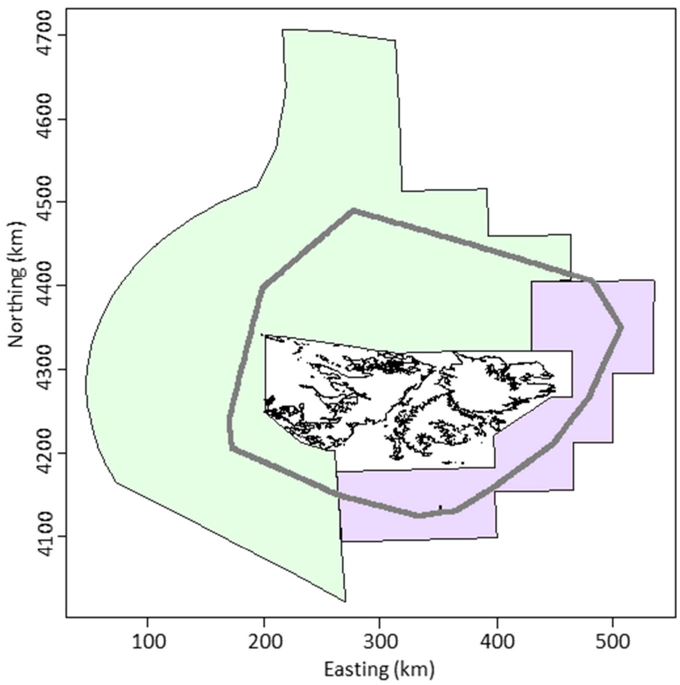

Fig. 1. Groundfish (green) and calamari pre-season (mauve) survey areas, with axial loop (dark grey) used to define relative distances for the inverse distance weighting algorithm.

Uncertainty of the biomass was estimated by a hierarchical bootstrap algorithm. For 30,000 iterations, survey trawls and their catches were first randomly re-sampled with replacement, whereby each year's groundfish survey and parallel calamari pre-season survey were re-sampled separately so that both 'halves' of the survey area retained about the same relative coverage. Second, each re-sampled trawl was given a random uniform re-assignment of its coordinate position between start latitude and longitude and end latitude and longitude. Third, the isolation parameters were re-calculated for the randomized set of trawl data, and the inverse distance weighted algorithm re-applied. One iteration might thus re-sample any trawl twice or more, but each would have a slightly different position. To infer uncertainty, 95% confidence intervals and standard deviations of the 30,000 bootstrap iterations were used.

4. Results

4.1. Trawls and catch

A total of 1,158 bottom trawls were carried out during the February groundfish and calamari pre-season surveys from 2010–2011, and 2015–2020. A range of 80 to 97 trawls were carried out during groundfish surveys, and 52 to 59 trawls were carried out during calamari pre-season surveys. Total catches of the commercial species examined in both February 2020 groundfish and calamari pre-season surveys were 47.8 t and 283.8 t respectively (Appendix I).

The Patagonian squid had the greatest mean catch (202 t) across years, followed by rock cod with a mean catch of 105 t per year. However, catches of rock cod continually declined since 2010 to reach its lowest in 2020 (11 t). Banded grenadier, red cod and toothfish also had declining catch trends. Hoki had a mean catch of 32 t per year, whereas southern blue whiting had a mean catch of 28 t per year. The rest of the species had a mean catch < 16 t per year. The catch per species and year, and the combined species catch per year are detailed in Table II.

Table II. Catches (t) of species in groundfish and calamari pre-season surveys in Falkland Islands waters during February 2010–2011, and 2015–2020.

Year	Argentine short-fin squid	Banded grenadier	Common hake	Hoki	Kingclip	Patagonian squid	Red cod	Rock cod	Southern blue whiting	Toothfish	Total	Mean
2010	0.88	8.05	1.31	79.78	3.24	356.76	13.54	164.59	21.87	1.39	651.41	65.14
2011	1.95	6.20	1.67	55.99	8.59	50.51	23.54	249.38	52.29	2.42	452.56	45.26
2015	31.87	6.58	3.17	26.36	14.73	186.14	21.81	198.27	24.12	0.77	513.82	51.38
2016	0.09	3.28	0.69	38.92	5.45	66.90	19.95	77.31	79.36	1.75	293.69	29.37
2017	2.49	3.97	2.94	3.70	4.26	185.23	13.82	76.13	6.41	2.50	301.44	30.14
2018	10.70	7.54	1.73	30.02	3.59	115.84	13.30	35.92	29.51	1.93	250.09	25.01
2019	9.41	2.51	2.75	7.55	4.42	386.26	13.68	27.94	8.38	0.83	463.73	46.37
2020	17.92	2.62	0.73	14.38	3.62	272.08	3.71	10.98	5.10	0.49	331.62	33.16
Total	75.31	40.75	14.95	256.7	47.9	1619.72	123.35	840.52	227.04	12.08		
Mean	9.41	5.09	1.87	32.09	5.98	202.47	15.42	105.07	28.38	1.51		

4.2. Biomass, distribution and size structure

Biomass estimates for all species examined from 2010–2011, and from 2015–2020 are presented in Table III. Species biomass patterns are described in each species' section.

Table III. Estimated biomass (t) of species in Falkland Islands waters during February 2010–2011, and 2015–2020. The 95% confidence intervals are indicated in parentheses.

Year	Argentine short-fin squid	Banded grenadier	Common hake	Hoki
2010	8620.30 (3508.71–3828.03)	86113.09 (46234.37–110793.53)	9013.04 (6042.43–12604.24)	272080.22 (197644.96–472481.97)
2011	9288.77 (6719.00–2632.60)	49786.15 (23217.66–85309.35)	10334.86 (8472.85–12860.06)	227165.49 (174666.72–288834.04)
2015	253660.38 (130050.90–475960.46)	63463.84 (35323.91–83107.47)	15910.43 (13962.24–18586.06)	129562.42 (40753.69–175529.10)
2016	205.79 (147.73–269.07)	34022.36 (10100.62–53672.60)	3686.67 (2987.50–4187.28)	167312.12 (83510.52–231697.65)
2017	11704.86 (7474.80–8341.05)	35448.14 (20274.99–42862.44)	12319.36 (10297.85–15690.47)	28863.12 (16842.07–39751.29)
2018	44746.56 (30210.12–64517.95)	34826.63 (28021.67–44133.08)	8573.04 (6100.14–10865.04)	139665.90 (91380.06–203699.81)
2019	59998.2 (39966.2–96500.69)	21025.83 (10238.58–35813.59)	11098.5 (9394.96–14468.65	41398.97 (6433.57–188848.89)
2020	148023.20 (90413.40–195436.03)	39380.98 (10615.29–47304.68)	3346.38 (2851.53–3972.17)	77732.82 (20133.68– 165424.57)

Table III. *continued*

Year	Kingclip	Patagonian squid	Red cod	Rock cod
2010	21617.44 (13740.07–31108.56)	203558.43 (162047.16–250085.16)	93194.65 (19743.66–150576.55)	709535.66 (530503.55–1086153.89)
2011	42618.29 (29182.03–65107.93)	49266.77 (40184.80–68417.16)	161733.35 (41760.22–252434.63)	1090654.84 (726139.02–1767088.84)
2015	79128.92 (30842.99–130266.84)	111351.39 (80460.29–169743.16)	106878.11 (45428.59–160292.1)	352570.42 (268194.30–429993.32)
2016	24791.36 (13831.38–39084.50)	39946.94 (33264.42–53333.28)	105369.20 (29467.04–154110.28)	235339.08 (178466.99–318771.08)
2017	19034.72 (11915.28–28978.89)	189748.92 (148470.98–239866.69)	60319.76 (23204.51–89308.37)	138641.20 (111389.70–171927.94)
2018	14464.94 (10843.68–20518.68)	61015.22 (43769.59–93736.02)	55845.34 (19149.62–114403.45)	87595.83 (61319.43–119778.94)
2019	21780.38 (15007.69–29223.3)	195631.6 (169258.47–246690.55)	81324.05 (36498.66–114029.39)	37793.3 (27321.99–52723.14)
2020	14886.91 (10351.98– 26525.09)	96135.36 (77679.89– 136705.30)	22654.32 (11566.08–34435.10)	22335.25 (13168.10–29418.72)

Table III. *continued*

Year	Southern blue whiting	Toothfish
2010	73563.23 (27341.64–98431.47)	9845.88 (7461.10–12152.61)
2011	236328.33 (45116.64–399094.57)	11554.45 (8071.33–14427.83)
2015	66221.71 (13050.55–102946.04)	3706.51 (1433.24–4408.06)
2016	332096.18 (26505.92–433238.55)	8219.23 (5721.33–10734.75)
2017	43252.74 (1284.65–57549.59)	8649.98 (5690.86–10369.9)
2018	58802.02 (17715.83–69838.20)	8782.20 (6261.69–10926.90)
2019	6626.38 (210.31–39098.78)	6833.77 (3192.88–8551.75)
2020	9559.20 (31.09–22890.97)	3201.06 (2079.74–3587.13)

4.2.1. Argentine short-fin squid (*Illex argentinus*)

The biomass of the Argentine short-fin squid was relatively low during 2010 and 2011 (< 10,000 t each). The maximum biomass was estimated in 2015 (253,660 t) whereas the lowest biomass was estimated for 2016 (206 t); an increasing trend in biomass was observed from 2016 to reach 148,023 t in 2020 (Fig. 2; Table III). In 2020, this species was distributed throughout the north of the Falkland Islands, with the highest densities to the north of East Falkland (14,745 kg/km^2; Fig. 3). Across years, the Argentine short-fin squid was mainly distributed through the north of West and East Falkland, with the highest density to the north of East Falkland during 2015 (74,427 kg/km^2; Appendix II). Length frequency histograms show a range of sizes of *I. argentinus* from 5 cm to 34 cm across years (Fig. 4). There were considerable incursions of *I. argentinus* into the FICZ and FOCZ during 2015, which is reflected in the wide range of sizes observed in that year. There was no statistically significant change in mean length of *I. argentinus* from 2010 to 2020 (p = 0.86).

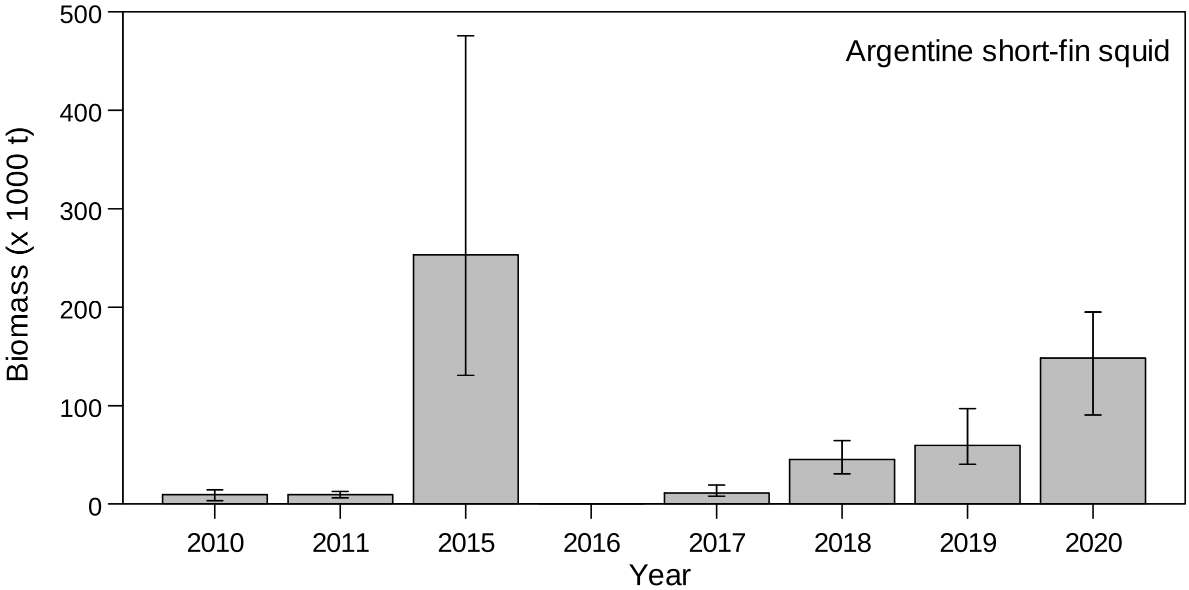

Fig. 2 Mean biomass (t) ± 95% confidence intervals of the Argentine short-fin squid (*Illex argentinus*) in Falkland Islands waters during 2010–2011, and 2015–2020. Note the data gap from 2012 to 2014.

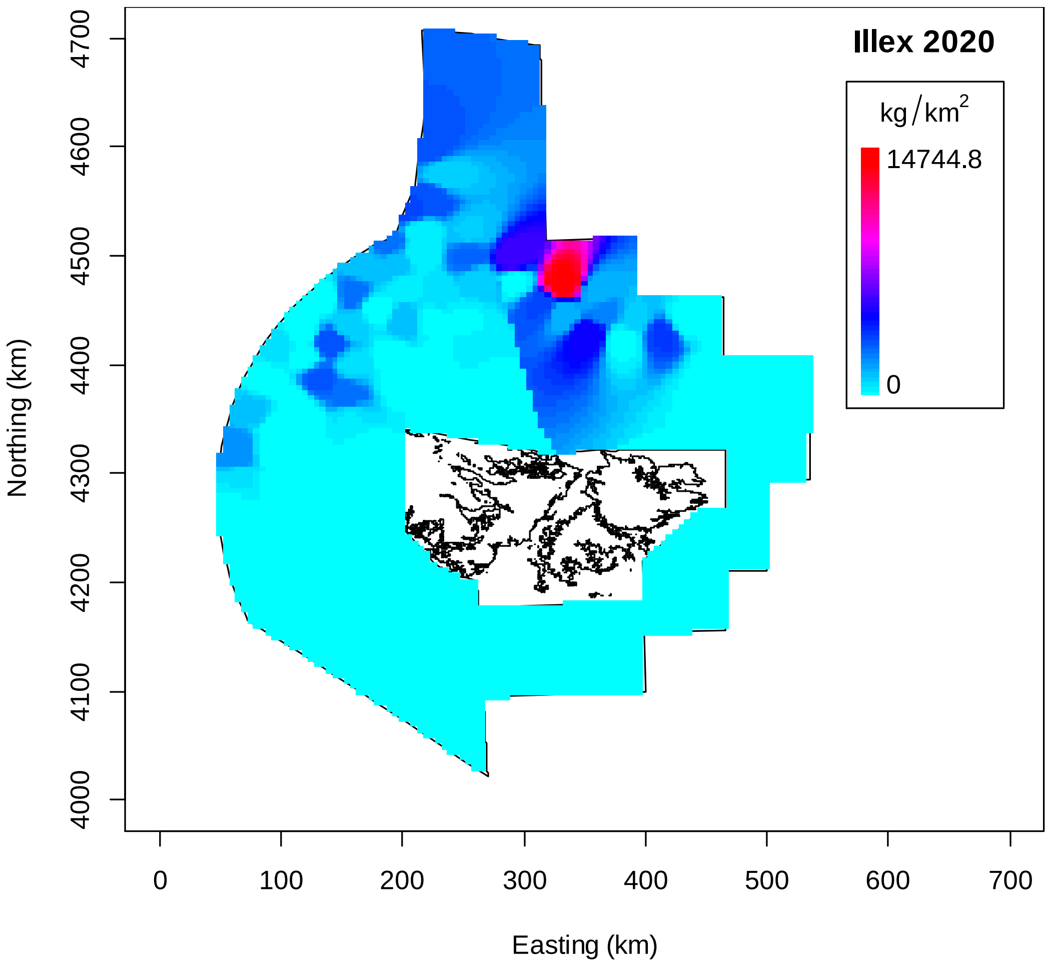

Fig. 3. Density of the Argentine short-fin squid (*Illex argentinus*) around the Falkland Islands during 2020.

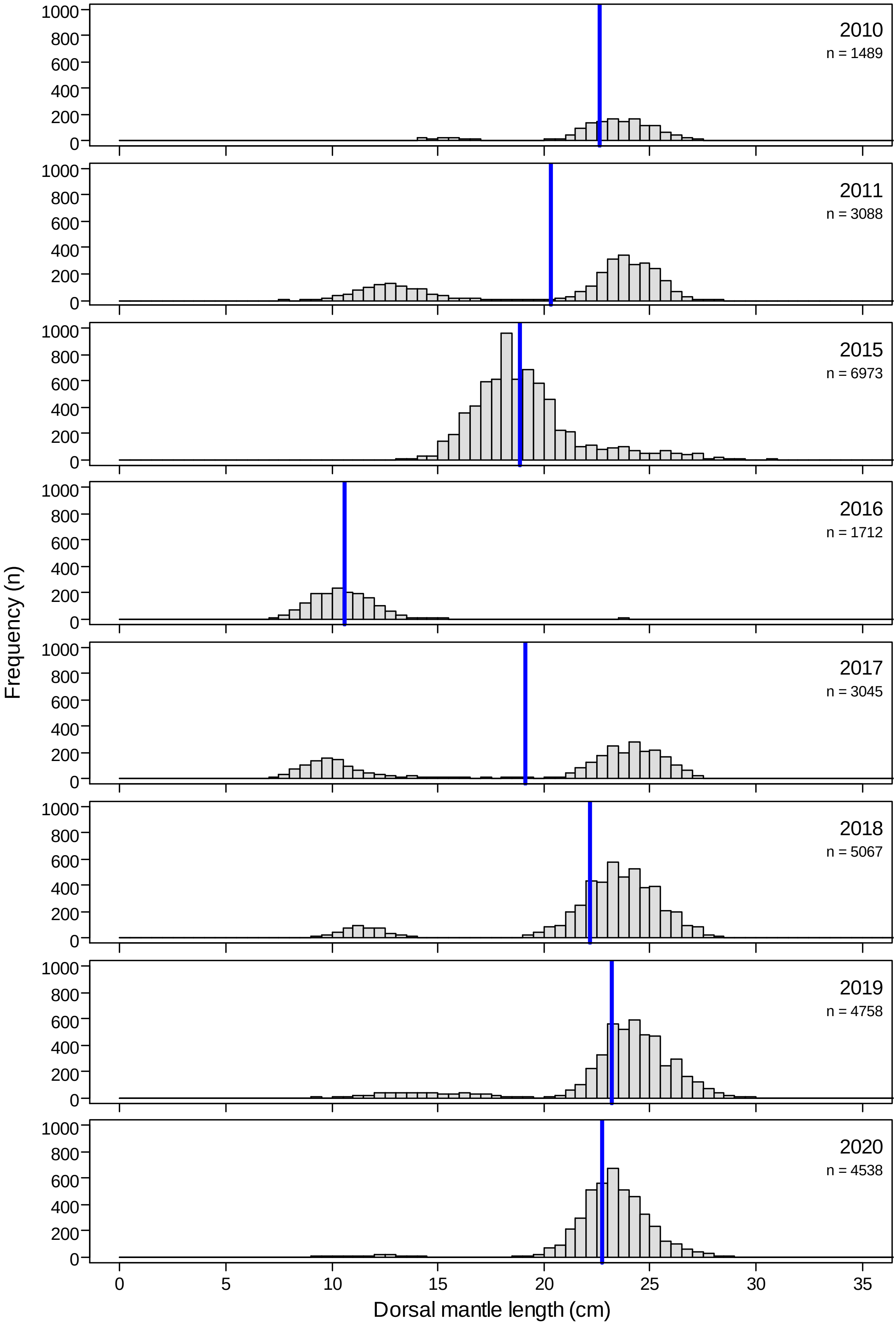

Fig. 4. Length-frequency distribution of Argentine short-fin squid (*Illex argentinus*) around the Falkland Islands during 2010–2011, and 2015–2020. Mean length is indicated by the blue line. Note the data gap from 2012 to 2014.

