February bottom trawl survey biomasses of fishery species in Falkland Islands waters, 2010–2021

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Reviewed and approved on 7 May 2021 by:

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Director of Natural Resources
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1. Summary

Survey biomass assessments of 11 commercial species: Argentine shortfin squid, banded whiptail grenadier, common hake, hoki, kingclip, Patagonian squid, red cod, rock cod, southern blue whiting, southern hake, and toothfish were carried out in Falkland Islands waters. The assessments were based on catch data of 1,293 bottom trawls taken during the February parallel groundfish and calamari pre-season surveys from 2010, 2011, and 2015 to 2021.

Species CPUE, catch, and biomass estimates were generally consistent with each other. Four species had statistically significant declining trends in biomass from 2010 to 2021; of these species rock cod had the greatest decrease in biomass. The biomass of rock cod in 2021 was only 8% of its biomass in 2010; for red cod it was 37%, for southern hake it was 41%, and for toothfish it was 47%. Biomass linear trends of banded whiptail grenadier, hoki, kingclip, southern blue whiting, Argentine shortfin squid and common hake were not statistically significant. It is noted 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 2021, the geographic distributions of the Argentine shortfin squid and common hake were to the north-west in Falkland Island waters. Kingclip and red cod occurred mainly along the west. Banded whiptail grenadier, hoki, southern blue whiting, southern hake, and toothfish were located mainly to the south-west. Patagonian squid and rock cod were caught around Falkland Islands waters but mainly to the south.

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 shortfin 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*) into the shelf are favoured by intrusions of sub-Antarctic waters (Laptikhovsky et al. 2008; Arkhipkin & Laptikhovsky 2010).

Squids and fishes 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). Total catches reached a maximum of 462,487 t in 2015, in part due to the unusual large intrusion of *I. argentinus* in Falkland Islands waters from April to May 2015 (Winter 2015) that resulted in record catches (332,862 t) for this species that year. Contrastingly, total catches since 2016 (mean 163,134 t) have been amongst the lowest since 1987 (Falkland Islands Government 1989, 2020).

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 2020) 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 Falkland Island Conservation Zones (FICZ and FOCZ) based on commercial and scientific surveys.

The Falkland Islands Fisheries Department (FIFD) has carried out parallel groundfish and calamari pre-season surveys every February since 2010, except for 2012, 2013, and 2014. The groundfish surveys are conducted along the north, west and south-west of Falkland Islands waters. The calamari pre-season surveys are conducted along the '*Loligo Box*' to the east of the Falkland Islands. The original objective of these surveys was to provide a synchronous biomass 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. It is noted, however, that Falkland Islands waters represent only part of the range for most species examined, and for some migratory species February is not a time of peak abundance, i.e. common hake (Arkhipkin et al. 2015), kingclip (Arkhipkin et al. 2012), and southern blue whiting (Barabanov 1982). Stations to the south-west of the FICZ have also not been sampled equally in all years, which may influence biomass estimates for species that occur in that area during February, such as banded whiptail grenadier, hoki, southern blue whiting, and toothfish.

This report summarizes catch data jointly from the groundfish survey and the calamari pre-season survey, 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), and species of current commercial value are included in this report.

3. Methods

3.1. Trawl stations and biological sampling

Concurrent groundfish and calamari pre-season research surveys were carried out during February 2010–2011 and 2015–2021 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.

On both surveys, all species from the catch of each trawl station were sorted by FIFD scientific personnel and the vessel's factory crew. FIFD scientific personnel recorded the total catch of each species assessed by a combination of weighing on an electronic balance to the nearest 0.01 kg and factory production records. Catches were assessed for eleven species that represent important commercial targets here and in other nations' fishing zones (Table I). Random samples of up to 100 individuals of each species were measured to the lowest 1 cm for finfish and to the lowest 0.5 cm for squids to produce length-frequency histograms. Dorsal mantle length was measured for Argentine shortfin squid and Patagonian squid. Total length was measured for common hake, kingclip, red cod, rock cod, southern blue whiting, southern hake, and toothfish. Pre-anal length was measured for banded whiptail grenadier and hoki. Hereafter, these different length measurements will be referred to as 'length' only.

The duration of each trawl was approximately 60 min on the bottom during groundfish surveys, and 120 min on the bottom during calamari pre-season surveys. 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, 2020, 2021), Randhawa et al. (2020), and Trevizan et al. *in prep*. These surveys were designed to be consistent in the number and position of stations across years. However, there were variations in the number of stations mainly to the south-west of the FICZ for specific purposes of the February 2018 and 2020 groundfish surveys (Gras et al. 2018; Randhawa et al. 2020).

Table I. Species assessed in groundfish and calamari pre-season surveys in Falkland Islands waters during February 2010–2011 and 2015–2021. Geographic distributions taken from http://www.fao.org/fishery/species/search/en

Common name	Scientific name	Distribution
Argentine shortfin squid	*Illex argentinus*	Southwest Atlantic: Brazil, Uruguay, Argentina, Falkland Islands.
Banded whiptail 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.
Southern hake	*Merluccius australis*	Southwest Atlantic: Argentina, Falkland Islands. Southern Pacific: Chile, New Zealand.
Toothfish	*Dissostichus eleginoides*	Southwest Atlantic: Argentina, Falkland Islands. Southeast Pacific: Chile. Southwest Pacific: Macquarie Island. Southern Ocean: South Georgia.

3.2. Abundance estimations

Station and catch data were recorded during the surveys, checked and uploaded to the FIFD database, from which the data were available for analyses. Trawls were excluded if not quantifiable for the following reasons: 1) the doors did not open properly, 2) the net broke during the trawl, or 3) if the net was quickly filled with medusae, which resulted in the trawl being interrupted (Appendix I).

CPUE per species were calculated for every year as the total catch weight of the species in both February surveys divided by the total fishing effort in both February surveys. 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, net horizontal opening was derived from the distance between trawl doors (Seafish 2010). For groundfish surveys, the triangulation method that derives net horizontal opening from the distance between trawl doors is unsuitable because the geometry of the net is different. Since 2016, groundfish survey net horizontal opening has instead been measured directly from Marport sensors fitted to the extremities of the survey vessel's trawl net wings. If net horizontal opening was not recorded due to failure of the Marport sensors, it was estimated from door spread, net vertical opening and trawl speed using a generalized additive model.

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 5×5 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 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).

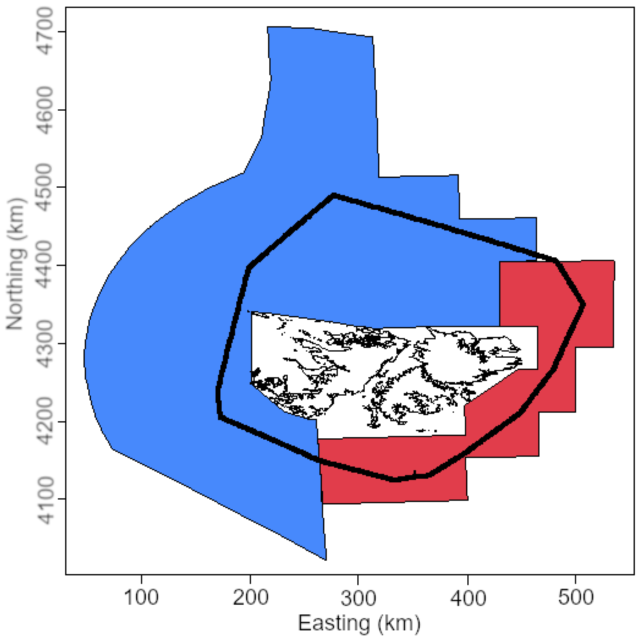


Fig. 1. Groundfish (blue) and calamari pre-season (red) survey areas, with axial loop (black line) used to define relative distances for the inverse distance weighting algorithm.

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 of the 30,000 bootstrap iterations were used. Linear regression was implemented to examine changes in biomass through time.

4. Results

4.1. Trawls and overall catches

A total of 1,293 bottom trawls were carried out during the February groundfish and calamari pre-season surveys from 2010–2011 and 2015–2021; a range of 79 to 97 trawls were carried out during groundfish surveys per year, and 52 to 59 trawls were carried out during calamari pre-season surveys per year. In 2021, a total of 80 trawls were carried out during the groundfish survey, and 55 trawls were carried out during the calamari pre-season survey (Appendix I).

Patagonian squid had the highest mean catch (211.7 t) and rock cod had the second highest mean catch (99.7 t) across years. However, combined catches of rock cod continually declined since 2011 (249.4 t) to reach the lowest level in 2020 (11 t). Similarly, hoki, red cod, and southern hake had decreasing catches through time. In February 2021, Patagonian squid had the highest catch (285.5 t) and rock cod had the second highest catch (57.2 t) across species. Higher rock cod catches in February 2021 were due to the presence of large aggregations in the '*Loligo Box*' caught in the calamari pre-season survey (Fig. 2; Appendix II).

4.2. Abundance, distribution and size structure

4.2.1. Argentine shortfin squid (*Illex argentinus*)

The highest CPUE of Argentine shortfin squid in the time series was estimated for 2015 with 158 kg/h. The following year saw the greatest decline in CPUE in the time series with only 0.5 kg/h. In 2021, CPUE was estimated at 54 kg/h (Fig. 2). The pattern of CPUE was consistent with catch and biomass patterns. Catches of this species were higher in groundfish surveys compared with calamari pre-season surveys at any year. Catches were usually below 11 t every year, except for 2015 and 2020 when nearly 32 t and 18 t were caught, respectively (Fig. 2; Appendix II). The biomass of the Argentine shortfin 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); a total of 43,310 t were estimated in 2021 (Fig. 2; Appendix III). The inter-annual biomass linear trend was not significant overall for the period 2010 to 2021 ($p = 0.58$; Appendix IV).

In 2021, this species was distributed to the north-west of West Falkland, with the highest densities near the limit of the FICZ (13,433 kg/km^2; Fig. 3). This may be an indication of high abundances outside Falkland Islands waters at the time of the surveys, just before this species starts migrating into Falkland Islands waters. Across years, the Argentine shortfin squid was mainly distributed through the north of West and East Falkland, with the highest density in the time series reported to the north of East Falkland during 2015 (74,426 kg/km^2; Appendix V).

Length frequency histograms show a range of sizes of *I. argentinus* from 5 cm to 35.5 cm across years. Two groups were detected every year. The modal dorsal mantle length of the smaller group ranged from 9.5 cm to 18.0 cm, and the modal dorsal mantle length of the larger group ranged from 23.0 cm to 25.0 cm, with 2021 having the largest modal length for the large group across years (Fig. 4).

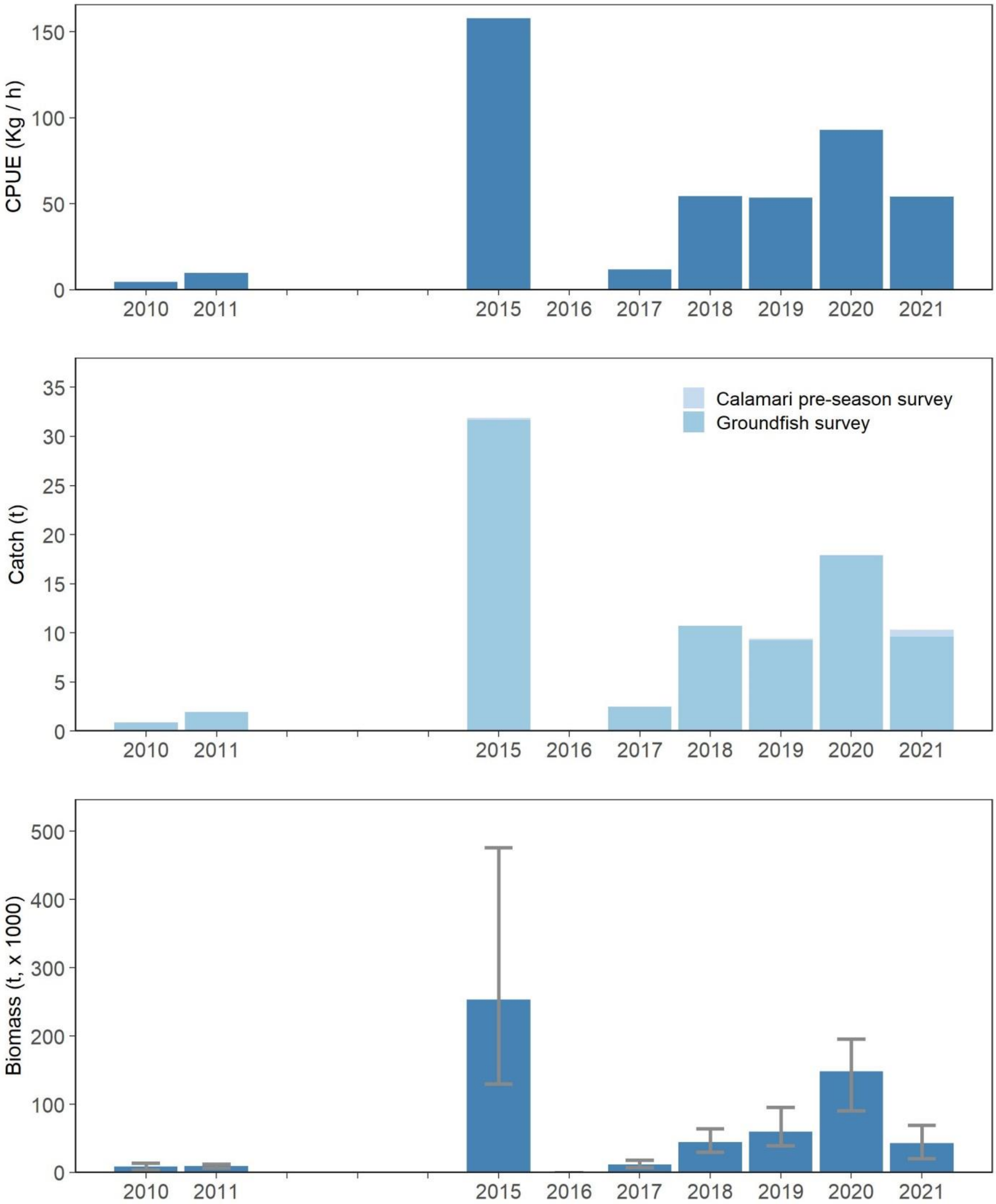


Fig. 2. CPUE (kg/h), catch (t) and mean biomass (t) ± 95% confidence intervals of the Argentine shortfin squid (*Illex argentinus*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

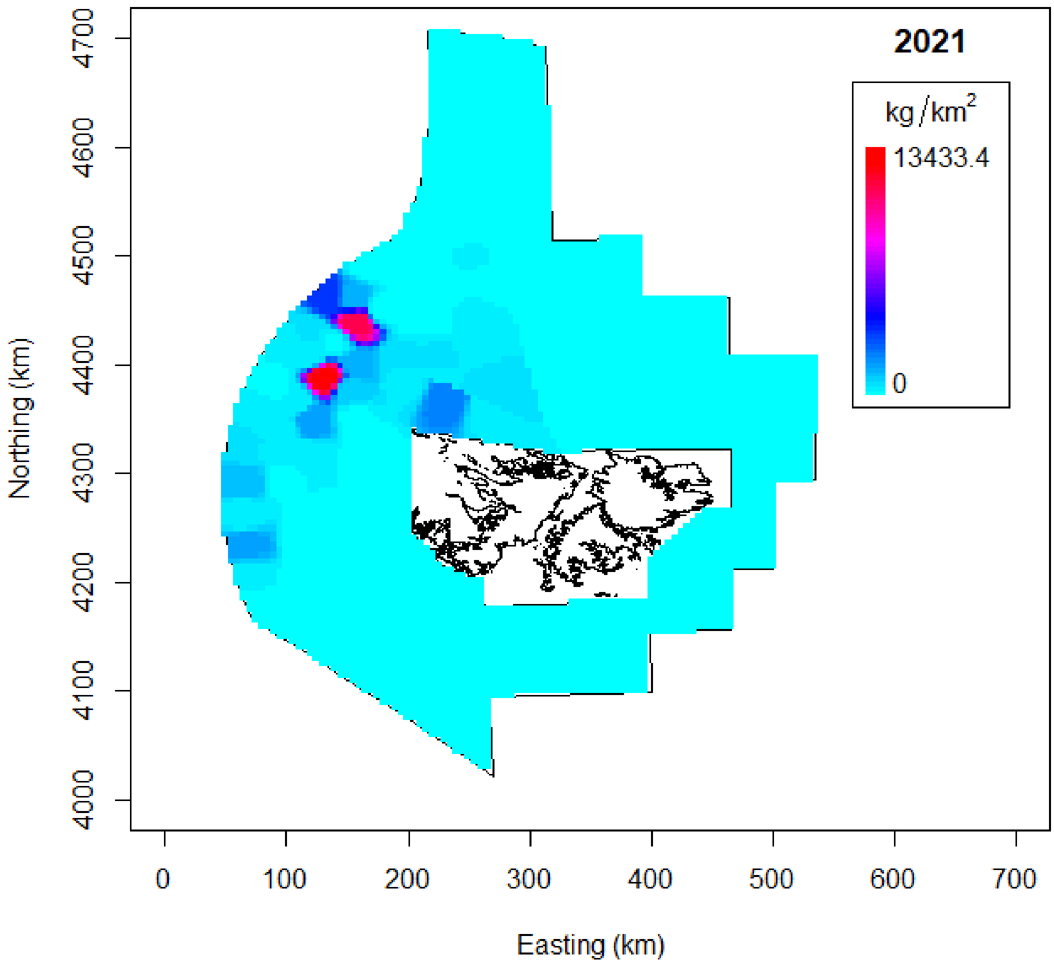


Fig. 3. Density of the Argentine shortfin squid (*Illex argentinus*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters.

