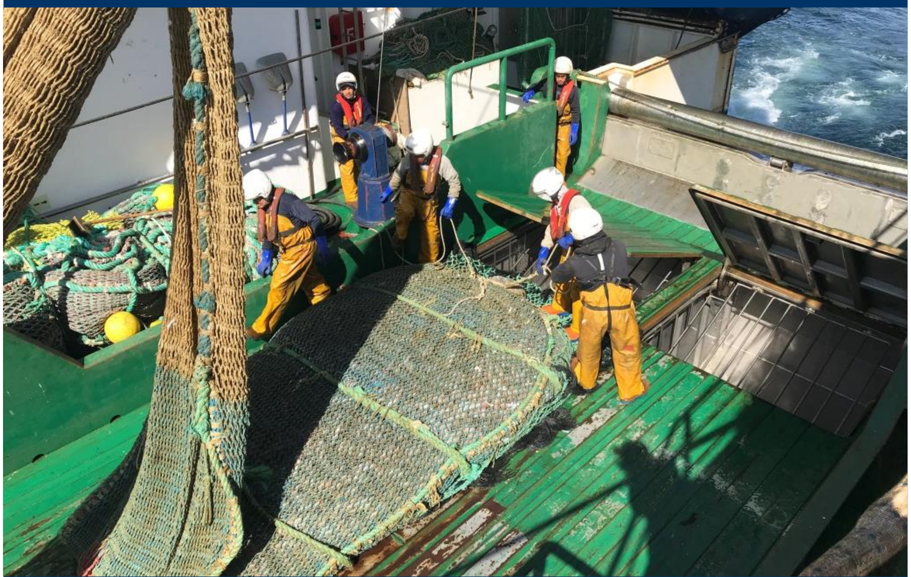
February trawl survey biomasses of fishery species in Falkland Islands waters, 2010–2019



Ramos JE, Winter A

Fisheries Department
Directorate of Natural Resources
Falkland Islands Government
Stanley, Falkland Islands

5 August 2019

SA–2019–08

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Participating/Contributing Scientific Staff

Jorge E. Ramos (R scripts, data analyses, elaboration of report)
Andreas Winter (R Scripts, elaboration of report)

Acknowledgements

We thank the captains and crews of the commercial fishing vessels, and the scientific observers of the Falkland Islands Fisheries Department (FIFD) that facilitated and assisted in catch and biological data collection. Alex Blake (FIFD data analyst) assisted with data inquiries.

For citation purposes this publication should be referenced as follows:

Ramos JE, Winter A (2019) February trawl survey biomasses of fishery species in Falkland Islands waters, 2010–2019. SA–2019–08. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 46 pp.

Distribution: Public Domain

Reviewed and approved on 5 August 2019

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1. Summary

A stock assessment of 10 commercial species, i.e. Argentine shortfin squid, banded grenadier, common hake, hoki, kingclip, Patagonian squid, red cod, rock cod, southern blue whiting, and toothfish, was conducted based on catch data of 1,019 bottom trawls carried out during the February groundfish and calamari pre-season surveys from 2010–2011, and 2015–2019 around Falkland Islands waters.

The biomass of rock cod declined approximately 19x from 2010 (709,536 t) to 2019 (37,793 t). Hoki biomass declined 7x from 2010 (272,080 t) to 2019 (41,399 t), whereas banded grenadier declined 4x from 2010 (86,113 t) to 2019 (21,026 t). Southern blue whiting, once one of the largest finfish stocks exploited in Falkland waters, reached its lowest biomass level in 2019 with 6,626 t, probably because southwestern deep water stations were not carried out during the February 2019 research survey. Other species had highly fluctuating inter-annual biomass levels.

The geographic distribution of the Argentine short-fin squid, common hake, kingclip, and rock cod was spread through the north of the Falkland Islands. Banded grenadier, Patagonian squid and southern blue whiting occurred mainly to the south of the Falkland Islands. Red cod was found mainly towards the west of West Falkland. Hoki and toothfish occurred around the Falkland Island Conservation Zone (FICZ) and Falkland Outer Conservation Zone (FOCZ).

Rock cod and banded grenadier had statistically significant decreases in size (length) distributions from 2010 to 2019; common hake, hoki and kingclip had non-significant decreases in size distributions over that period.

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 Straits 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, 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 banded grenadier *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 31 years of historical catch data (mean 152,099 t; Falkland Islands Government 1989, 2018). 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*). 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 2018) 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 FOCZ.

Since 2010, the Falkland Islands Fisheries Department (FIFD) has carried out seven 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, kingclip *Genypterus blacodes* and red cod *Salilota australis*, have decreased in some areas around the Falkland Islands (Gras *et al.*, 2018; Ramos & Winter 2019). This report summarizes catch data from both groundfish surveys in the finfish zone and calamari pre-season surveys in the '*Loligo'* box, to estimate the biomass of commercial species in Falkland Islands waters since 2010. Included are previous and current index species (southern blue whiting and rock cod, respectively), species currently of commercial value, and species with potential to sustain a fishery.

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 2015–2019 on board of different fishing trawlers to cover the Falkland Islands fishing zone (Fig. 1). All trawls were bottom trawls; GPS latitude, GPS longitude, net height, trawl door spread, and trawl speed were recorded on the ship's bridge during the progress of each trawl.

At each station, all species from the catch were sorted mainly by the factory crew. The total catch of each species assessed was weighed with an electronic balance to the nearest 0.01 kg. In the groundfish surveys, random samples of up to 100 individuals of each species were measured to the nearest size class lower limit (i.e. 1 cm size class for finfish and 0.5 cm size class for squids) to produce length frequency histograms. In the calamari pre-season surveys, a similar biological sampling protocol was implemented for rock cod. To maximize the time series catch and biological information base for juvenile toothfish, all catches of toothfish were collected from all trawl stations. Specimens from other species were taken opportunistically.

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), and Winter *et al*. (2011, 2015, 2016, 2017, 2018, 2019).

Length-frequency modes were calculated for each year and linear regression was implemented to examine changes in modal length through time.

3.2. Biomass estimations

Station and catch data were retrieved from the FIFD database. 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: trawl width × distance. 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. Groundfish surveys earlier than 2016 received trawl widths retroactively calculated using a linear function of either trawl net height 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).

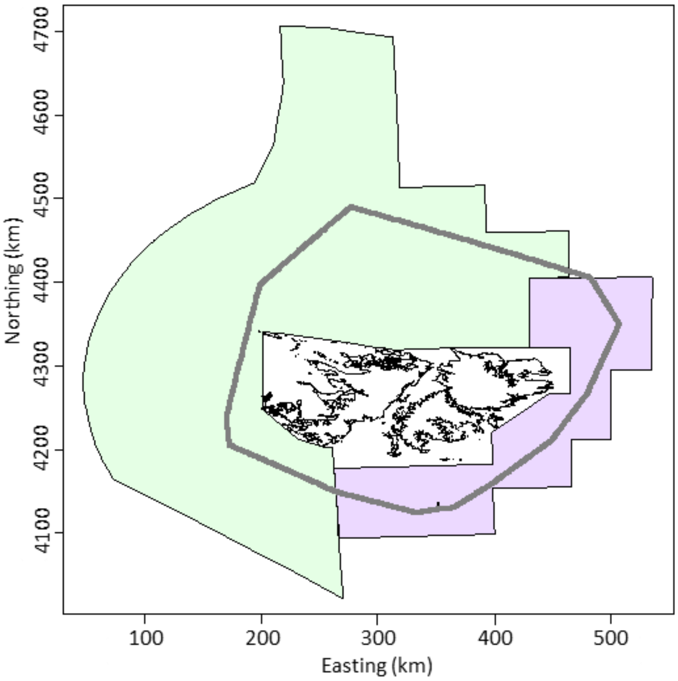

Fig. 1. Groundfish (green) and calamari pre-season (mauve) survey areas, with axial loop (dark grey) used to define relative distances for the inverse distance weighting algorithm.

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 1,019 bottom trawls were carried out during the February groundfish and calamari pre-season surveys from 2010–2011, and 2015–2019. A range of 83 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, groundfish and calamari pre-season surveys combined, were 250 t to 651 t (Appendix I).

Combined catches of the groundfish and calamari pre-season surveys per species were as follows: Catch of the Argentine short-fin squid was below 2 t during 2010 and 2011. Catch increased to 32 t in 2015 and declined to <100 kg in 2016. However, catch increased gradually to reach 9.4 t in 2019. Banded grenadier had an overall declining catch trend from 8 t in 2010 to 2.5 t in 2019, except for 2017 when 7.5 t were captured. Common hake catch was variable with 1 t caught in 2010 and nearly 3 t caught in 2019. Hoki catch had a declining trend, from 80 t in 2010 to 7.6 t in 2019. Kingclip catch was 3 t in 2010 and increased towards 2015 (15 t); however, it declined to 5.4 t in 2016. Kingclip catches remained below 5 t from 2017 to 2019. Catches of the Patagonian squid were the highest amongst the species examined. Approximately 357 t were caught in 2010; catches decreased since 2011 and remained below 200 t until 2018. Minimum catches for this species occurred in 2011 (50.5 t) and 2016 (67 t). In 2019, catches reached a maximum of 386 t since 2010. Red cod catches were below 24 t at all years. In 2010, a total of 13.5 t were caught; catches then increased to reach a maximum of 23.5 t in 2011 but decreased gradually from 22 t in 2015 to 14 t in 2019. Rock cod catches increased from 2010 (165 t) to 2011 (249 t) but declined every year since 2015 (198 t) to reach a minimum in 2019 (28 t). Catches of southern blue whiting increased from 2010 (22 t) to 2011 (52 t); 24 t were caught in 2015 and 79 t in 2016. Catches were < 30 t since 2017 and only 8.4 t were caught in 2019. Toothfish catches were the lowest across the species examined (< 2.5 t per year). A total of 1.4 t were caught in 2010 and 2.4 t in 2011. Only 770 kg were caught in 2015; catches increased towards 2017 (2.5 t) but decreased to only 829 kg in 2019. The combined species catch per year had a decreasing trend from 2010 (651 t) to 2018 (250 t) but increased from 2018 to 2019 (464 t). The catch per species and year and the combined catch per year can be consulted in Appendix II.

4.2. Biomass, distribution and size structure

Biomass estimates for all species examined from 2010–2011, and from 2015–2019 are presented in Table I. Species biomass patterns are described in each species' section.

Table I. Estimated biomass (t) of species in Falkland Islands waters during February 2010–2011, and 2015–2019. The 95% confidence intervals are indicated in parentheses.

Common name	2010	2011	2015	2016	2017	2018	2019
Argentine shortfin squid	8620.30 (3508.71–3828.03)	9288.77 (6719.00–2632.60)	253660.38 (130050.90–475960.46)	205.79 (147.73–269.07)	11704.86 (7474.80–8341.05)	44746.56 (30210.12–64517.95)	59998.2 (39966.2–96500.69)
Banded grenadier	86113.09 (46234.37–110793.53)	49786.15 (23217.66–85309.35)	63463.84 (35323.91–83107.47)	34022.36 (10100.62–53672.60)	35448.14 (20274.99–42862.44)	34826.63 (28021.67–44133.08)	21025.83 (10238.58–35813.59)
Common hake	9013.04 (6042.43–12604.24)	10334.86 (8472.85–12860.06)	15910.43 (13962.24–18586.06)	3686.67 (2987.50–4187.28)	12319.36 (10297.85–15690.47)	8573.04 (6100.14–10865.04)	11098.5 (9394.96–14468.65
Hoki	272080.22 (197644.96–472481.97)	227165.49 (174666.72–288834.04)	129562.42 (40753.69–175529.10)	167312.12 (83510.52–231697.65)	28863.12 (16842.07–39751.29)	139665.90 (91380.06–203699.81)	41398.97 (6433.57–188848.89)
Kingclip	21617.44 (13740.07–31108.56)	42618.29 (29182.03–65107.93)	79128.92 (30842.99–130266.84)	24791.36 (13831.38–39084.50)	19034.72 (11915.28–28978.89)	14464.94 (10843.68–20518.68)	21780.38 (15007.69–29223.3)
Patagonian squid	203558.43 (162047.16–250085.16)	49266.77 (40184.80–68417.16)	111351.39 (80460.29–169743.16)	39946.94 (33264.42–53333.28)	189748.92 (148470.98–239866.69)	61015.22 (43769.59–93736.02)	195631.6 (169258.47–246690.55)
Red cod	93194.65 (19743.66–150576.55)	161733.35 (41760.22–252434.63)	106878.11 (45428.59–160292.1)	105369.20 (29467.04–154110.28)	60319.76 (23204.51–89308.37)	55845.34 (19149.62–114403.45)	81324.05 (36498.66–114029.39)
Rock cod	709535.66 (530503.55–1086153.89)	1090654.84 (726139.02–1767088.84)	352570.42 (268194.30–429993.32)	235339.08 (178466.99–318771.08)	138641.20 (111389.70–171927.94)	87595.83 (61319.43–119778.94)	37793.3 (27321.99–52723.14)
Southern blue whiting	73563.23 (27341.64–98431.47)	236328.33 (45116.64–399094.57)	66221.71 (13050.55–102946.04)	332096.18 (26505.92–433238.55)	43252.74 (1284.65–57549.59)	58802.02 (17715.83–69838.20)	6626.38 (210.31–39098.78)
Toothfish	9845.88 (7461.10–12152.61)	11554.45 (8071.33–14427.83)	3706.51 (1433.24–4408.06)	8219.23 (5721.33–10734.75)	8649.98 (5690.86–10369.9)	8782.20 (6261.69–10926.90)	6833.77 (3192.88–8551.75)

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

The biomass of the Argentine short-fin squid was relatively low during 2010 (8,620 t) and 2011 (9,289 t). An increase in biomass was observed in 2015 (253,660 t), although it decreased again to its lowest in 2016 (206 t). Biomass remained low since 2016 but has increased gradually to 59,998 t in 2019 (Fig. 2; Table I). This species was mainly distributed to the north-west of West Falkland during 2010, 2011, and 2017–2019. However, relatively high densities were also observed to the north-east of East Falkland during 2015 and 2016. The maximum densities per 5 x 5 grid per year across the time series ranged from 47 kg/km^2 in 2016 to 74,427 kg/km^2 in 2015 (Fig. 3). Two modal lengths were evident in most years; whereas considerable incursions of *I. argentinus* into the FICZ and FOCZ occurred during 2015, which may be reflected in the wide range of sizes observed in that year. The change in size of *I. argentinus* from 2010 to 2019 was not statistically significant (p = 0.49; Fig. 4).

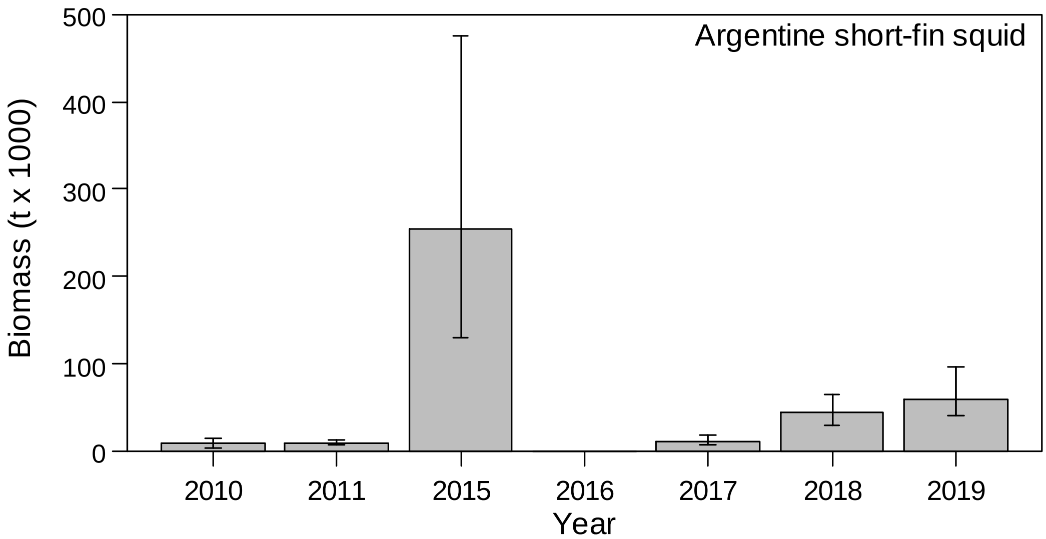

Fig. 2 Mean biomass (t) ± 95% confidence intervals of the Argentine short-fin squid (*Illex argentinus*) in Falkland Islands waters during 2010–2011, and 2015–2019. Note the data gap from 2012 to 2014.