4.2.2. Banded grenadier (*Coelorinchus fasciatus*)

The biomass of banded grenadier had a decreasing trend from 2010 (86,113 t) to 2020 (39,381 t; Fig. 5; Table III), although the lowest biomass was estimated in 2019 (21,026 t); 95% confidence intervals showed overlap of biomass estimates among the years examined. Banded grenadier was predominantly distributed to the south-west of West Falkland during 2020, with the maximum density estimated at 3,790 kg/km^2 (Fig. 6). Across years, there was a consistent pattern of distribution to the south-west of West Falkland with maximum densities ranging from 2,302 kg/km^2 in 2017 to 9,127 kg/km^2 in 2011 (Appendix III). Length frequency histograms of banded grenadier show a range of sizes from 2 cm to 20 cm, with modal length at 9–10 cm across years (Fig. 7). There was no statistically significant change in mean length of *C. fasciatus* from 2010 to 2020 (p = 0.30).

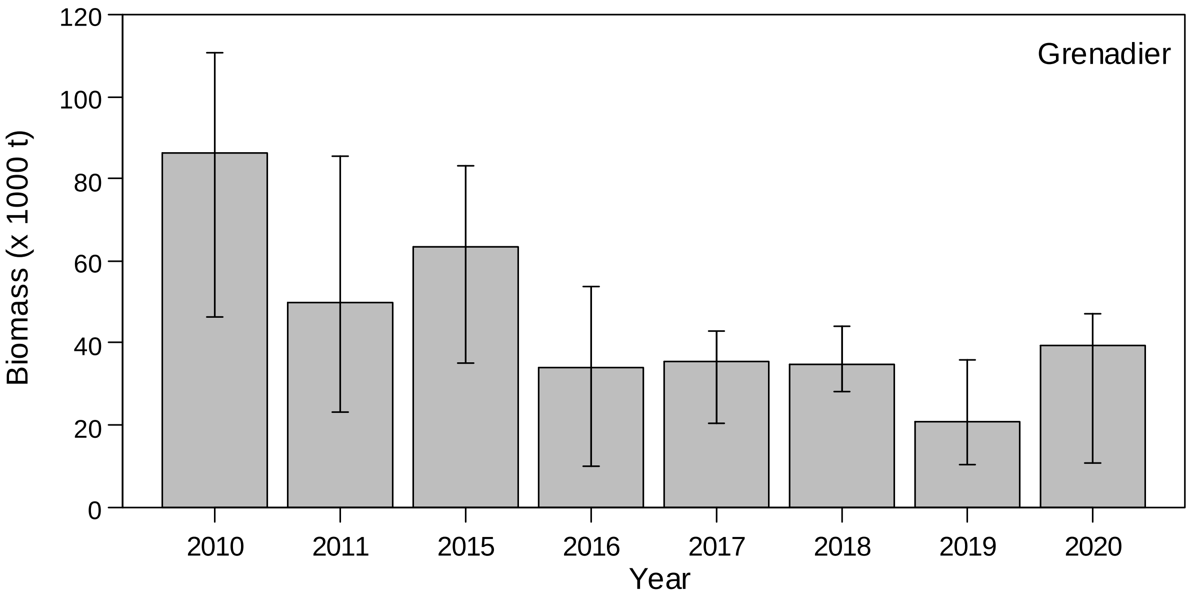

Fig. 5. Mean biomass (t) ± 95% confidence intervals of banded grenadier (*Coelorinchus fasciatus*) in Falkland Islands waters during 2010–2011, and 2015–2020. Note the data gap from 2012 to 2014.

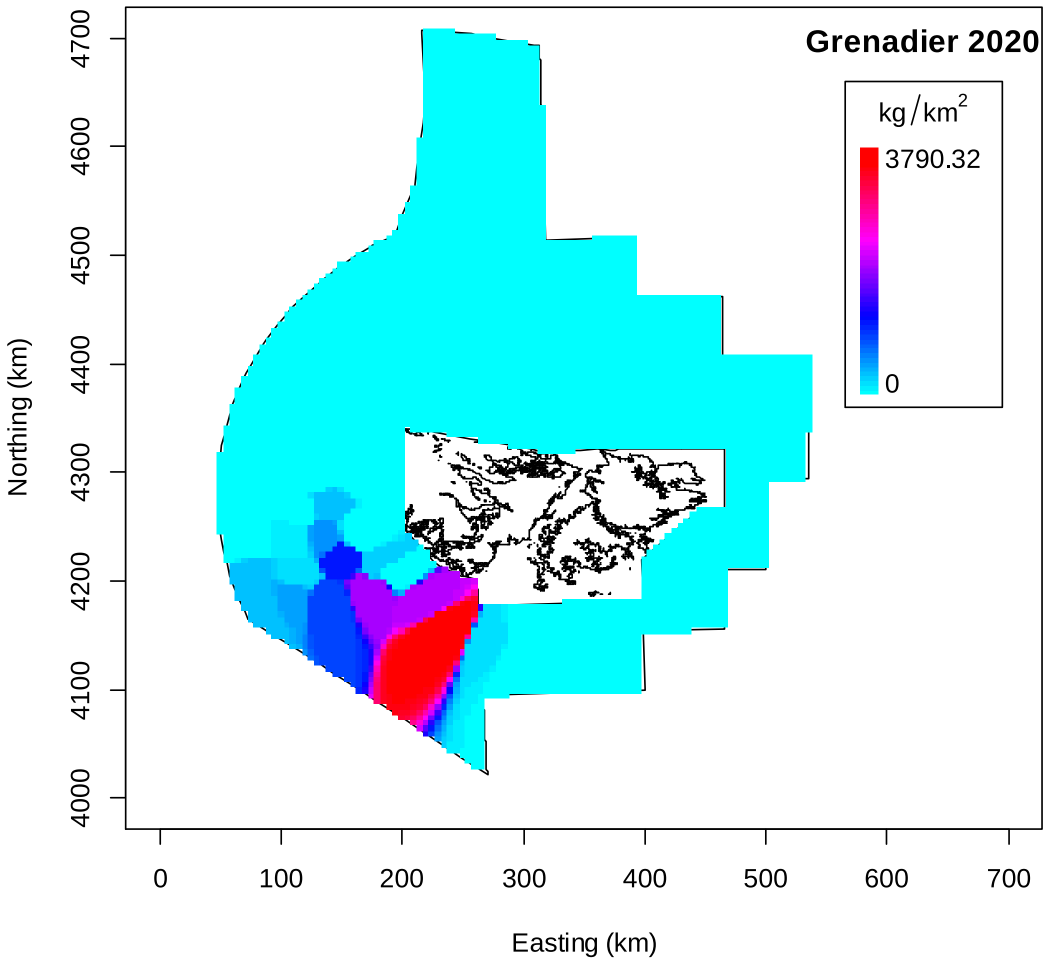

Fig. 6. Density of banded grenadier (*Coelorinchus fasciatus*) around the Falkland Islands during 2020.

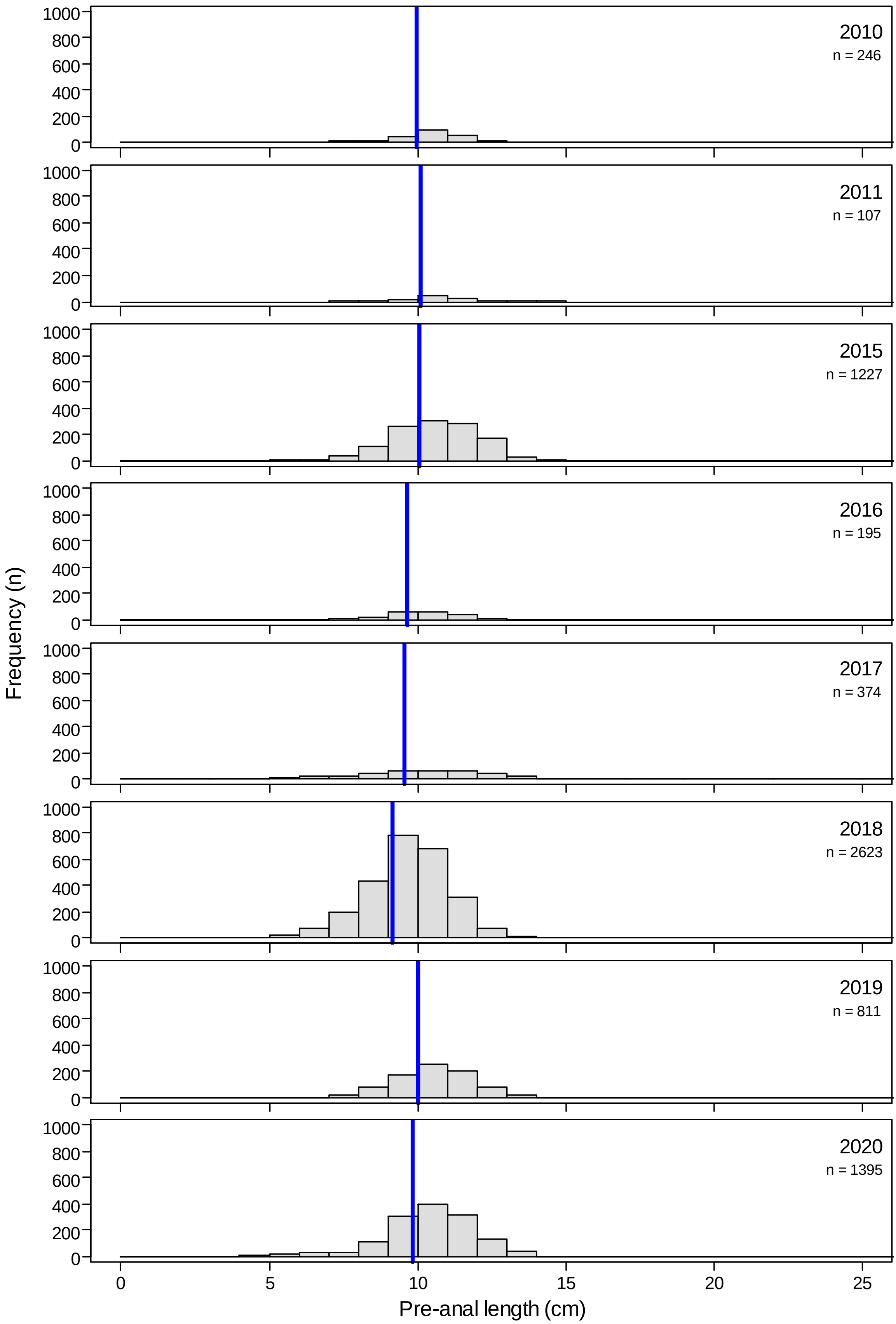

Fig. 7. Length frequency of banded grenadier (*Coelorinchus fasciatus*) around the Falkland Islands during 2010–2011, and 2015–2020. Mean length is indicated by the blue line. Note the data gap from 2012 to 2014.

4.2.3. Common hake (*Merluccius hubbsi*)

The biomass of common hake was variable across years; it increased from 2010 (9,013 t) to 2015 (15,910 t), followed by a considerable decrease in 2016 (3,687 t). An increase in biomass was observed from 2017 to 2019 (> 8,500 t each year); however, the lowest biomass in the time series was estimated for 2020 (3,346 t; Fig. 8; Table III). In 2020, common hake was mainly distributed to the north and north-west of West Falkland with the highest density estimated at 206 kg/km^2 (Fig. 9). Across years, high densities were detected to the north-west offshore or near the limit of the FICZ, with the highest density estimated in 2017 (1,322 kg/km^2; Appendix IV). Length frequency histograms show a wide range of common hake sizes across the time series, from 13 cm to 95 cm (Fig. 10). Mean length varied across years; however, there was a statistically significant decline in mean length from 2010 (50 cm) to 2020 (43 cm) at a rate of 0.97 cm/year ($p = 0.03$).

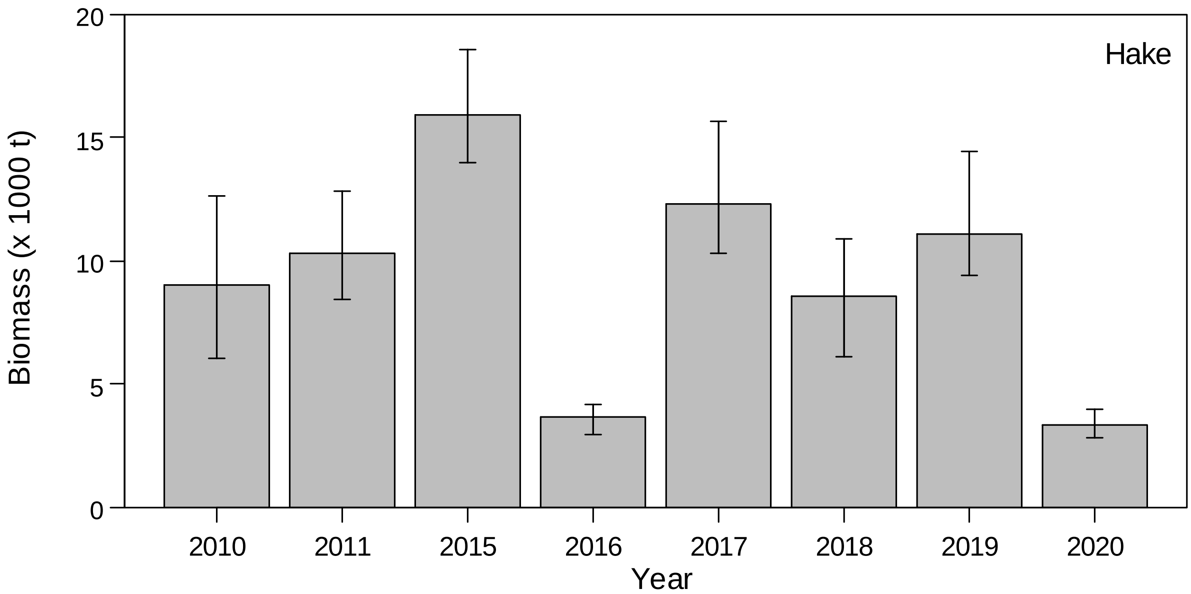

Fig. 8. Mean biomass (t) ± 95% confidence intervals of common hake (*Merluccius hubbsi*) in Falkland Islands waters during 2010–2011, and 2015–2020. Note the data gap from 2012 to 2014.

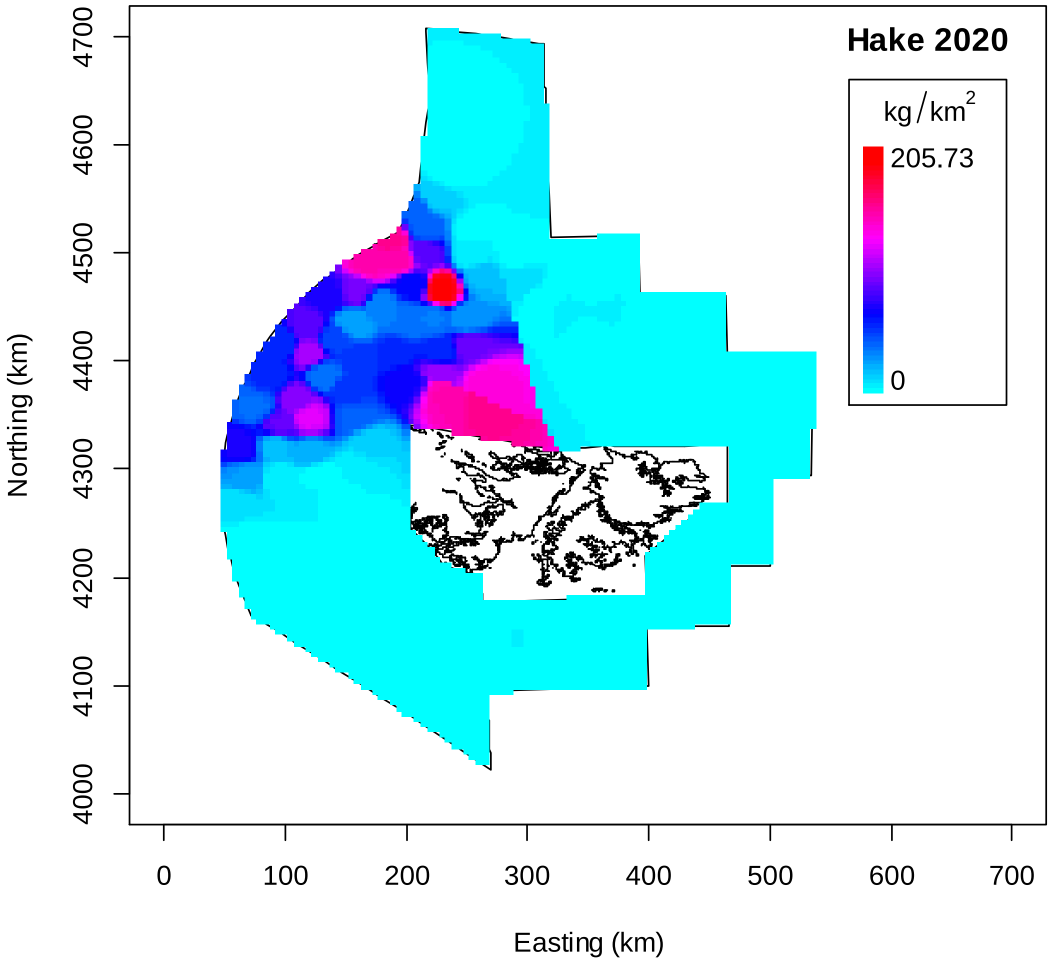

Fig. 9. Density of common hake (*Merluccius hubbsi*) around the Falkland Islands during 2020.

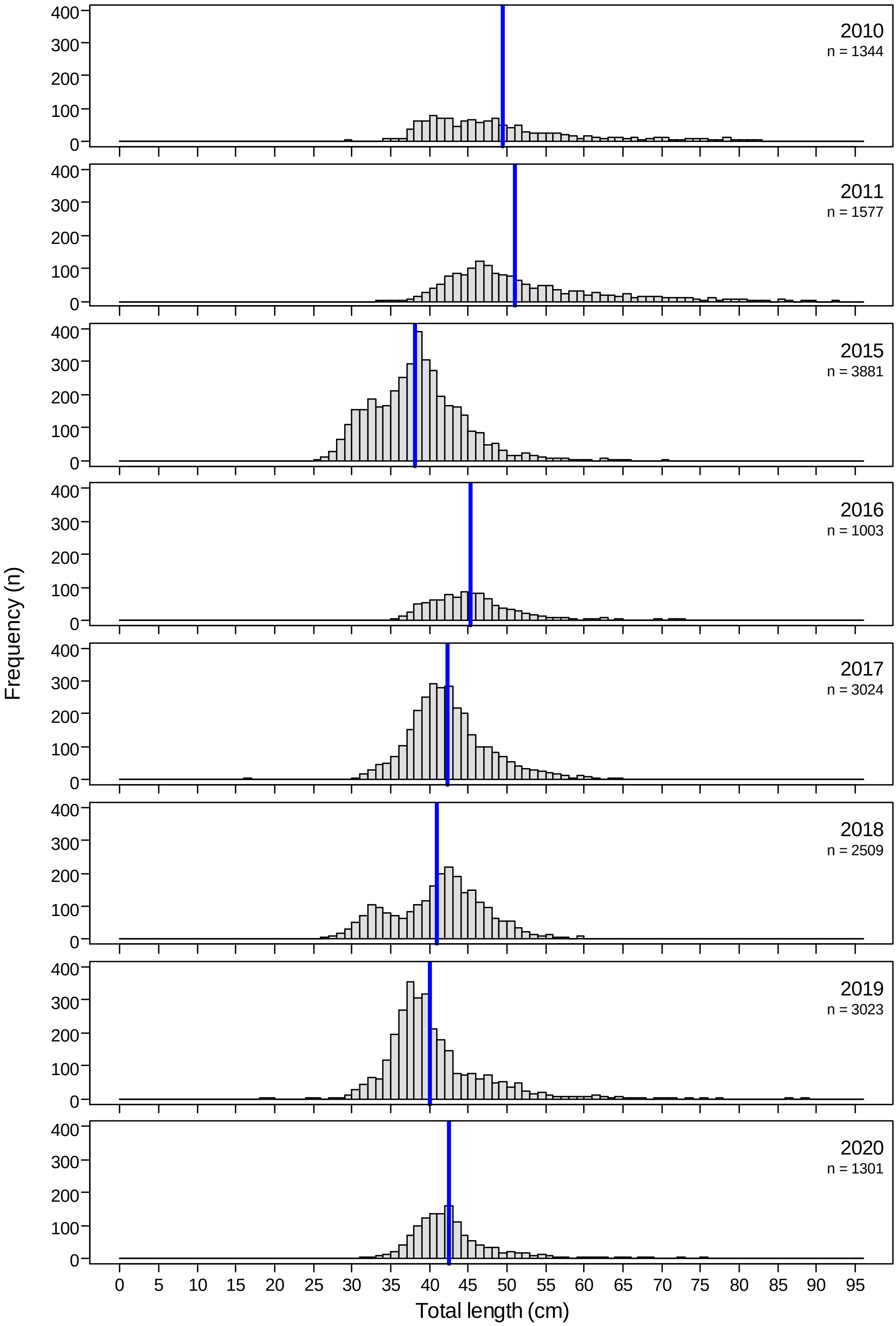

Fig. 10. Length frequency of common hake (*Merluccius hubbsi*) around the Falkland Islands during 2010–2011, and 2015–2020. Mean length is indicated by the blue line. Note the data gap from 2012 to 2014.