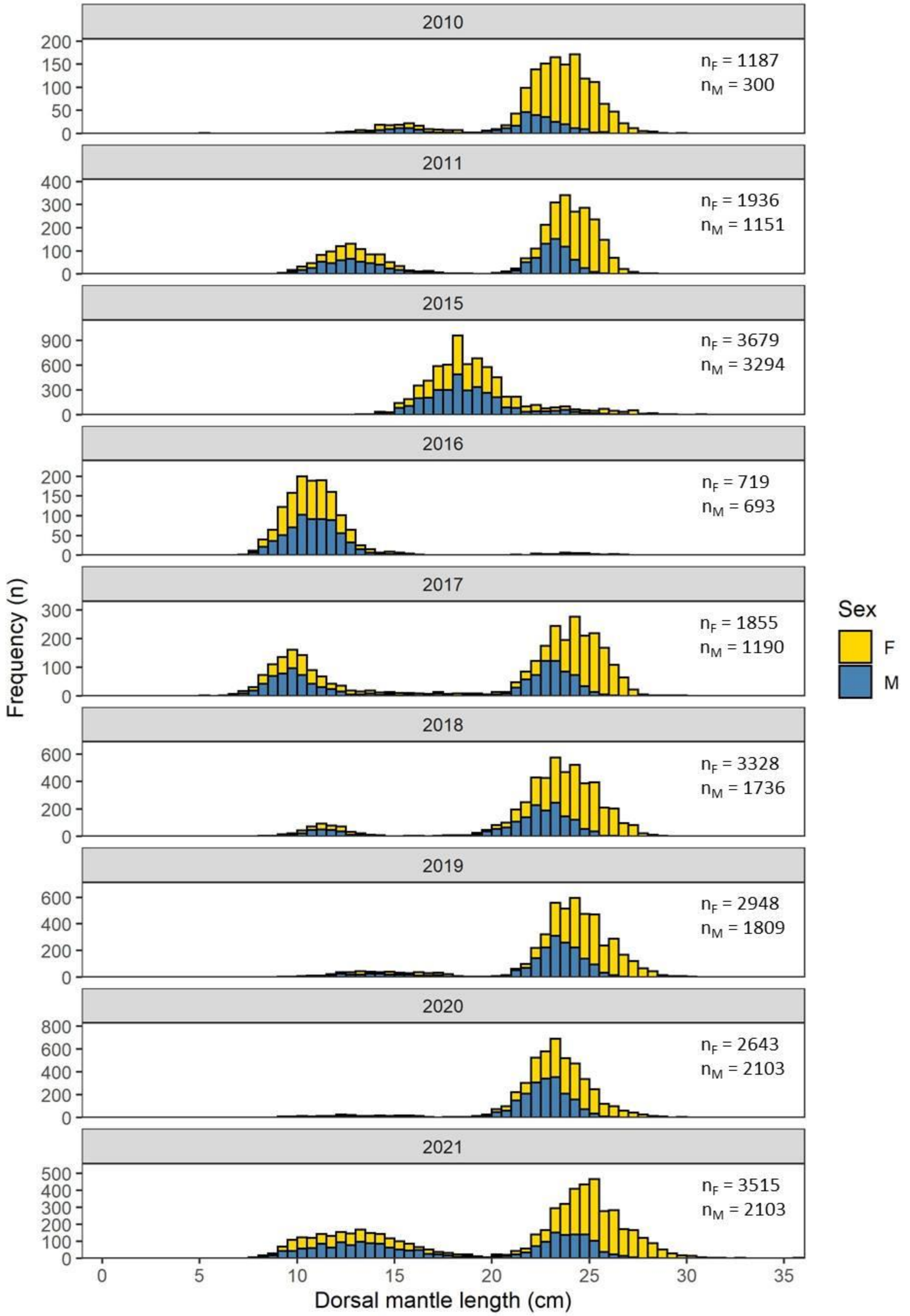


Fig. 4. Length-frequency distribution of Argentine shortfin squid (*Illex argentinus*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

4.2.2. Banded whiptail grenadier (*Coelorinchus fasciatus*)

CPUE of banded whiptail grenadier oscillated across years, with the highest CPUE estimated for 2010 (41 kg/h). Relatively high CPUEs were also observed in 2015 (33 kg/h), 2018 (38 kg/h), and 2021 (34 kg/h; Fig. 5). The CPUE pattern was consistent with the catch pattern across years. Catches of this species were higher in groundfish surveys compared with calamari pre-season surveys at any year, and catches ranged between 2.5 t and 8 t (Fig. 5; Appendix II). The biomass of banded whiptail grenadier appear to have a decreasing trend from 2010 (86,113 t) to 2019 (22,217 t), followed by an increase in biomass from 2019 to 2021 (66,298 t; Fig. 5; Appendix III). However, 95% confidence intervals showed overlap of biomass estimates among the years examined. Accordingly, there was no statistically significant linear trend in biomass from 2010 to 2021 ($p = 0.17$; Appendix IV). These findings suggest that the stock of banded whiptail grenadier is relatively stable. Patterns of abundance for this stock should be examined at a specific range of depths given its higher presence at deeper stations.

Banded whiptail grenadier was predominantly distributed to the south-west of West Falkland during 2021, with the maximum density estimated at 5,244 kg/km^2 (Fig. 6). Across years, there was a consistent pattern of distribution to the south-west of West Falkland with the highest density in 2011 (9,127 kg/km^2; Appendix VI).

Length frequency histograms of banded whiptail grenadier show a range of sizes from 2 cm to 20 cm pre-anal length. One modal length was evident every year and remained constant through time, i.e. 9–10 cm pre-anal length (Fig. 7).

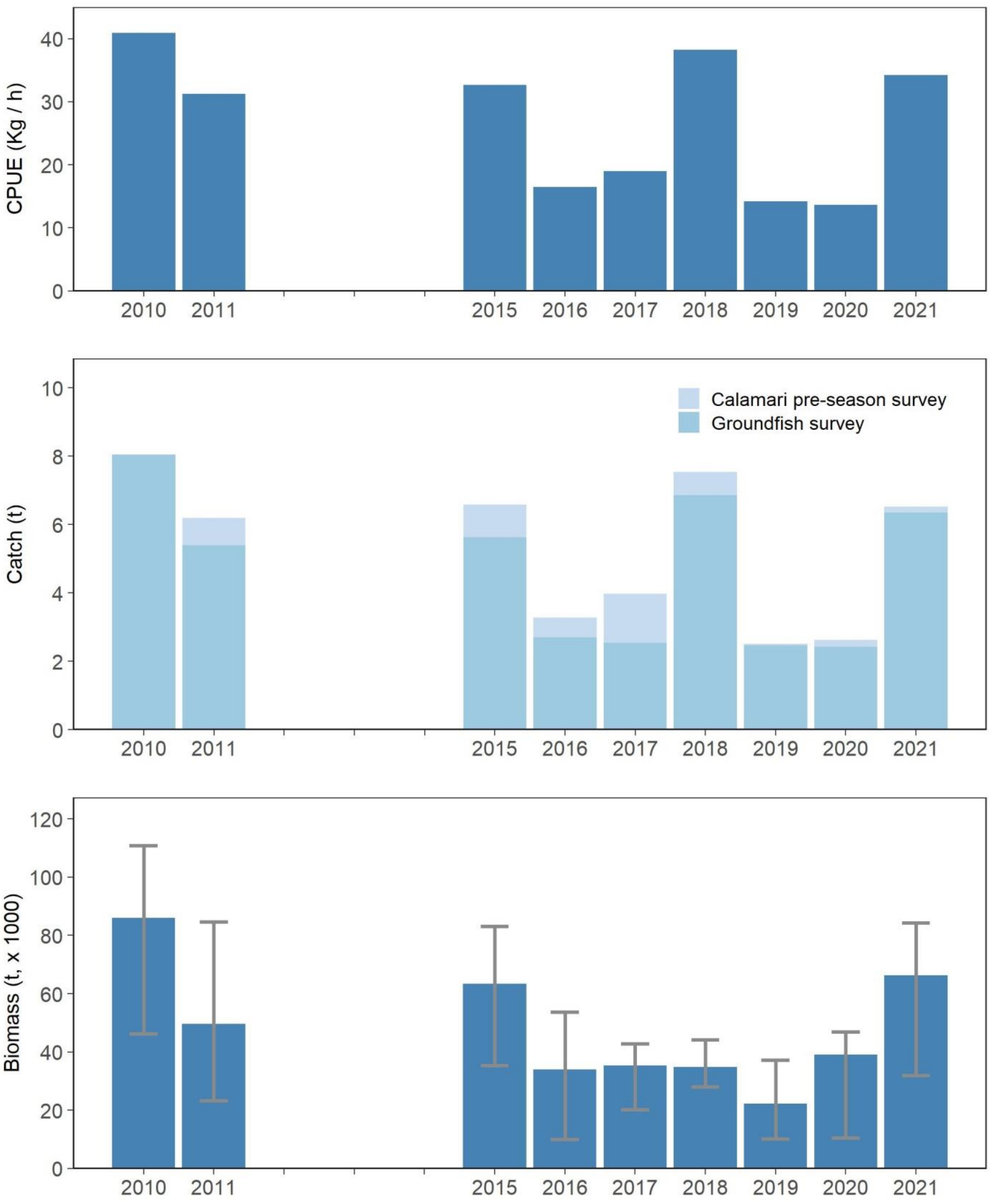


Fig. 5. CPUE (kg/h), catch (t) and mean biomass (t) ± 95% confidence intervals of banded whiptail grenadier (*Coelorinchus fasciatus*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

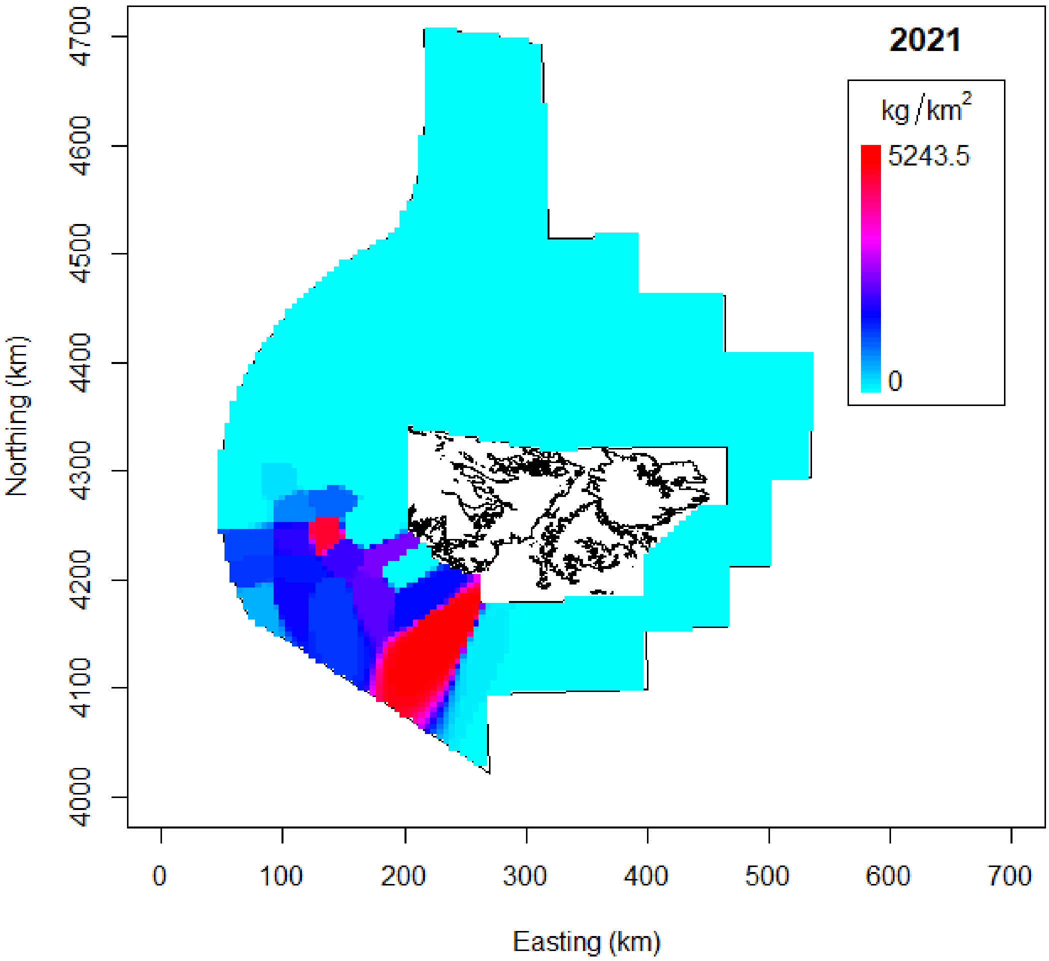


Fig. 6. Density of banded whiptail grenadier (*Coelorinchus fasciatus*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters.