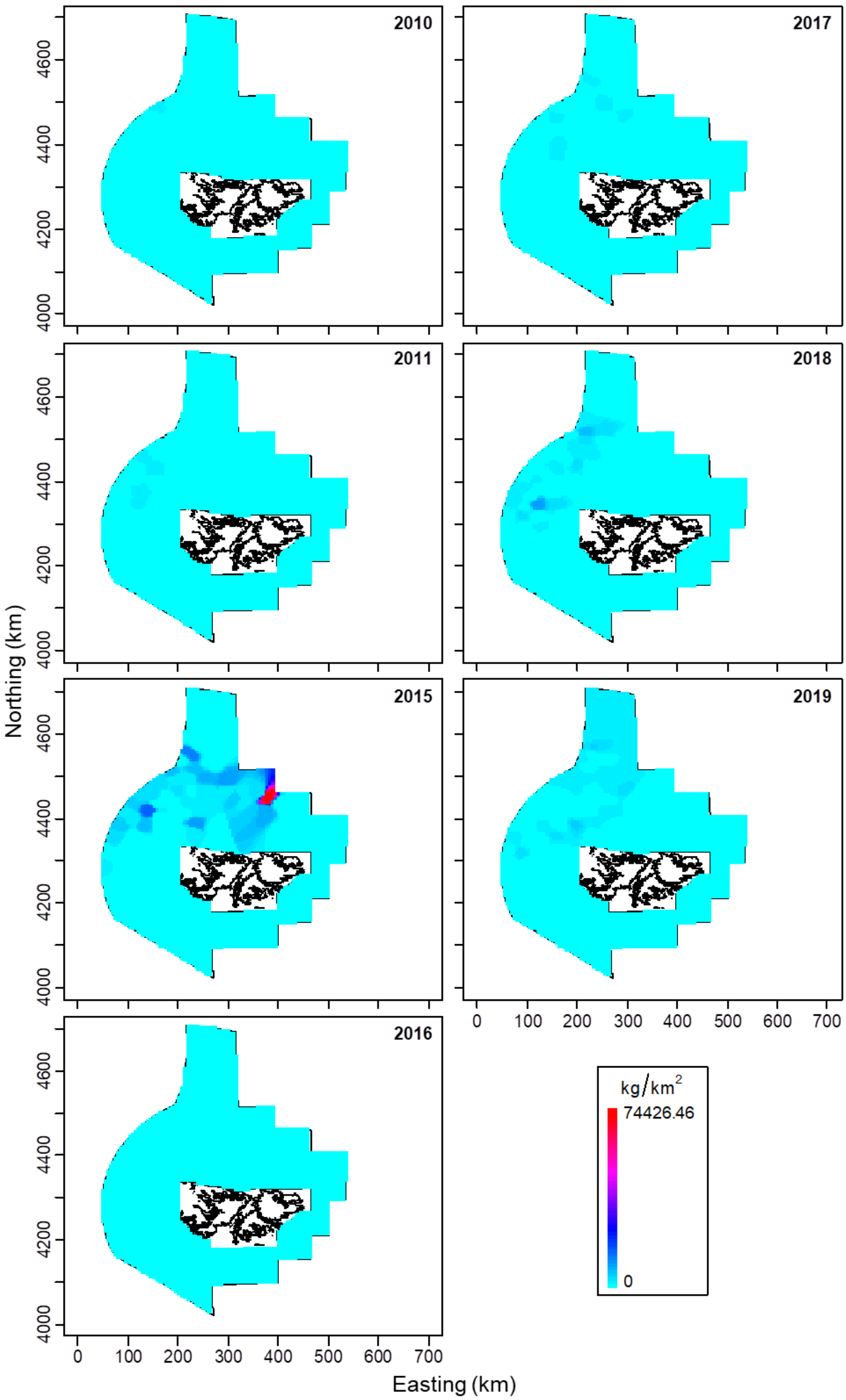

Fig. 3. Density of the Argentine short-fin squid (*Illex argentinus*) around the Falkland Islands during 2010–2011, and 2015–2019.

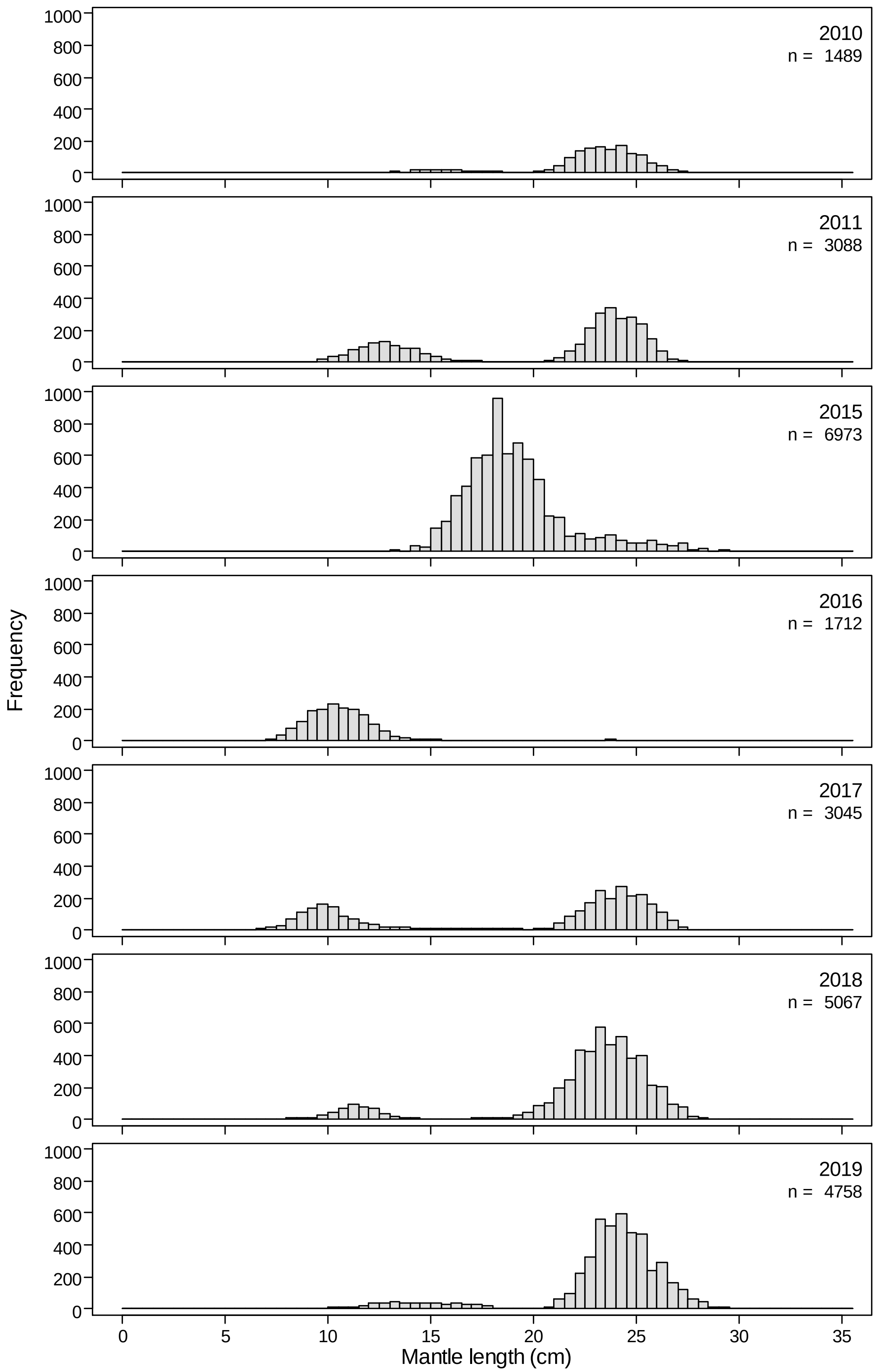

Fig. 4. Length-frequency distribution of Argentine short-fin squid (*Illex argentinus*) around the Falkland Islands during 2010–2011, and 2015–2019.

4.2.2. Banded grenadier (*Coelorinchus fasciatus*)

The biomass of banded grenadier has a decreasing trend since 2010, when the maximum biomass was estimated (86,113 t) in the time series. Mean biomass seemed to decrease to reach its lowest level in 2019 (21,026 t; Fig. 5; Table I), except for 2015 when an apparent increase was observed (63,464 t). However, 95% confidence intervals showed overlap of biomass estimates among the years examined. Banded grenadier was predominantly distributed to the south-west of West Falkland through the time series. The maximum densities per 5 x 5 grid per year across the time series ranged from 2,302 in 2017 to 9,127 kg/km^2 in 2011 (Fig. 6). Length frequencies of banded grenadier remained constant through the time series, with modal pre-anal length at 9–10 cm (Fig. 7).

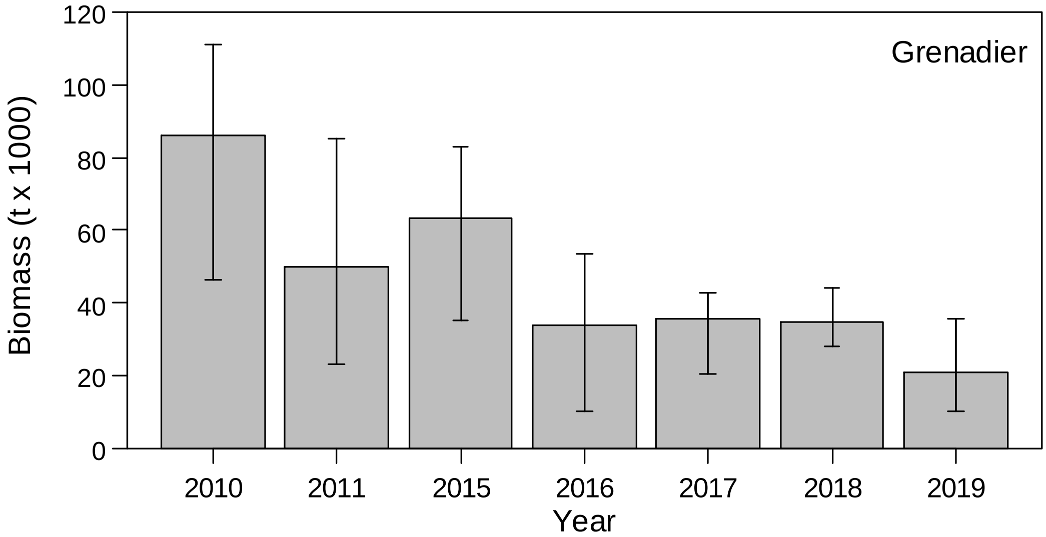

Fig. 5. Mean biomass (t) ± 95% confidence intervals of banded grenadier (*Coelorinchus fasciatus*) in Falkland Islands waters during 2010–2011, and 2015–2019. Note the data gap from 2012 to 2014.

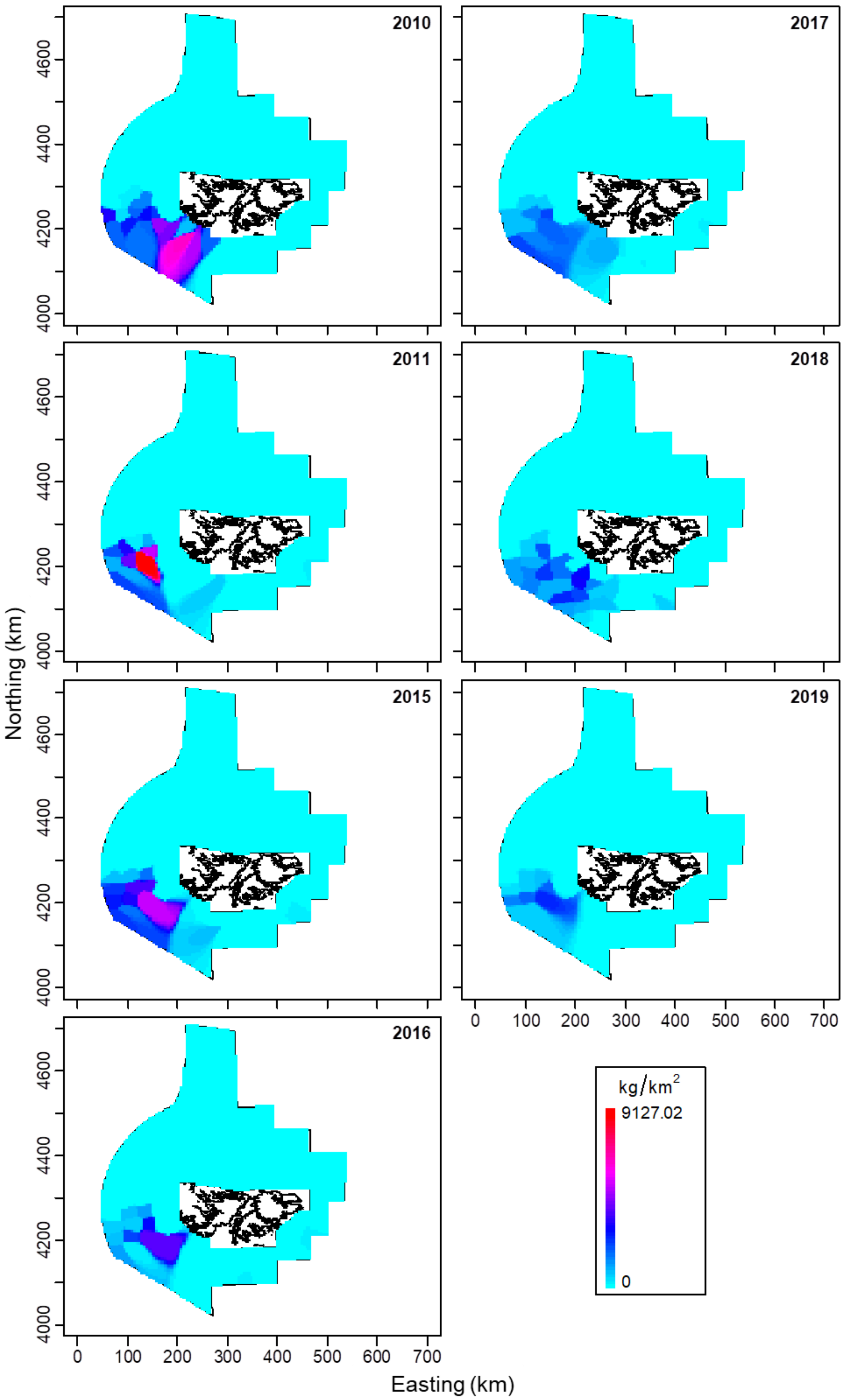

Fig. 6. Density of banded grenadier (*Coelorinchus fasciatus*) around the Falkland Islands during 2010–2011, and 2015–2019.