4.2.4. Hoki (*Macruronus magellanicus*)

The biomass of hoki had a decreasing trend since 2010, when the maximum biomass in the time series was estimated (272,080 t). Biomass decreased to its lowest in 2017 (28,863 t); a biomass of 77,733 t was estimated in 2020 (Fig. 11; Table III). In 2020, hoki was found to the south-west edge of the FICZ at densities reaching a high of 22,975 kg/km^2 (Fig. 12). The distribution of hoki was patchy and variable from year to year. From 2010 to 2015, hoki occurred over the entire FICZ and FOCZ. From 2016 to 2020 its distribution was localized mainly to the south-west of West Falkland. The maximum densities across the time series ranged from 5,338 kg/km^2 in 2017 to 65,972 kg/km^2 in 2010 (Appendix V). Length frequency histograms show a range of hoki sizes across the time series, from 11 cm to 46 cm (Fig. 13). There was a statistically significant declining trend in mean length of hoki from 28 cm in 2010 to 21 cm in 2020 at a rate of 0.62 cm/year ($p < 0.001$).

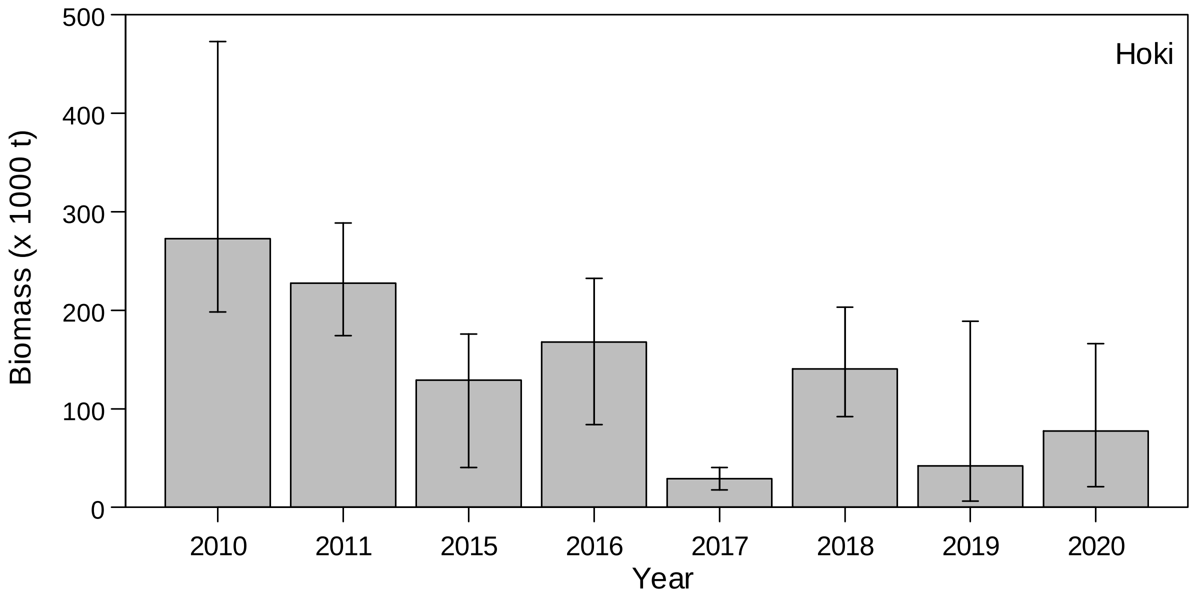

Fig. 11. Mean biomass (t) ± 95% confidence intervals of hoki (*Macruronus magellanicus*) in Falkland Islands waters during 2010–2011, and 2015–2020. Note the data gap from 2012 to 2014.

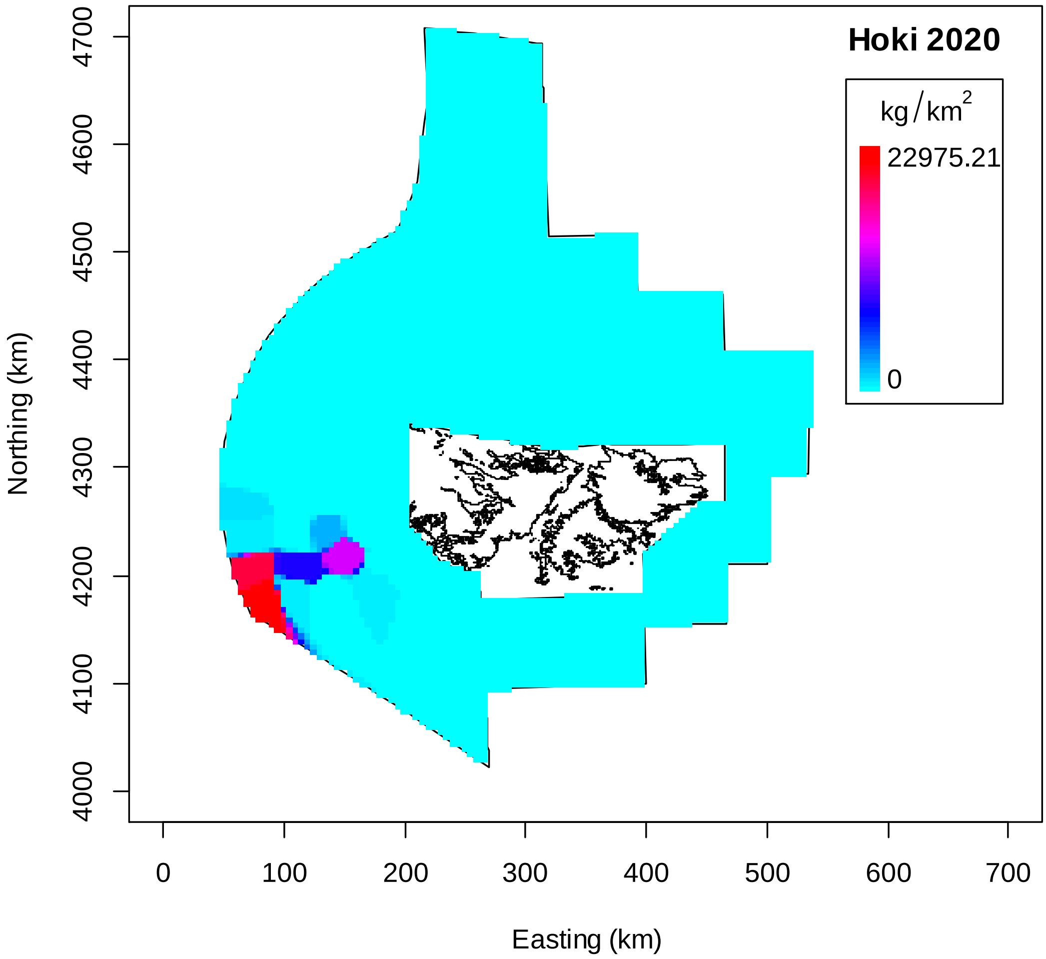

Fig. 12. Density of hoki (*Macruronus magellanicus*) around the Falkland Islands during 2020.

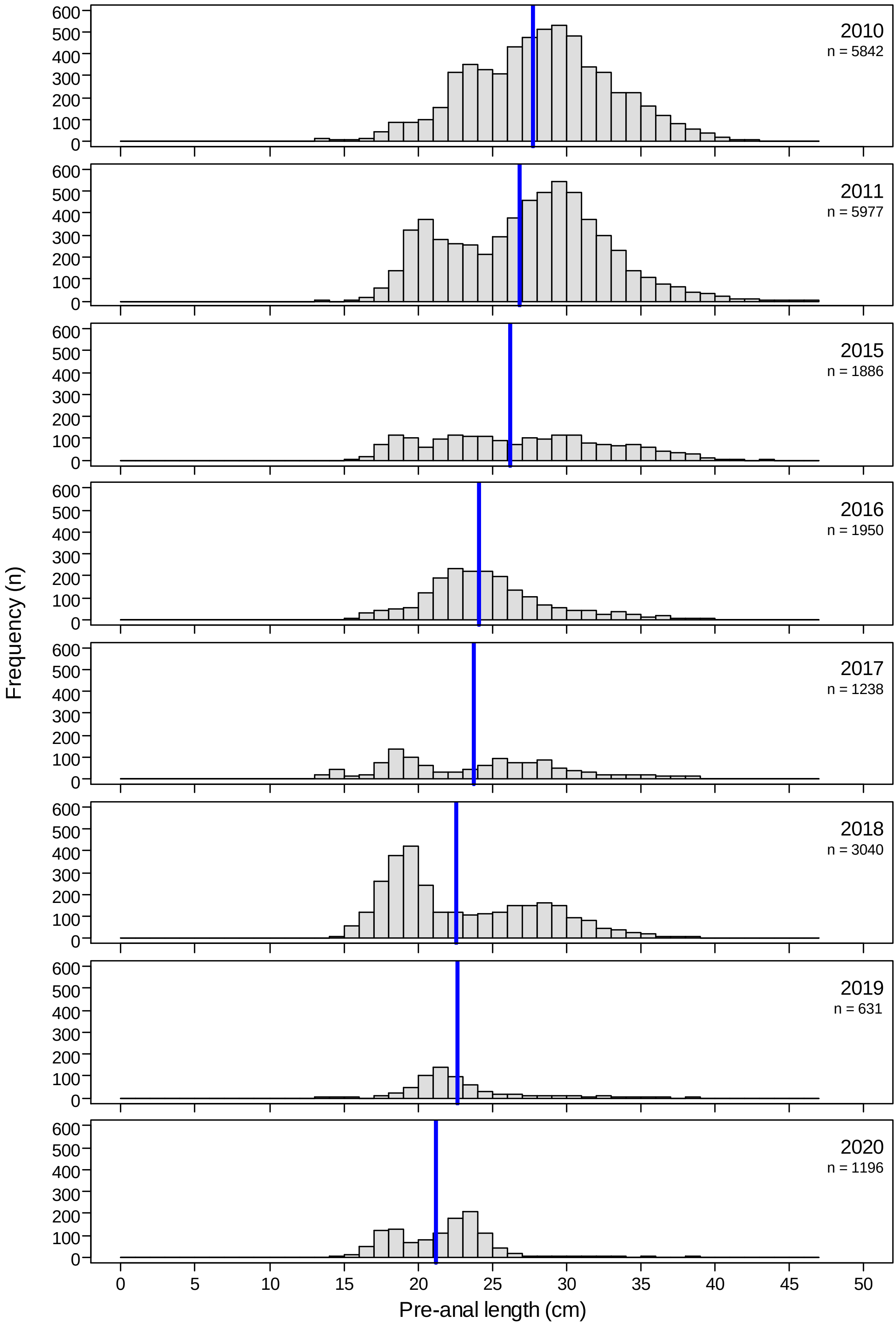

Fig. 13. Length frequency of hoki (*Macruronus magellanicus*) around the Falkland Islands during 2010–2011, and 2015–2020. Mean length is indicated by the blue line. Note the data gap from 2012 to 2014.

4.2.5. Kingclip (*Genypterus blacodes*)

The biomass of kingclip increased from 2010 (21,617 t) to 2015 (79,129 t). However, it declined in 2016 (24,791 t) and has since remained under 25,000 t per year. The second lowest biomass (14,887 t) was estimated for 2020 (Fig. 14; Table III). Throughout the time series, kingclip was dispersed around the FICZ and FOCZ, except for the south-east. In 2020, the highest density (3,637 kg/km^2) occurred to the south-west near West Falkland (Fig. 15), whereas the maximum densities throughout the time series ranged from 1,667 kg/km^2 in 2018 to 32,777 kg/km^2 in 2015 (Appendix VI). Length frequency histograms show a wide range of kingclip sizes across the time series, from 17 cm to 153 cm (Fig. 16). Mean length of kingclip increased from 65 cm in 2010 to 69 cm in 2016 followed by a decrease to 60 cm in 2020. There was no statistically significant decline in mean length of kingclip from 2010 to 2020 ($p = 0.15$).

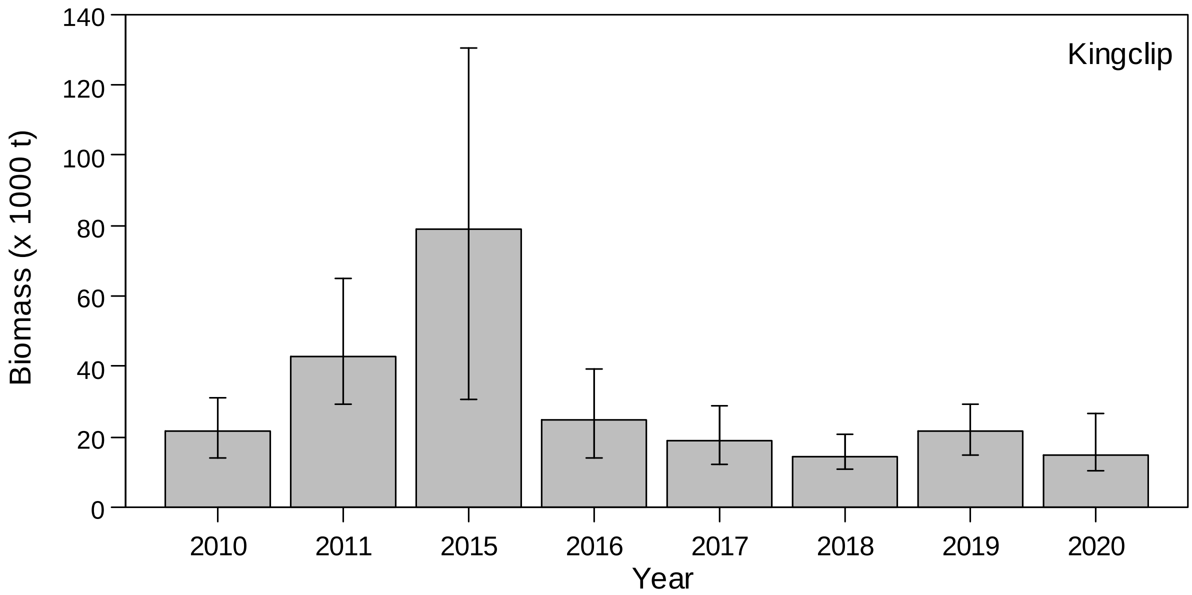

Fig. 14. Mean biomass (t) ± 95% confidence intervals of kingclip (*Genypterus blacodes*) in Falkland Islands waters during 2010–2011, and 2015–2020. Note the data gap from 2012 to 2014.

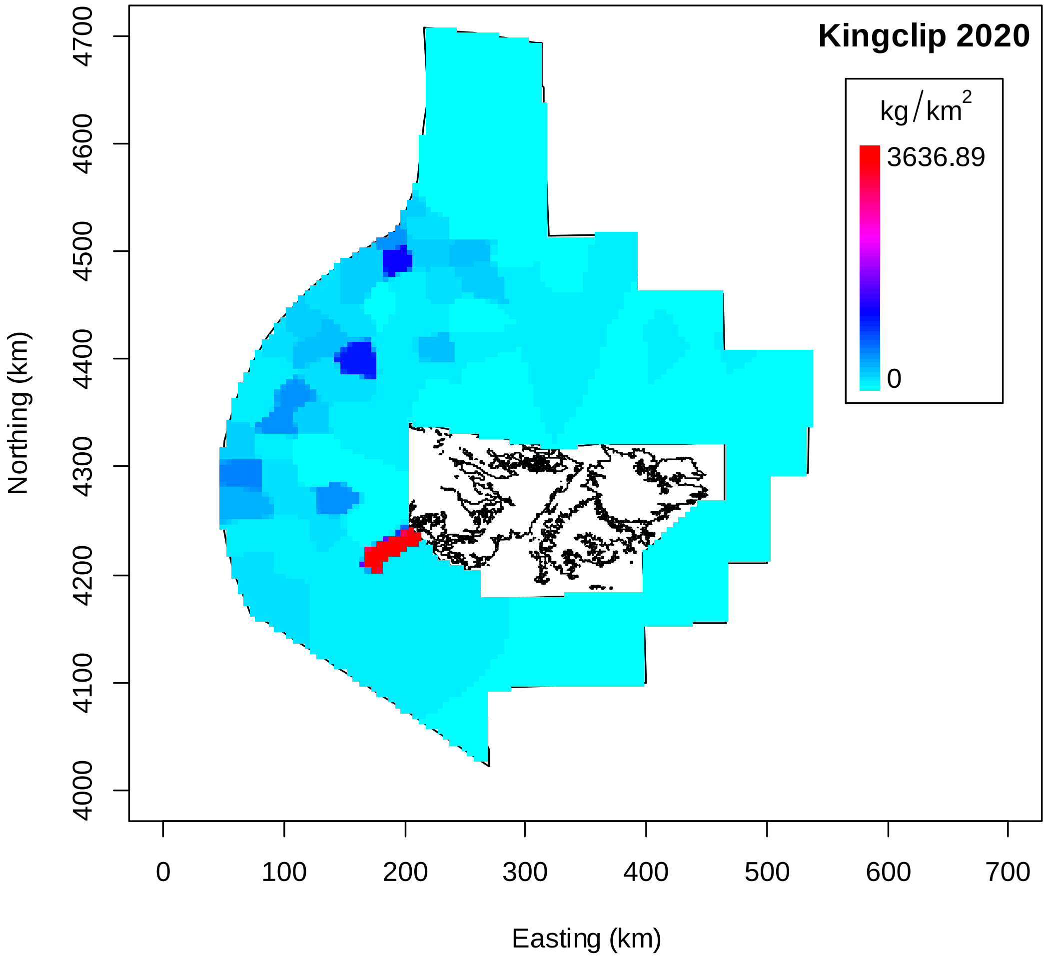

Fig. 15. Density of kingclip (*Genypterus blacodes*) around the Falkland Islands during 2020.