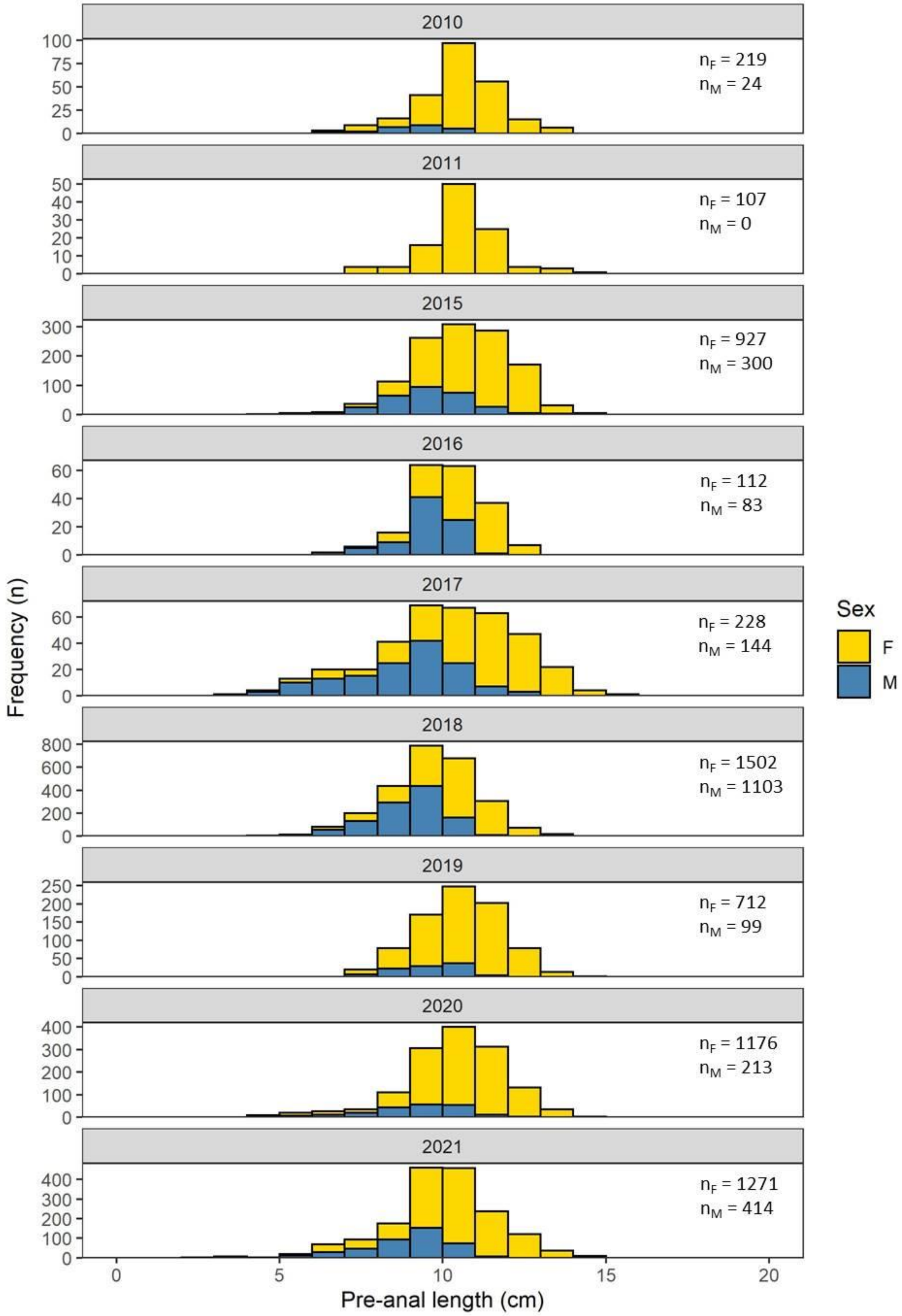


Fig. 7. Length frequency of banded whiptail grenadier (*Coelorinchus fasciatus*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

4.2.3. Common hake (*Merluccius hubbsi*)

CPUE of common hake was relatively stable from 2010 to 2011, and from 2015 to 2020 but had a considerable increase in 2021 (43 kg/h; Fig. 8). Nearly all common hake were caught in groundfish surveys through the time series. Catches reached a maximum in 2021 (8.2 t), whereas catches remained below 3.2 t the rest of the years (Fig. 8; Appendix II). The biomass of common hake oscillated and remained under 20,000 t every February from 2010 to 2020. In 2021, biomass reached its highest in the time series with 33,688 t (Fig. 8; Appendix III). Considerable biomass variation through time is consistent with the absence of a statistically significant linear trend in biomass from 2010 to 2021 ($p = 0.41$; Appendix IV).

In 2021, common hake was mainly distributed to the north-west of West Falkland with the highest density estimated at 3,393 kg/km^2 (Fig. 9). Migration into Falkland Islands waters takes place in February, when the surveys are being conducted. Changes in oceanographic conditions may result in year-to-year abundance variability for this species during February. Across years, high densities were detected to the north-west offshore or near the limit of the FICZ, with the highest density estimated in 2021 (3,393 kg/km^2; Appendix VII).

Length frequency histograms show a wide range of common hake sizes, from 13 cm to 95 cm total length, across the time series. Overlap of sizes does not allow comparing the modal length of each cohort through time. In 2021, the modal length was detected at 39 cm total length (Fig. 10).

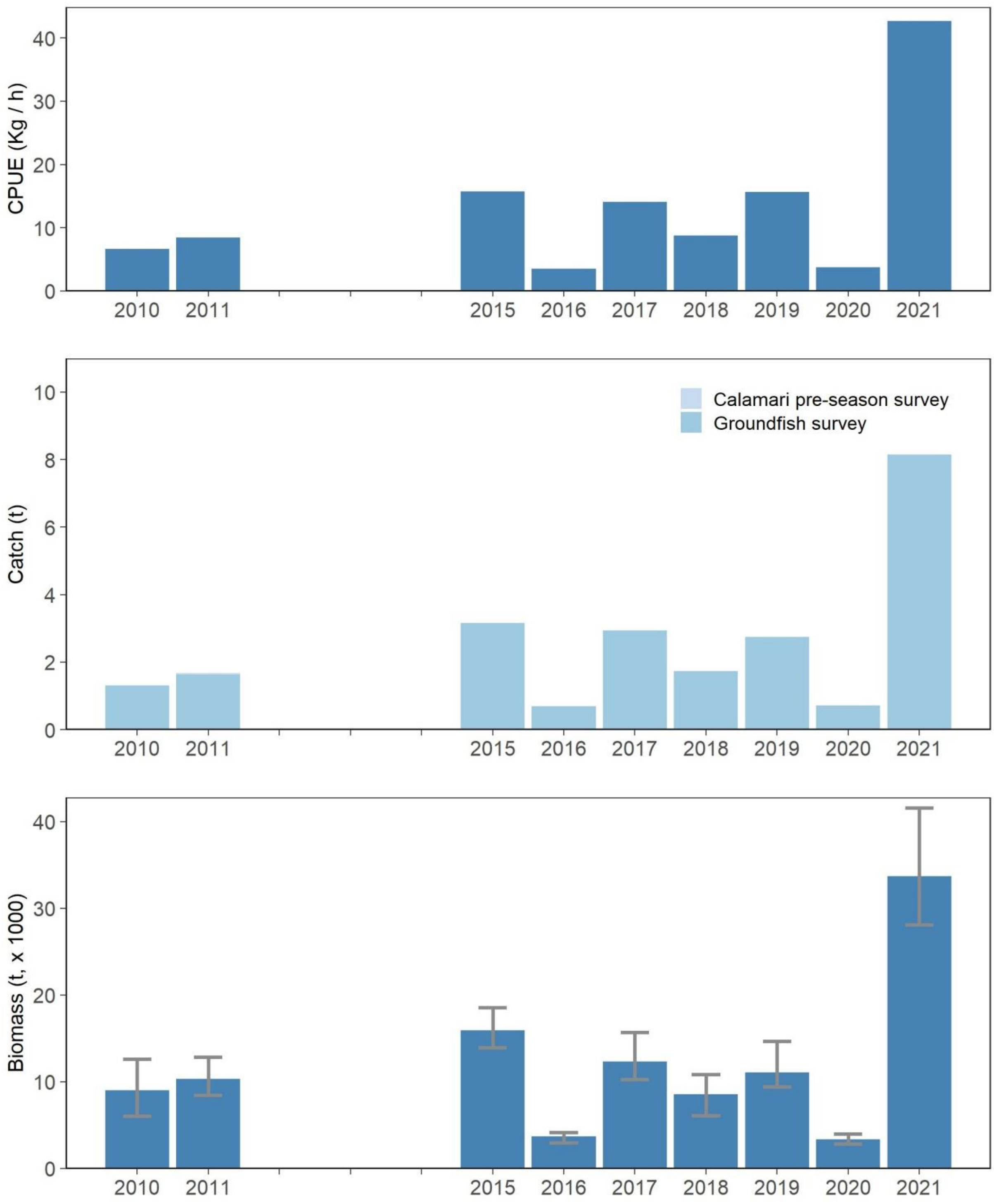


Fig. 8. CPUE (kg/h), catch (t) and mean biomass (t) ± 95% confidence intervals of common hake (*Merluccius hubbsi*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

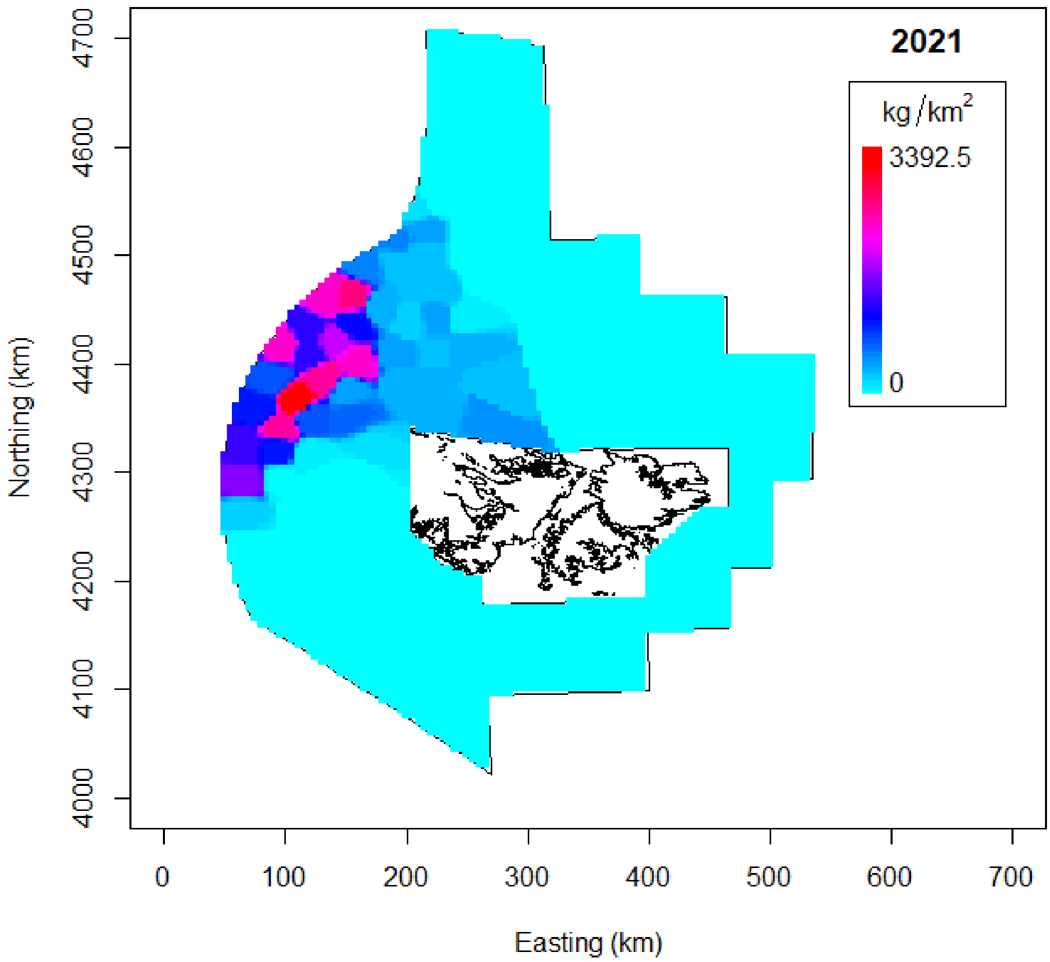


Fig. 9. Density of common hake (*Merluccius hubbsi*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters.

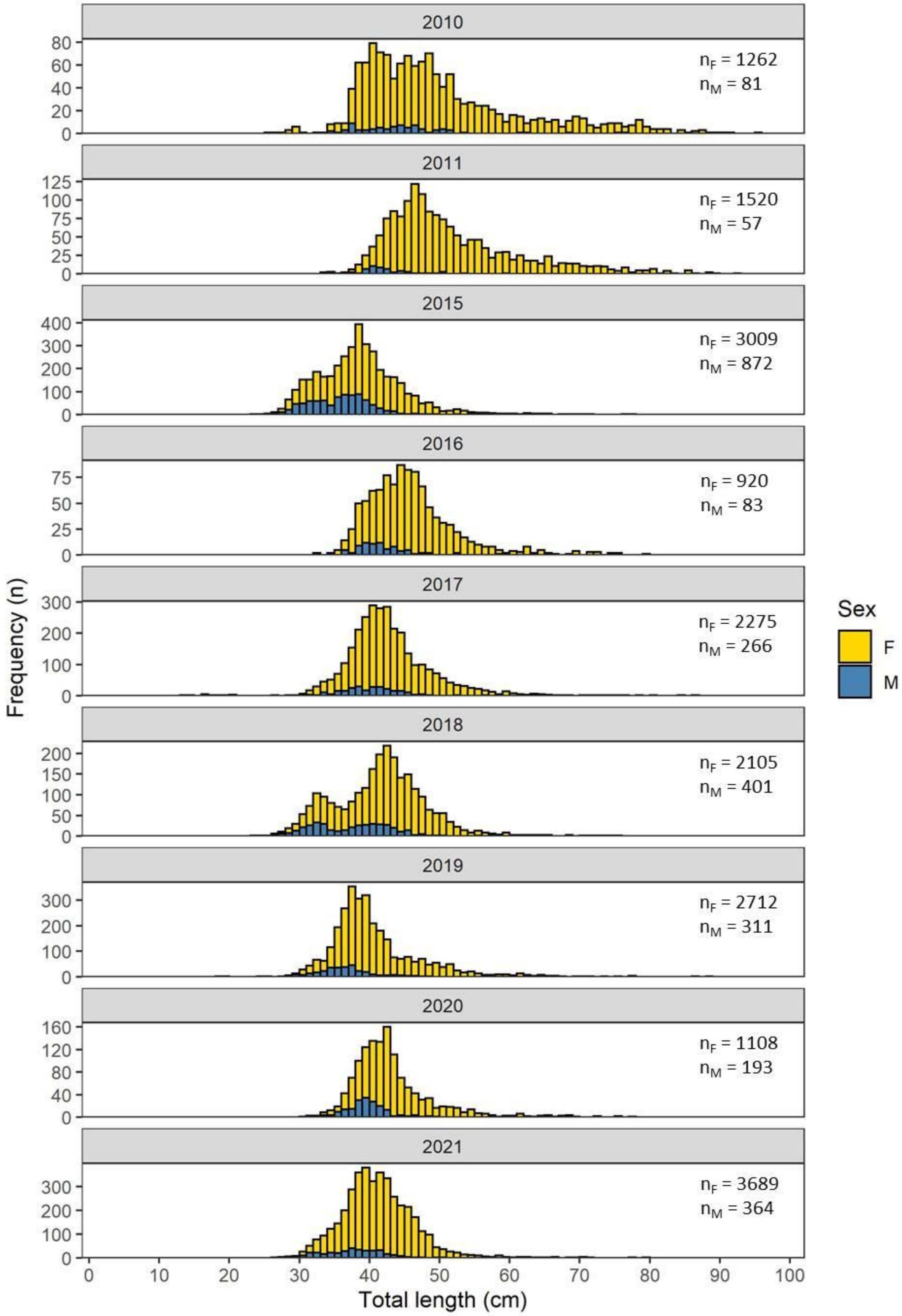


Fig. 10. Length frequency of common hake (*Merluccius hubbsi*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

4.2.4. Hoki (*Macruronus magellanicus*)

CPUE of hoki had its maximum in 2010 with 405 kg/h; the fourth highest CPUE in the time series was estimated for 2021 with 162 kg/h (Fig. 11). CPUE estimates are consistent with the pattern of catches, which had its maximum in 2010 (79.8 t), whereas 30.8 t were caught in 2021. The proportions of hoki catches were relatively similar between February groundfish and calamari pre-season surveys in 2010, 2011, 2015, and 2016. Since 2017, hoki were caught mainly in groundfish surveys (Fig. 11; Appendix II). Total effort was similar across years and ranged between 176 h (2019) to 209 h (2017); total effort in 2021 (191 h) was within the range of the time series. However, the highest biomass in the time series was estimated for 2021, largely due to the exceptionally high catch in one trawl (station 3362 of the groundfish survey), with a maximum density of hoki of 146,193 kg/km^2 (Fig. 12). The biomass for hoki in February 2021 estimated excluding station 3362 was 147,691 t. As hoki are schooling fish, this exceptional catch was not considered erroneous but reflects the very wide 95% confidence interval for biomass in 2021 (Fig. 11). The linear trend in biomass from 2010 to 2021 was not statistically significant ($p = 0.36$; Appendix IV).

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 (Appendix VIII). In 2021, hoki was found to the south-west edge of the FICZ (Fig. 12).

Length frequency histograms show a range of sizes from 11 cm to 46 cm pre-anal length across the time series. Several cohorts are present each year but these cannot be identified with certainty given the overlap in sizes. In 2021, the modal length was detected at 24 cm pre-anal length (Fig. 13).