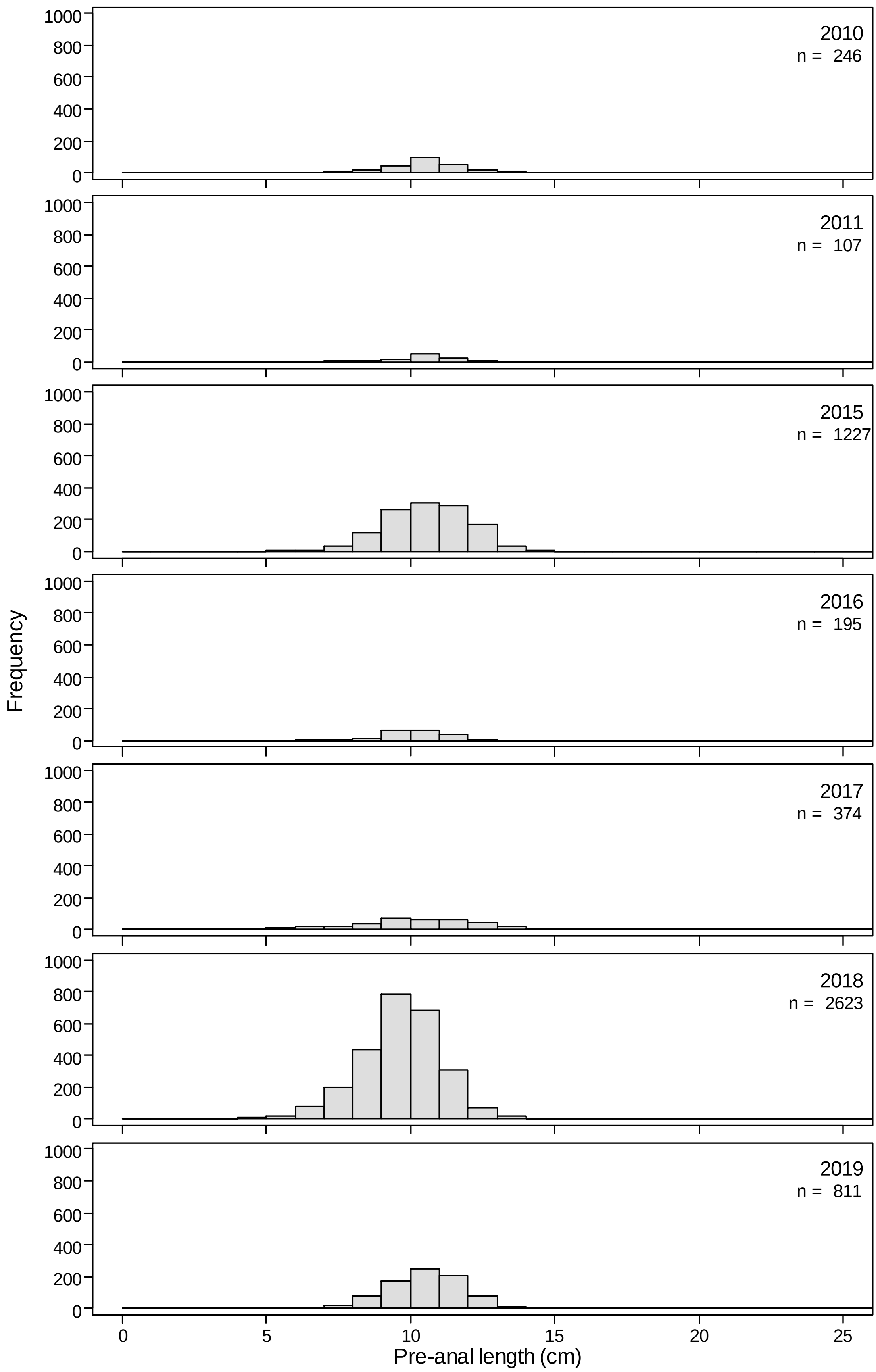

Fig. 7. Length frequency of banded grenadier (*Coelorinchus fasciatus*) around the Falkland Islands during 2010–2011, and 2015–2019.

4.2.3. Common hake (*Merluccius hubbsi*)

The biomass of common hake increased from 2010 (9,013 t) to 2015 (15,910 t), although this was followed by a considerable decrease to reach its lowest in 2016 (3,687 t). An increase in biomass was observed in 2017 (12,319 t) and has remained above 8,000 t in 2018 (8,573 t) and 2019 (11,099 t; Fig. 8; Table I). Common hake was mainly observed to the north-west of West Falkland across the time series. Greater densities per 5 x 5 grid were detected offshore or near the limit of the FICZ. The greatest densities occurred near shore of West Falkland in 2016 and 2018. The maximum densities per year across the time series ranged from 245 kg/km^2 in 2016 to 1,322 kg/km^2 in 2017 (Fig. 9). Modal total length was about 47 cm in 2011, which decreased to 39 cm total length in 2015. There was another decrease in modal total length from 41 cm in 2017 to 38 cm in 2019; however, the change in size of common hake from 2010 to 2019 was not statistically significant (p = 0.1; Fig. 10).

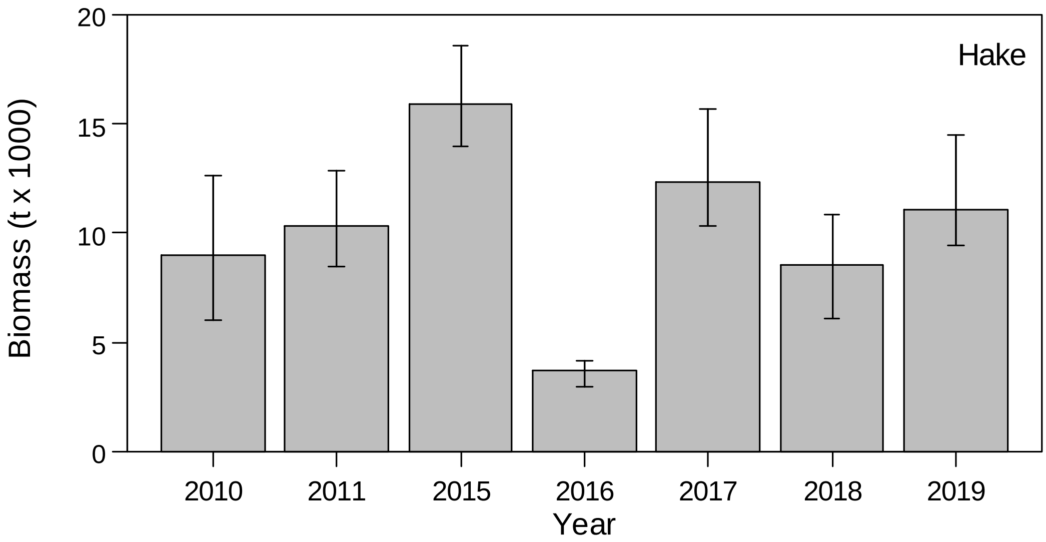

Fig. 8. Mean biomass (t) ± 95% confidence intervals of common hake (*Merluccius hubbsi*) in Falkland Islands waters during 2010–2011, and 2015–2019. Note the data gap from 2012 to 2014.

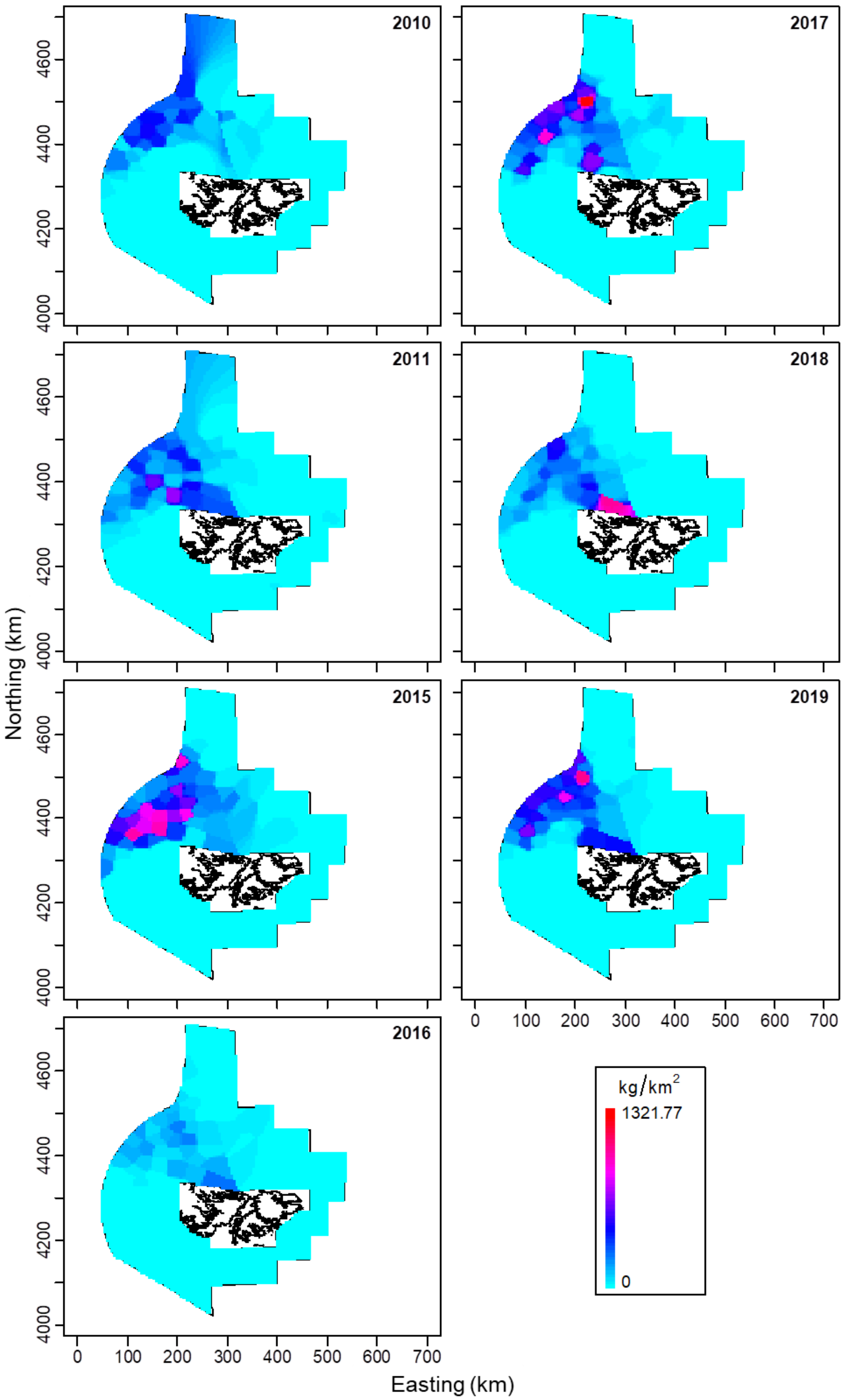

Fig. 9. Density of common hake (*Merluccius hubbsi*) around the Falkland Islands during 2010–2011, and 2015–2019.

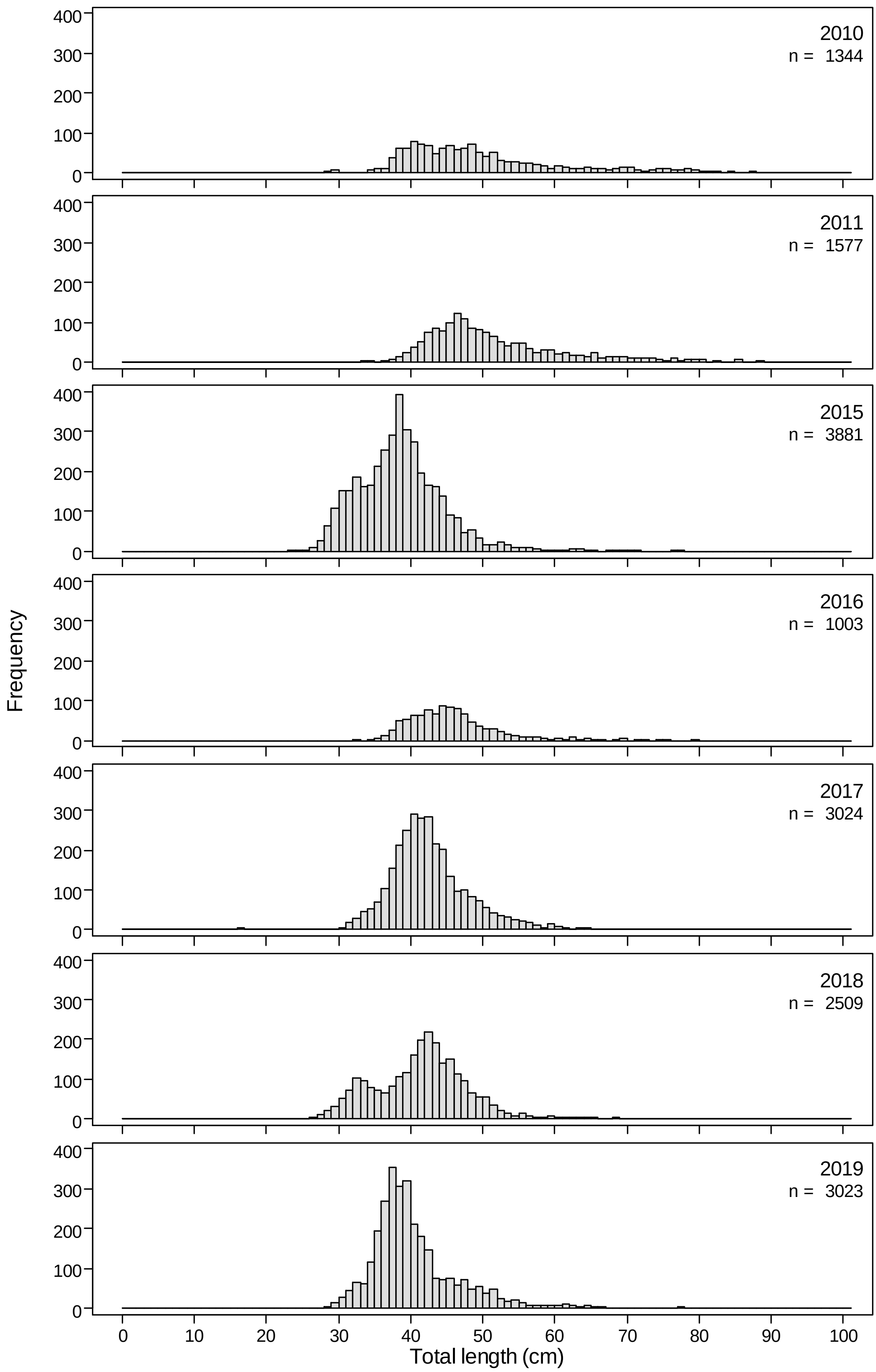

Fig. 10. Length frequency of common hake (*Merluccius hubbsi*) around the Falkland Islands during 2010–2011, and 2015–2019.

4.2.4. Hoki (*Macruronus magellanicus*)

The biomass of hoki had a decreasing trend since 2010, year when the maximum biomass in the time series was estimated (272,080 t). Biomass decreased to its lowest in 2017 (28,863 t); an increase occurred in 2018 (139,666 t) but decreased again in 2019 (41,399 t; Fig. 11; Table I). The distribution of hoki was patchy and variable from year to year. From 2010 to 2015, hoki occurred over the entire FICZ and FOCZ. The distribution changed in 2016 where it was localized along the south of both West and East Falkland Islands. In 2017, hoki was mainly found to the south-west of West Falkland, and during 2018 and 2019 it was localized only to the south-west of West Falkland. The maximum densities per 5 x 5 grid per year across the time series ranged from 5,338 kg/km^2 in 2017 to 65,972 kg/km^2 in 2010 (Fig. 12). Modal pre-anal length of hoki decreased from 30 cm in 2010 to around 22 cm in 2019, however this decline in size was not statistically significant (p = 0.09; Fig. 13).