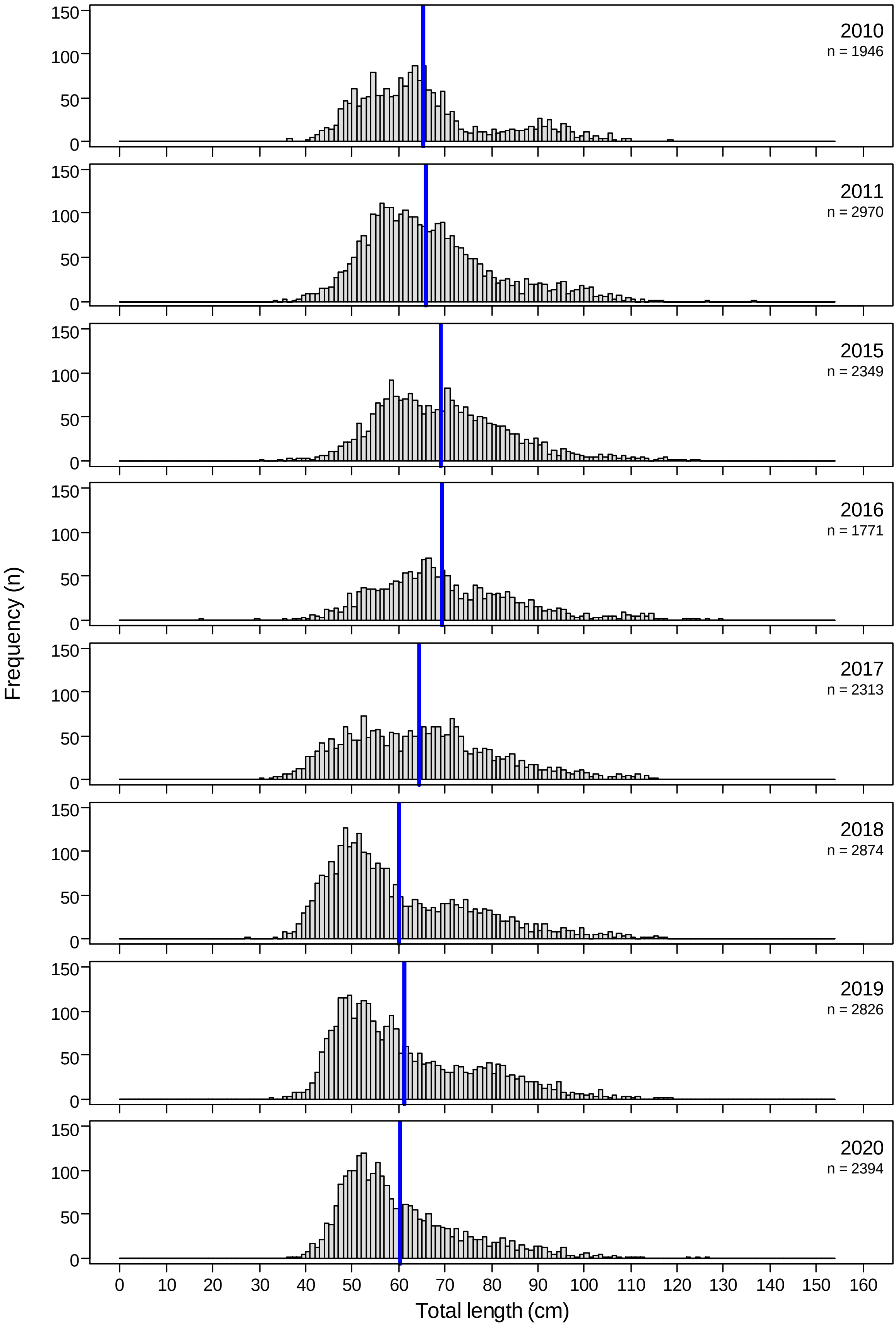

Fig. 16. Length frequency of kingclip (*Genypterus blacodes*) around the Falkland Islands during 2010–2011, and 2015–2020. Mean length is indicated by the blue line. Note the data gap from 2012 to 2014.

4.2.6. Patagonian squid (*Doryteuthis gahi*)

The biomass of the Patagonian squid has been variable from year to year since 2010 (203,558 t), year when the maximum biomass was estimated. The lowest biomass occurred in 2016 (39,947 t) whereas relatively high biomasses were estimated in 2017 (189,749 t) and 2019 (195,632 t). The biomass in 2020 was estimated at 96,135 t (Fig. 17; Table III). *Doryteuthis gahi* was mainly found to the south and south-east of East Falkland. In 2020, the maximum density was 15,867 t (Fig. 18), whereas the maximum densities throughout the time series ranged from 7,132 kg/km^2 in 2016 to 37,527 kg/km^2 in 2015 (Appendix VII). Length frequency histograms show a wide range of Patagonian squid sizes, from 1 cm to 33 cm, across the time series (Fig. 19). Mean length ranged from 8.5 cm to 10.5 cm; there was no statistically significant change in mean length of *D. gahi* across years ($p = 0.85$).

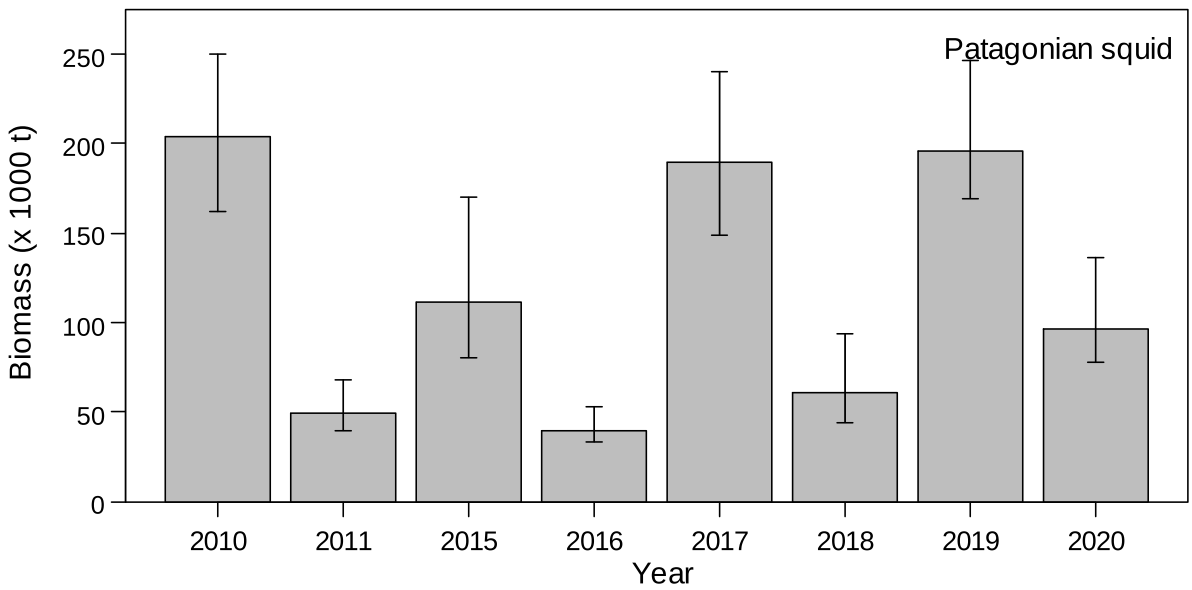

Fig. 17. Mean biomass (t) ± 95% confidence intervals of the Patagonian squid (*Doryteuthis gahi*) in Falkland Islands waters during 2010–2011, and 2015–2020. Note the data gap from 2012 to 2014.

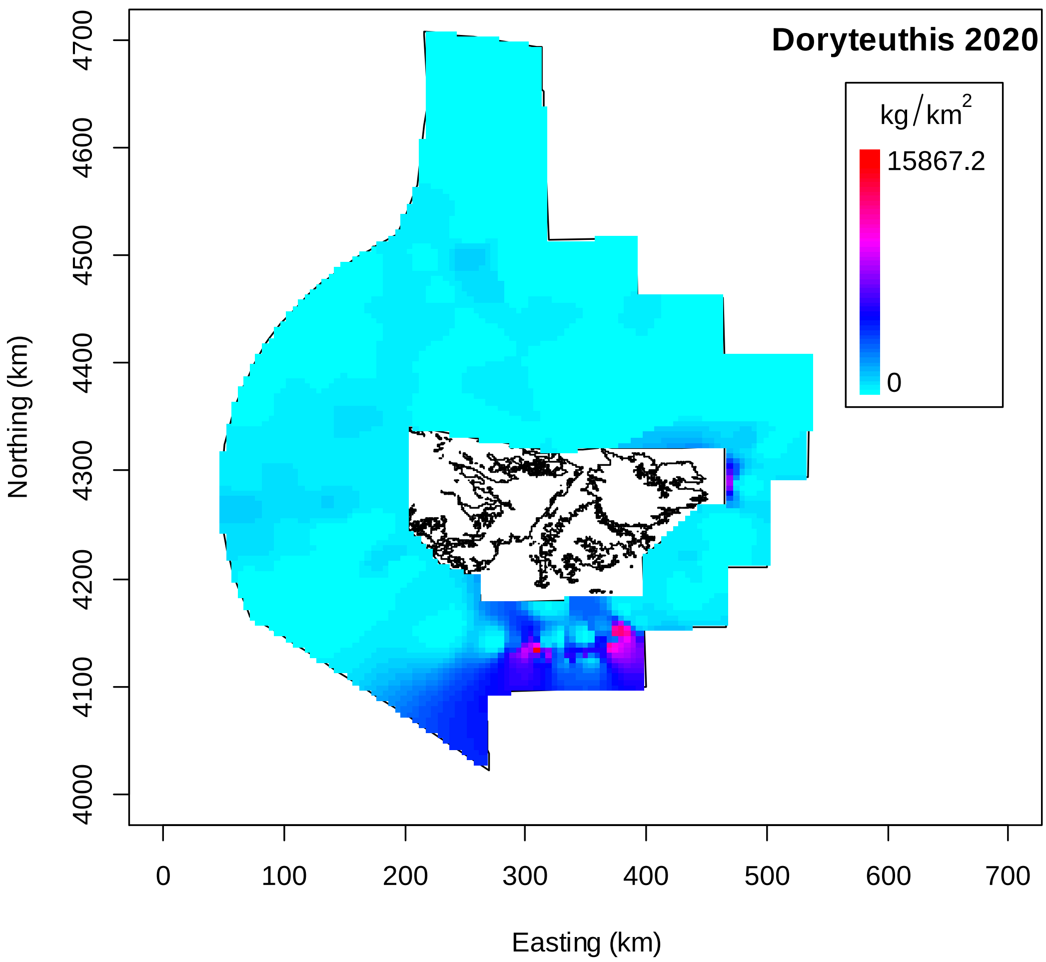

Fig. 18. Density of the Patagonian squid (*Doryteuthis gahi*) around the Falkland Islands during 2020.

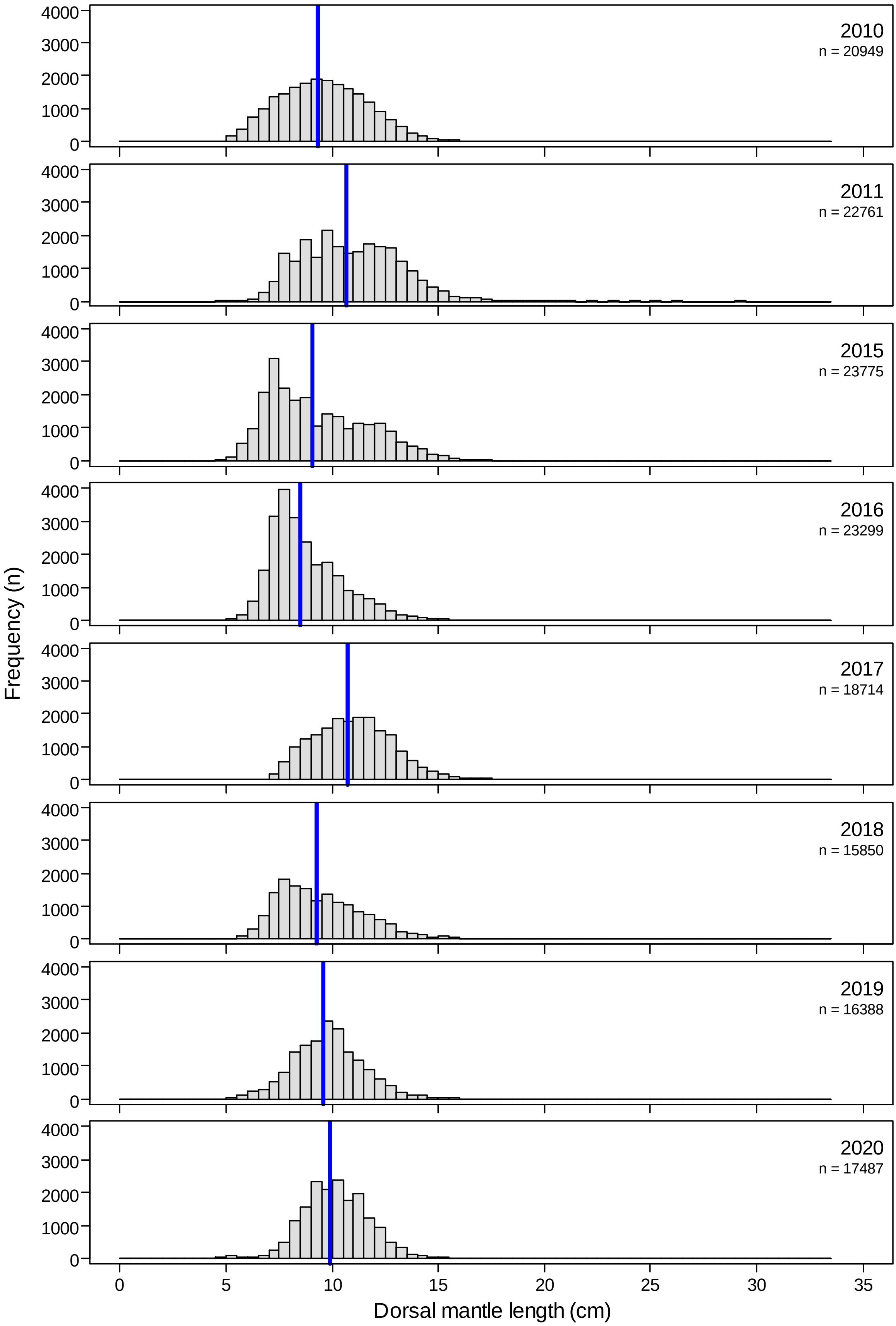

Fig. 19. Length frequency of the Patagonian squid (*Doryteuthis gahi*) around the Falkland Islands during 2010–2011, and 2015–2020. Mean length is indicated by the blue line. Note the data gap from 2012 to 2014.

4.2.7. Red cod (*Salilota australis*)

The biomass of red cod increased from 2010 (93,195 t) to 2011 (161,733 t). It decreased the following years to 22,654 t in 2020, the lowest biomass estimated in the time series. However, overlapping of 95% confidence intervals of biomass estimates were observed across years (Fig. 20; Table III). Through the time series, red cod was found mainly to the west of West Falkland. From 2010 to 2017, high densities were mainly located near the west limit of the FICZ. However, from 2018 the highest densities occurred near the west shore and to the north of West Falkland, i.e. 3,119 kg/km^2 in 2020 (Fig. 21). The highest densities across the time series ranged from 8,841 kg/km^2 in 2019 to 38,175 kg/km^2 in 2016 (Appendix VIII). Length frequency histograms show a wide range of red cod sizes across the time series (i.e. 4–85 cm), probably due to the presence of several cohorts (Fig. 22). Mean length decreased from 37 cm in 2010 to 30 cm in 2017, and from 39 cm in 2018 to 33 cm in 2020. There was no statistically significant change in mean length for this species across years (p = 0.76).

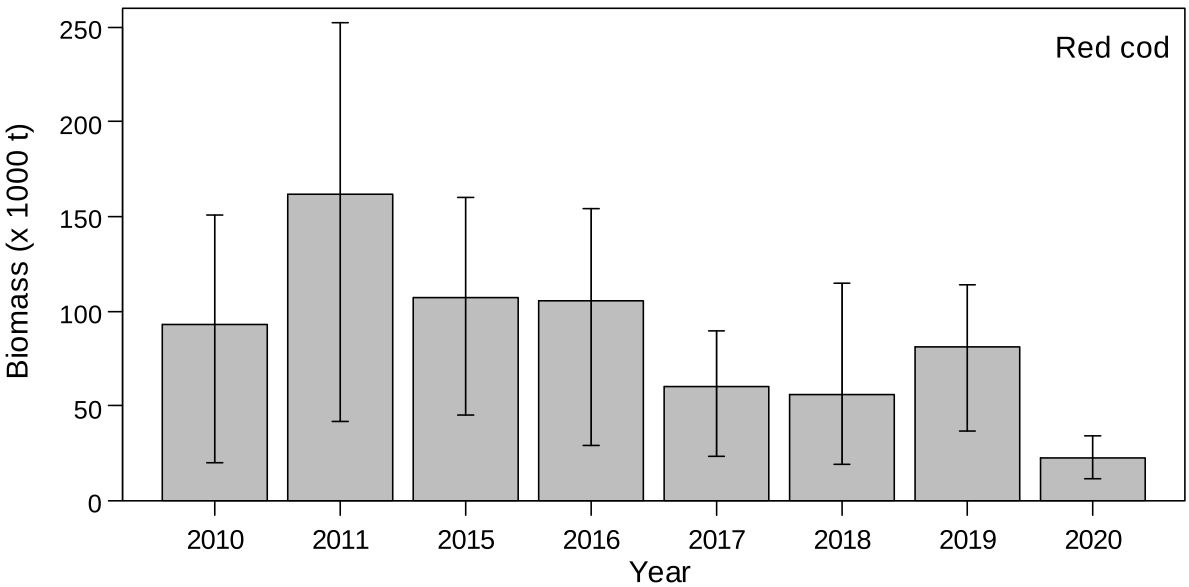

Fig. 20. Mean biomass (t; bold black line) ± 95% confidence intervals (grey dashed lines) of red cod (*Salilota australis*) in Falkland Islands waters during 2010–2011, and 2015–2020. Note the data gap from 2012 to 2014.

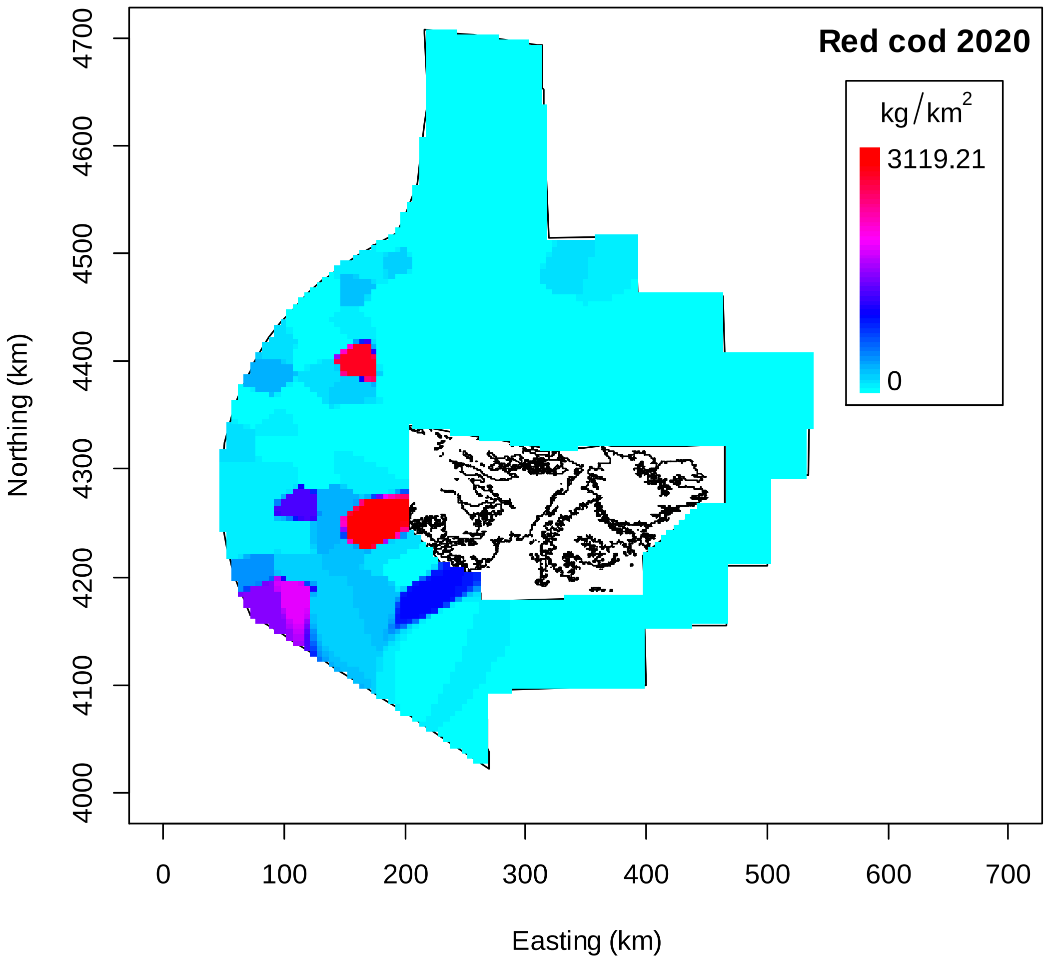

Fig. 21. Density of red cod (*Salilota australis*) around the Falkland Islands during 2020.