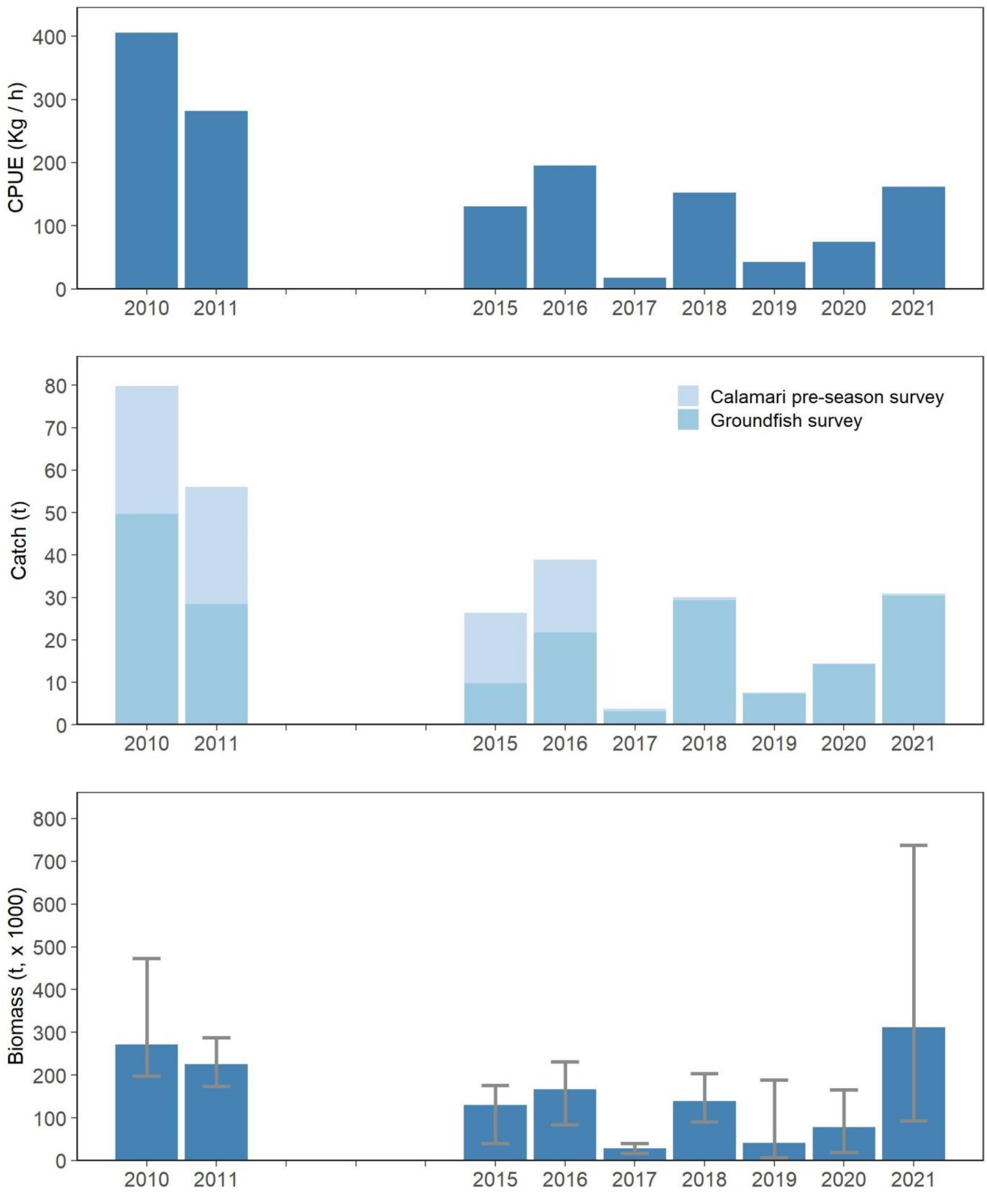


Fig. 11. CPUE (kg/h), catch (t) and mean biomass (t) ± 95% confidence intervals of hoki (*Macruronus magellanicus*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

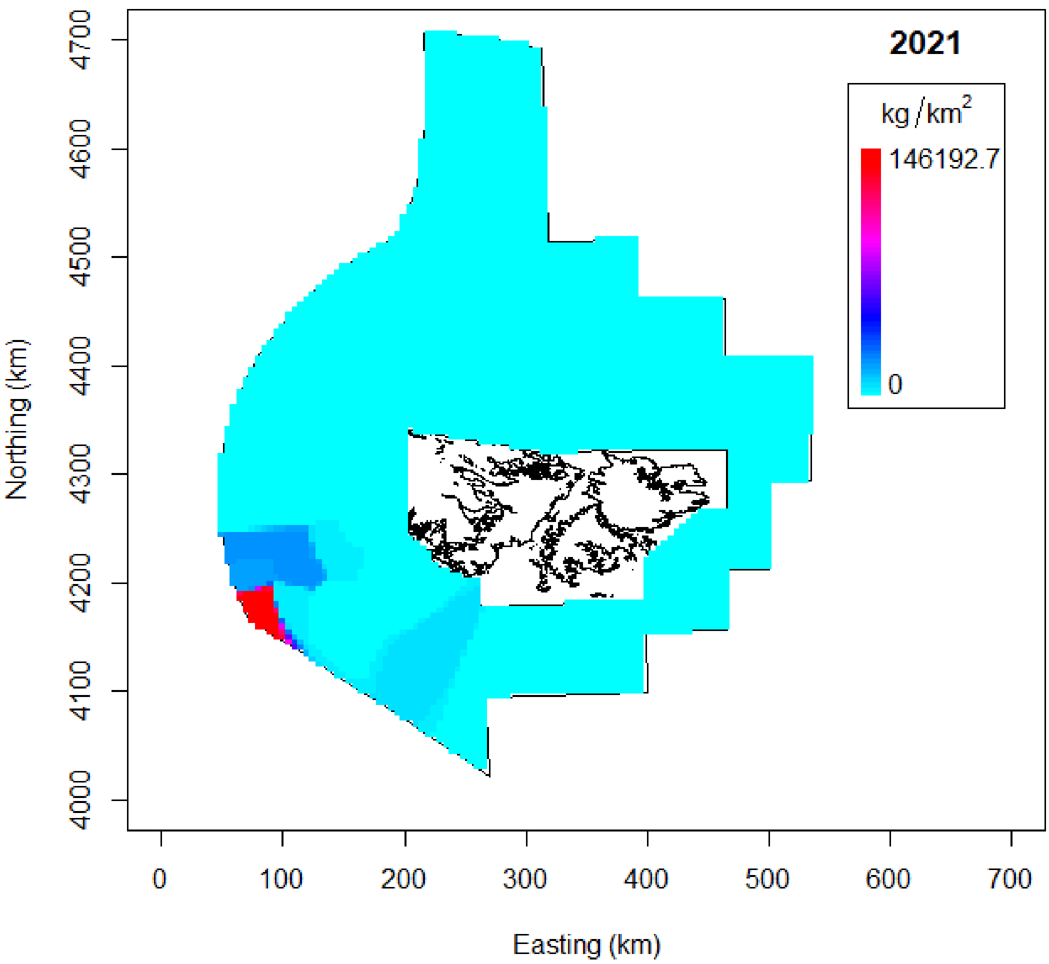


Fig. 12. Density of hoki (*Macruronus magellanicus*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters.

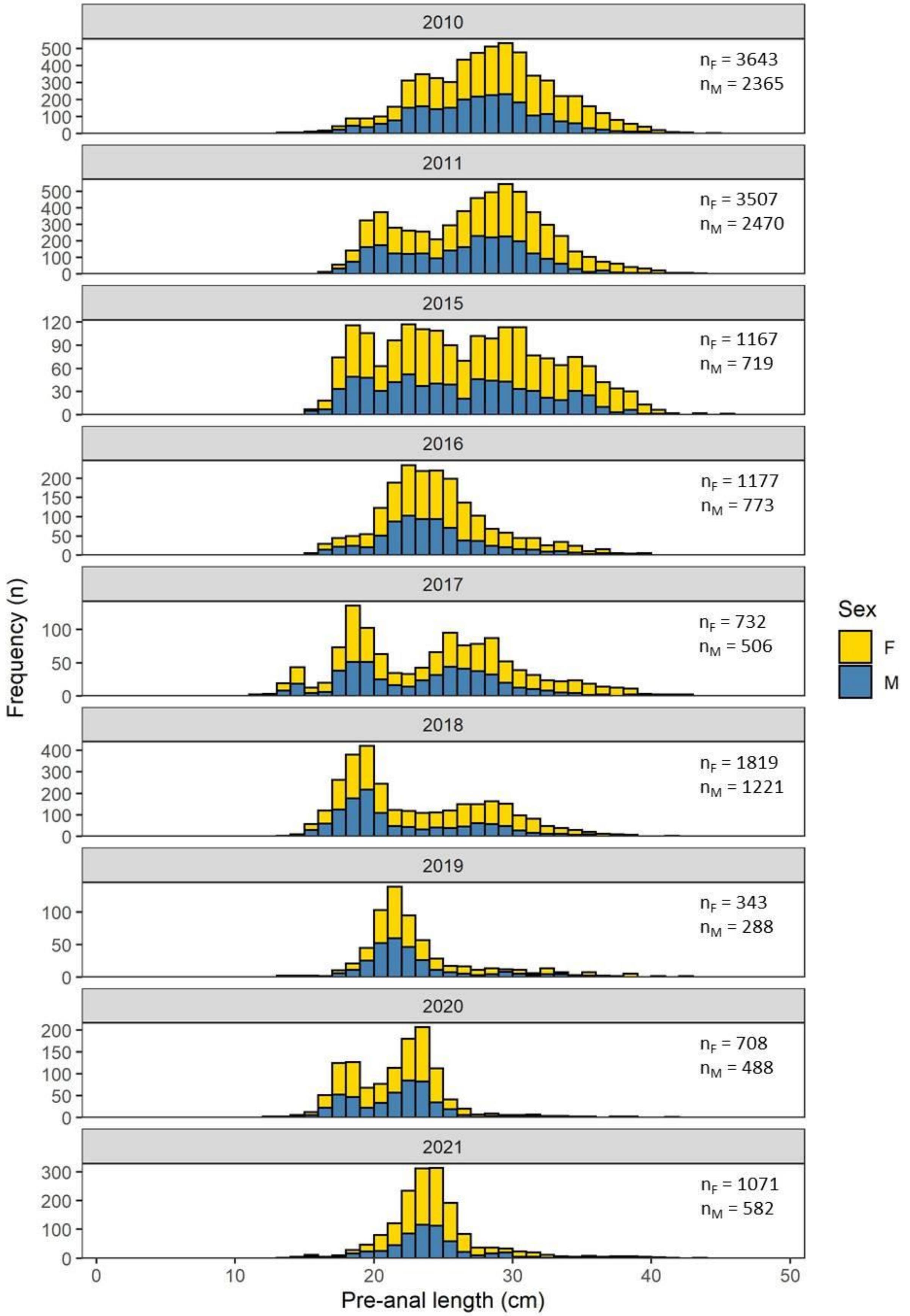


Fig. 13. Length frequency of hoki (*Macruronus magellanicus*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

4.2.5. Kingclip (*Genypterus blacodes*)

CPUE of kingclip was relatively stable across years, with one peak in 2015 (73 kg/h) and a second smaller peak in 2011 (43 kg/h); the CPUE of kingclip in 2021 was estimated at 25 kg/h (Fig. 14). Total catches and biomass estimates of kingclip were consistent with CPUE. Most kingclip were caught in groundfish surveys compared with calamari pre-season surveys. The highest catch of kingclip occurred in 2015 with 14.7 t, whereas 4.8 t were caught in 2021 (Fig. 14; Appendix II). Kingclip biomass was usually < 45,000 t every February, except for February 2015 that had the highest biomass (79,129 t) in the time series. In 2021, the biomass of kingclip was estimated at 20,977 t (Fig. 14; Appendix III). There was no statistically significant linear trend in biomass from 2010 to 2021 ($p = 0.33$; Appendix IV).

Throughout the time series, kingclip was dispersed around the FICZ and FOCZ, except for the south-east. In 2021, the highest densities (3,373 kg/km^2) occurred to the south-west near West Falkland and to the north (Fig. 15), whereas the highest density in the time series was 32,777 kg/km^2 to the north-west in 2015 (Appendix IX).

Length frequency histograms show a wide range of kingclip sizes across the time series, from 23 cm to 153 cm total length. Overlap of lengths prevents identifying each cohort and making comparison of modal lengths for each cohort through time (Fig. 16).

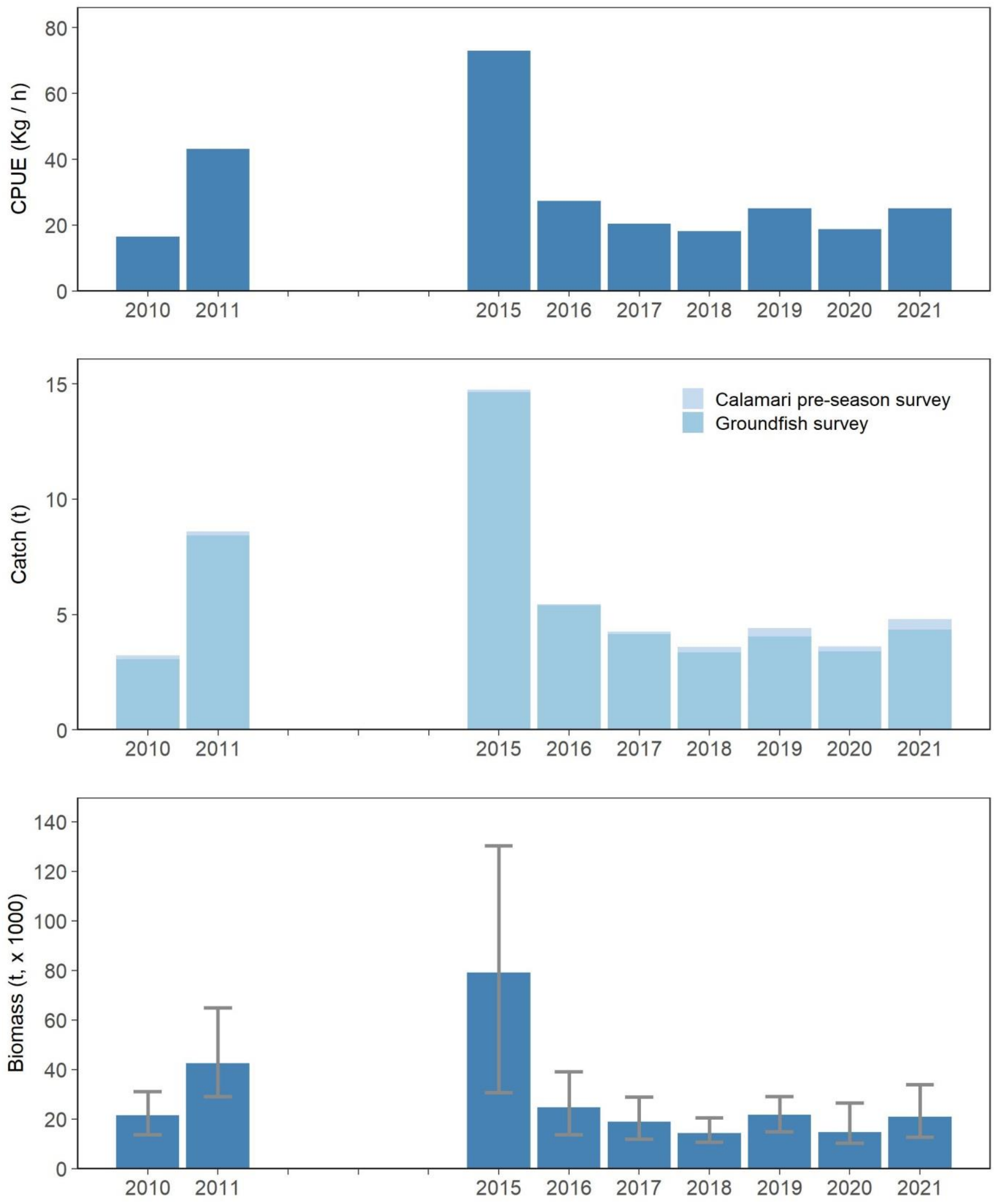


Fig. 14. CPUE (kg/h), catch (t) and mean biomass (t) ± 95% confidence intervals of kingclip (*Genypterus blacodes*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