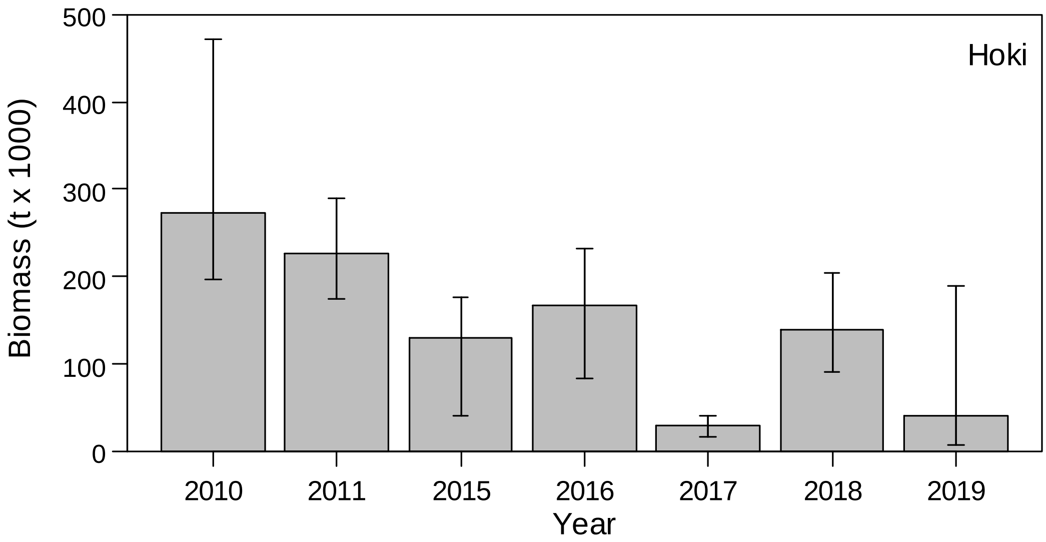

Fig. 11. Mean biomass (t) ± 95% confidence intervals of hoki (*Macruronus magellanicus*) in Falkland Islands waters during 2010–2011, and 2015–2019. Note the data gap from 2012 to 2014.

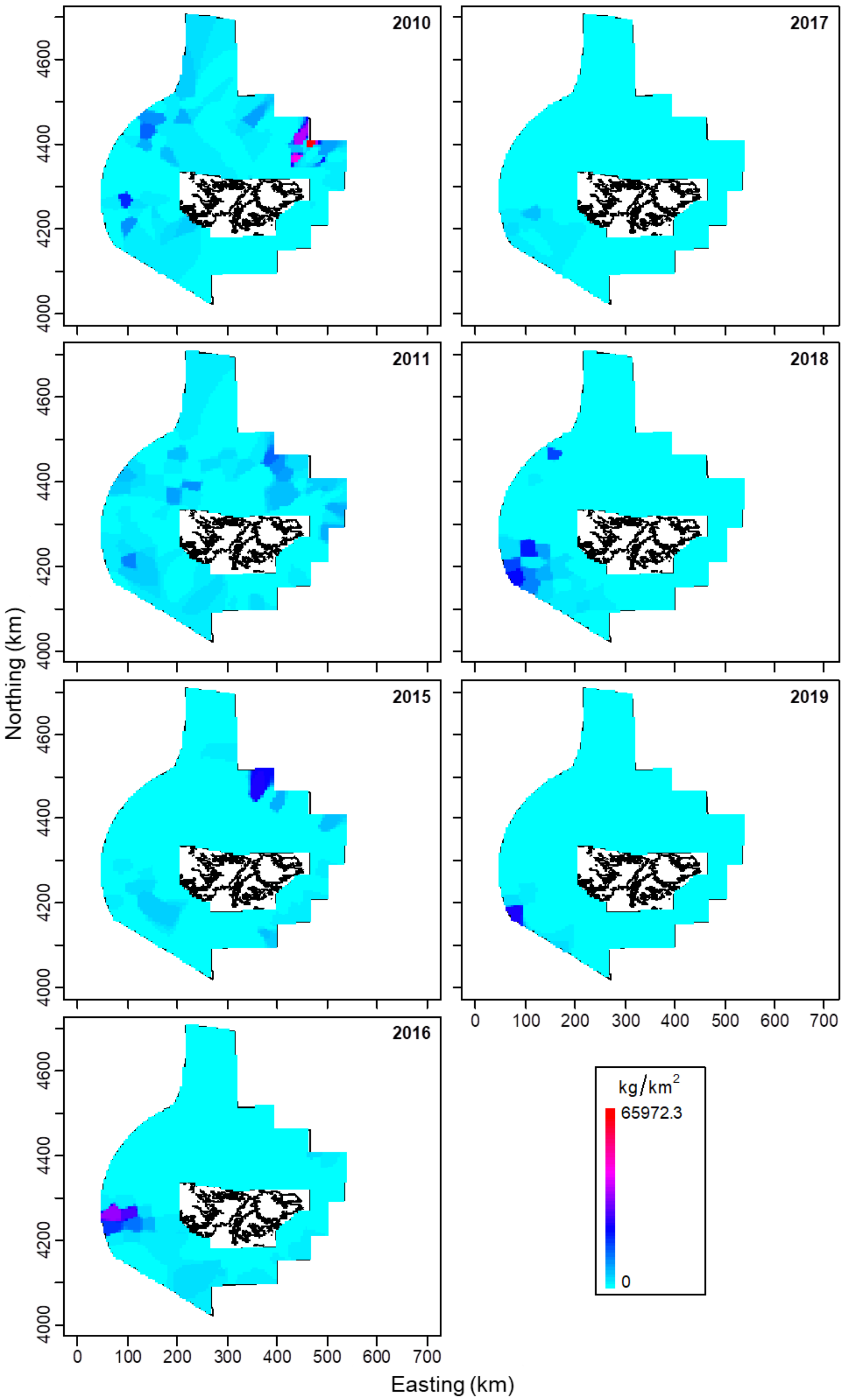

Fig. 12. Density of hoki (*Macruronus magellanicus*) around the Falkland Islands during 2010–2011, and 2015–2019.

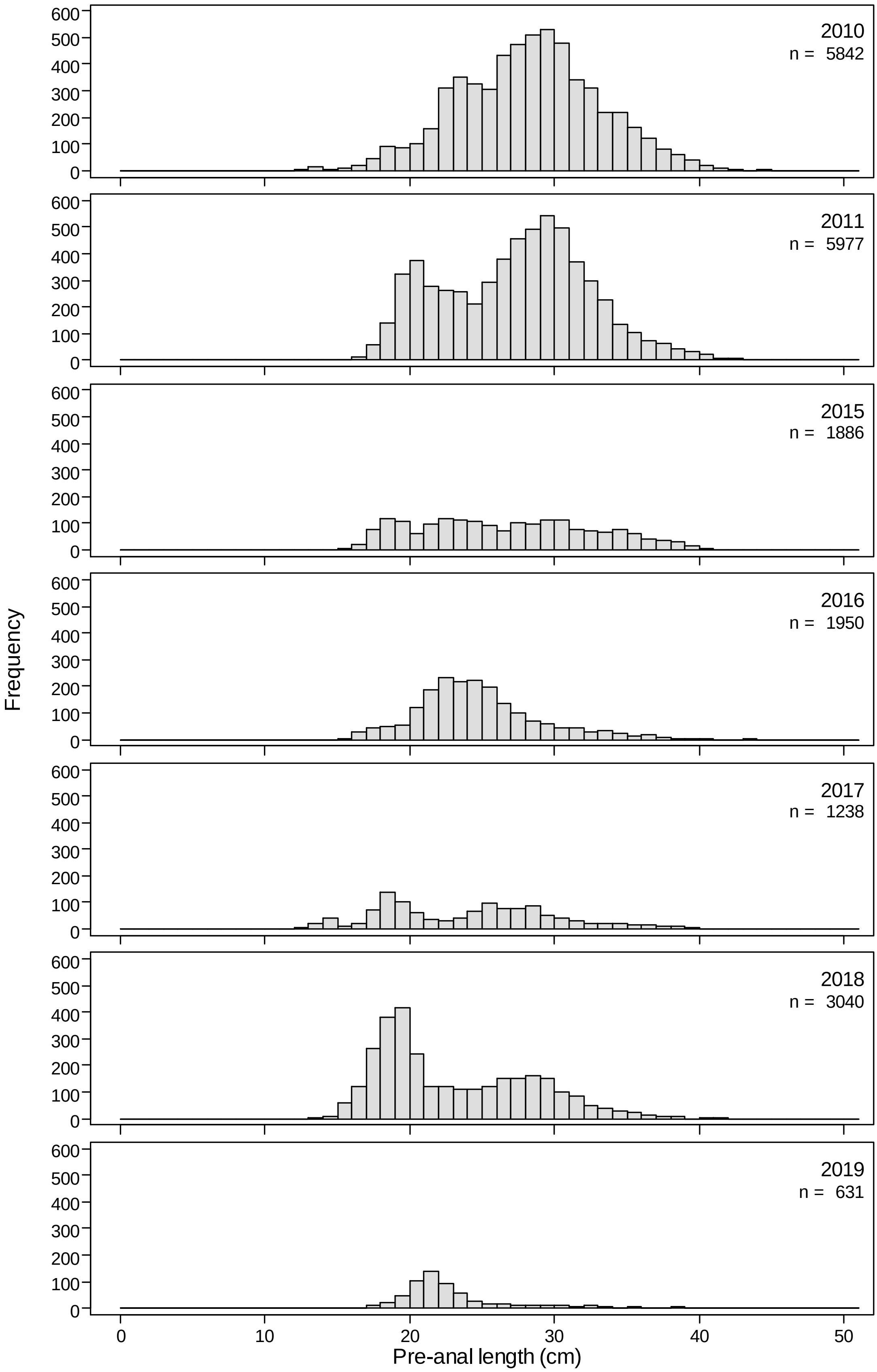

Fig. 13. Length frequency of hoki (*Macruronus magellanicus*) around the Falkland Islands during 2010–2011, and 2015–2019.

4.2.5. Kingclip (*Genypterus blacodes*)

The biomass of kingclip increased from 2010 (21,617 t) to 2015 (79,129 t). However, since 2016 (24,791 t) it has remained under 25,000 t. The lowest biomass was estimated for 2018 (14,465 t) and in 2019 it was 21,780 t (Fig. 14; Table I). Kingclip was dispersed over the FICZ and FOCZ, except for the south-east. The maximum densities per 5 x 5 grid per year across the time series ranged from 1,667 kg/km^2 in 2018 to 32,777 kg/km^2 in 2015 (Fig. 15). Modal total length of kingclip decreased from approximately 64 cm in 2010 to 50 cm in 2019 although this decline in size was not statistically significant (p = 0.43; Fig. 16).

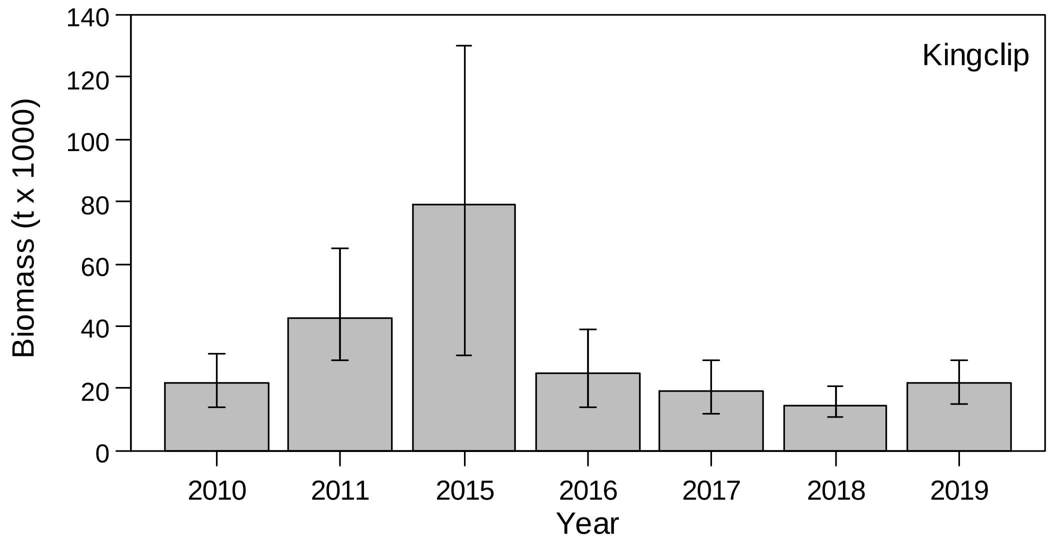

Fig. 14. Mean biomass (t) ± 95% confidence intervals of kingclip (*Genypterus blacodes*) in Falkland Islands waters during 2010–2011, and 2015–2019. Note the data gap from 2012 to 2014.

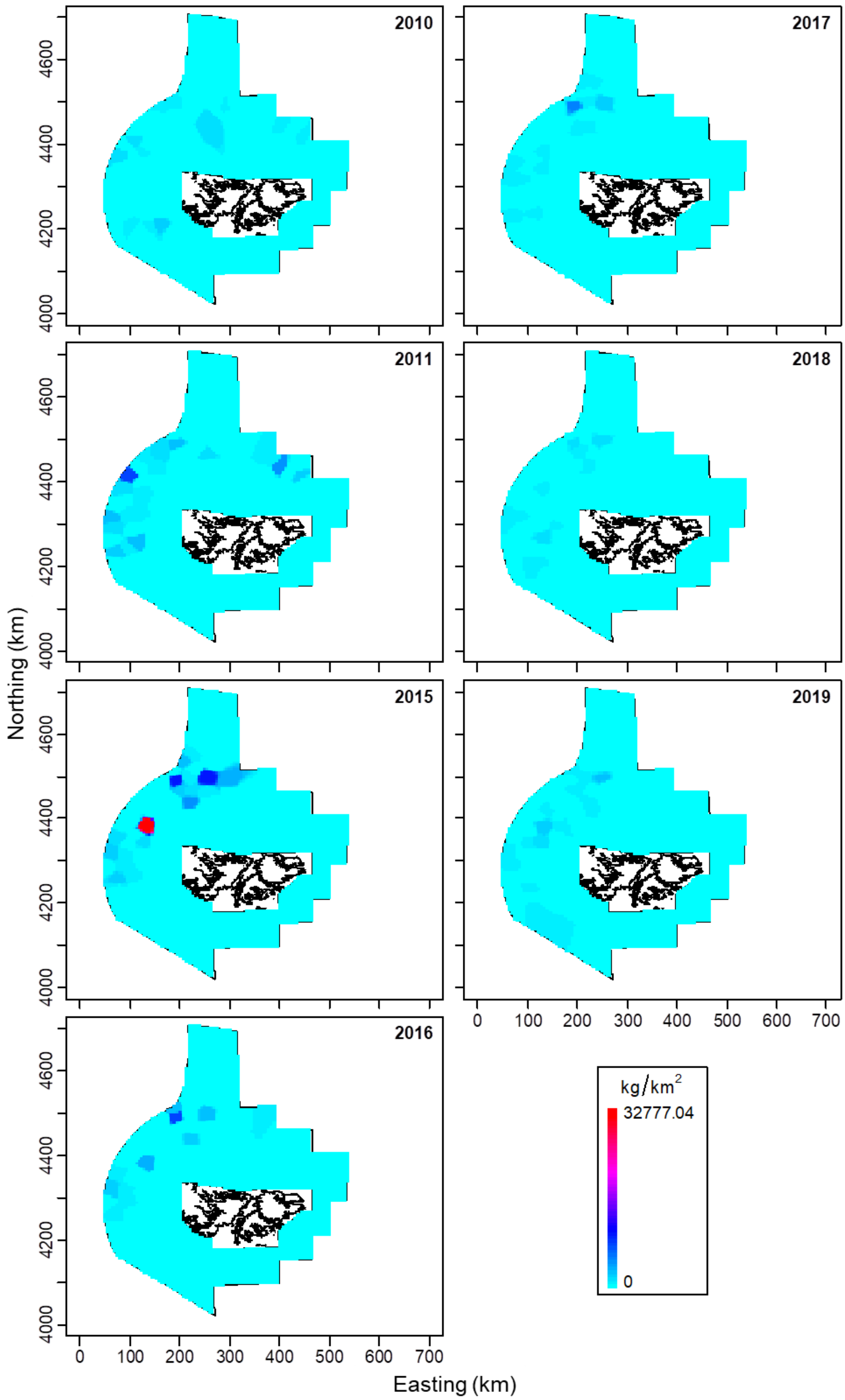

Fig. 15. Density of kingclip (*Genypterus blacodes*) around the Falkland Islands during 2010–2011, and 2015–2019.