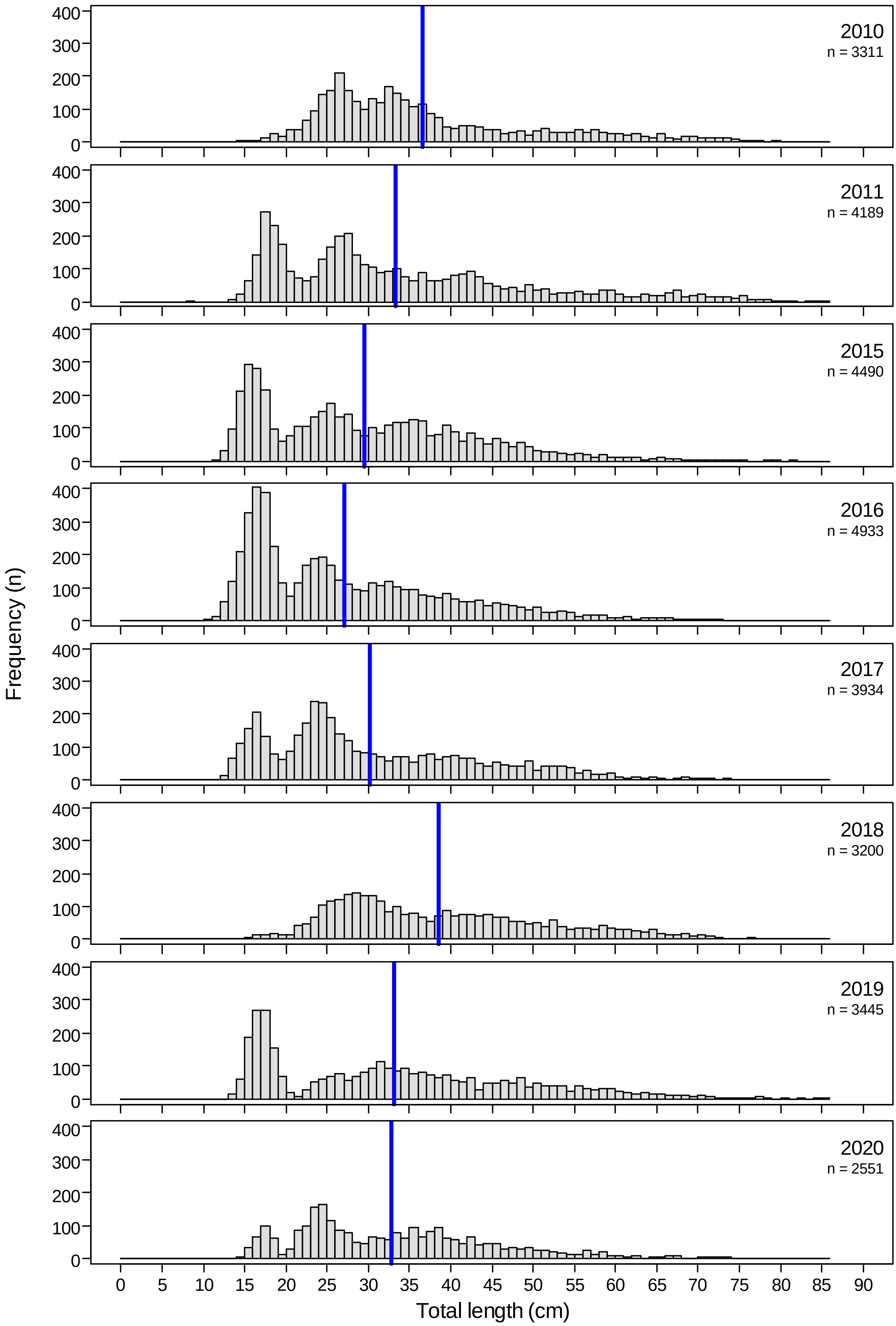

Fig. 22. Length frequency of red cod (*Salilota australis*) around the Falkland Islands during 2010–2011, and 2015–2020. Mean length is indicated by the blue line. Note the data gap from 2012 to 2014.

4.2.8. Rock cod (*Patagonotothen ramsayi*)

Rock cod biomass increased from 2010 (709,536 t) to 2011 (1,090,655 t); however there was a declining trend since 2011 with the lowest biomass estimated in 2020 (22,335 t; Fig. 23; Table III). In 2020, rock cod occurred mainly to the south-west of West Falkland at densities reaching a high of 2,071 kg/km^2 (Fig. 24). This species had a patchy distribution around the Falkland Islands throughout the time series and the highest densities ranged from 8,709 kg/km^2 in 2019 to 823,781 kg/km^2 in 2011 (Appendix IX). There was a wide range of sizes for rock cod throughout the time series (i.e. 4–43 cm; Fig. 25). There was a statistically significant declining trend in mean length from 22 cm in 2010 to 18 cm in 2020 at a rate of 0.47 cm/year ($p = 0.006$).

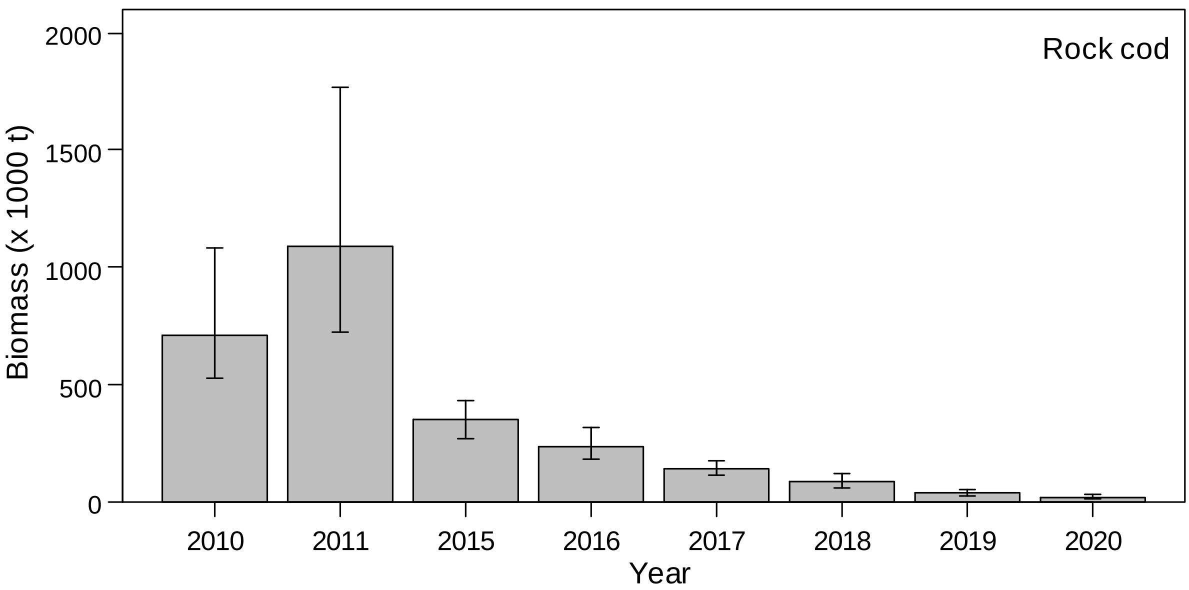

Fig. 23. Mean biomass (t) ± 95% confidence intervals of rock cod (*Patagonotothen ramsayi*) in Falkland Islands waters during 2010–2011, and 2015–2020. Note the data gap from 2012 to 2014.

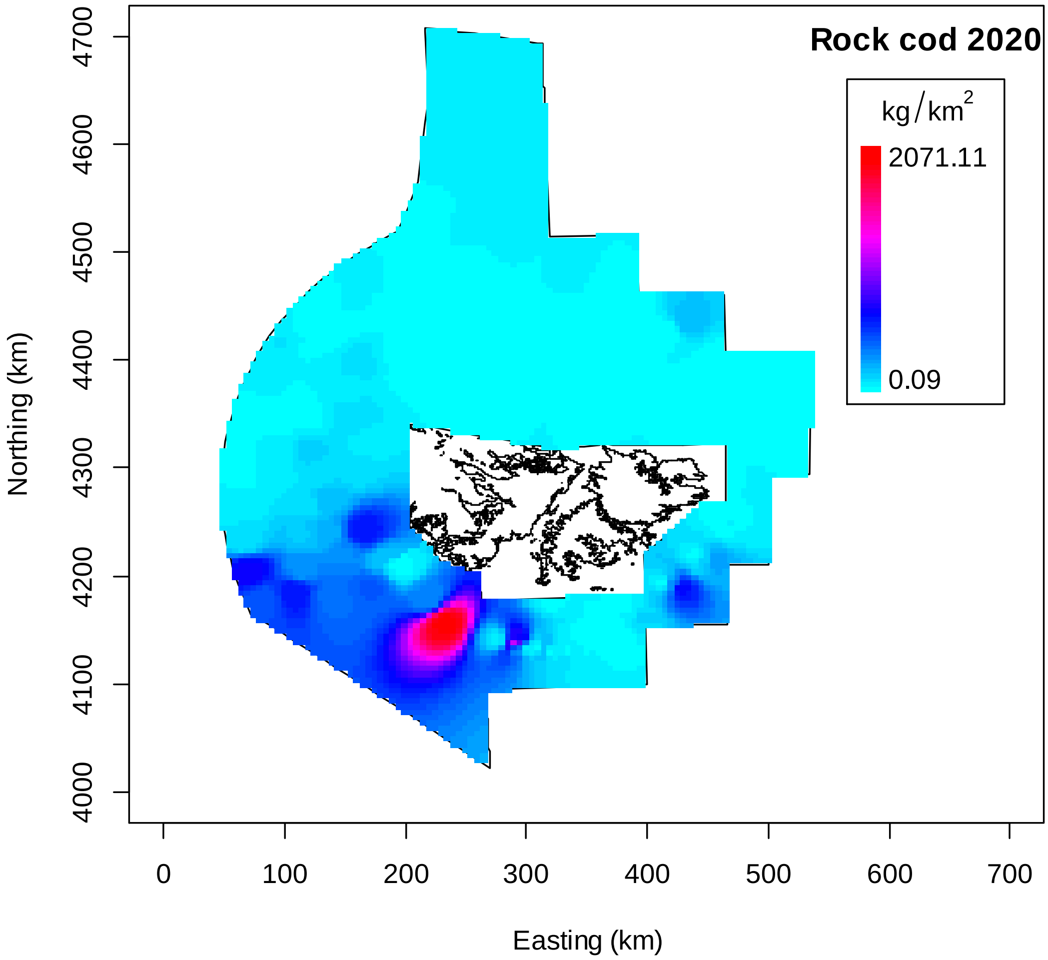

Fig. 24. Density of rock cod (*Patagonotothen ramsayi*) around the Falkland Islands during 2020.

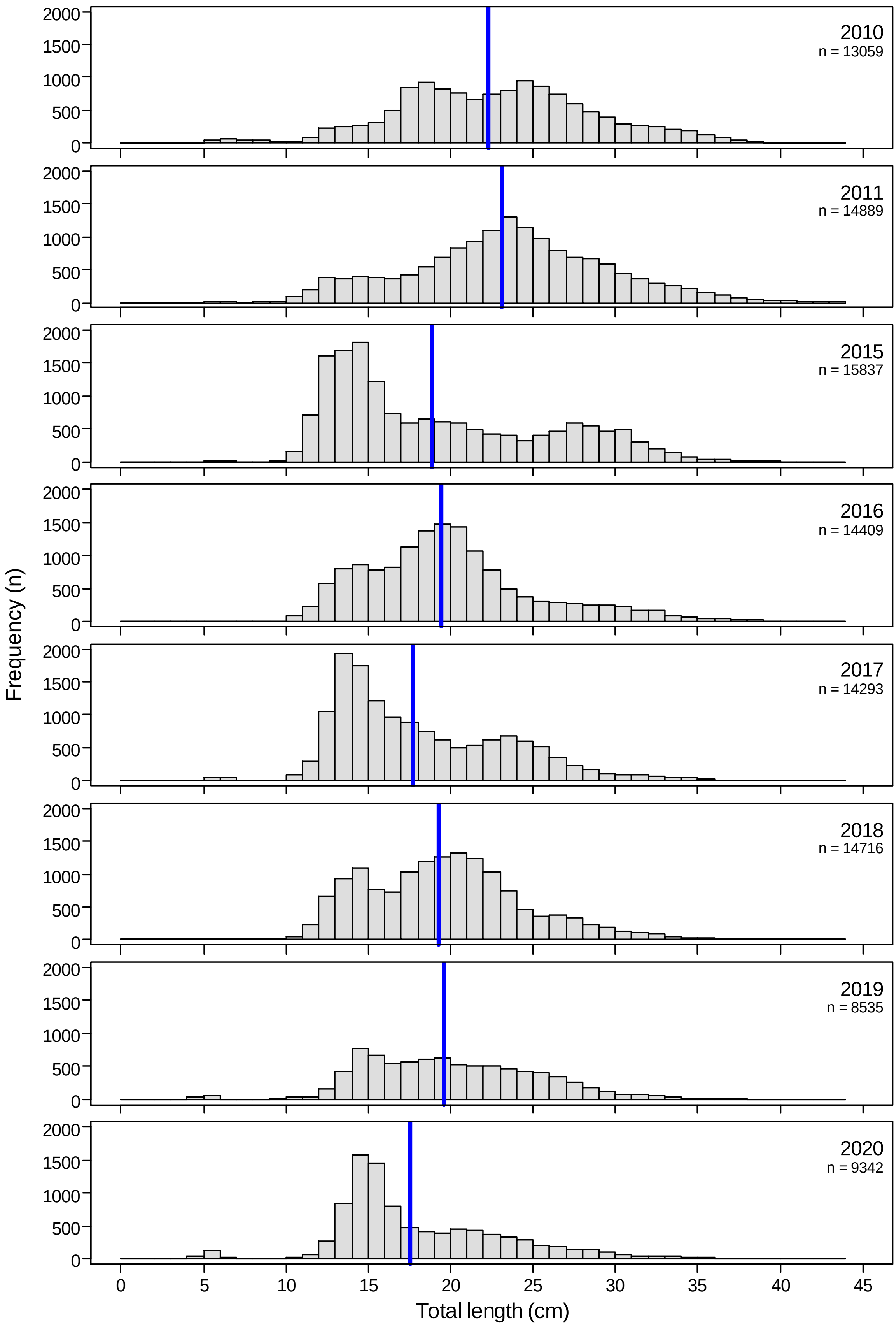

Fig. 25. Length frequency of rock cod (*Patagonotothen ramsayi*) around the Falkland Islands during 2010–2011, and 2015–2020. Mean length is indicated by the blue line. Note the data gap from 2012 to 2014.

4.2.9. Southern blue whiting (*Micromesistius australis australis*)

Southern blue whiting biomass was below 75,000 t per year throughout the time series, except for 2011 (236,328 t) and 2016 (332,096 t). The second lowest biomass in the time series was estimated for 2020 (9,559 t; Fig. 26; Table III). In 2020, southern blue whiting occurred mainly to the south of the FICZ, with the highest density estimated at 3,716 kg/km^2 (Fig. 27). Throughout the time series, southern blue whiting occurred mainly to the south of the FICZ and to the north-east of East Falkland; the highest densities ranged from 6,626 kg/km^2 in 2019 to 203,954 kg/km^2 in 2016 (Appendix X). Southern blue whiting decreased gradually in catch numbers throughout the time series, and therefore in the number of individuals sampled from 2010 (n = 2,033) to 2020 (n = 144), except for 2018 (n = 2,780). Length of southern blue whiting ranged from 6 cm to 72 cm throughout the time series (Fig. 28). Mean length was variable across years, the largest mean length of the time series was estimated in 2020 (43 cm), and there was no statistically significant change in mean length from 2010 to 2020 (p = 0.97).

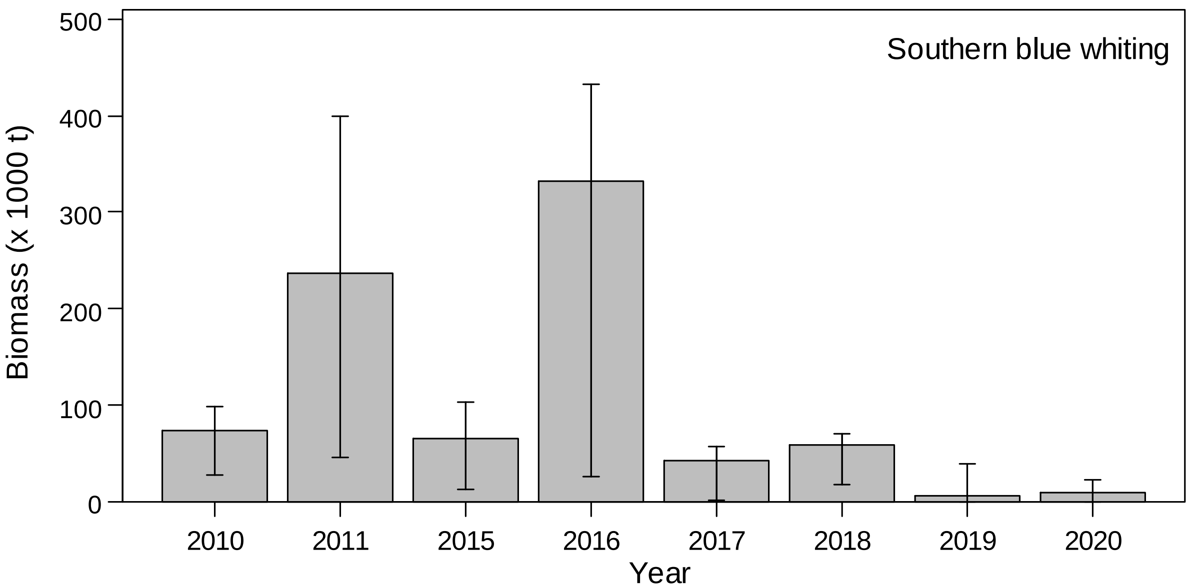

Fig. 26. Mean biomass (t) ± 95% confidence intervals of southern blue whiting (*Micromesistius australis australis*) in Falkland Islands waters during 2010–2011, and 2015–2020. Note the data gap from 2012 to 2014.