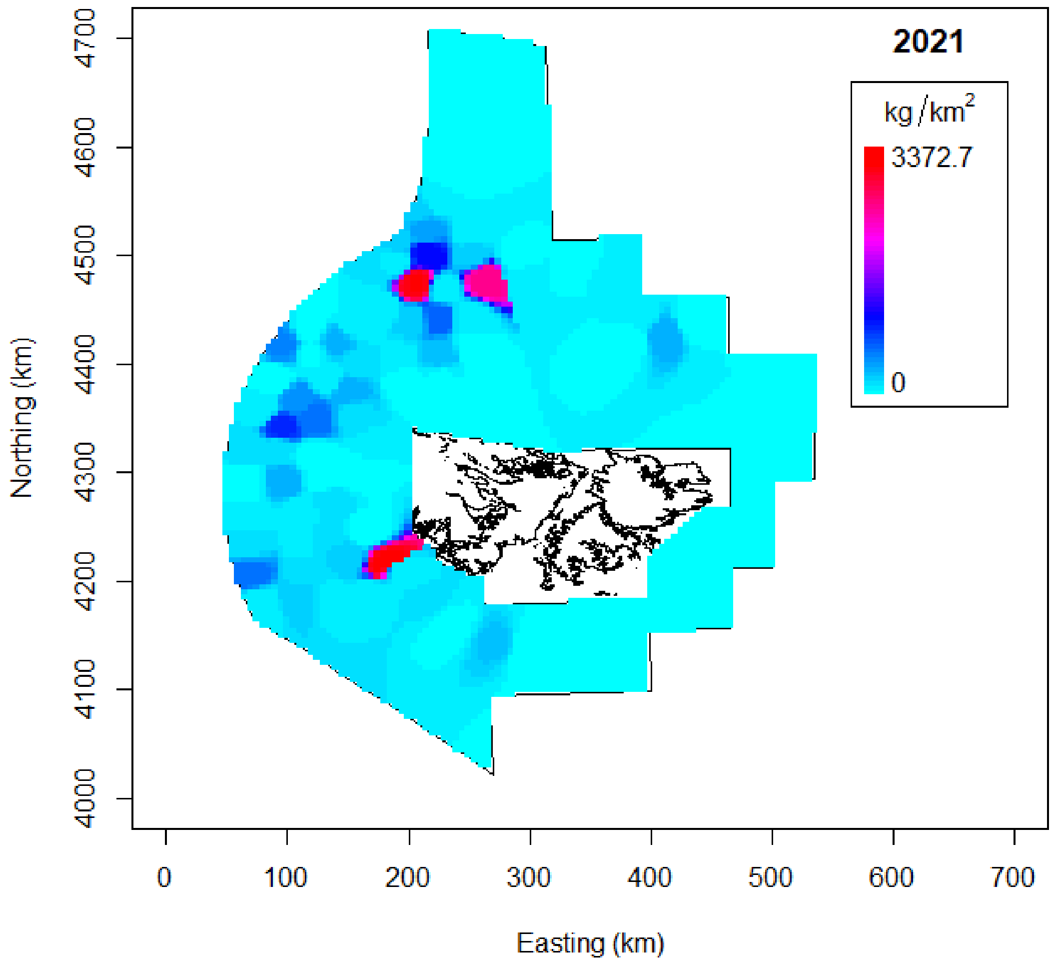


Fig. 15. Density of kingclip (*Genypterus blacodes*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters.

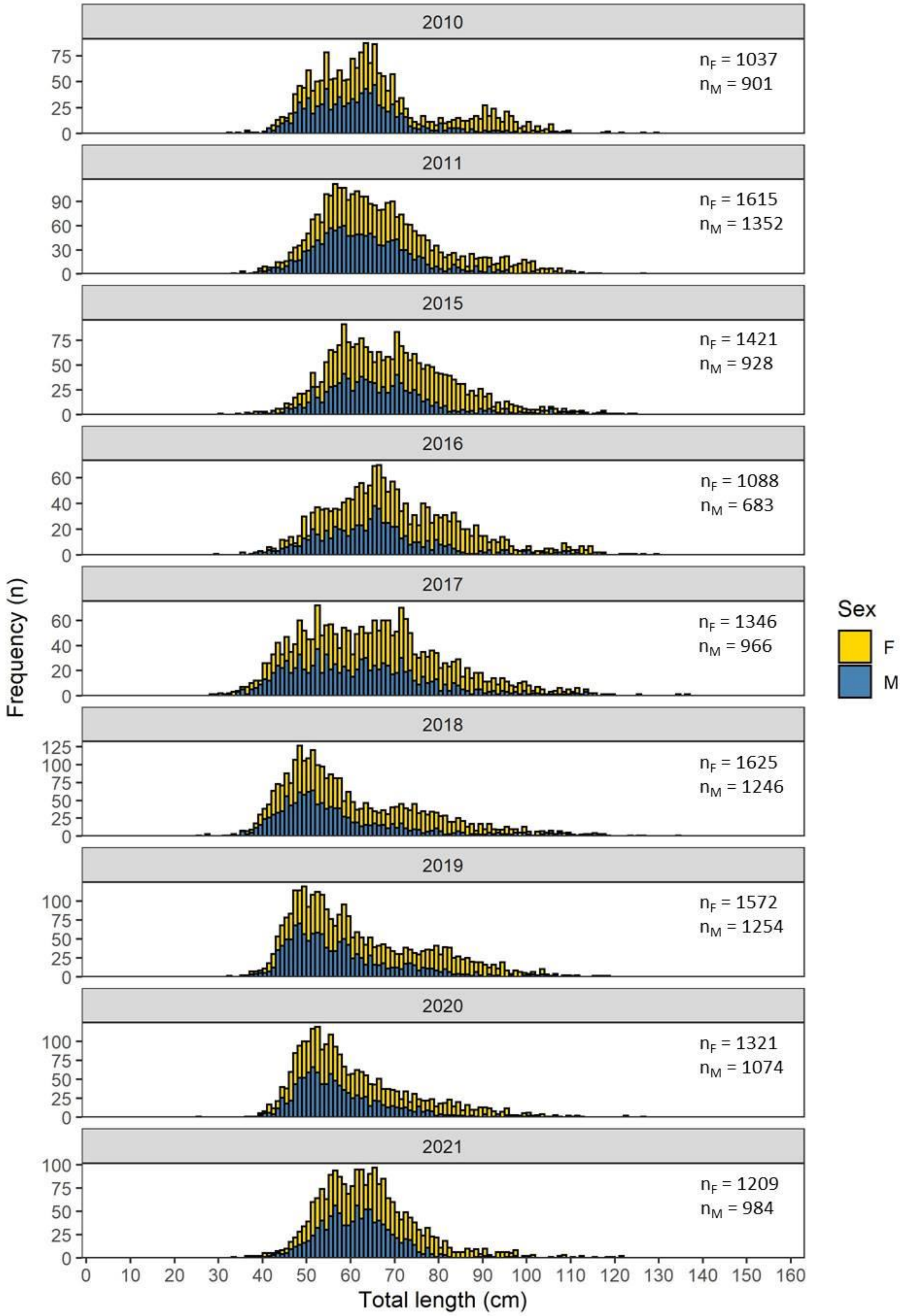


Fig. 16. Length frequency of kingclip (*Genypterus blacodes*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

4.2.6. Patagonian squid (*Doryteuthis gahi*)

CPUE of the Patagonian squid ranged between 254 kg/h in 2011 to 2,193 kg/h in 2019; CPUE in 2021 was estimated at 1,497 kg/h (Fig. 17). The pattern of CPUE and catch were consistent. Patagonian squids were mostly caught in calamari pre-season surveys. The highest catch of Patagonian squid was estimated for 2019 (386 t), and the third highest catch of this species in the time series was estimated for 2021 (286 t; Fig. 17; Appendix II). The biomass of the Patagonian squid has been variable from year to year. The average biomass per year is 120,700 t; the maximum biomass in the time series was estimated in 2019 with 214,661 t. In 2021, the biomass was estimated at 114,110 t, below the average in the time series (Fig. 17; Appendix III). There was no statistically significant linear trend in biomass from 2010 to 2021 ($p = 0.94$; Appendix IV).

Doryteuthis gahi was mainly found to the south and south-east of East Falkland. In 2021, the maximum density was 11,314 kg/km^2 (Fig. 18), whereas the highest density throughout the time series was 37,527 kg/km^2 in 2015 (Appendix X).

Length frequency histograms show a wide range of Patagonian squid sizes, from 3 cm to 33 cm, across the time series. Two groups were evident only in some years. In 2021, the two groups had modal lengths at 8 cm and at 11 cm dorsal mantle length, respectively (Fig. 19).

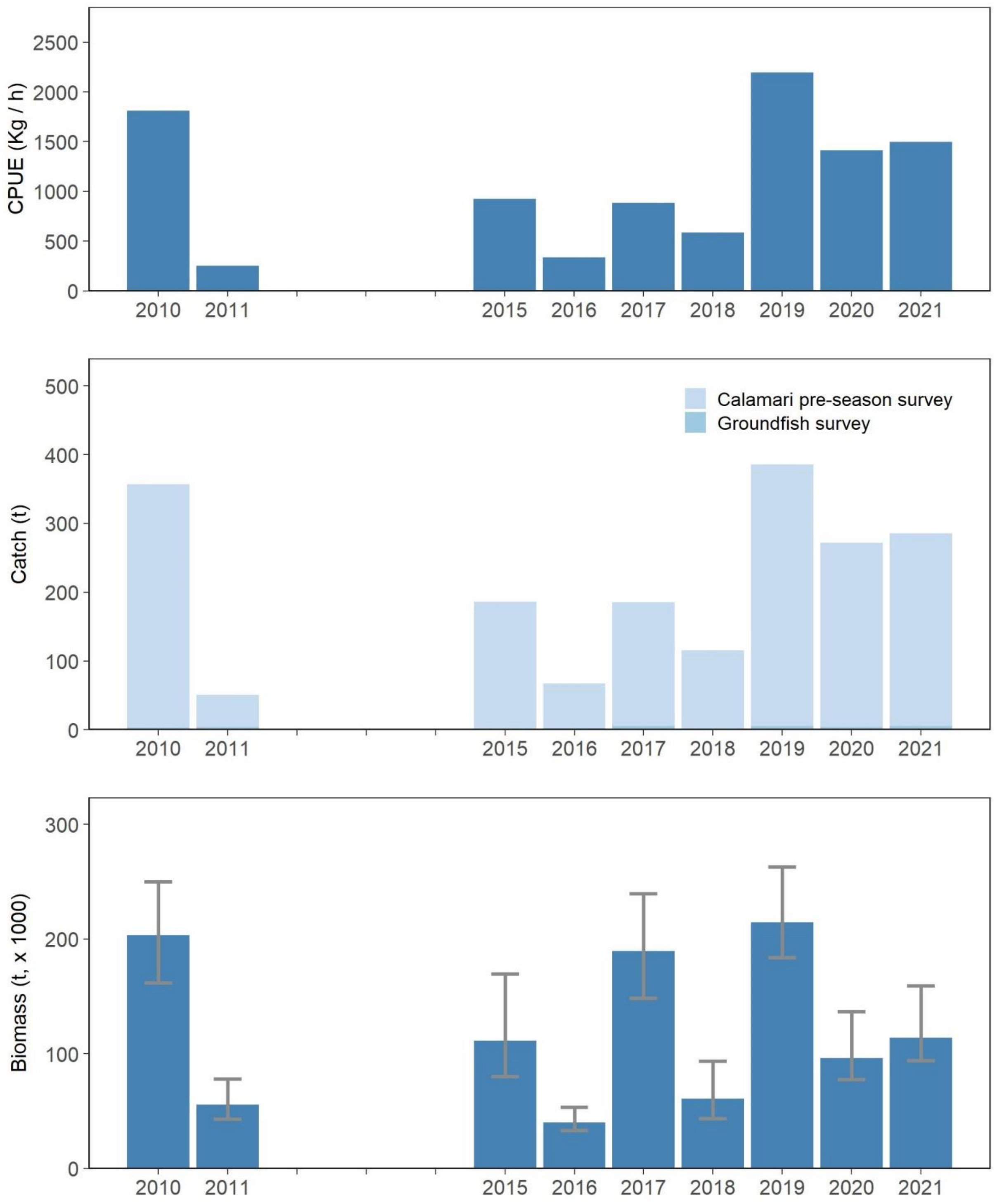


Fig. 17. CPUE (kg/h), catch (t) and mean biomass (t) ± 95% confidence intervals of the Patagonian squid (*Doryteuthis gahi*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

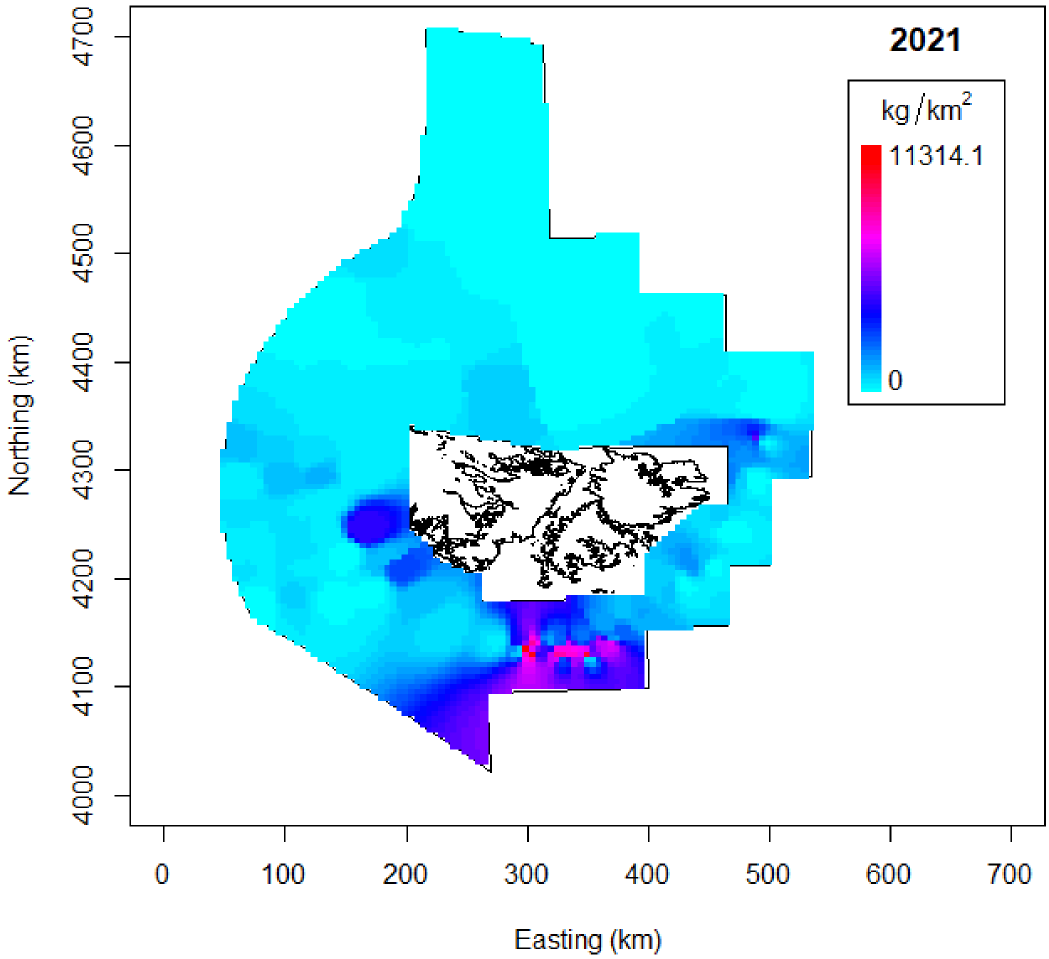


Fig. 18. Density of the Patagonian squid (*Doryteuthis gahi*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters.