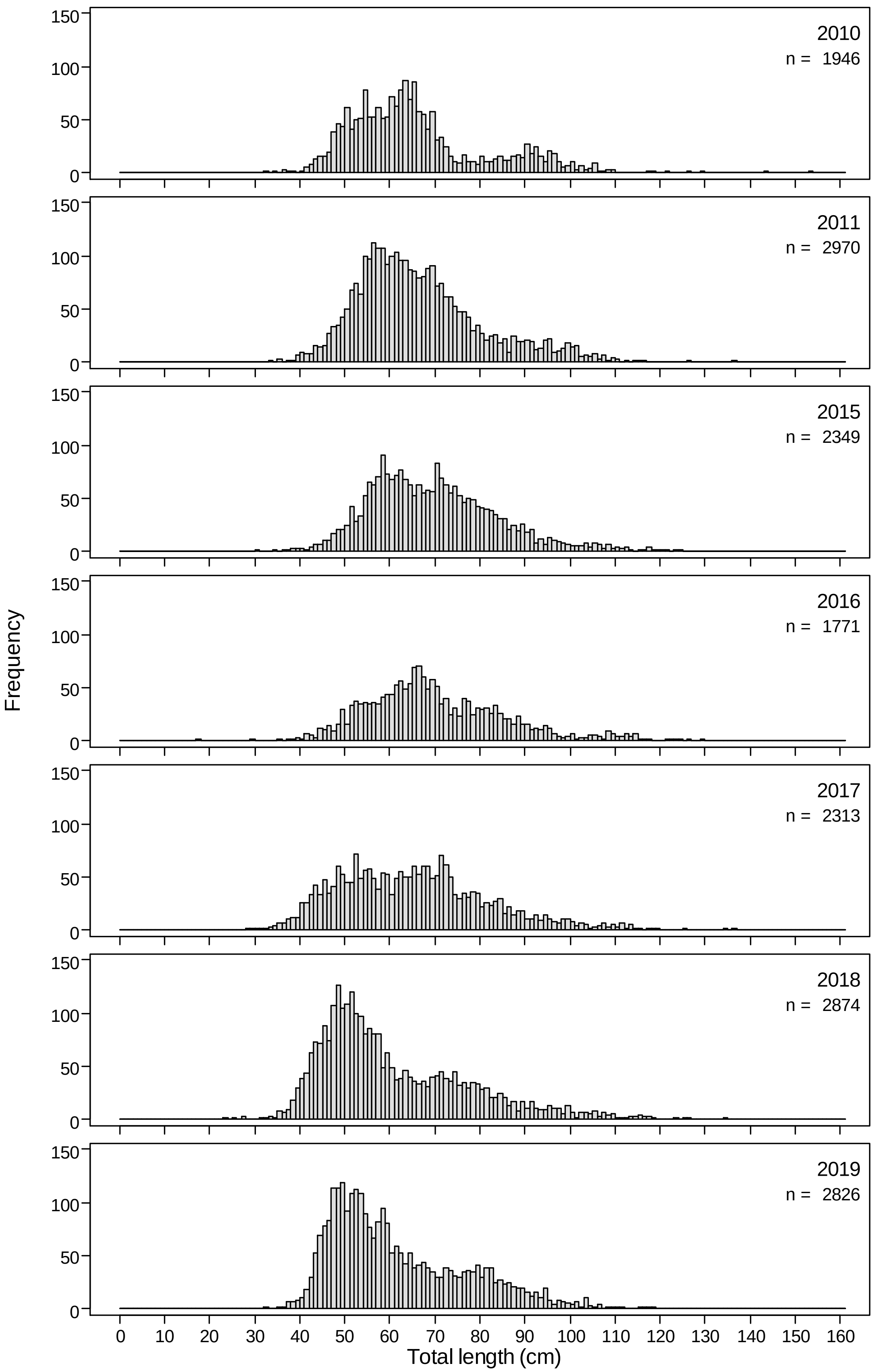

Fig. 16. Length frequency of kingclip (*Genypterus blacodes*) around the Falkland Islands during 2010–2011, and 2015–2019.

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 (39,957 t); however, there was an increase in 2017 (189,749 t) followed by a decrease in 2018 (61,015 t) and a subsequent increase in 2019 (195,632 t; Fig. 17; Table I). *Doryteuthis gahi* was mainly found to the south and south-east of East Falkland. The maximum densities per 5 x 5 grid per year across the time series ranged from 7,132 kg/km^2 in 2016 to 37,399 kg/km^2 in 2015 (Fig. 18). Modal mantle length of the Patagonian squid appeared to decrease from 9 cm in 2010 to 7 cm in 2015. However, modal mantle length was variable in the following years and it was 9.5 cm in 2019. The change in size of *D. gahi* was not statistically significant (p = 0.87; Fig. 19).

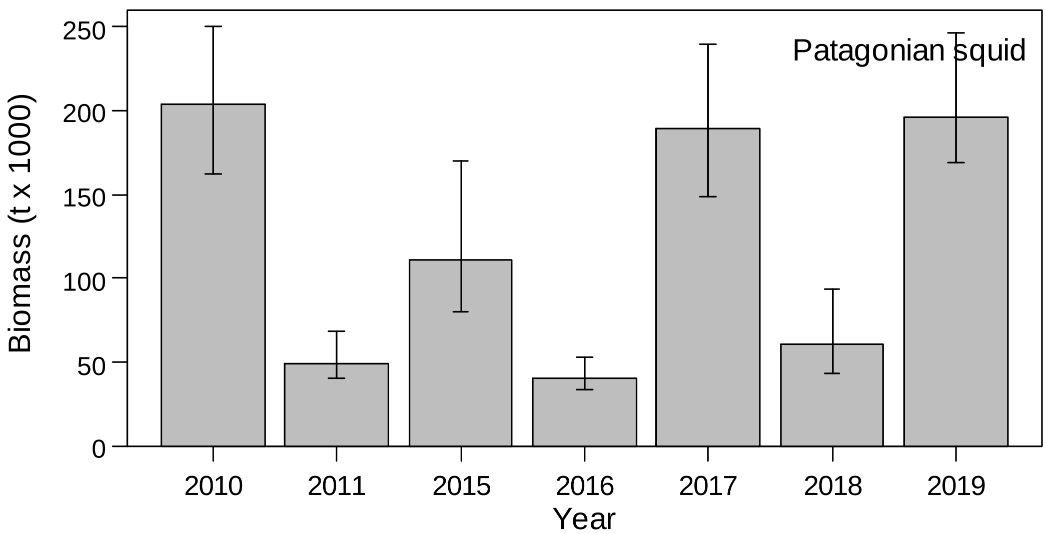

Fig. 17. Mean biomass (t) ± 95% confidence intervals of the Patagonian squid (*Doryteuthis gahi*) in Falkland Islands waters during 2010–2011, and 2015–2019. Note the data gap from 2012 to 2014.

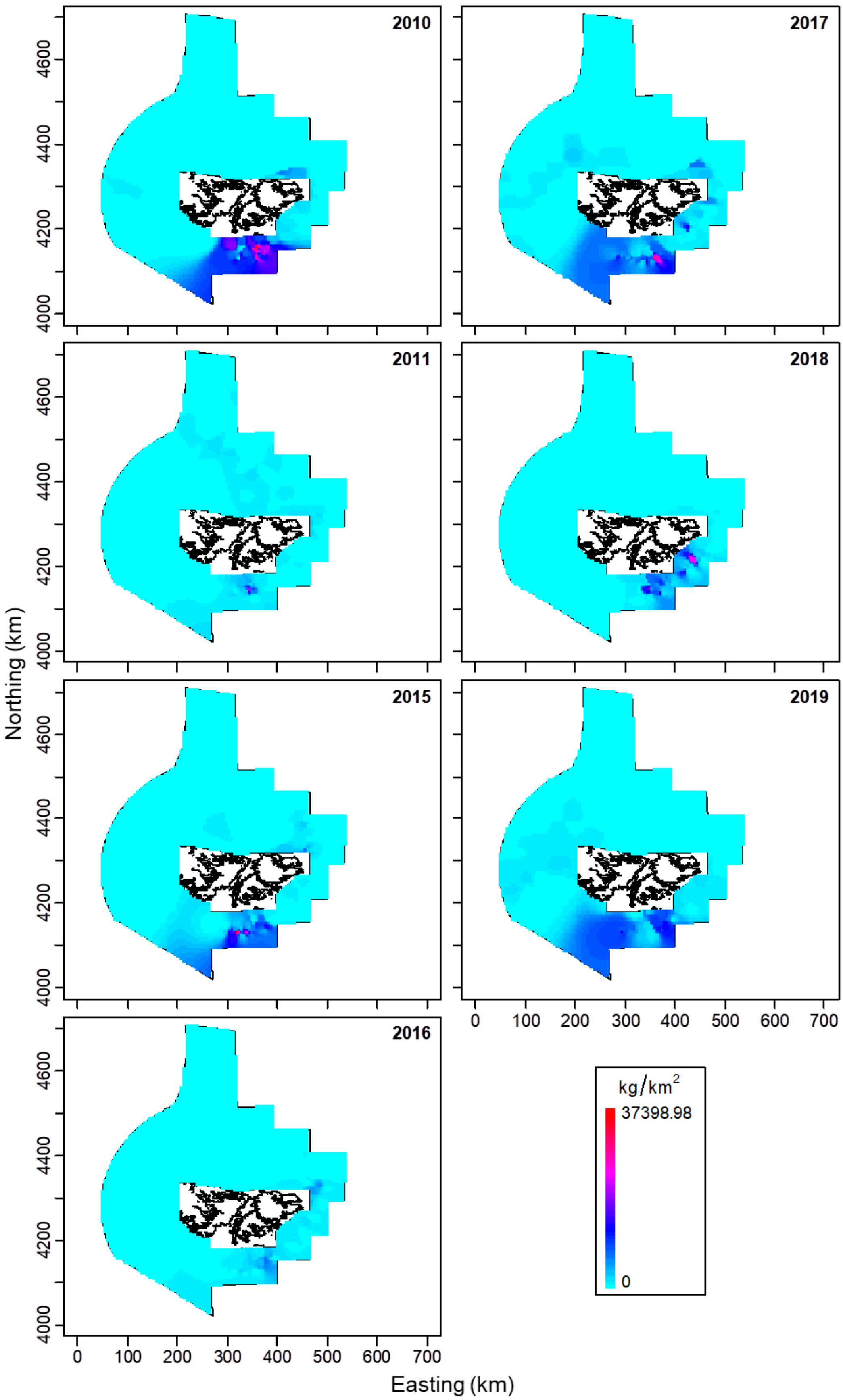

Fig. 18. Density of the Patagonian squid (*Doryteuthis gahi*) around the Falkland Islands during 2010–2011, and 2015–2019.

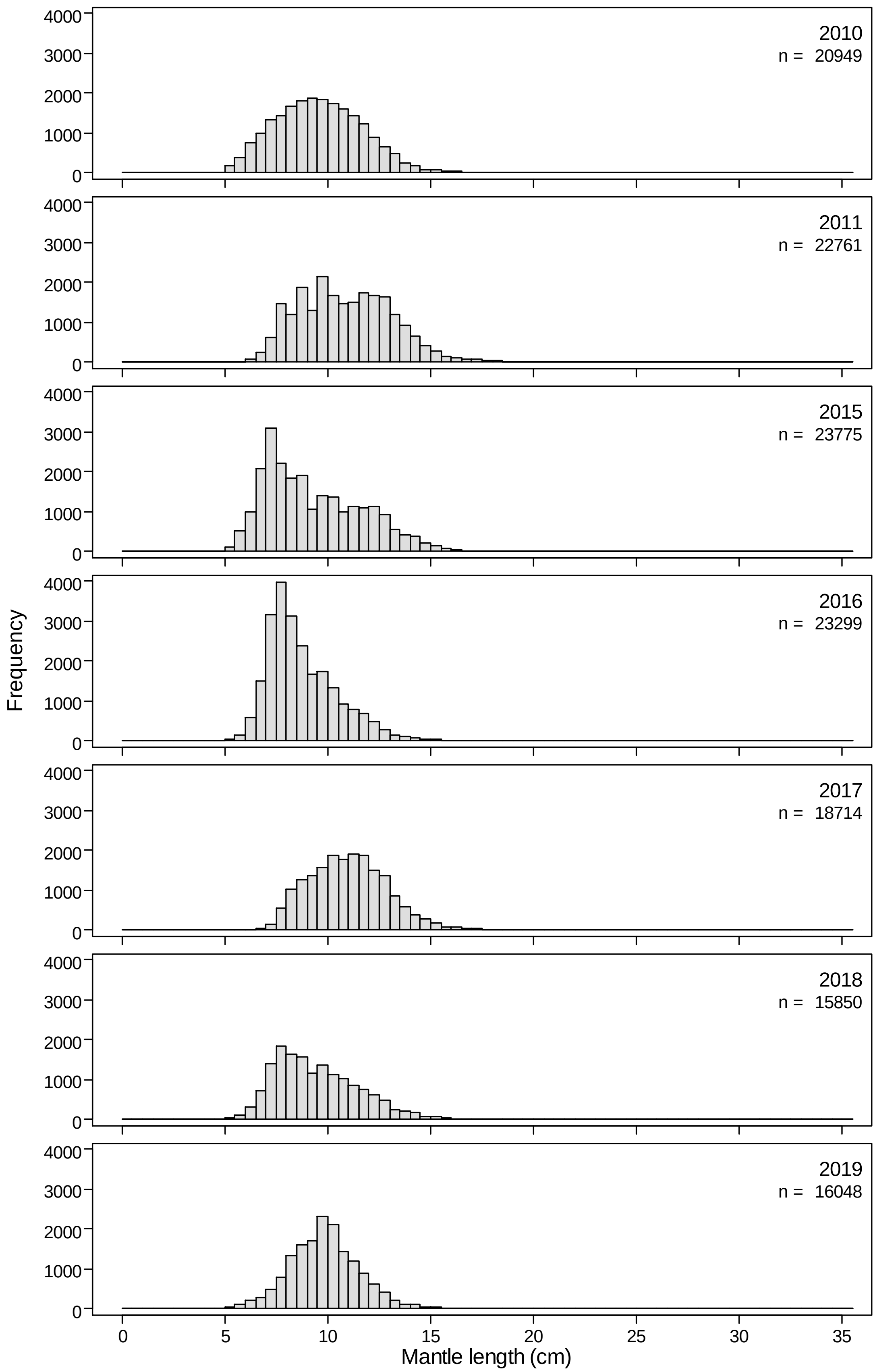

Fig. 19. Length frequency of the Patagonian squid (*Doryteuthis gahi*) around the Falkland Islands during 2010–2011, and 2015–2019.

4.2.7. Red cod (*Salilota australis*)

The biomass of red cod increased from 2010 (93,195 t) to 2011 (161,733 t). However, it decreased from 2016 (109,878 t) to the lowest biomass in 2018 (55,845 t). In 2019, the biomass was estimated at 81,324 t. Overlap of 95% confidence intervals of biomass estimates were observed through the time series (Fig. 20; Table I). Red cod was found mainly to the west of West Falkland. From 2010 to 2017 the maximum densities per 5 x 5 grid were located near the west limit of the FICZ, except for 2011 where high densities were also observed to the north of East Falkland. In 2018 and 2019, the highest densities occurred near the west shore and to the north of West Falkland. The maximum densities per year across the time series ranged from 8,841 kg/km^2 in 2019 to 38,175 kg/km^2 in 2016 (Fig. 21). Red cod had a wide range of size probably due to the presence of several cohorts. Modal total length was approximately 27 cm in 2010 and in the following years it was around 16–18 cm, except for 2018 when modal total length was around 29 cm. The trend in size of red cod was not statistically significant (0.71; Fig. 22).