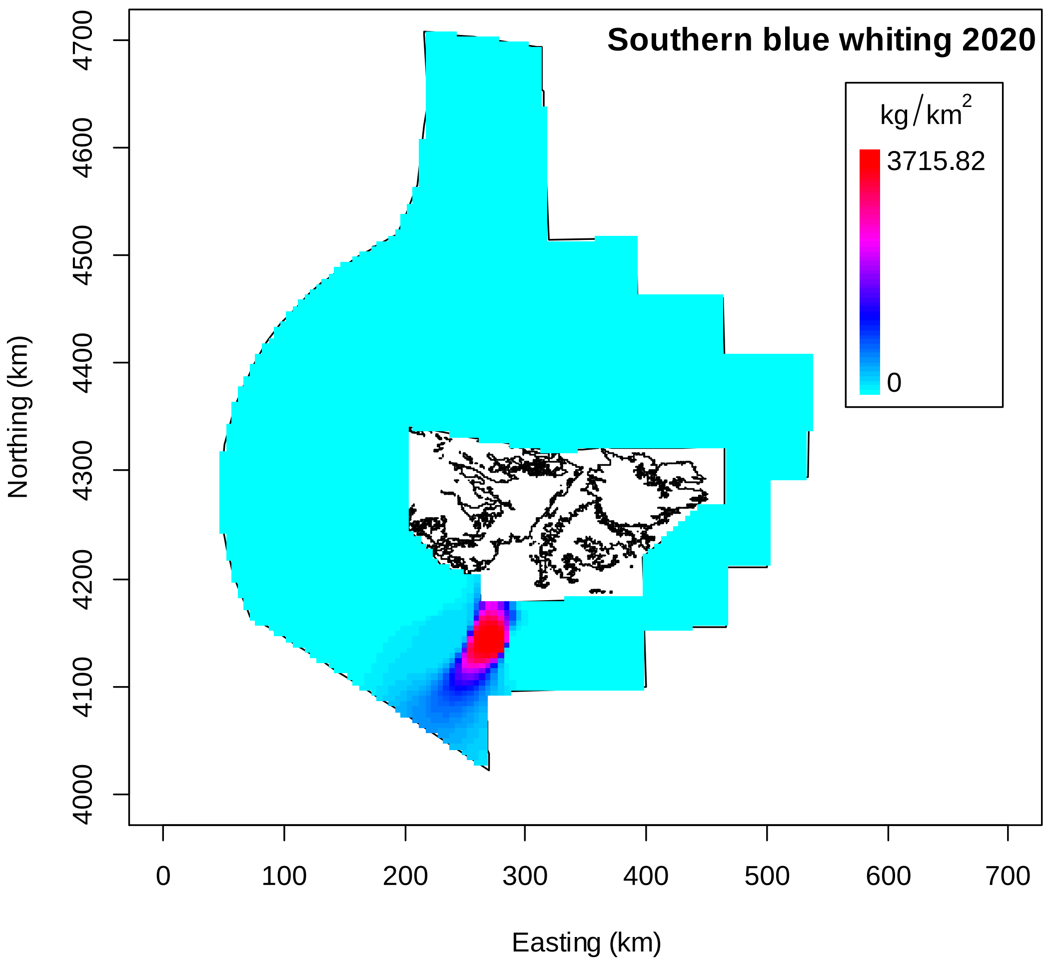

Fig. 27. Density of southern blue whiting (*Micromesistius australis australis*) around the Falkland Islands during 2020.

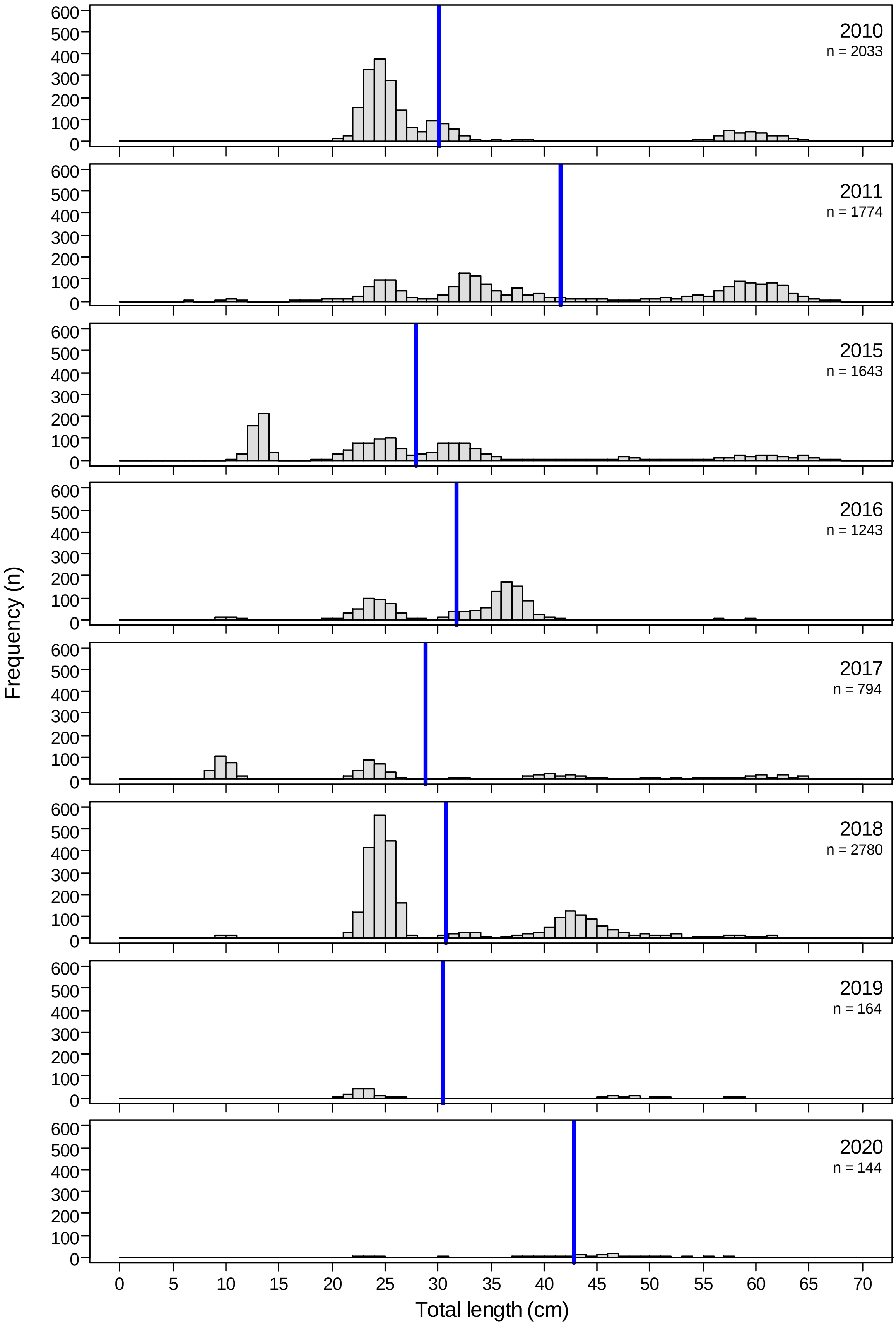

Fig. 28. Length frequency of southern blue whiting (*Micromesistius australis australis*) around the Falkland Islands during 2010–2011, and 2015–2020. Mean length is indicated by the blue line. Note the data gap from 2012 to 2014.

4.2.10. Toothfish (*Dissostichus eleginoides*)

Adult toothfish are caught mainly using longline; therefore, the information provided in this report is not representative of the adult portion of the toothfish population. The survey biomass of toothfish has remained below 12,000 t pear year since 2010, with the lowest biomass estimated in 2020 (3,201 t; Fig. 29; Table III). In 2020, the highest densities of toothfish were detected across the south-west of West Falkland (174 kg/km^2; Fig. 30). Toothfish had a patchy distribution around the Falkland Islands throughout the time series, with the highest densities ranging from 197 kg/km^2 in 2015 to 902 kg/km^2 in 2018 (Appendix XI). Length frequency histograms show that toothfish had a range of sizes from 5 cm to 115 cm throughout the time series (Fig. 31). Mean length decreased from 46 cm in 2010 to 30 cm in 2015, and increased again to 49 cm in 2020. There was no statistically significant change in mean length of toothfish from 2010 to 2020 ($p = 0.66$).

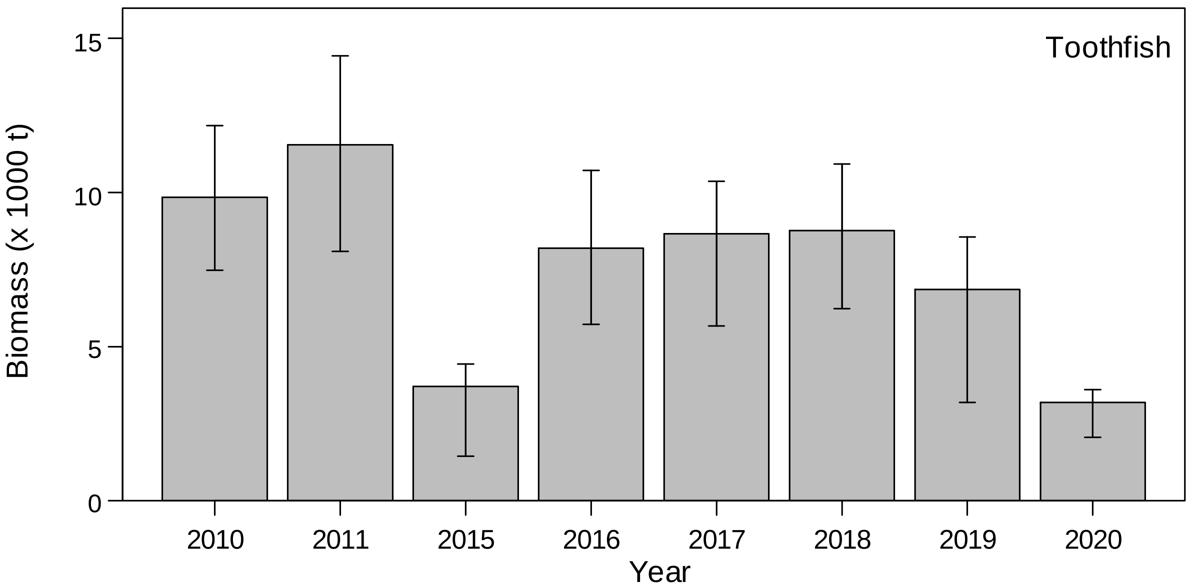

Fig. 29. Mean biomass (t) ± 95% confidence intervals of toothfish (*Dissostichus eleginoides*) in Falkland Islands waters during 2010–2011, and 2015–2020. Note the data gap from 2012 to 2014.

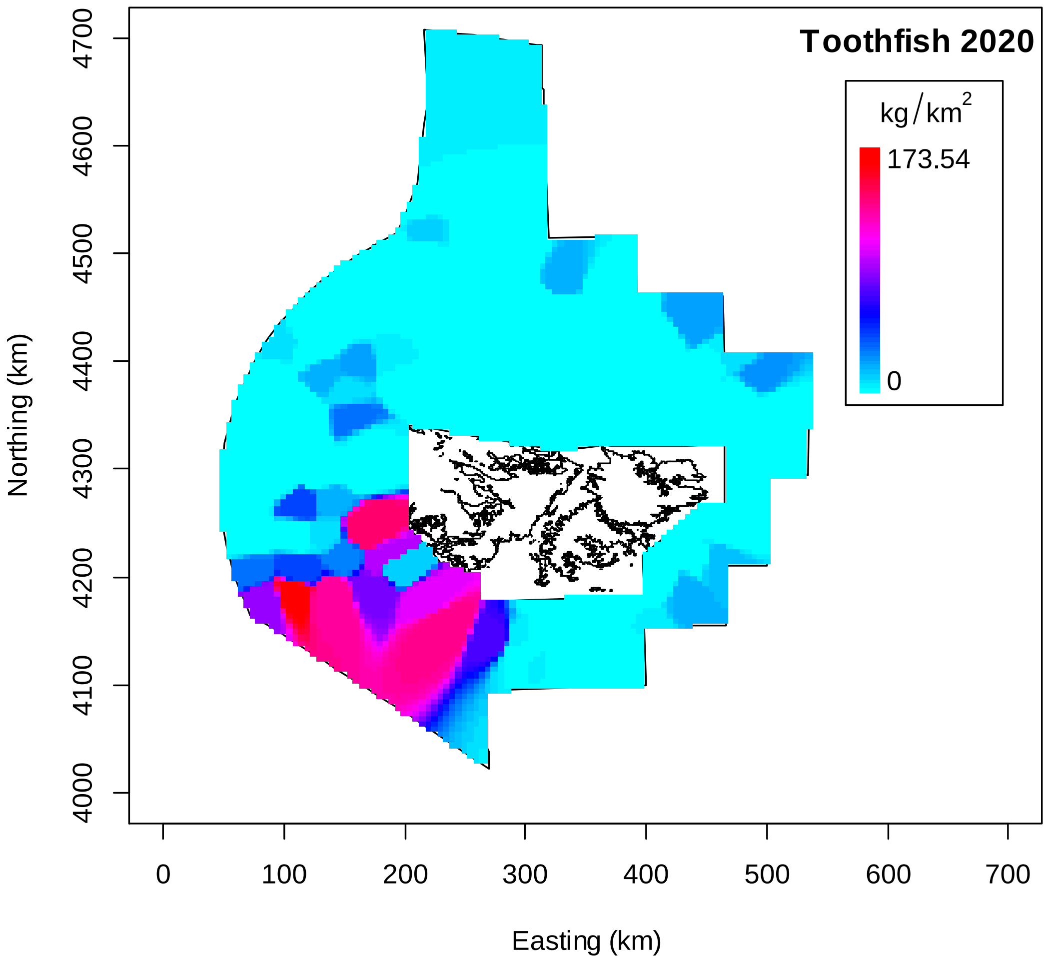

Fig. 30. Density of toothfish (*Dissostichus eleginoides*) around the Falkland Islands during 2020.

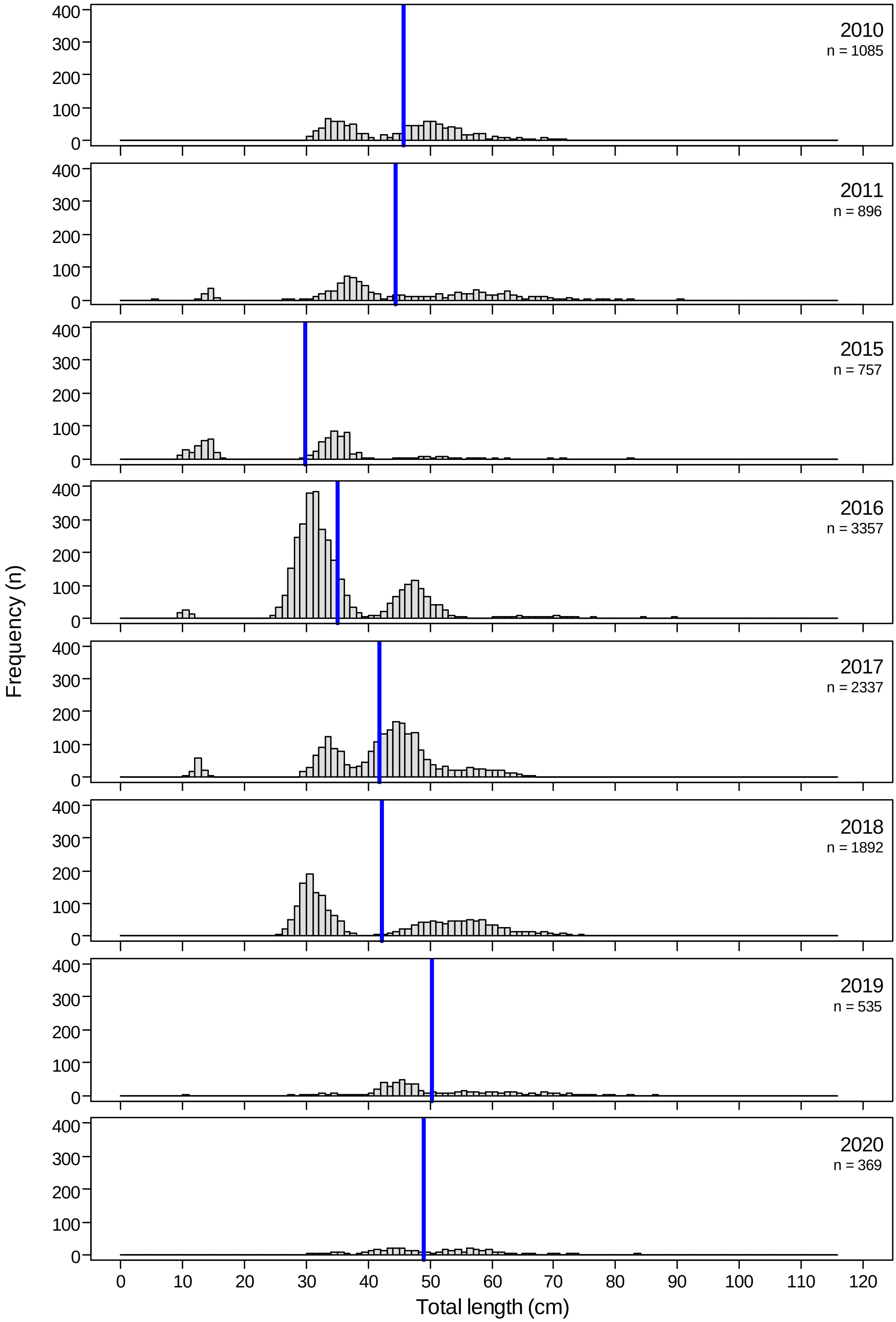

Fig. 31. Length frequency of toothfish (*Dissostichus eleginoides*) around the Falkland Islands during 2010–2011, and 2015–2020. Mean length is indicated by the blue line. Note the data gap from 2012 to 2014.

5. Discussion

The biomass estimated for nine commercial species from the February trawl research surveys declined from 2010 to 2020. Rock cod had the greatest decrease in biomass; it was estimated that its biomass in 2020 (22,335 t) was only 3% of its biomass in 2010 (709,536 t). Southern blue whiting biomass in 2020 (9,559 t) was 13% of its biomass in 2010 (73,563 t). Red cod biomass in 2020 (22,654 t) was 24% of its biomass in 2010 (93,195 t). Hoki biomass in 2020 (77,733 t) was 29% of its biomass in 2010 (272,080 t). Toothfish biomass in 2020 (3,201 t) was 33% of its biomass in 2010 (9,846 t). Common hake biomass in 2020 (3,346 t) was 37% of its biomass in 2010 (9,013 t). Banded grenadier biomass in 2020 (39,381 t) was 46% of its biomass in 2010 (86,113 t). Patagonian squid biomass in 2020 (96,135 t) was 47% of its biomass in 2010 (203,558 t), and kingclip biomass in 2020 (14,887 t) was 69% of its biomass in 2010 (21,617 t).

Rock cod continues with a considerable declining trend in biomass since 2010, which is consistent with the declining biomass trend estimated from 2006 to 2018 based on commercial data (Winter 2019). The continuing decrease in rock cod abundance may also be due to a possible change in its geographic distribution inferred from increasing out-of-zone catches since 2016 (Falkland Islands Fisheries Department 2018). Declining biomass trends of southern blue whiting, hoki and kingclip that were estimated including commercial catch data (Ramos & Winter 2019b,c,d) are also consistent with our findings based on research data. However, southern blue whiting and hoki had an increase in biomass in 2020 compared with 2019. This may be due to several reasons: 1) the effect of the no-fishing area to the south and south-west of the Falkland Islands, from 1 July to 15 October since 2007, mandated for S-licensed vessels targeting both species (Falkland Islands Government 2019); 2) the S-licence not being used since 2017, and therefore reducing fishing pressure on both species under this licence; 3) additional stations carried out in the 2018 and 2020 groundfish surveys to the southwest of the FICZ, which may result in higher biomass estimates during both years. The biomasses of the Argentine short-fin squid and banded grenadier also increased in 2020 compared with 2019. Patagonian squid had highly fluctuating inter-annual biomass. Red cod biomass had a similar pattern, from 2010 to 2017, compared with biomass estimates by Winter (2018) using a Bayesian state-space implementation of the Graham-Schaefer model (BSM).