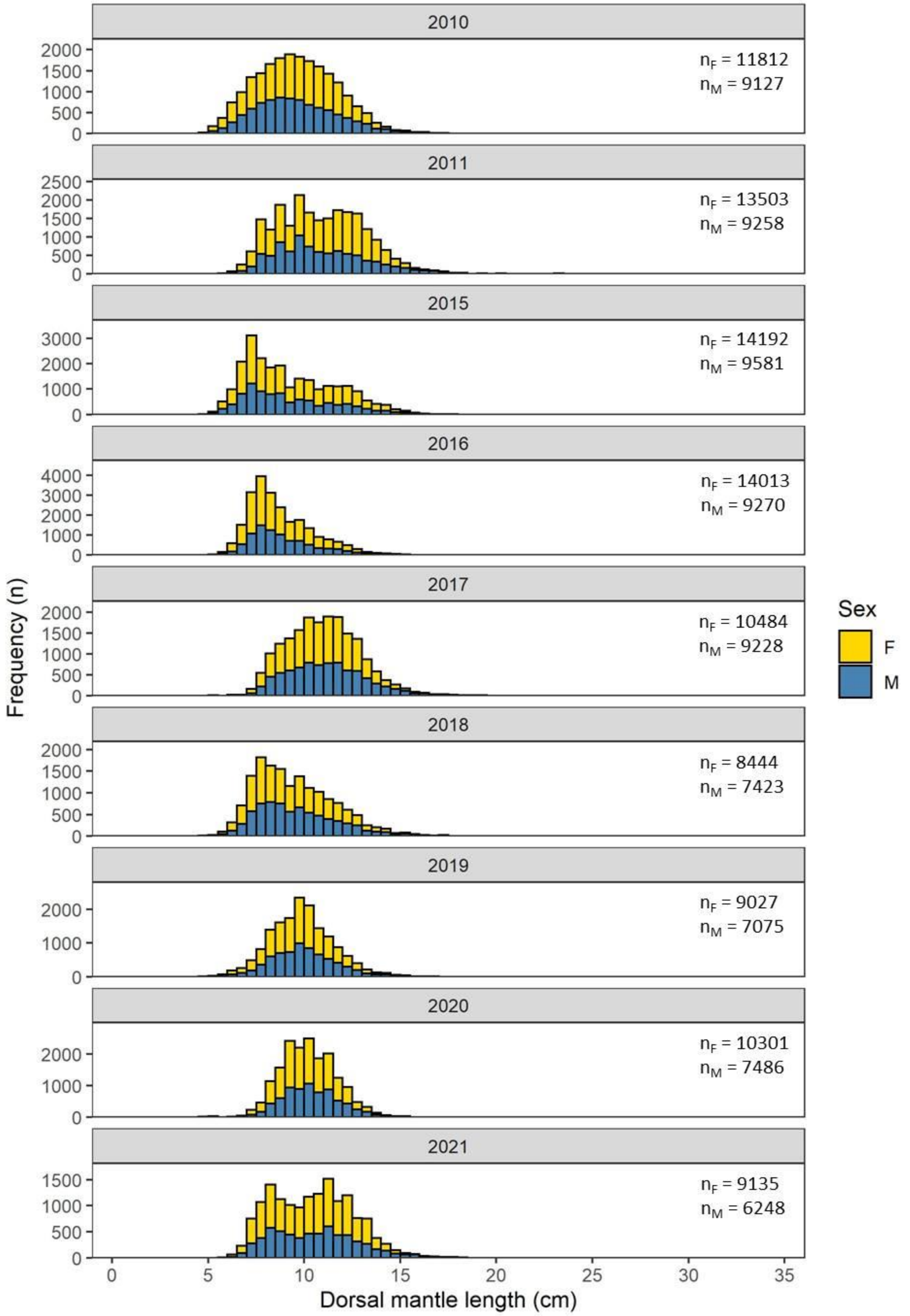


Fig. 19. Length frequency of the Patagonian squid (*Doryteuthis gahi*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

4.2.7. Red cod (*Salilota australis*)

CPUE of red cod saw an evident decline in 2020 (19 kg/h) and 2021 (32 kg/h) compared with the relatively higher CPUEs estimated for other years (66–119 kg/h; Fig. 20). Red cod was predominantly caught in groundfish surveys compared with calamari pre-season surveys. Catch declined from 2011 and was lower in 2020 (3.7 t) and 2021 (6 t) compared with previous years (13.3–23.5 t; Fig. 20; Appendix II). The biomass of red cod had its maximum in 2011 (161,779 t). Biomass decreased the following years to 22,661 t in 2020, the lowest biomass estimated in the time series. In 2021, the biomass of red cod was estimated at 34,341 t (Fig. 20; Appendix III). There was a statistically significant decrease in biomass trend from 2010 to 2021 ($p = 0.01$; Appendix IV).

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. In 2021, the highest densities occurred near the west limit of the FICZ and to the north of West Falkland, i.e. 4,848 kg/km^2 (Fig. 21). The highest density in the time series was 38,175 kg/km^2 in 2016 (Appendix XI).

Length frequency histograms show a wide range of red cod sizes across the time series (i.e. 10–85 cm total length), probably due to the presence of several cohorts. Poor recruitment to the fishery occurred in 2010, 2018, 2020, and 2021; individuals recently recruited to the fishery had modal lengths between 15 cm and 18 cm total length (Fig. 22).

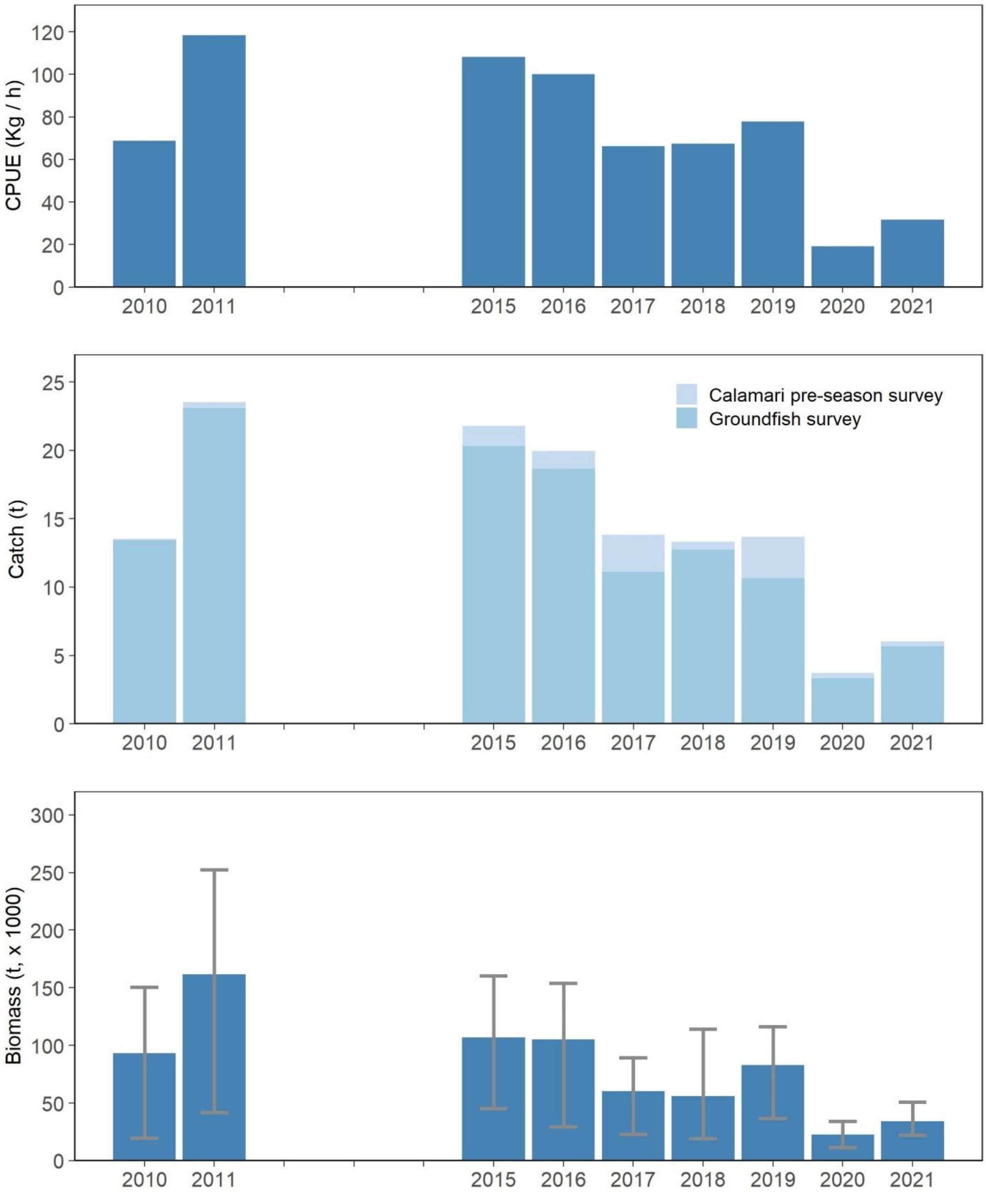


Fig. 20. CPUE (kg/h), catch (t) and mean biomass (t; bold black line) ± 95% confidence intervals (grey dashed lines) of red cod (*Salilota australis*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

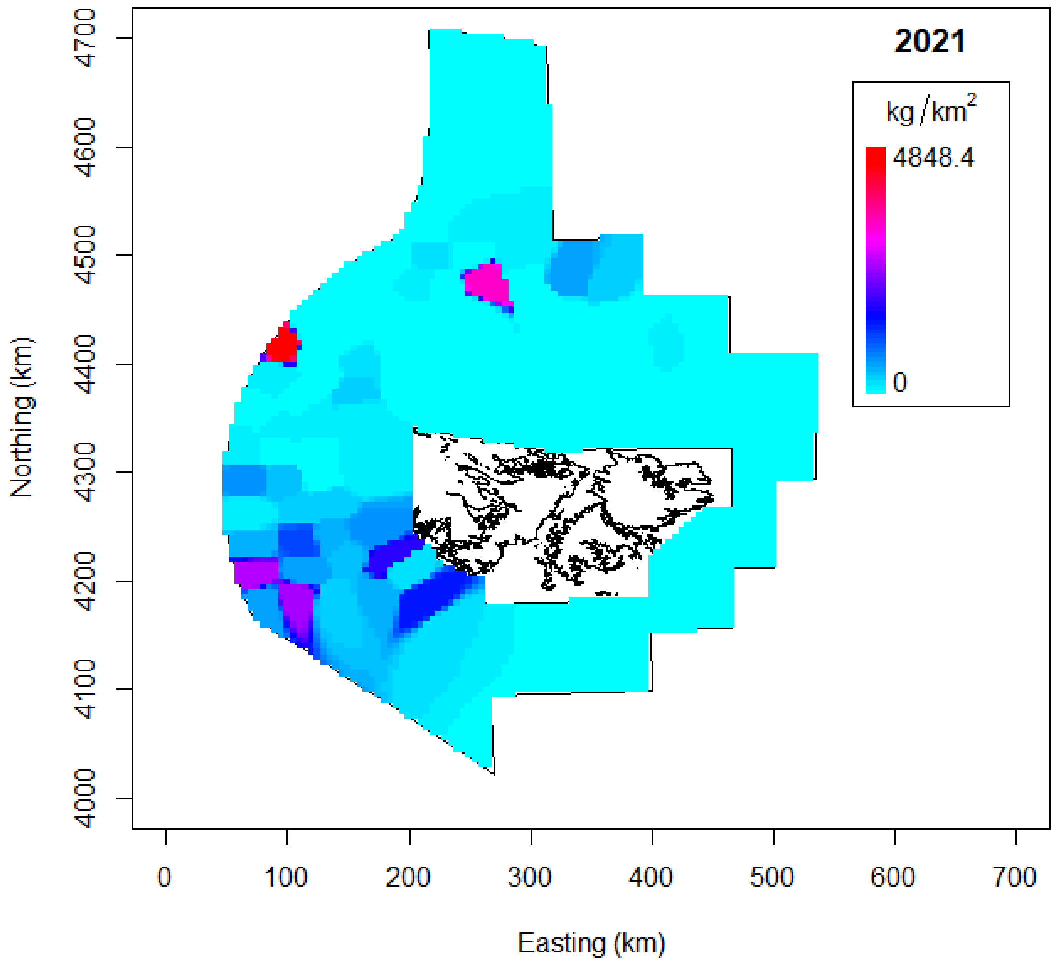


Fig. 21. Density of red cod (*Salilota australis*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters.

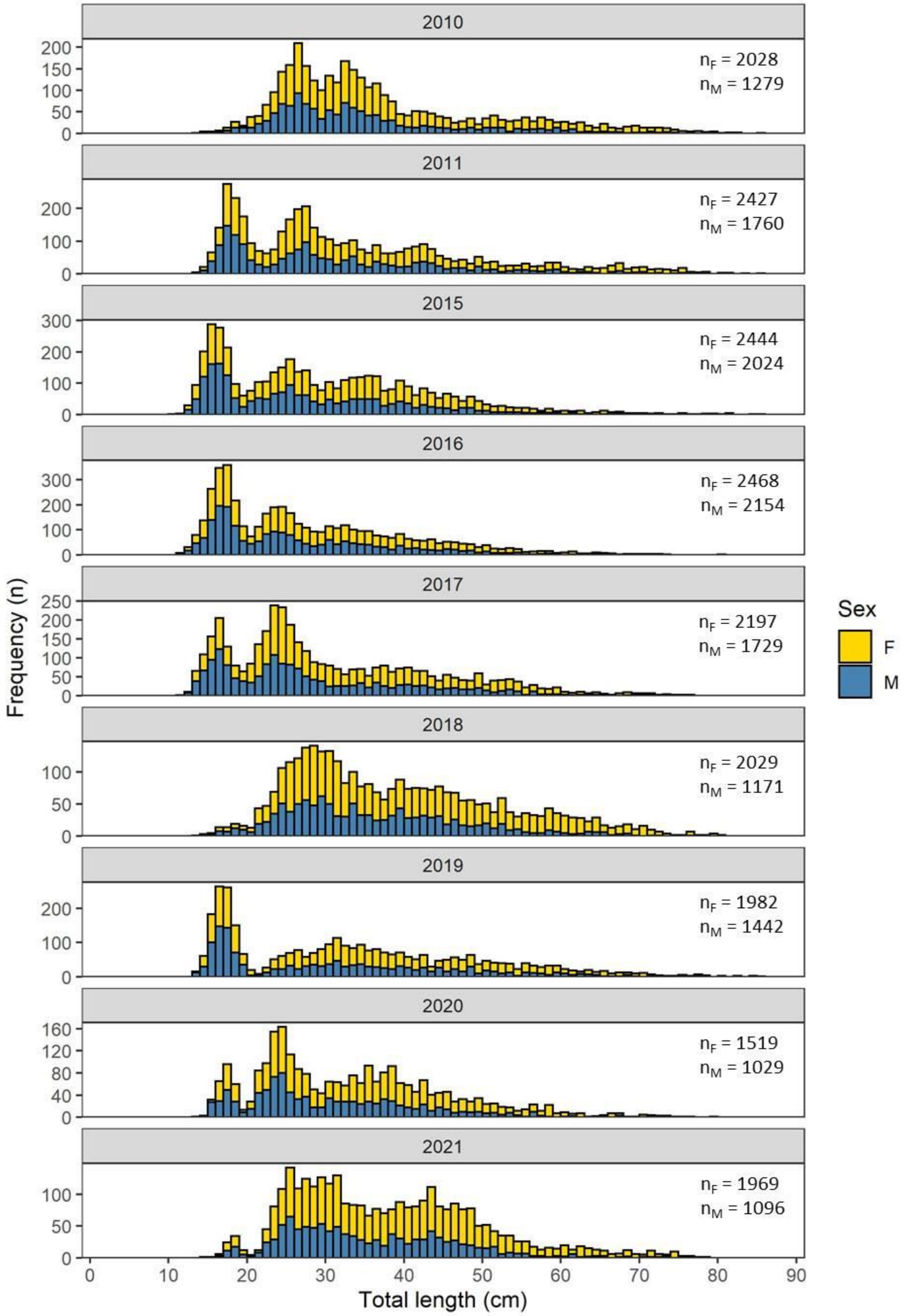


Fig. 22. Length frequency of red cod (*Salilota australis*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

4.2.8. Rock cod (*Patagonotothen ramsayi*)

CPUE of rock cod had its maximum in 2011 with 1,255 kg/h followed by a declining trend to the lowest estimate in 2020 with 57 kg/h; in 2021 the CPUE was estimated at 300 kg/h (Fig. 23). Rock cod catches were higher in the February 2010 and 2011 groundfish surveys compared with the calamari pre-season surveys; however, catches of rock cod had been higher in calamari pre-season surveys compared with groundfish surveys since 2015. The highest catch of rock cod was reported in 2011 (249 t) and the lowest catch in 2020 (11 t). A total of 57 t of rock cod were caught in 2021, of which 11.3 t were from a single trawl (station 763) during the calamari pre-recruitment survey. Two other trawls had > 5 t each (stations 723 and 740) in the same survey (Fig. 23; Appendix II). Rock cod biomass increased from 2010 (709,536 t) to 2011 (1,089,328 t); however there was a declining trend since 2011 with the lowest biomass estimated in 2020 (22,246 t). In 2021, the biomass of rock cod was estimated at 59,109 t (Fig. 23; Appendix III). There was a significantly decreasing biomass trend from 2010 to 2021 ($p < 0.001$; Appendix IV), although 2021 represents the first year since 2011 of biomass not decreasing from the year before.