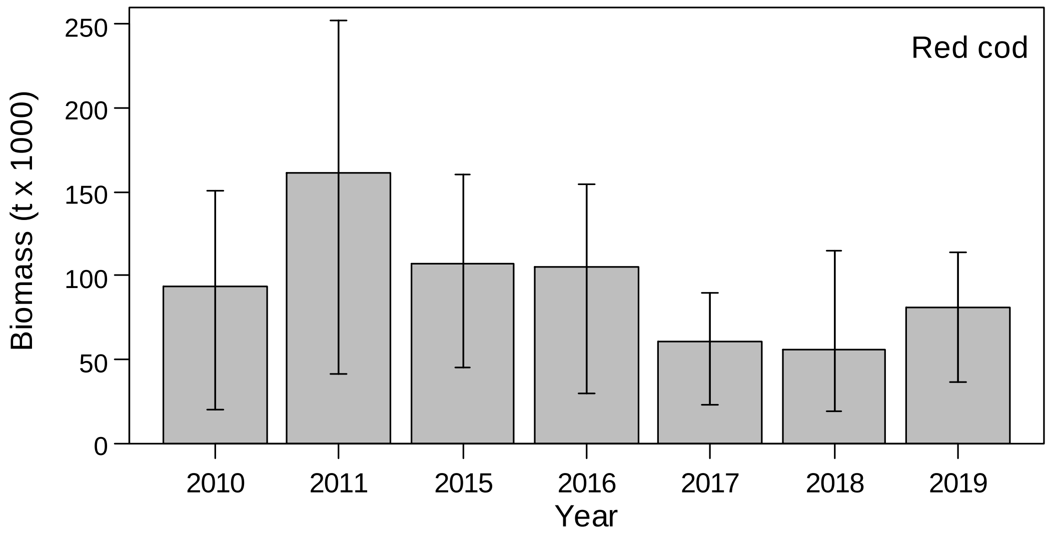

Fig. 20. Mean biomass (t; bold black line) ± 95% confidence intervals (grey dashed lines) of red cod (*Salilota australis*) in Falkland Islands waters during 2010–2011, and 2015–2019. Note the data gap from 2012 to 2014.

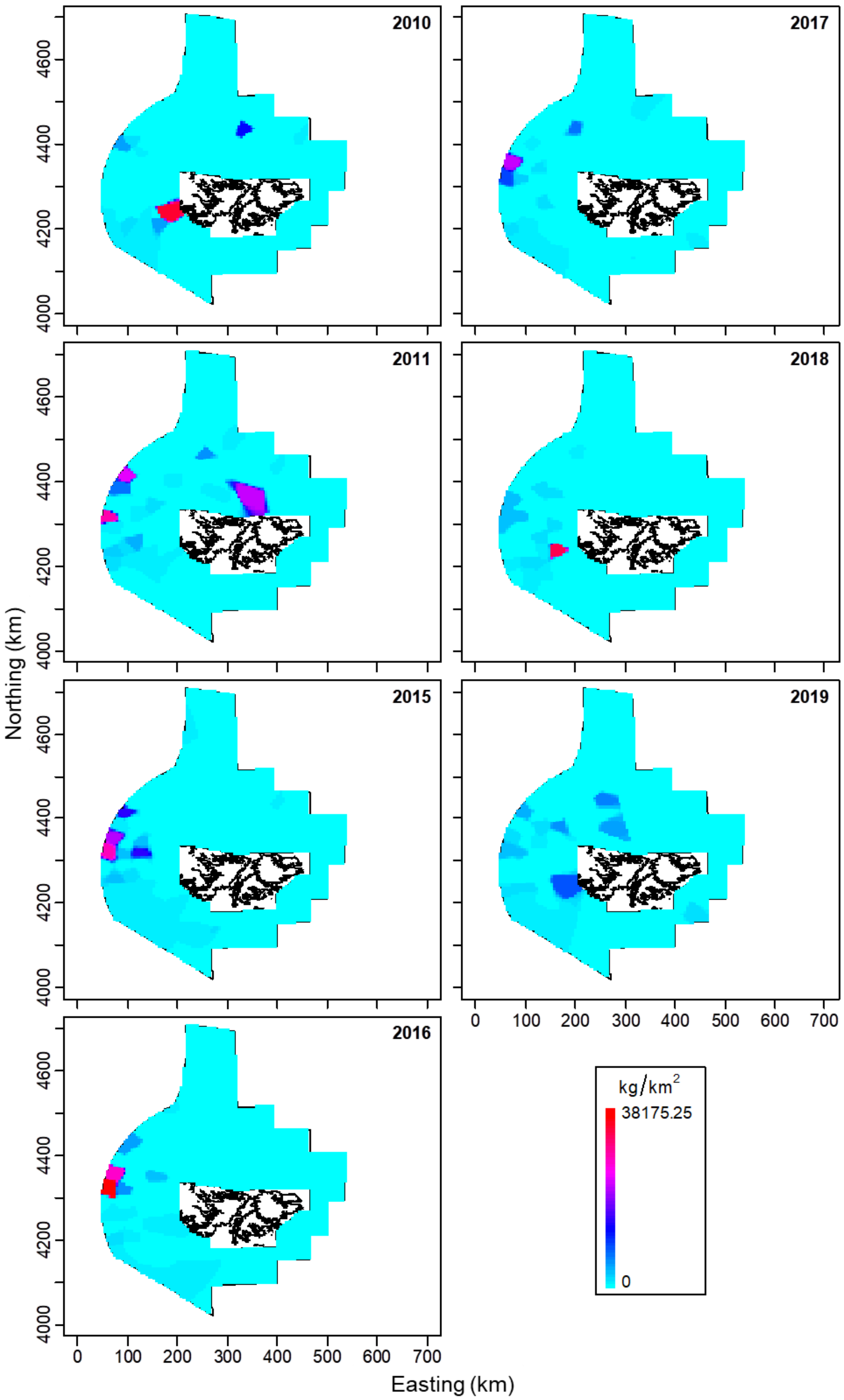

Fig. 21. Density of the red cod (*Salilota australis*) around the Falkland Islands during 2010–2011, and 2015–2019.

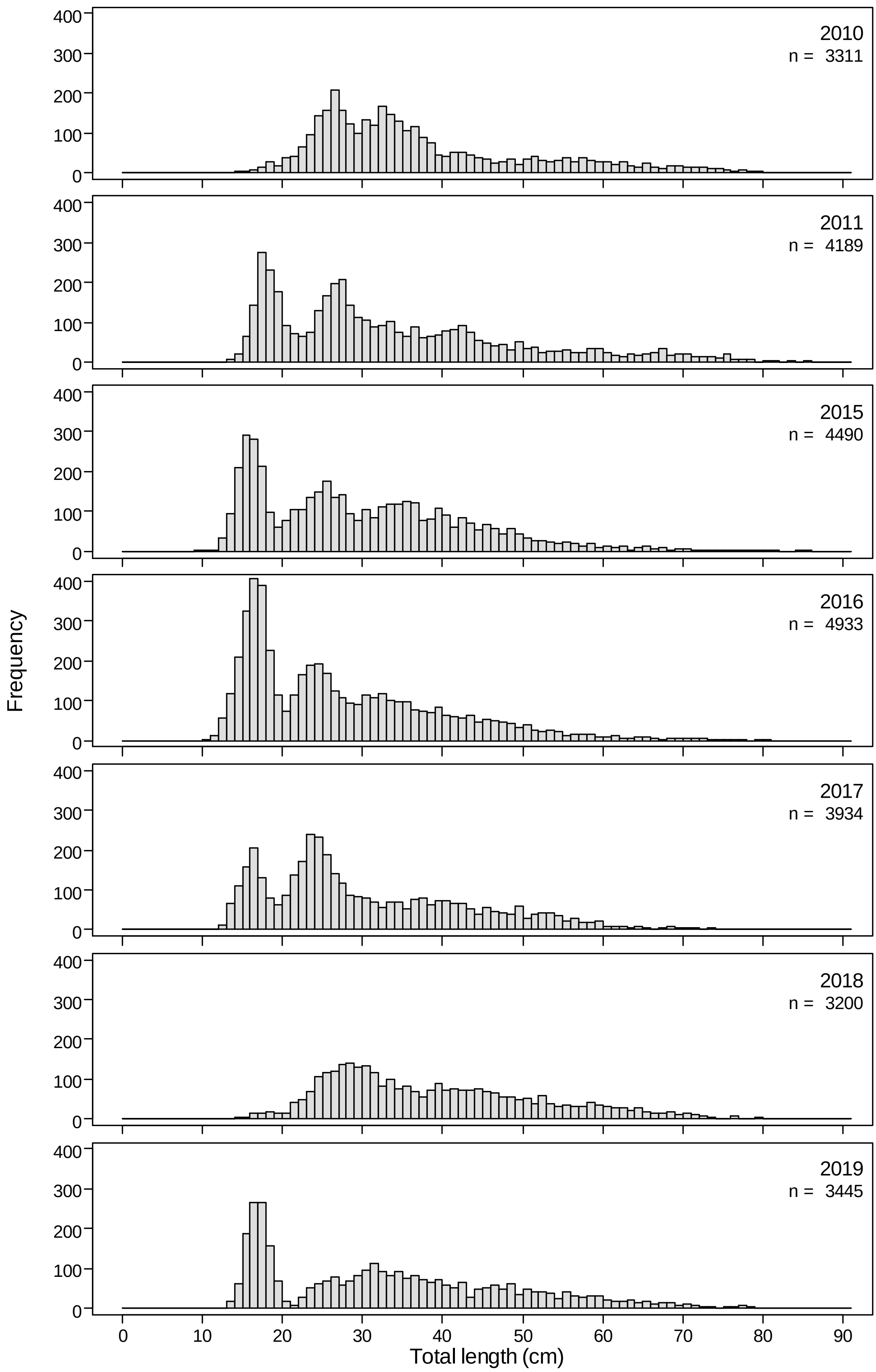

Fig. 22. Length frequency of the red cod (*Salilota australis*) around the Falkland Islands during 2010–2011, and 2015–2019.

4.2.8. Rock cod (*Patagonotothen ramsayi*)

Rock cod biomass had an overall declining trend, with the exception from 2010 (709,536 t) to 2011 (1,090,655 t). From 2015 (352,570 t) there was a constant decline to reach the lowest biomass in 2019 (87,596 t; Fig. 23; Table I). Rock cod had a patchy distribution around the Falkland Islands since 2010. However, in 2011 the density was localized to the north-east of East Falkland. The maximum densities per 5 x 5 grid per year across the time series ranged from 8,709 kg/km^2 in 2019 to 823,777 kg/km^2 in 2011 (Fig. 24). There was a wide range of sizes for rock cod; a total of 77 individuals were ≥ 40 cm total length through the time series, with maximum total length of 43 cm (n = 3) observed in 2011. In 2010, two length modes were observed at 19 cm and at 25 cm. Modal total length was variable in the following years. The 2019 surveys were characterized by the scarcity of rock cod, most of which were small individuals (~ 15 cm total length). The decline in size of rock cod was statistically significant (p = 0.04; Fig. 25).

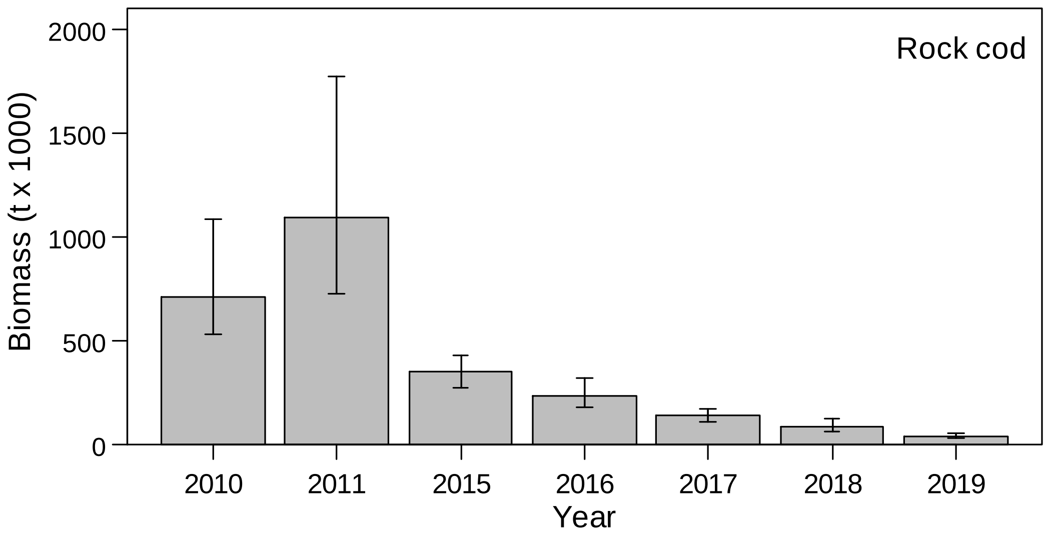

Fig. 23. Mean biomass (t) ± 95% confidence intervals of rock cod (*Patagonotothen ramsayi*) in Falkland Islands waters during 2010–2011, and 2015–2019. Note the data gap from 2012 to 2014.

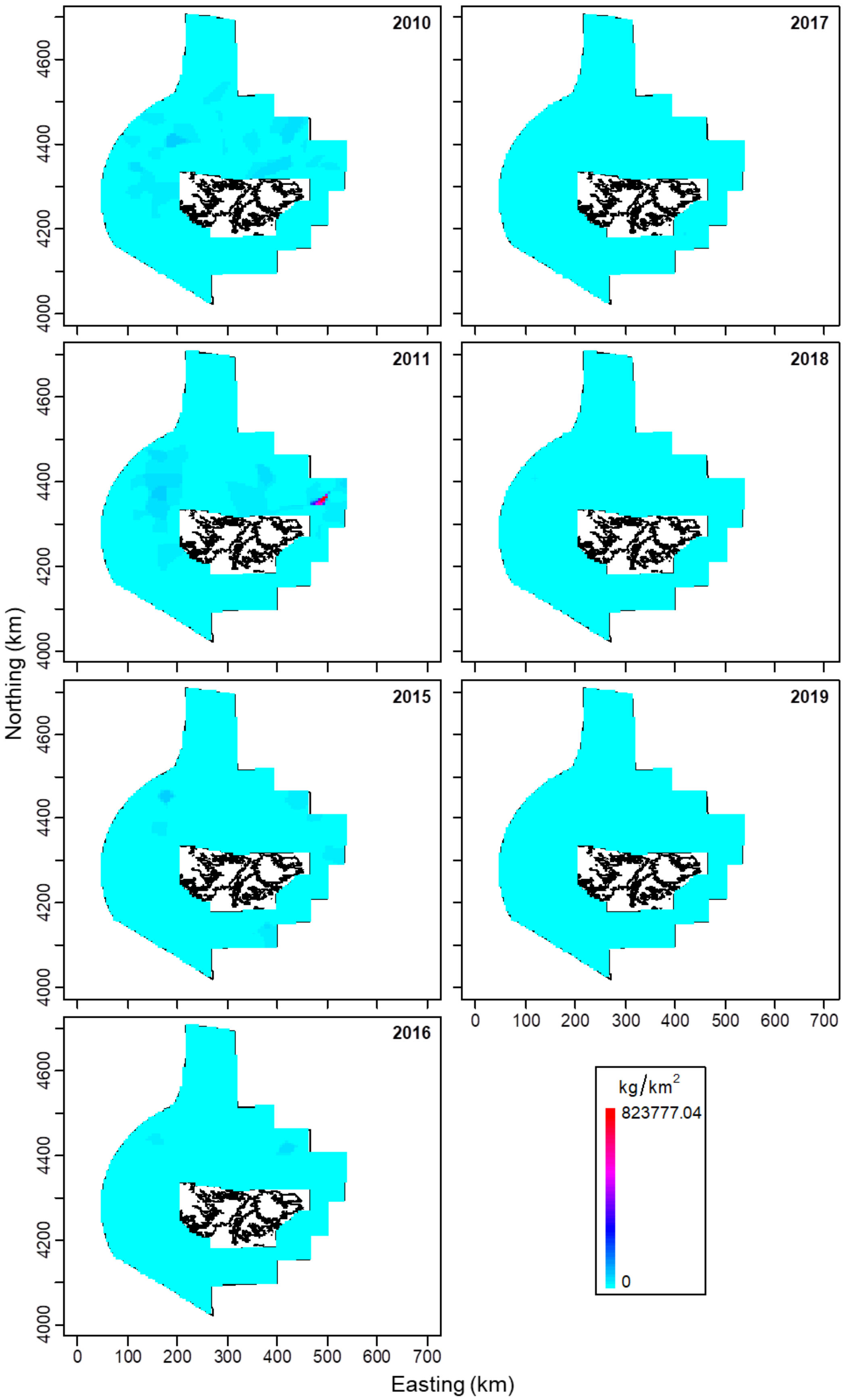

Fig. 24. Density of rock cod (*Patagonotothen ramsayi*) around the Falkland Islands during 2010–2011, and 2015–2019.