Toothfish biomass has remained below 12,000 t since 2010, with the lowest biomass estimate in 2020 (3,201 t). However, these findings represent only a portion of the population given that trawler vessels rarely catch adult toothfish individuals. A shift in fishing behaviour, i.e. vessels fishing deeper and further south in the FICZ to capture ridge scaled rattail *M. carinatus*, has led the finfish fishery to catch more toothfish over the last three years compared with previous years (Falkland Islands Government 2019). This is consistent with a decrease in toothfish biomass from 2010 (41,386 t) to 2018 (30,485 t) when considering catches from longliners, finfish and calamari trawlers in FICZ and FOCZ (Farrugia & Winter 2019). Similarly, most catches of the Argentine short-fin squid in Falkland Islands waters are taken by jiggers and a smaller proportion of the catch is taken by trawlers. Therefore, this study is only representative of the portion of the population of *I. argentinus* that is caught by bottom trawler vessels.

The species assessed are targeted across several nations' Exclusive Economic Zones and for some stocks the Falkland Islands contribute a small proportion of the total shared catch in the Southwest Atlantic and Southeast Pacific. For instance, the Falkland Islands contribute nearly 11% and 13% of the 10-year average catch of hoki and southern blue whiting shared with Argentina and Chile, respectively (Ramos & Winter 2019c,d). Declines in biomass of some stocks may thus be due to higher fishing pressure outside Falkland Islands waters.

Additional stations to the southwest were carried out in 2018 and 2020, which may have an effect on the biomass estimates for some species during both years. However, stations to the southwest during February are important because they are located in the zone of greater densities for banded grenadier, hoki, southern blue whiting, and toothfish, as found in this study.

Three species had statistically significant declines in mean length; these were rock cod, common hake and hoki. Concurrently, length at maturity of rock cod declined from 2003 to 2018 (Winter 2019), and modal length of hoki had a statistically significant decline from 2002 to 2018 when commercial data was taken into account (Ramos & Winter 2019c). The negative trends in mean length of other species from 2010 to 2020, such as kingclip, red cod, banded grenadier and the Patagonian squid were not statistically significant.

Accordingly, kingclip had a non-significant decrease in modal length from 62 cm in 1990 to 51 cm in 2018 (Ramos & Winter 2019b).

Southern blue whiting did not have a statistically significant decline in mean length but this result should be taken with caution because only a few individuals, and at lengths ≥ 19 cm were caught in 2019 and 2020. In contrast, significant declines were found in modal length of southern blue whiting caught in commercial trawlers from 2002 to 2018 (Ramos & Winter 2019d). The absence of individuals < 19 cm during 2019 and 2020 may be an indication of a decrease in recruitment to the fishery. Likewise, juvenile toothfish have not been found during late austral spring and summer to the south of the FICZ since 2018. Red cod did not have a statistically significant decrease in mean length; however this species had a significant decrease in modal length from 1988 to 2018 (Winter 2018). Analyses of length frequencies from longer time series and larger sample sizes in scientific surveys may provide more accurate body size trends.

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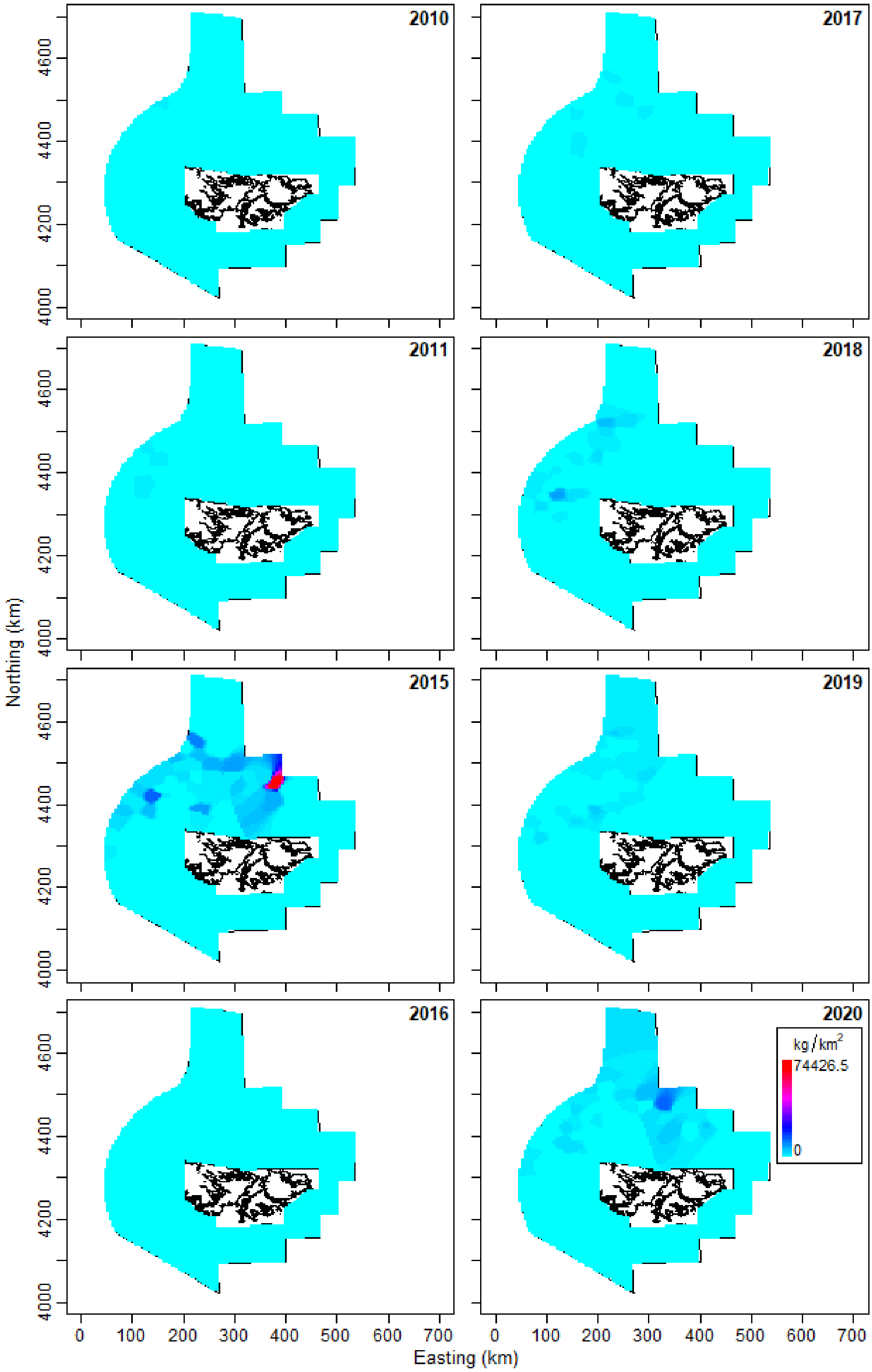
Appendix I

Groundfish (gf) and calamari pre-season (pr) surveys information. Catches per survey and combined total including Argentine short-fin squid, banded grenadier, common hake, hoki, kingclip, Patagonian squid, red cod, rock cod, southern blue whiting, and toothfish.

Year	Vessel		No. of trawls			Stations excluded		Catch (t)		
	gf	pr	gf	pr	total	gf	pr	gf	pr	total
2010	Castelo (ZDLT1)	Beagle F.I. (ZDLZ)	87	55	142	478, 501	NA	193.4	458.0	651.4
2011	Castelo (ZDLT1)	Venturer (ZDLP1)	88	58	146	NA	NA	195.3	257.3	452.6
2015	Castelo (ZDLT1)	Baffin Bay (MSPL9)	89	57	146	NA	NA	121.0	392.8	513.8
2016	Castelo (ZDLT1)	Sil (ZDLR1)	90	56	146	NA	638	87.1	206.6	293.7
2017	Castelo (ZDLT1)	Argos Vigo (ZDLU1)	90	58	148	2328	1002	47.2	254.3	301.4
2018	Monteferro (ZDLM3)	Castelo (ZDLT1)	97	59	156	143,144,156,164,183	NA	80.6	169.4	250.1
2019	Monteferro (ZDLM3)	Argos Cíes (ZDLS3)	83	52	135	NA	25,29,37	45.3	418.4	463.7
2020	Castelo (ZDLT1)	Argos Cíes (ZDLS3)	80	59	139	NA	NA	47.8	283.8	331.6

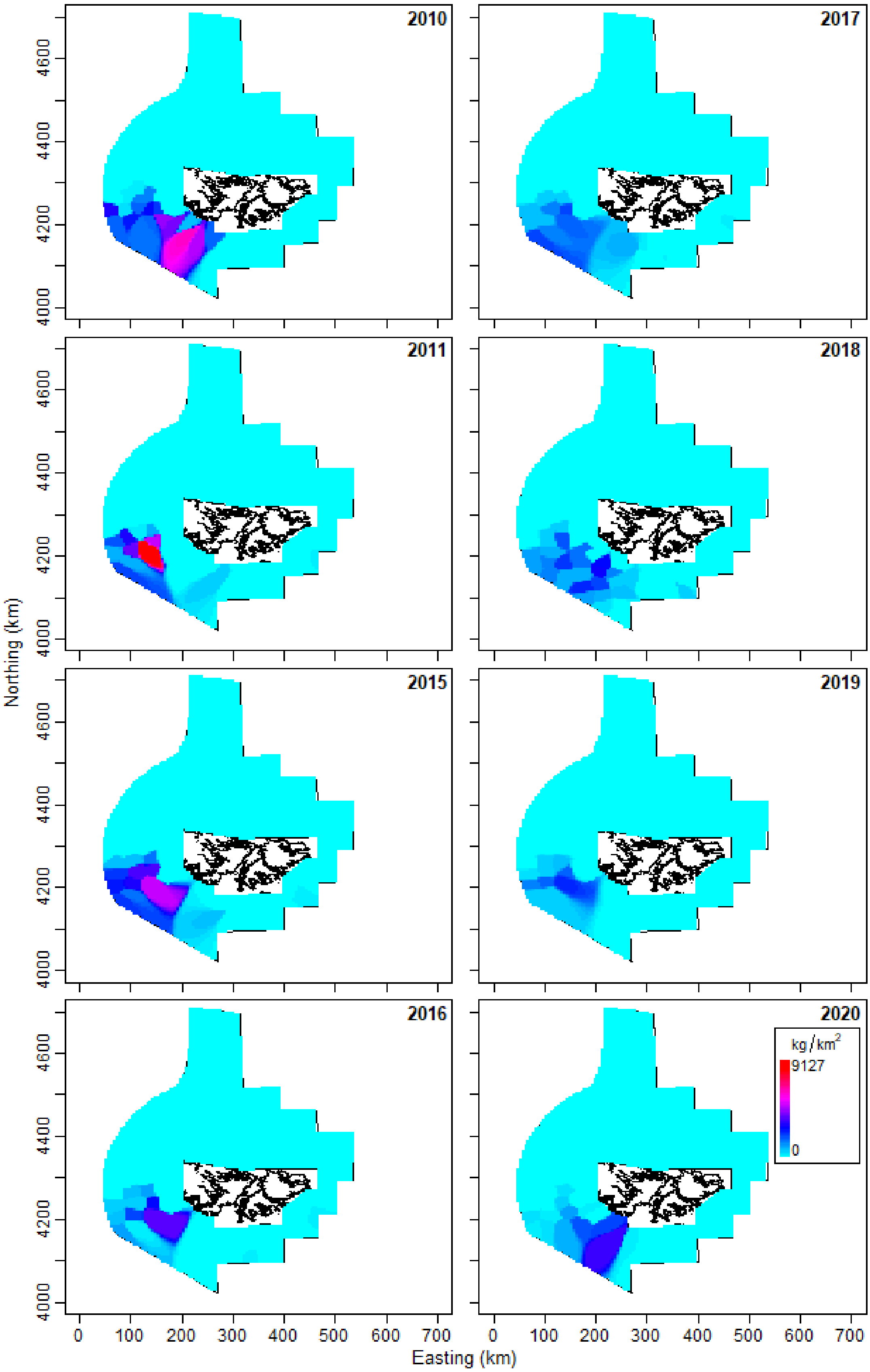
Appendix II

Comparative density of the Argentine short-fin squid (*Illex argentinus*) around the Falkland Islands during 2010–2011, and 2015–2020.



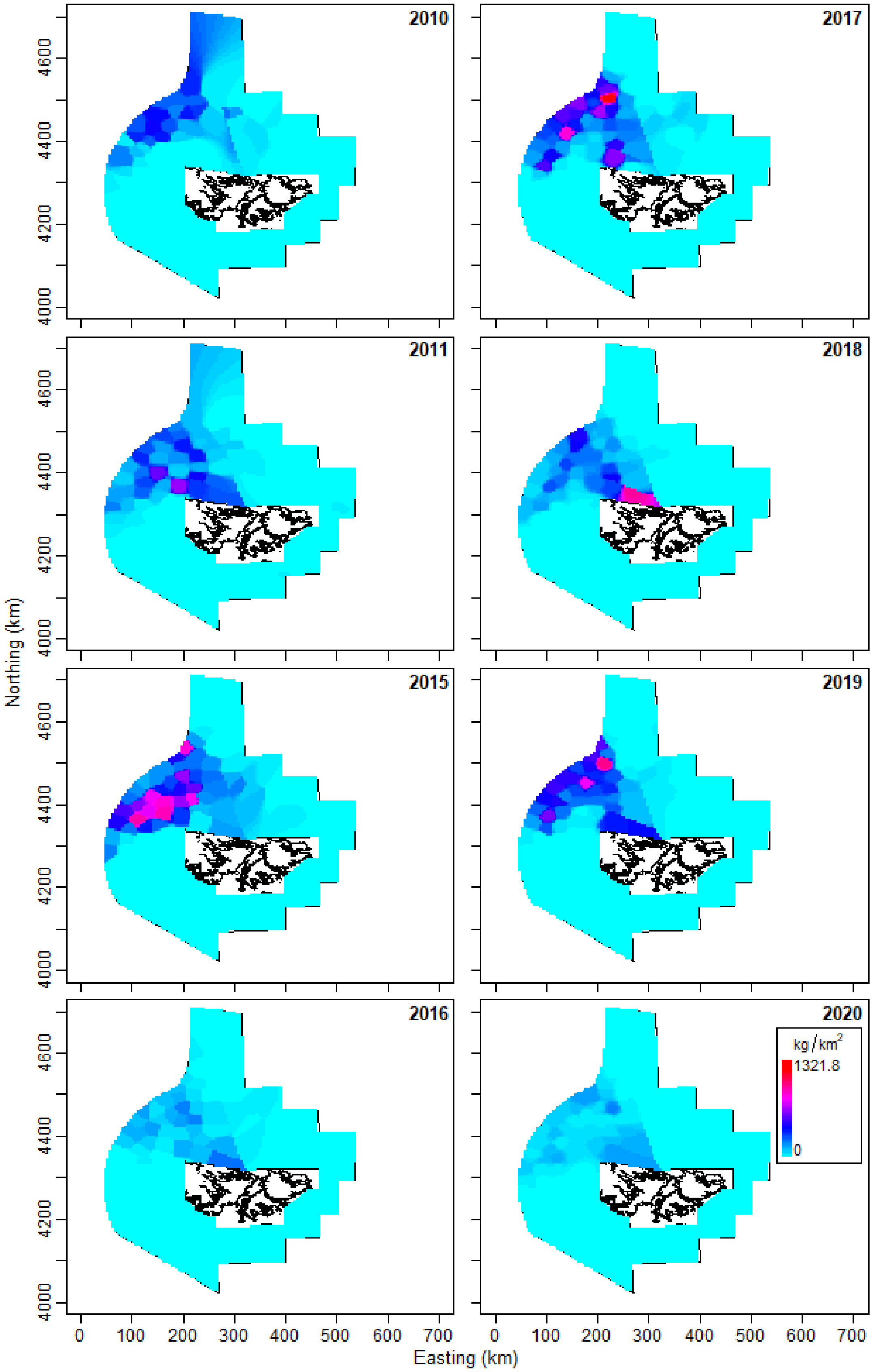
Appendix III

Comparative density of banded grenadier (*Coelorinchus fasciatus*) around the Falkland Islands during 2010–2011, and 2015–2020.



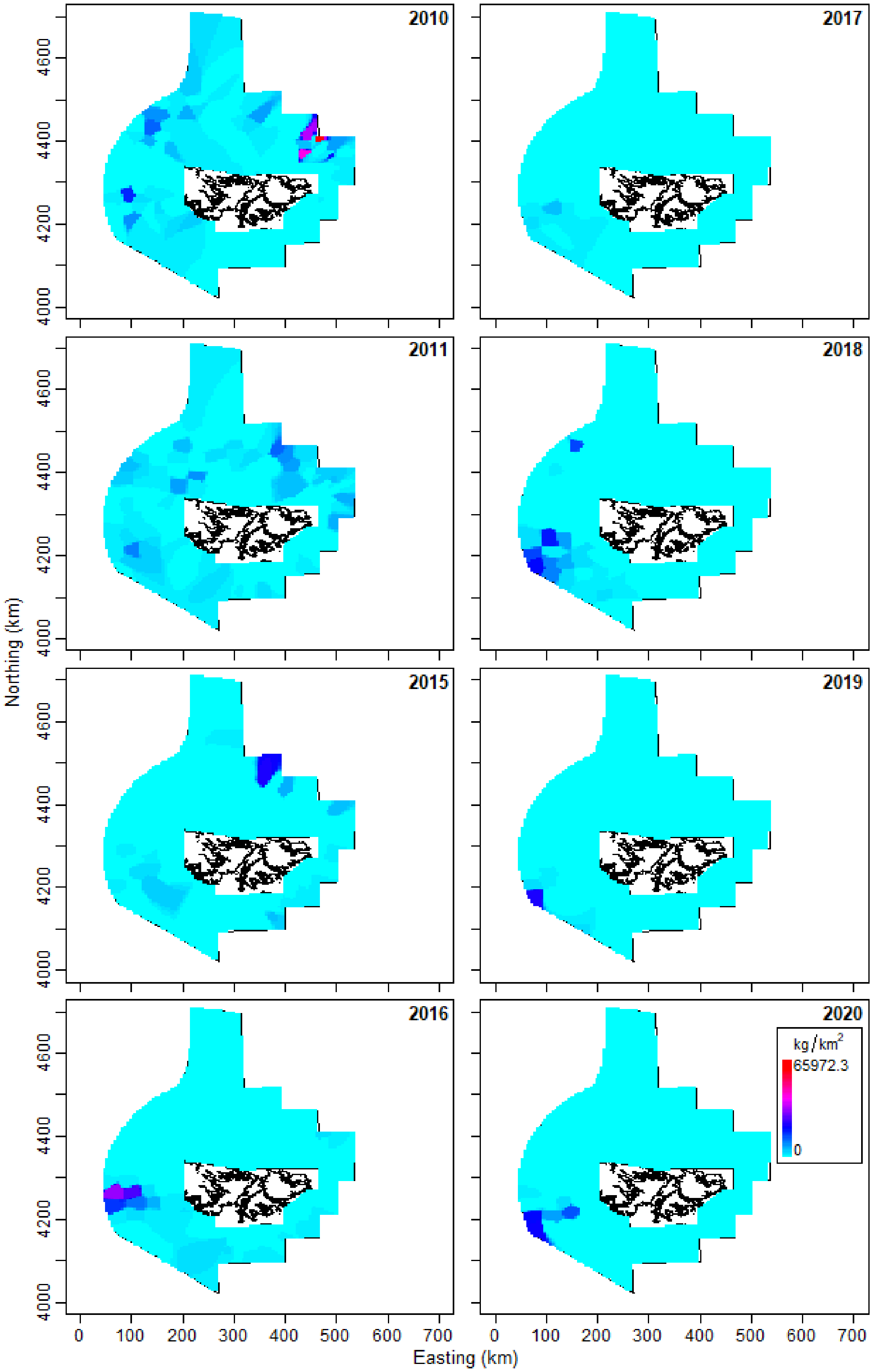
Appendix IV

Comparative density of common hake (*Merluccius hubbsi*) around the Falkland Islands during 2010–2011, and 2015–2020.