In 2021, rock cod occurred mainly to the south-east of East Falkland at densities reaching a high of 7,067 kg/km^2 (Fig. 24). This species had a patchy distribution around the Falkland Islands throughout the time series and the highest density was reported in 2011 (823,781 kg/km^2; Appendix XII).

Sizes of rock cod ranged widely throughout the time series (i.e. 4–43 cm) and belonged to different cohorts that cannot be differentiated because of overlap in lengths. The smaller cohort had modal length that remained at about 14 cm total length through time (Fig. 25).

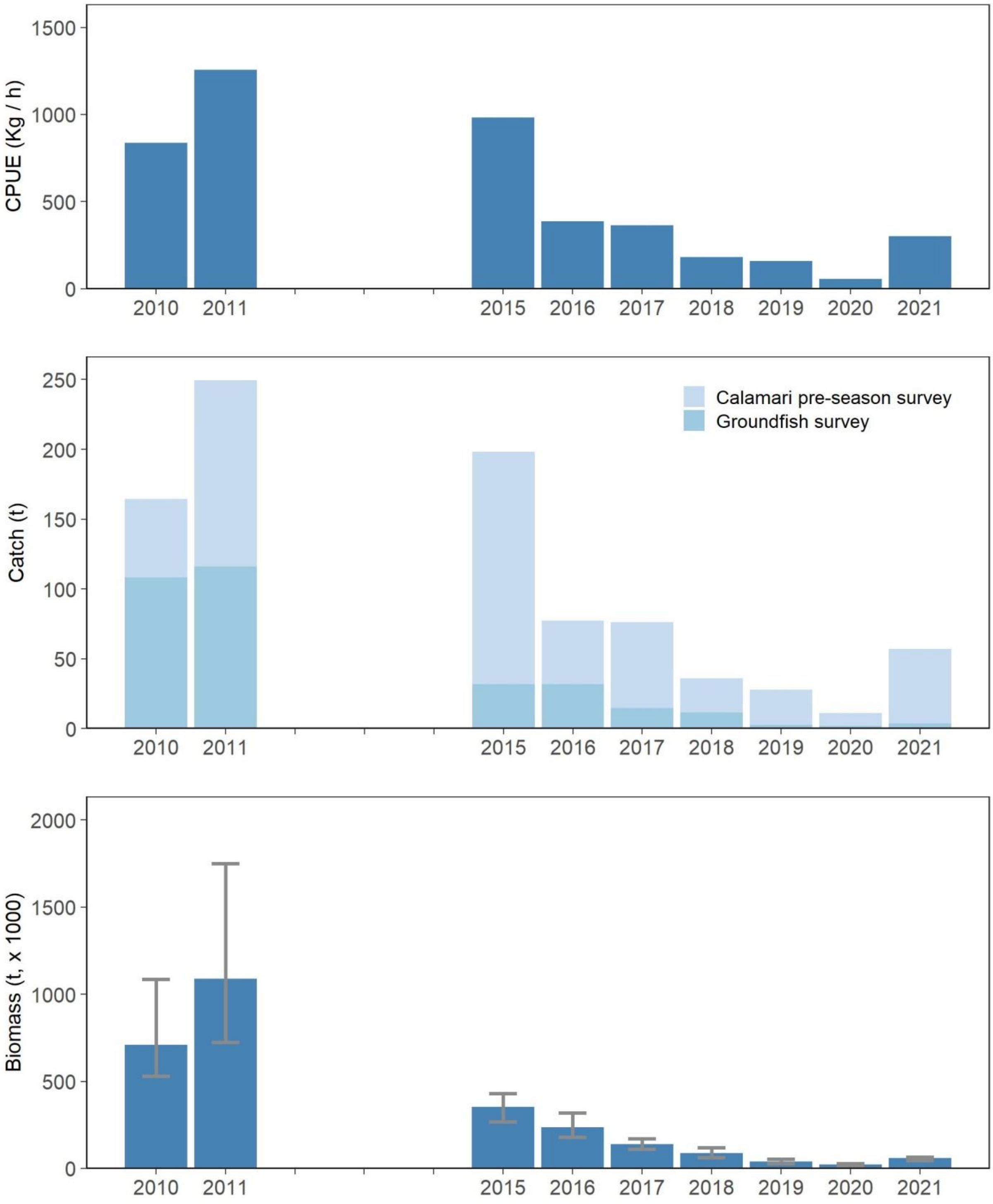


Fig. 23. CPUE (kg/h), catch (t) and mean biomass (t) ± 95% confidence intervals of rock cod (*Patagonotothen ramsayi*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

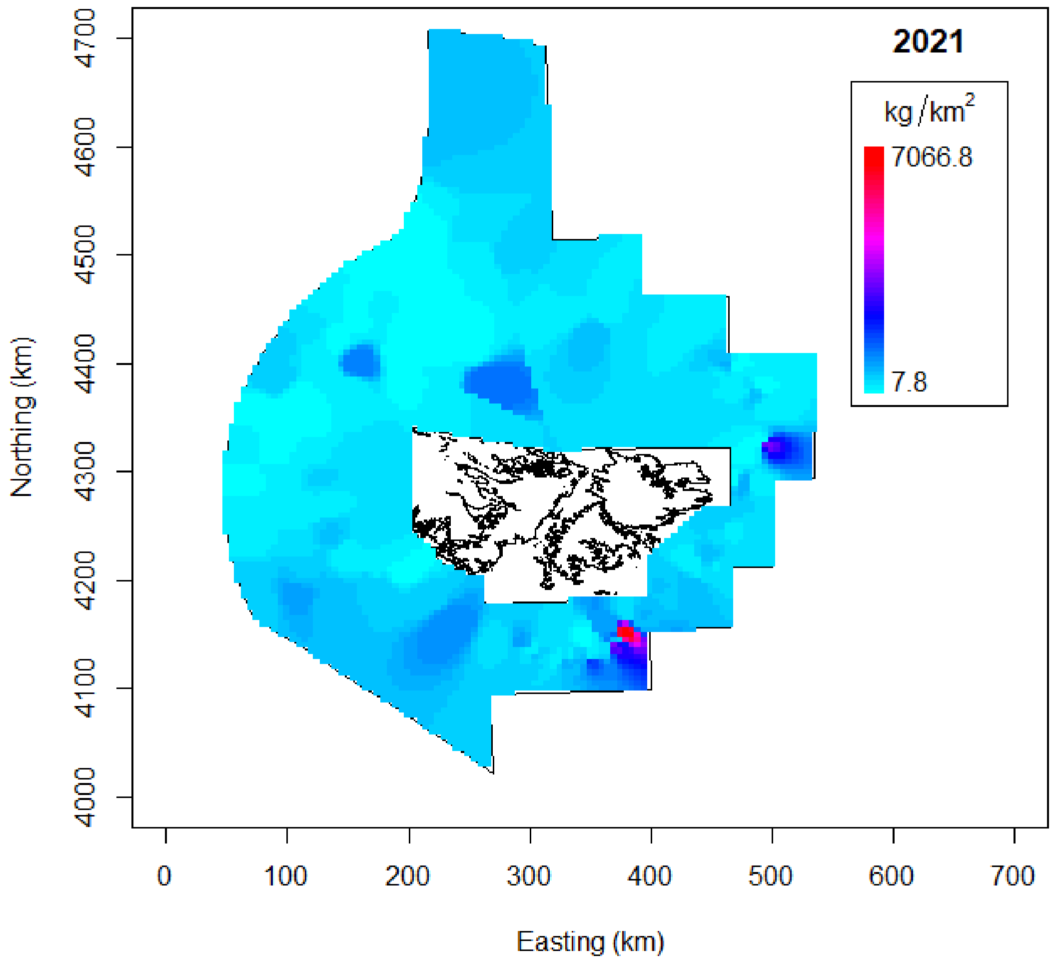


Fig. 24. Density of rock cod (*Patagonotothen ramsayi*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters.

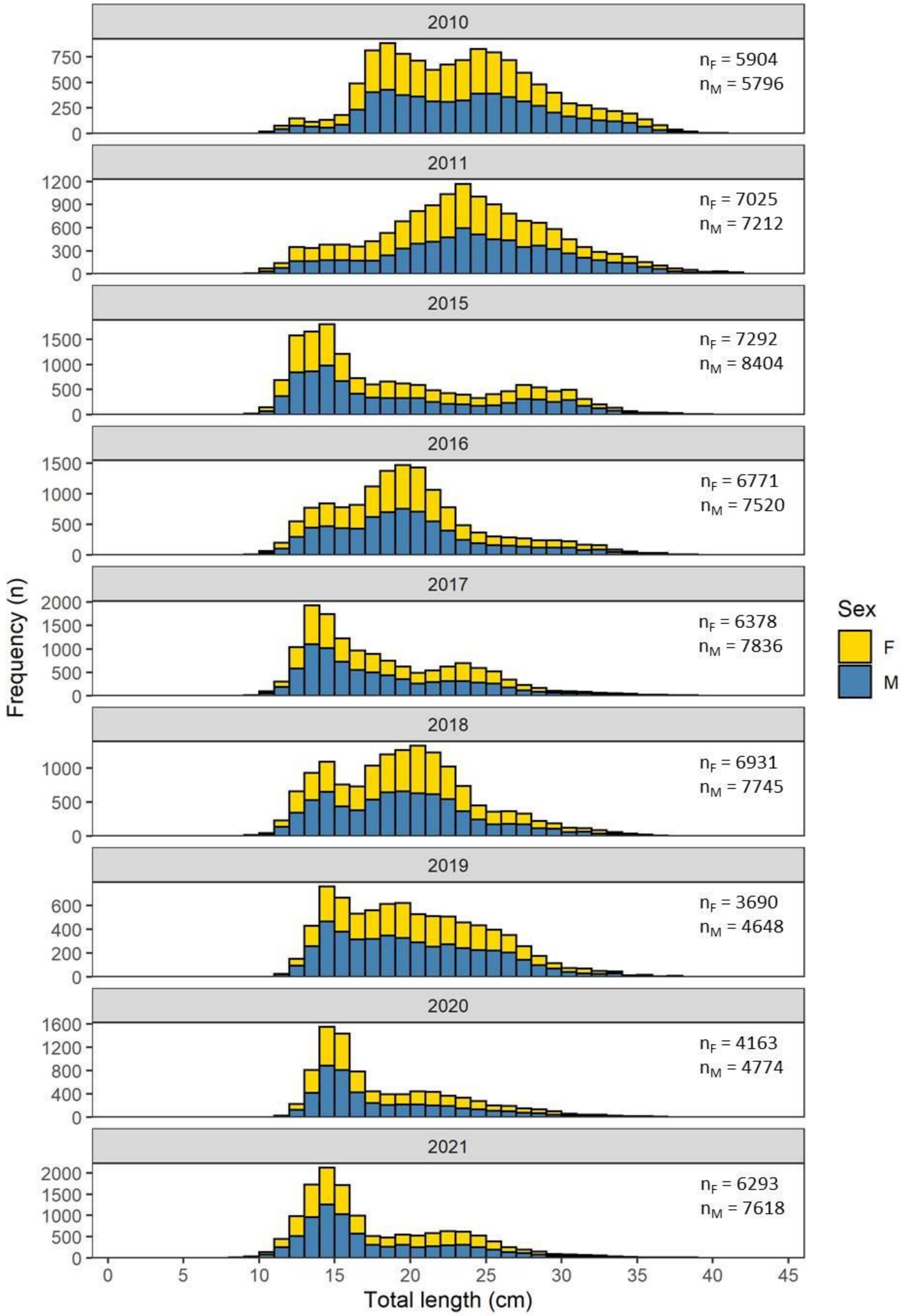


Fig. 25. Length frequency of rock cod (*Patagonotothen ramsayi*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

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

CPUE of southern blue whiting was ≤ 150 kg/h across years, except for the peaks of abundance observed in 2016 (398 kg/h) and 2011 (263 kg/h); approximately 64 kg/h of southern blue whiting were caught in 2021 (Fig. 26). Most catches of southern blue whiting occurred in the calamari pre-season surveys. The highest catch was reported in 2016 (79 t) and the lowest catch in 2020 (5 t); a total of 12 t were caught in 2021 (Fig. 26; Appendix II). Southern blue whiting biomass was below 75,000 t per year throughout the time series, except for 2011 (226,421 t) and 2016 (332,096 t). The third lowest biomass in the time series was estimated for 2021 (22,809 t; Fig. 26; Appendix III). There was no statistically significant linear trend in biomass from 2010 to 2021 ($p = 0.20$; Appendix IV).

In 2021, southern blue whiting occurred mainly to the south of the FICZ, with the highest density estimated at 4,255 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, with the highest density reported in 2016 (203,954 kg/km^2; Appendix XIII).

Southern blue whiting was caught in small numbers through the time series, and therefore the numbers of individuals sampled were small. Total length ranged from 6 cm to 72 cm through the time series. Several cohorts were present but the small number of samples and overlap in lengths do not allow identifying the modal length for each cohort. A small cohort was detected with constant total length at 23–25 cm (Fig. 28).

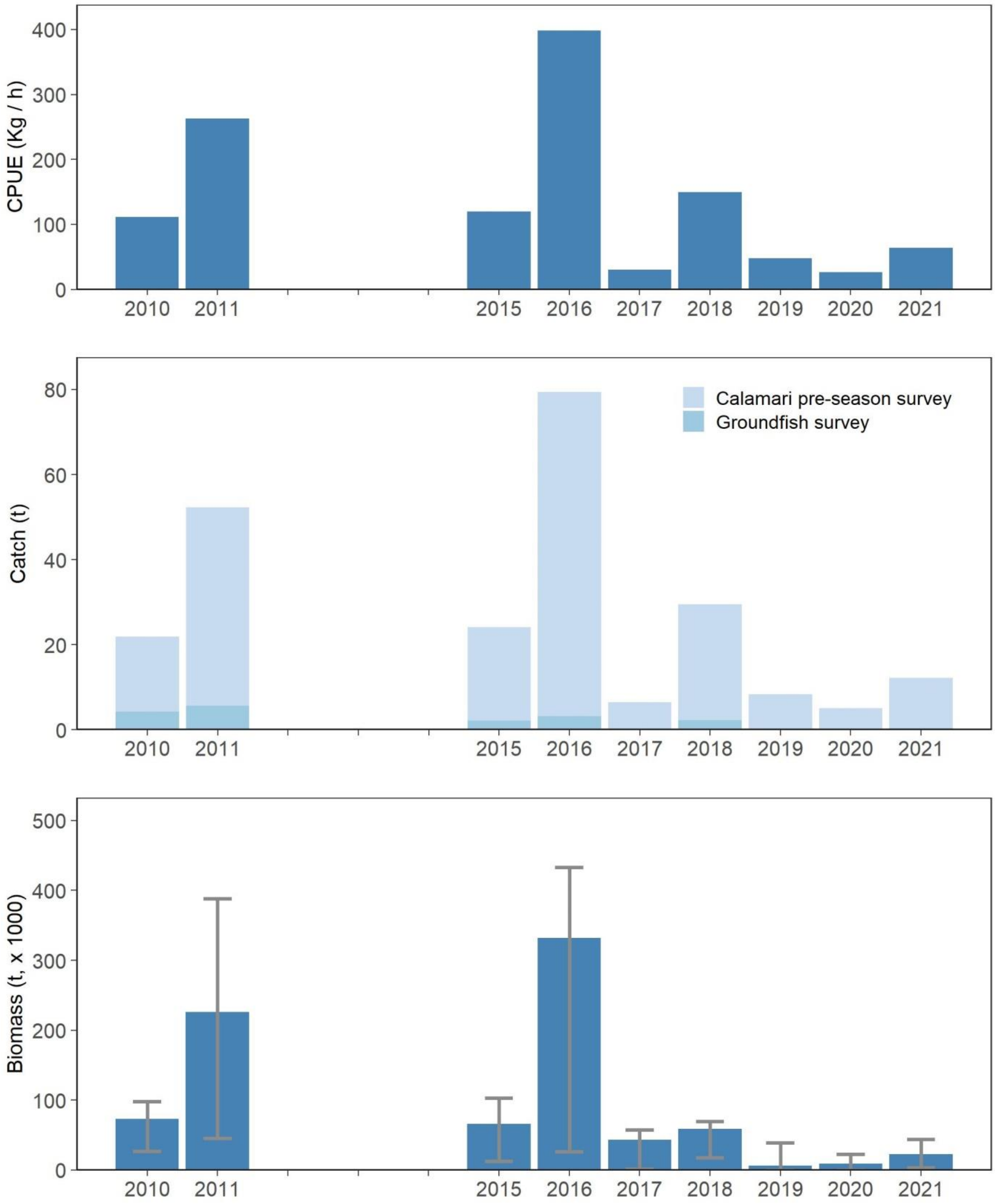


Fig. 26. CPUE (kg/h), catch (t) and mean biomass (t) ± 95% confidence intervals of southern blue whiting (*Micromesistius australis australis*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