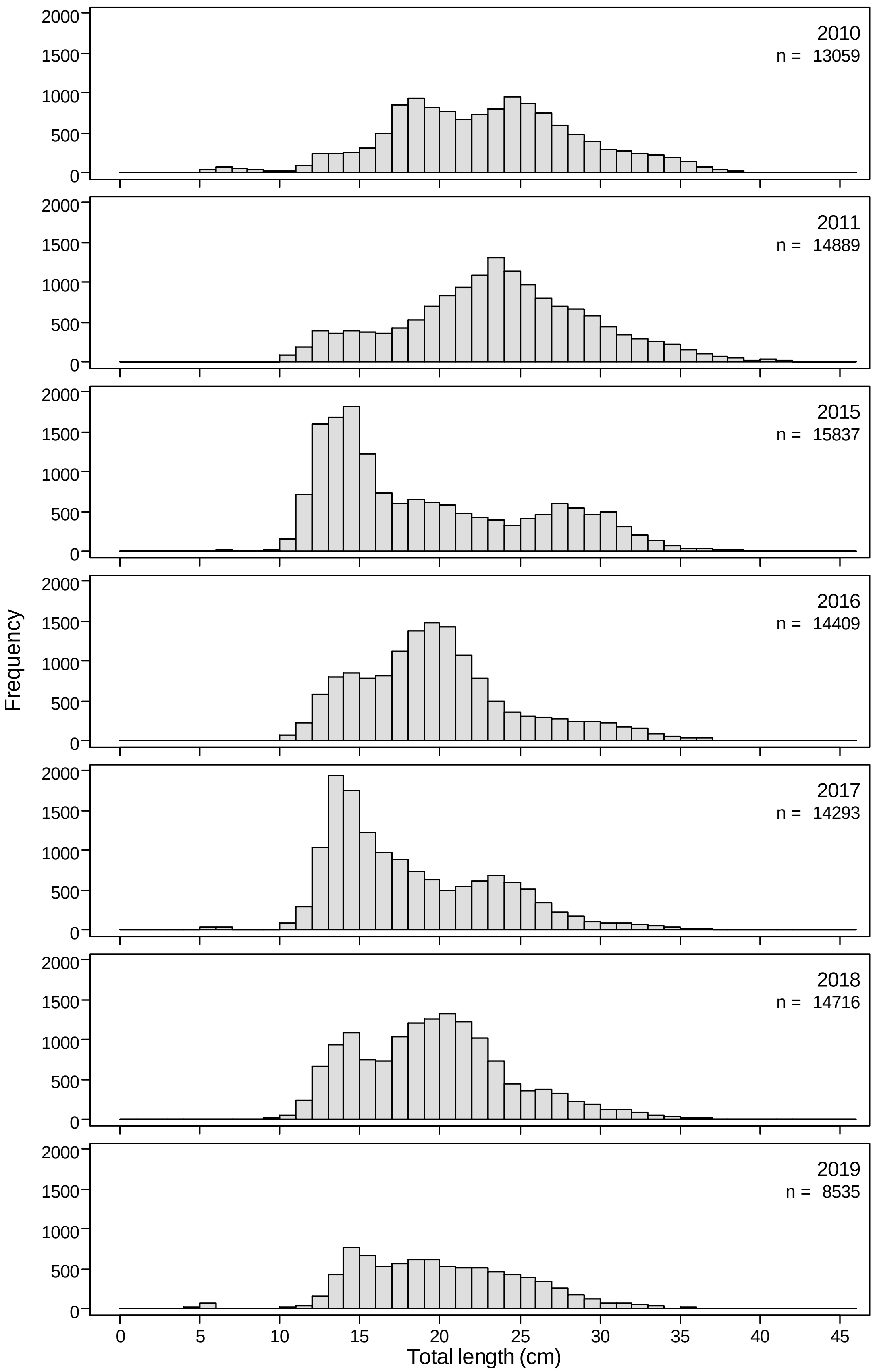

Fig. 25. Length frequency of rock cod (*Patagonotothen ramsayi*) around the Falkland Islands during 2010–2011, and 2015–2019.

4.2.9. Southern blue whiting (*Micromesistius australis*)

Southern blue whiting biomass was highly variable from 2010 (73,563 t) to 2017 (43,253 t). Relatively high biomass was estimated in 2011 (236,328 t) and the maximum biomass occurred in 2016 (332,096 t). Biomass remained at low levels from 2017; in 2018 the biomass was 58,802 t and in 2019 it reached its lowest level in the time series (6,626 t; Fig. 26; Table I), probably because southwestern deep water stations were not carried out during the February 2019 research survey. Southern blue whiting occurred mainly to the south of the FICZ and to the north-east of East Falkland. The maximum densities per 5 x 5 grid per year across the time series ranged from 6,626 kg/km^2 in 2019 to 332,096 kg/km^2 in 2016 (Fig. 27). Southern blue whiting decreased gradually in catch numbers from 2010 (n = 2,033) to 2019 (n = 164), with the exception of 2018 (n = 2,780). In 2010, two modal total lengths were observed at 25 cm and 58 cm. In 2018, two modal total lengths were detected at 25 cm and at 43 cm, whereas a few individuals were collected in 2019 with modal total length at 23 cm. The change in modal length of southern blue whiting from 2010 to 2019 was not statistically significant (p = 0.18; Fig. 28).

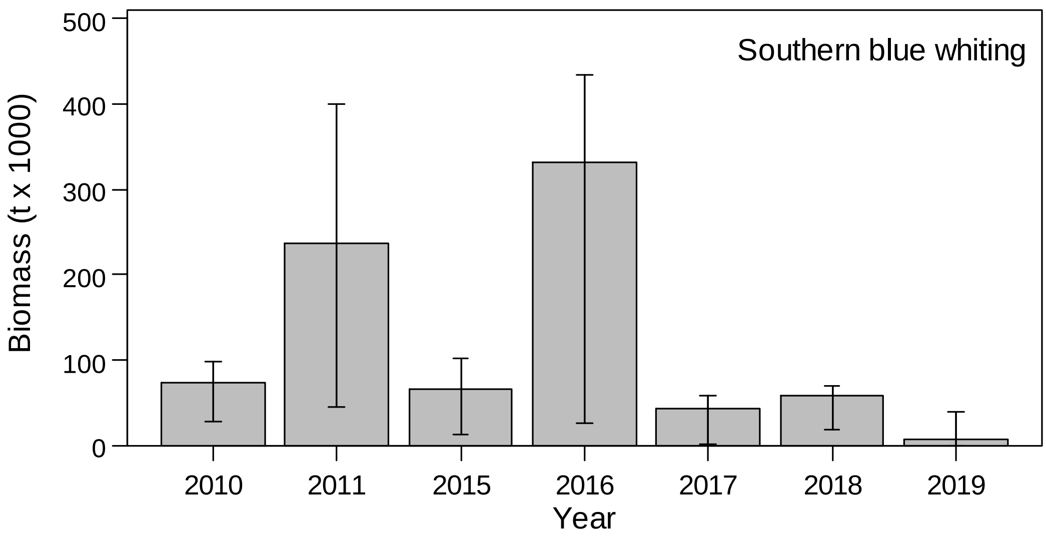

Fig. 26. Mean biomass (t) ± 95% confidence intervals of Southern blue whiting (*Micromesistius australis*) in Falkland Islands waters during 2010–2011, and 2015–2019. Note the data gap from 2012 to 2014.

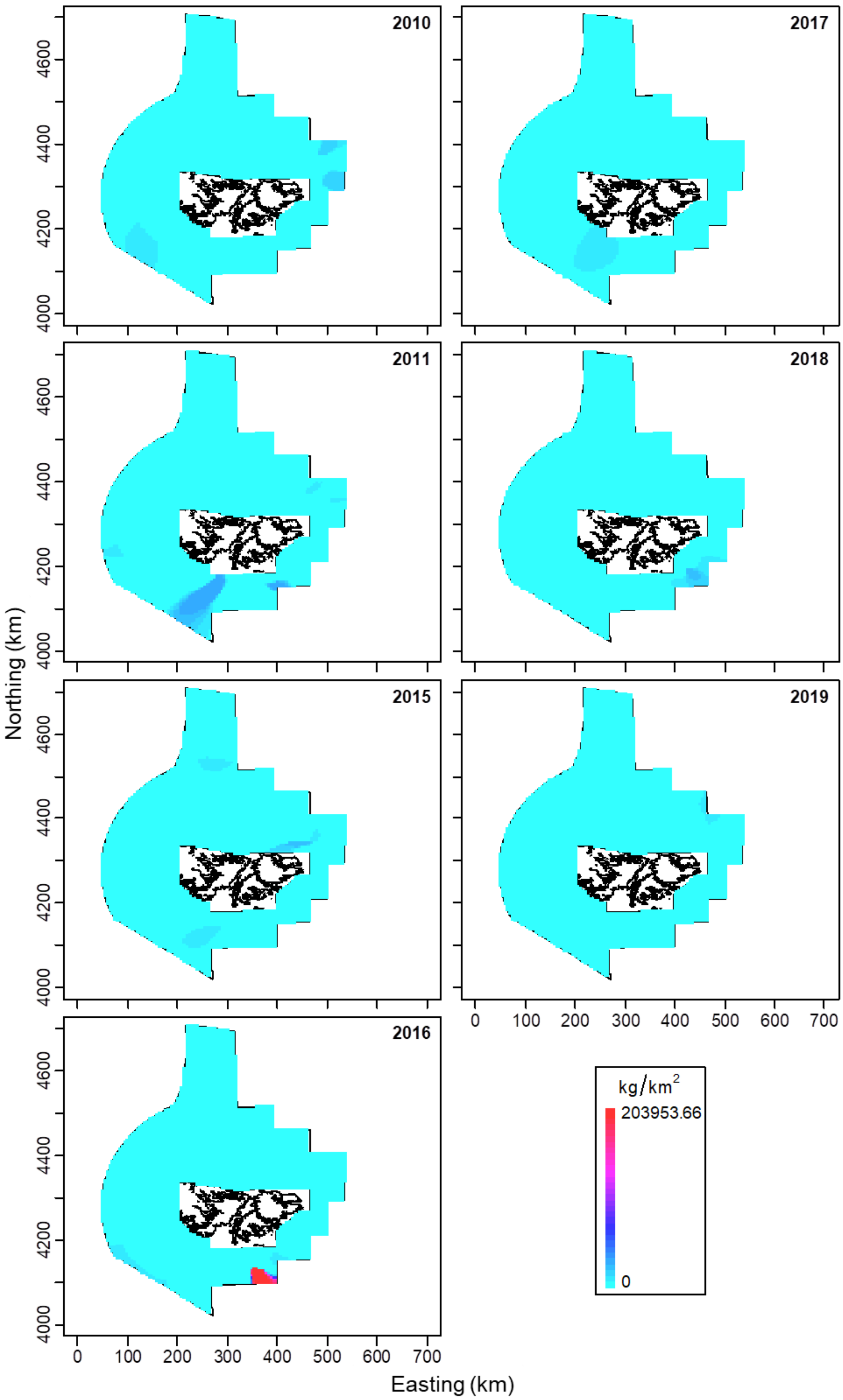

Fig. 27. Density of Southern blue whiting (*Micromesistius australis*) around the Falkland Islands during 2010–2011, and 2015–2019.

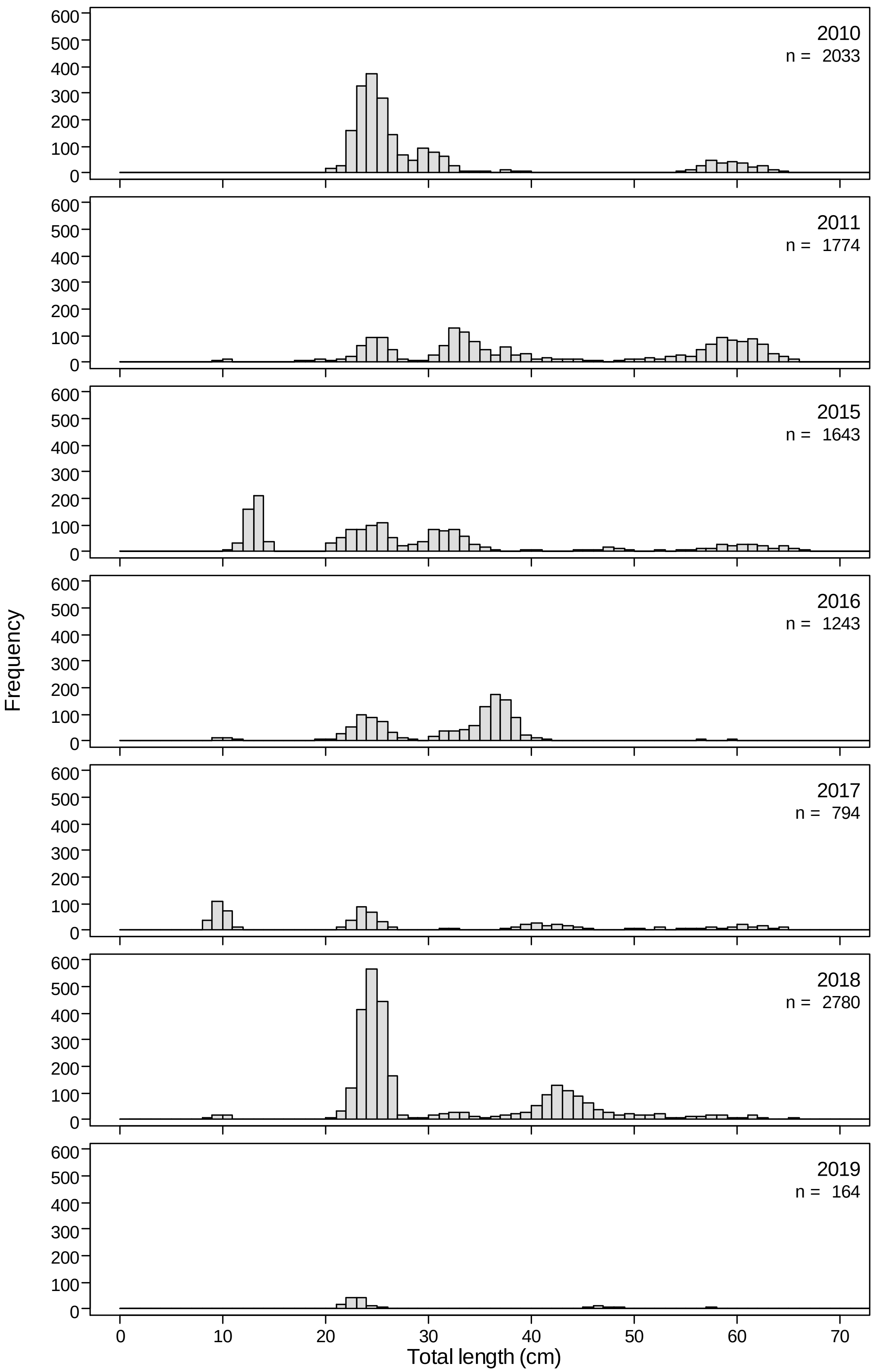

Fig. 28. Length frequency of Southern blue whiting (*Micromesistius australis*) around the Falkland Islands during 2010–2011, and 2015–2019.