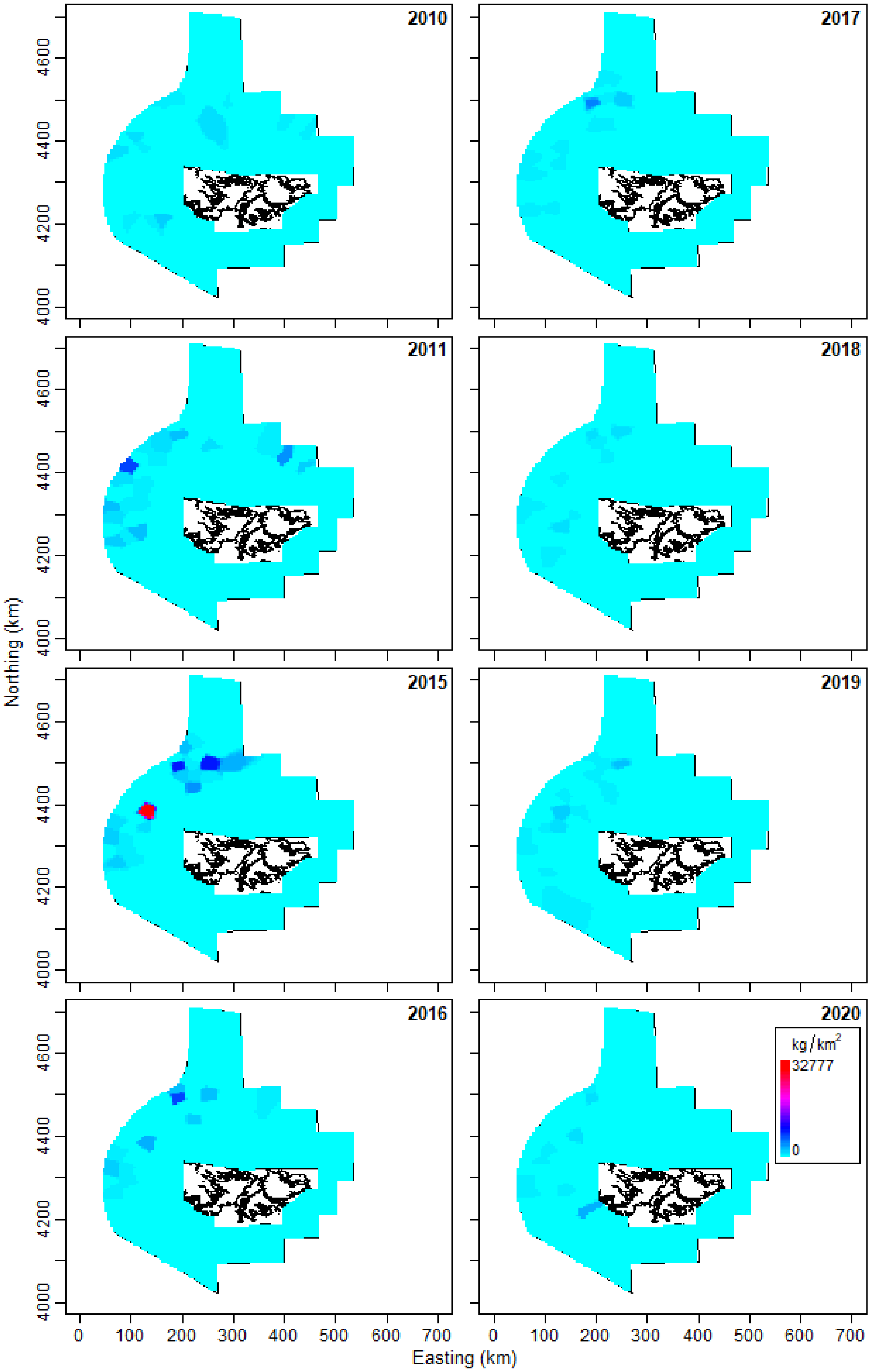
Appendix V

Comparative density of hoki (*Macruronus magellanicus*) around the Falkland Islands during 2010–2011, and 2015–2020.



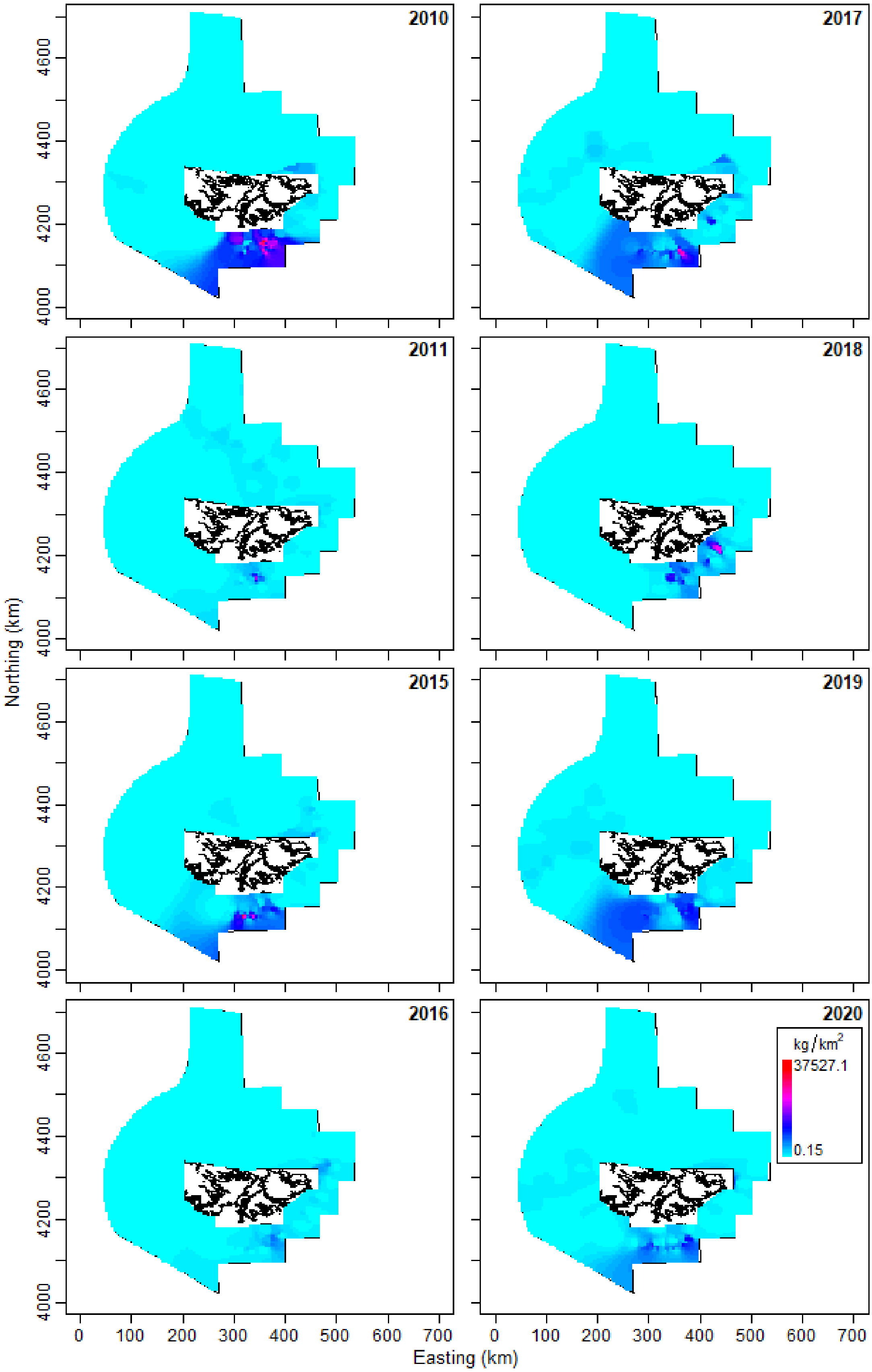
Appendix VI

Comparative density of kingclip (*Genypterus blacodes*) around the Falkland Islands during 2010–2011, and 2015–2020.



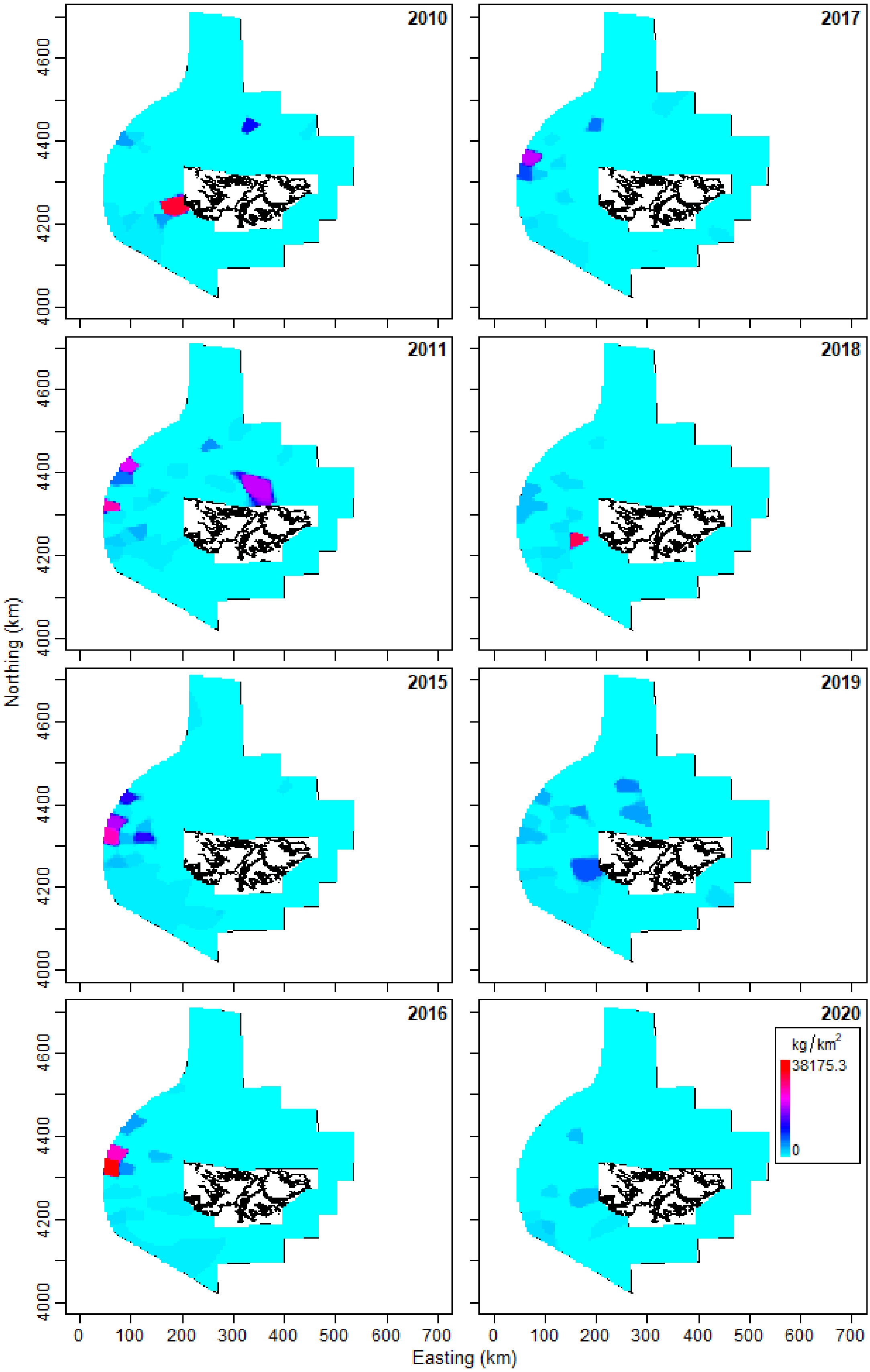
Appendix VII

Comparative density of the Patagonian squid (*Doryteuthis gahi*) around the Falkland Islands during 2010–2011, and 2015–2020.



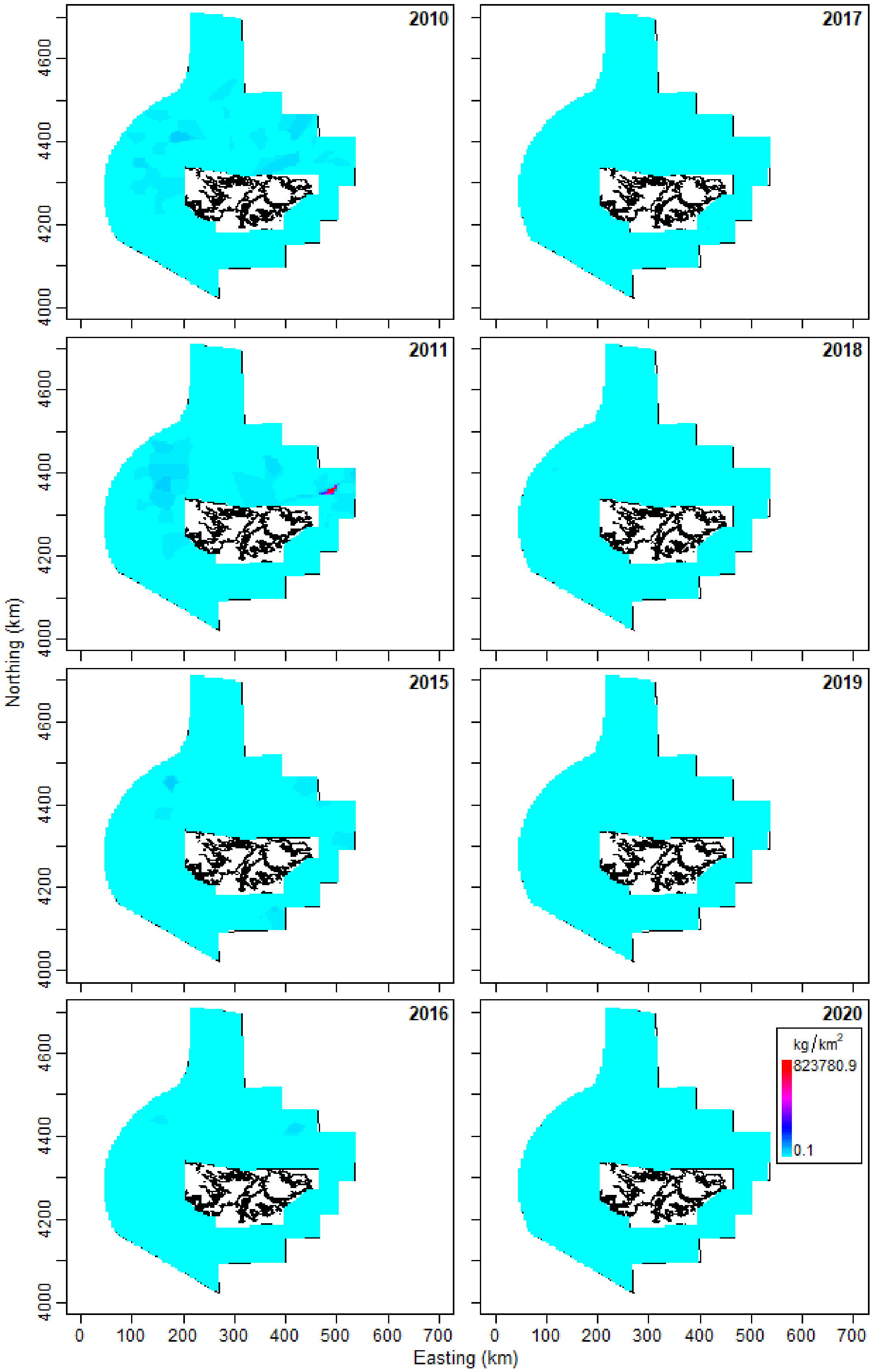
Appendix VIII

Comparative density of red cod (*Salilota australis*) around the Falkland Islands during 2010–2011, and 2015–2020.



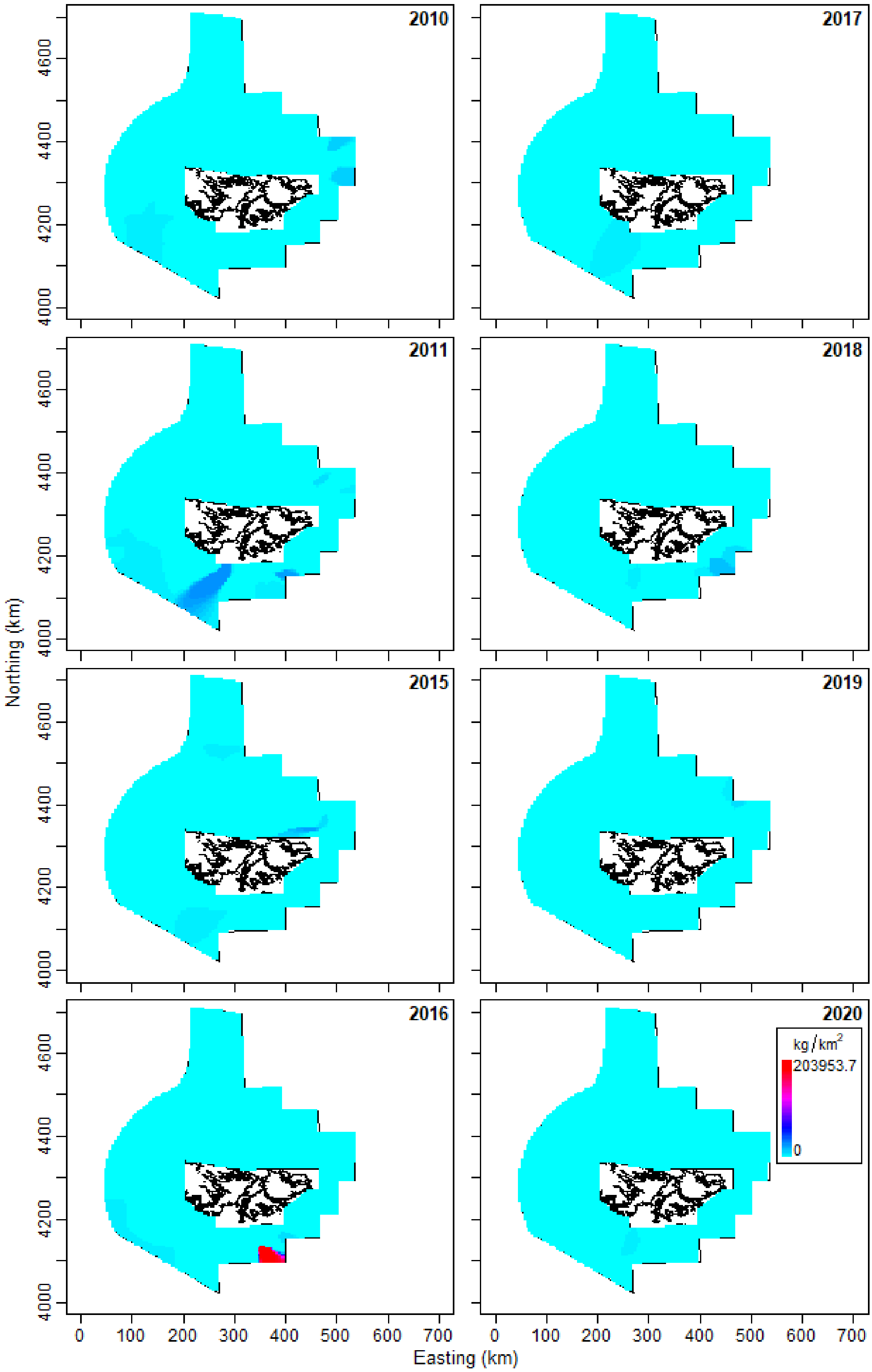
Appendix IX

Comparative density of rock cod (*Patagonotothen ramsayi*) around the Falkland Islands during 2010–2011, and 2015–2020.



Appendix X

Comparative density of southern blue whiting (*Micromesistius australis australis*) around the Falkland Islands during 2010–2011, and 2015–2020.



Appendix XI

Comparative density of toothfish (*Dissostichus eleginoides*) around the Falkland Islands during 2010–2011, and 2015–2020.