4.2.10. Toothfish (*Dissostichus eleginoides*)

Adult toothfish are caught mainly on longlines and not by trawl; therefore, the information provided in this report regarding toothfish is not representative of the adult portion of the toothfish population. The survey biomass of toothfish has remained below 12,000 t since 2010. The biomass increased in 2011 (11,555 t) compared with 2010. There was a decline in 2015 (3,707 t); biomass increased in 2016 (8,219 t), 2017 (8,650 t) and 2018 (8,782 t), and decreased in 2019 (6,834 t; Fig. 29; Table I). Toothfish has had a patchy distribution around the Falkland Islands since 2010. However, the maximum densities per 5 x 5 grid occurred to the south-west of West Falkland; in 2015 high densities were also observed to the north of the Falkland Islands. The maximum densities per 5 x 5 grid per year across the time series ranged from 197 kg/km^2 in 2015 to 902 kg/km^2 in 2018 (Fig. 30). In 2010, two modal total lengths were observed at 34 cm and around 50 cm. In 2018, two modal total lengths were detected at 31 cm and around 59 cm, whereas a few individuals collected in 2019 had a modal total length at 46 cm. The trend in modal length of toothfish from 2010 to 2019 was not statistically significant (0.88; Fig. 31).

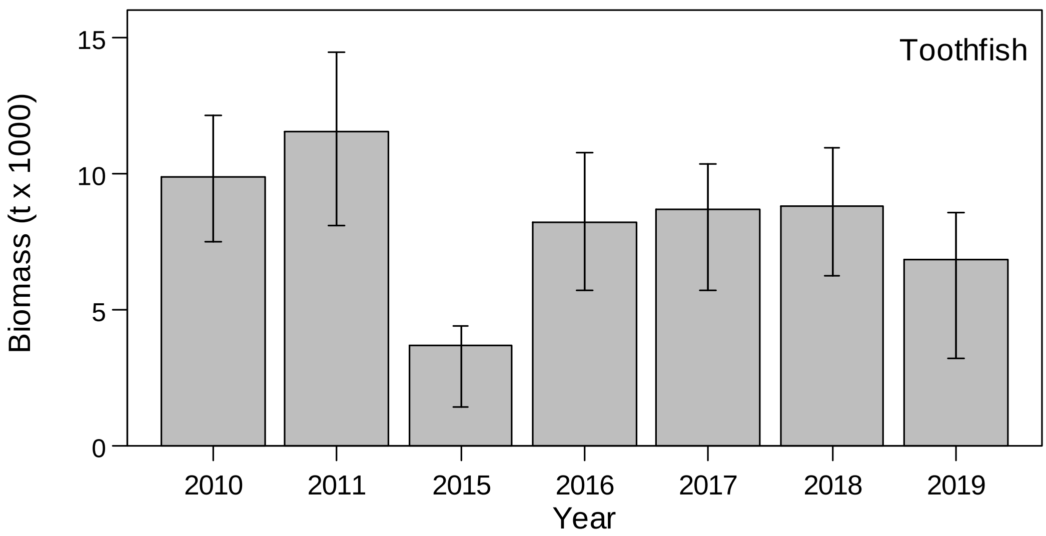

Fig. 29. Mean biomass (t) ± 95% confidence intervals of toothfish (*Dissostichus eleginoides*) in Falkland Islands waters during 2010–2011, and 2015–2019. Note the data gap from 2012 to 2014.

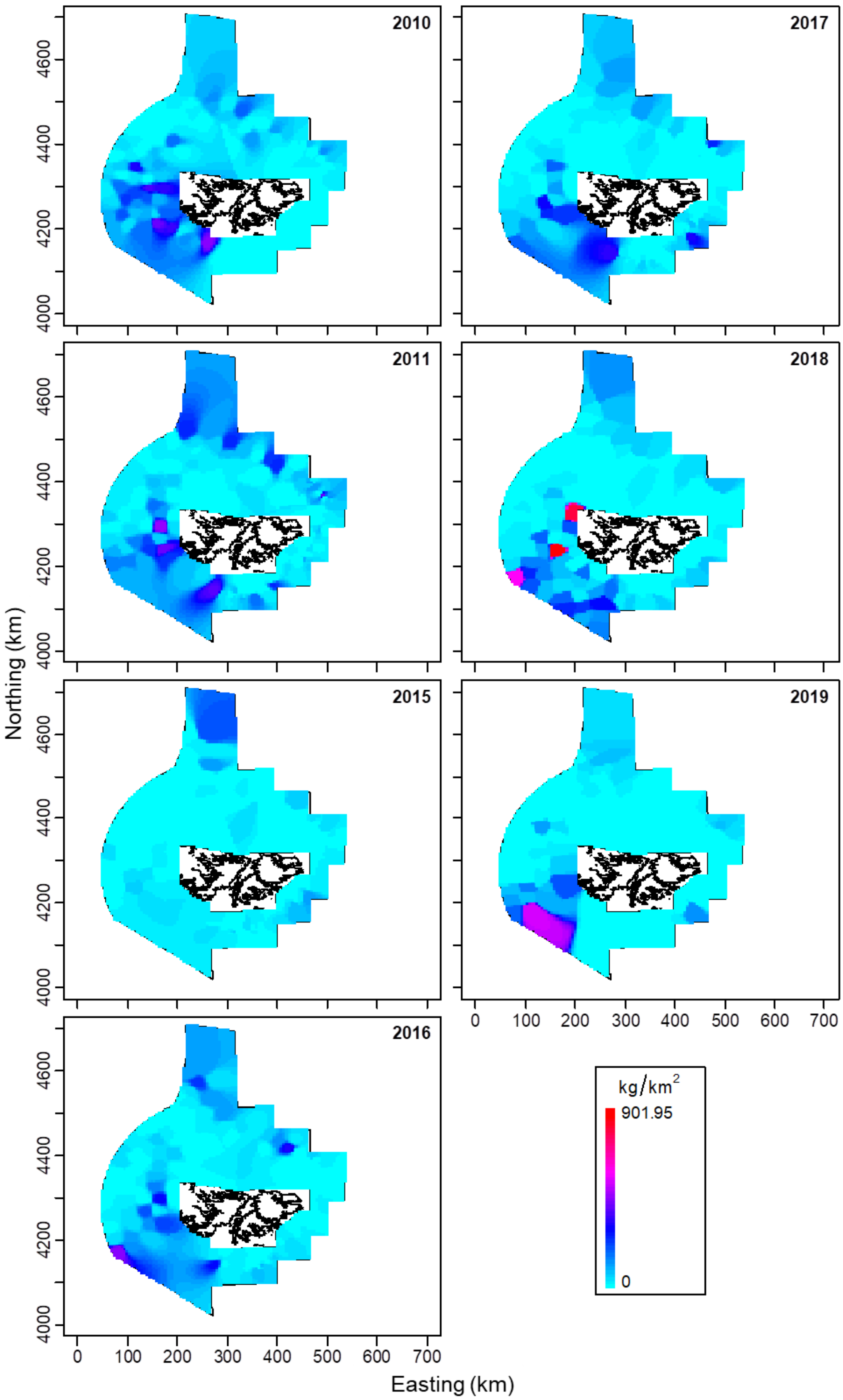

Fig. 30. Density of toothfish (*Dissostichus eleginoides*) around the Falkland Islands during 2010–2011, and 2015–2019.

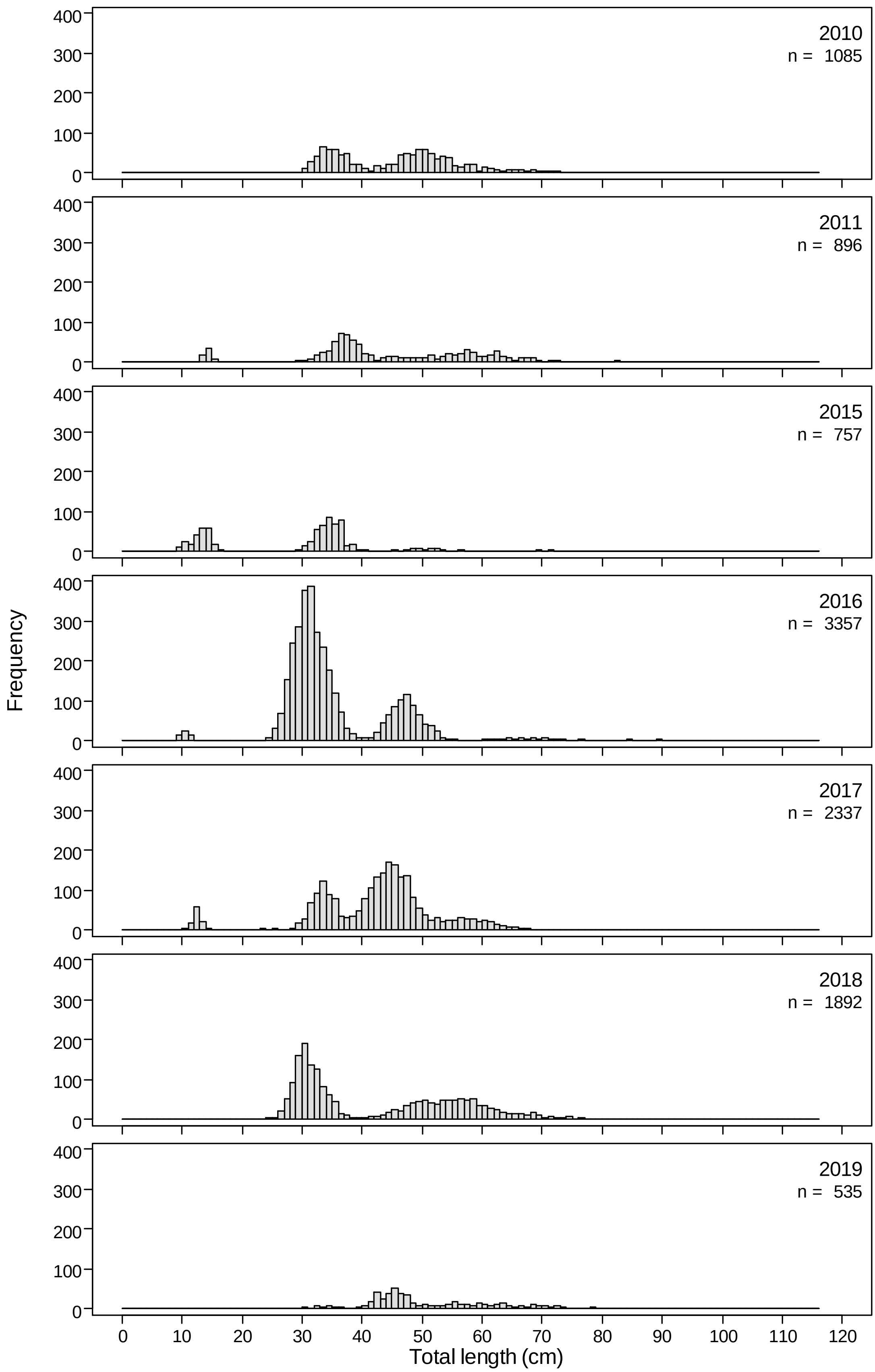

Fig. 31. Length frequency of toothfish (*Dissostichus eleginoides*) around the Falkland Islands during 2010–2011, and 2015–2019.

5. Discussion

The biomass of three species estimated from February trawl surveys declined significantly from 2010 to 2019. Rock cod had the greatest decrease in biomass, declining approximately 19x from 2010 (709,536 t) to 2019 (37,793 t). Hoki had the second greatest decline (7x) in biomass from 2010 (272,080 t) to 2019 (41,399 t). Banded grenadier declined 4x from 2010 (86,113 t) to 2019 (21,026 t). The biomass of the Argentine short-fin squid, common hake, kingclip and red cod was characterized by an increase from 2010 to 2015 that was followed by a decline in 2016 and a subsequent increase in 2019. Even when the biomass of these species were greater in 2019 than in 2010 (except for red cod), these fluctuated from year to year and therefore cannot be taken as an indication of an increase in biomass in the longer term. For instance, Ramos & Winter (2019) found that the biomass of kingclip has declined considerably since 1987. Patagonian squid had highly fluctuating inter-annual biomass, with > 180,000 t in 2010, 2017 and 2019, and < 62,000 t in 2011, 2016, and 2018. Southern blue whiting, once one of the largest finfish stocks exploited in Falkland waters (Falkland Islands Government 2018) reached its lowest biomass level in 2019 with only 6,626 t.

Toothfish biomass has remained below 12,000 t since 2010, with the lowest biomass estimate in 2015 (3,707 t). In 2019, the second lowest biomass was observed (6,834 t). 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 banded grenadier, has led the finfish fishery to catch much more toothfish over the last two years compared with previous years. 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).

During February, the species that were found north of the Falkland Islands were the Argentine short-fin squid, and rock cod; common hake and kingclip aggregated mainly towards the north-west. Considerable out-of-zone rock cod catches over the last couple of years suggest that the decrease in abundance of this species may also be a function of a change in its geographic distribution (Falkland Islands Fisheries Department 2018). Patagonian squid and southern blue whiting occurred mainly to the south of the Falkland

Islands, and banded grenadier to the south-west. Hoki and toothfish were found around the FICZ and FOCZ. Red cod was found mainly towards the west of West Falkland. The presence of the species observed in this study during February may be associated with a plume of productive waters surround the Falkland waters during the austral summer (Piola et al. 2018).

Two species had statistically significant declines in modal length; these are rock cod and banded grenadier. The modal total lengths of rock cod in 2010 were between 19 and 25 cm, whereas in 2019 most individuals were caught at ~ 15 cm. Accordingly, length at maturity of rock cod declined from 2003 to 2018 (Winter 2019). The negative trend in modal length of common hake, hoki and kingclip from 2010 to 2019 was 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 2019). Red cod was not found to have a statistically significant decrease in modal length from 2010 to 2019, however, this species had a significant decrease in modal length from 1988 to 2018 (Winter 2018). Analyses of length frequencies from longer time series may be able to detect significant changes in the size of the species examined in this study from 2010 to 2011, and from 2015 to 2019 (7 years only).

Changes in oceanographic conditions, e.g. temperature and productivity, are expected to have important ramifications on the distribution, abundance, phenology, size structure and catch of commercial species (Hatfield 2000; O'Connor *et al.* 2007; Pecl & Jackson 2008; Cheung *et al.* 2013; Arkhipkin *et al.* 2015). Therefore, examinations of the effect of oceanographic conditions on the marine resources in Falkland waters will provide further insights into the availability of these resources.

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Appendix I

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

Appendix II

Combined catches (t) of species during groundfish and calamari pre-season surveys in Falkland Islands waters during February 2010–2011, and 2015–2019.

Common name	**2010**	**2011**	**2015**	**2016**	**2017**	**2018**	**2019**
Argentine shortfin squid	0.88	1.95	31.87	0.09	2.49	10.70	9.41
Banded grenadier	8.05	6.20	6.58	3.28	3.97	7.54	2.51
Common hake	1.31	1.67	3.17	0.69	2.94	1.73	2.75
Hoki	79.78	55.99	26.36	38.92	3.70	30.02	7.55
Kingclip	3.24	8.59	14.73	5.45	4.26	3.59	4.42
Patagonian squid	356.76	50.51	186.14	66.90	185.23	115.84	386.26
Red cod	13.54	23.54	21.81	19.95	13.82	13.30	13.68
Rock cod	164.59	249.38	198.27	77.31	76.13	35.92	27.94
Southern blue whiting	21.87	52.29	24.12	79.36	6.41	29.51	8.38
Toothfish	1.39	2.42	0.77	1.75	2.50	1.93	0.83
Total	651.41	452.56	513.82	293.69	301.44	250.09	463.73