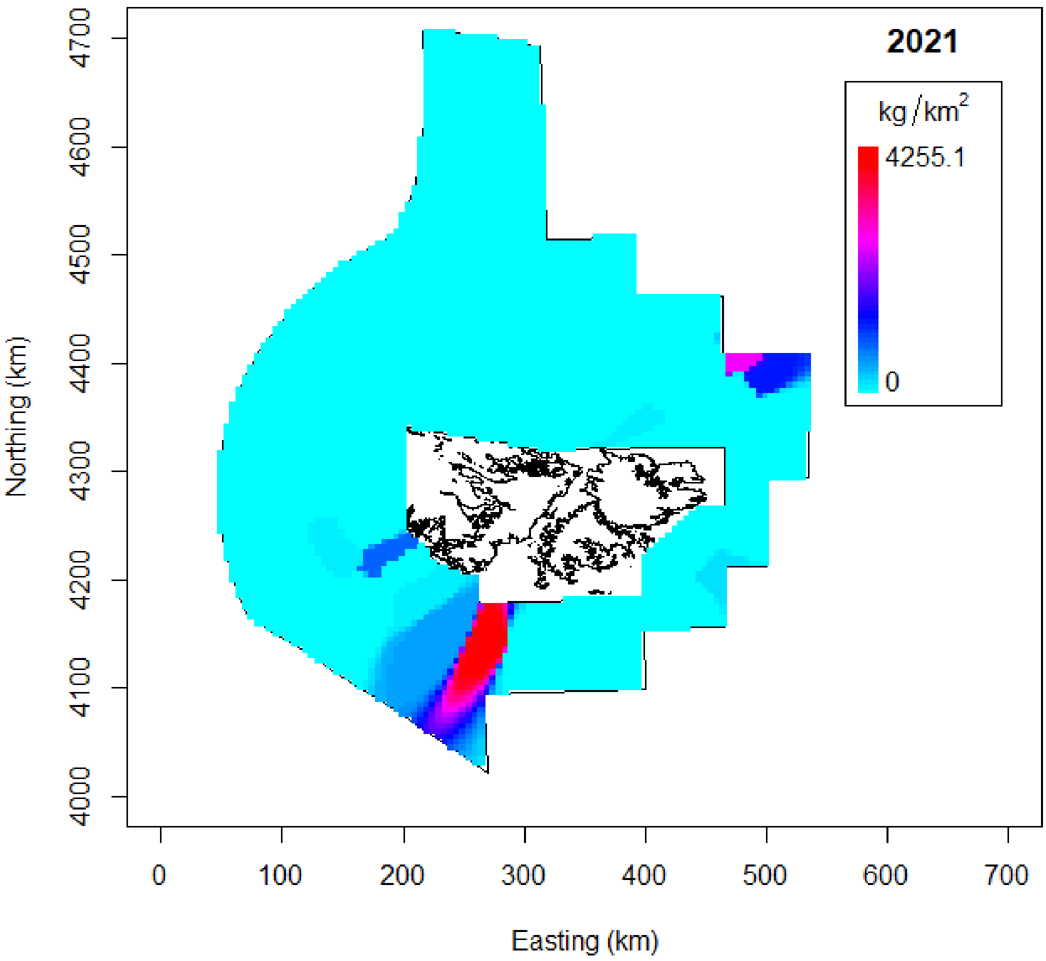


Fig. 27. Density of southern blue whiting (*Micromesistius australis australis*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters.

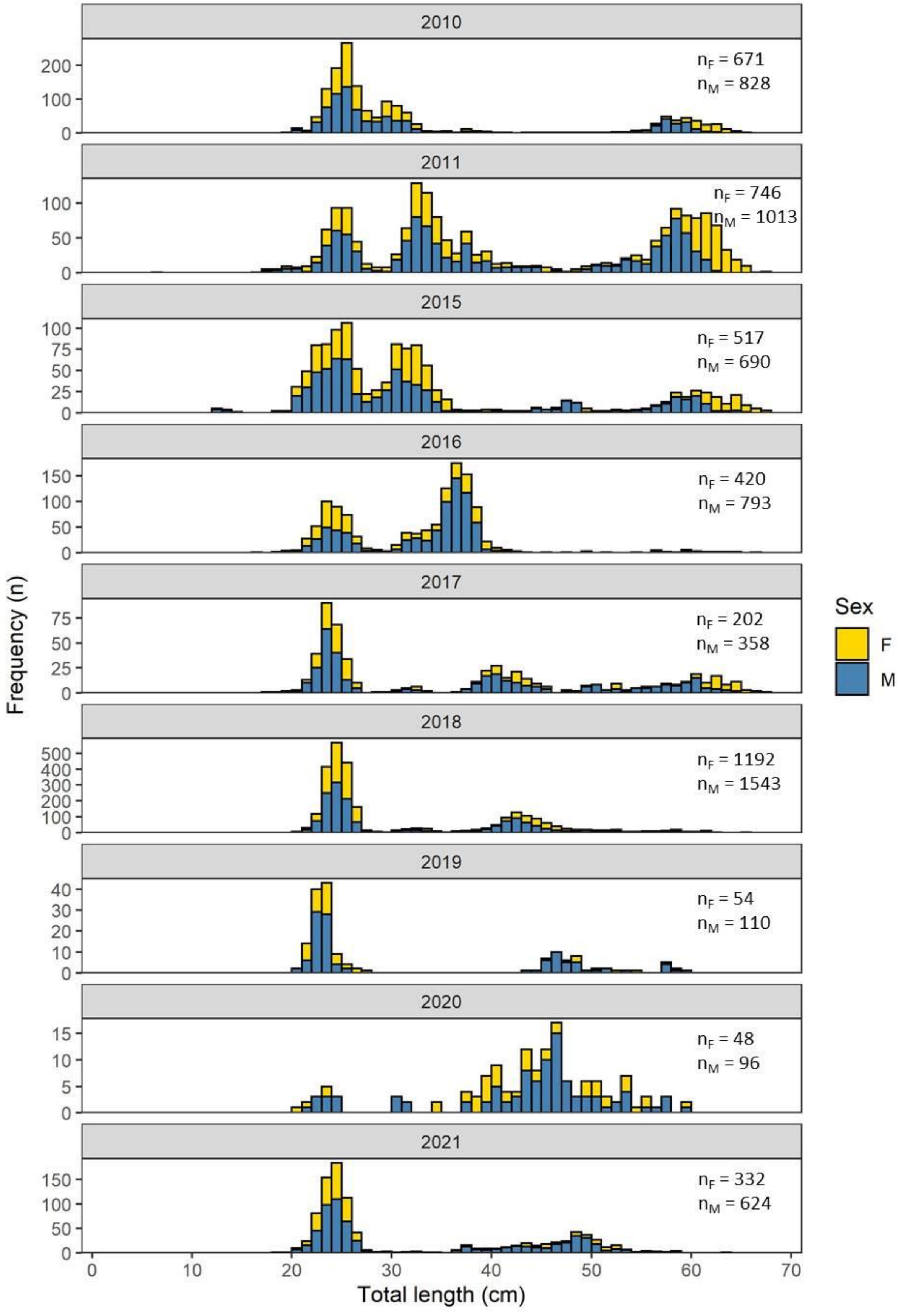


Fig. 28. Length frequency of southern blue whiting (*Micromesistius australis australis*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

4.2.10. Southern hake (*Merluccius australis*)

CPUE of southern hake through the time series was < 5 kg/h, with higher values in 2010 and 2011. From 2015, CPUE remained below 2 kg/h and in 2021 it was 1.4 kg/h (Fig. 29). Catches and biomass estimates had similar patterns compared with CPUE. Most catches of this species were from groundfish surveys. The highest catch in the time series was reported in 2010 (822 kg) and the lowest catch was reported in 2019 (51 kg); a total of 264 kg of southern hake were caught in 2021 (Fig. 29; Appendix II). Biomass estimates of southern hake have remained below 6,000 t every February since 2010, with the lowest biomass estimated in 2019 (501 t). In 2021, the biomass was estimated at 2,286 t (Fig. 29; Appendix III). There was a statistically significant decrease in biomass from 2010 to 2021 ($p < 0.001$; Appendix IV).

In 2021, the highest densities of southern hake were detected to the south-west of West Falkland (828 kg/km^2; Fig. 30). Southern hake was aggregated to the south-west of West Falkland throughout the time series, with the highest density reported in 2011 (923 kg/km^2; Appendix XIV).

Southern hake is caught in small numbers in Falkland Islands waters; hence the small number of samples. Length frequency histograms show range of sizes from 31 cm to 106 cm throughout the time series (Fig. 31).

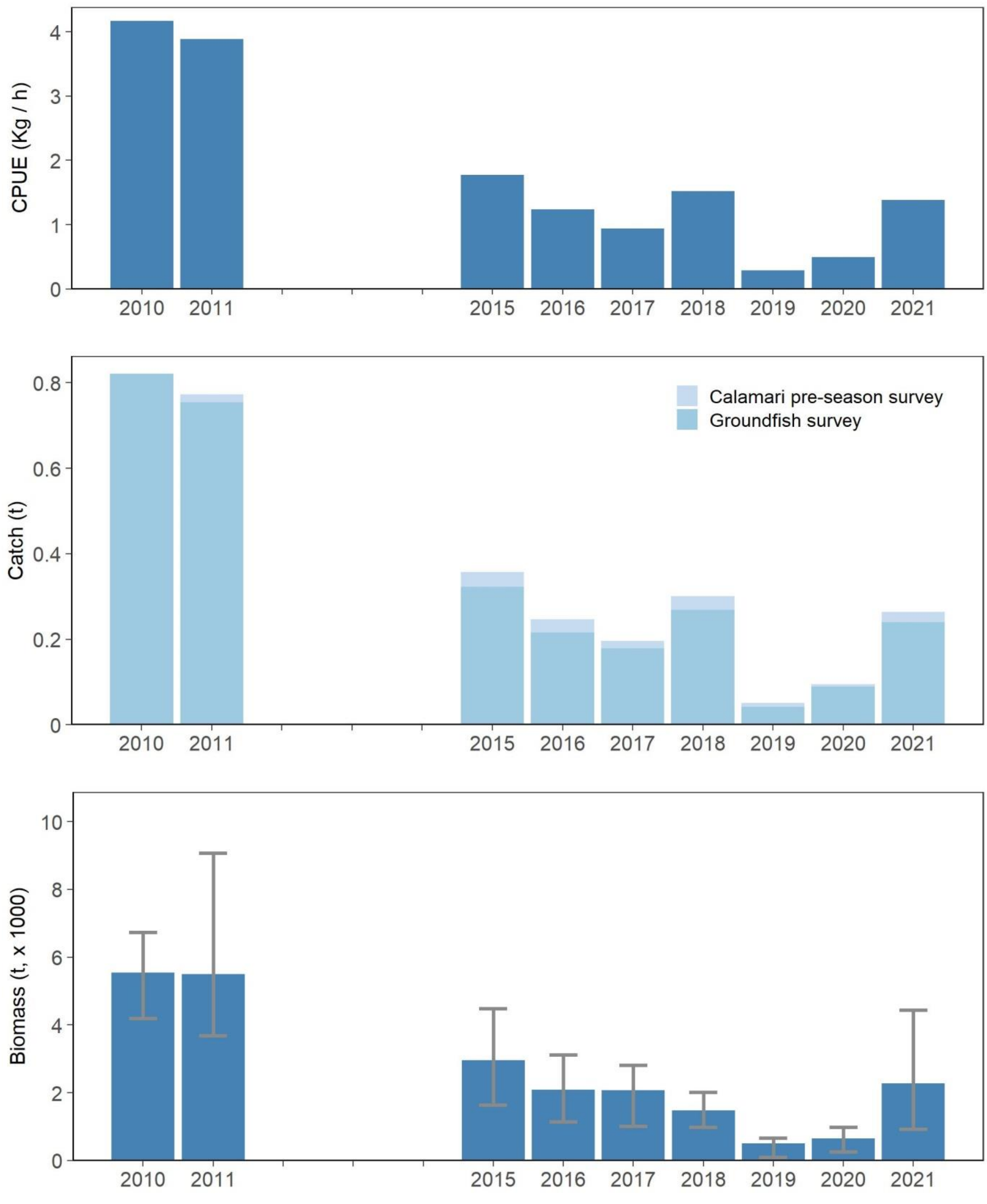


Fig. 29. CPUE (kg/h), catch (t) and mean biomass (t) ± 95% confidence intervals of southern hake (*Merluccius australis*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

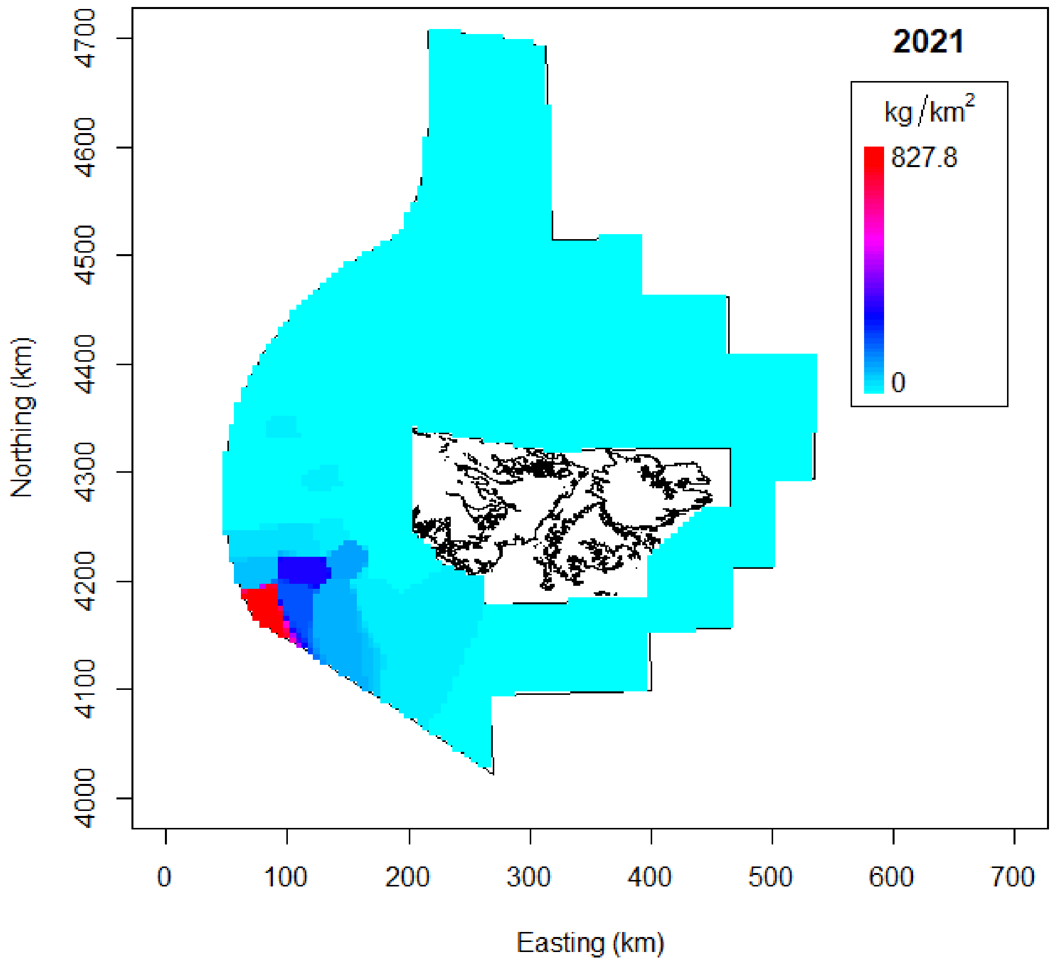


Fig. 30. Density of southern hake (*Merluccius australis*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters.

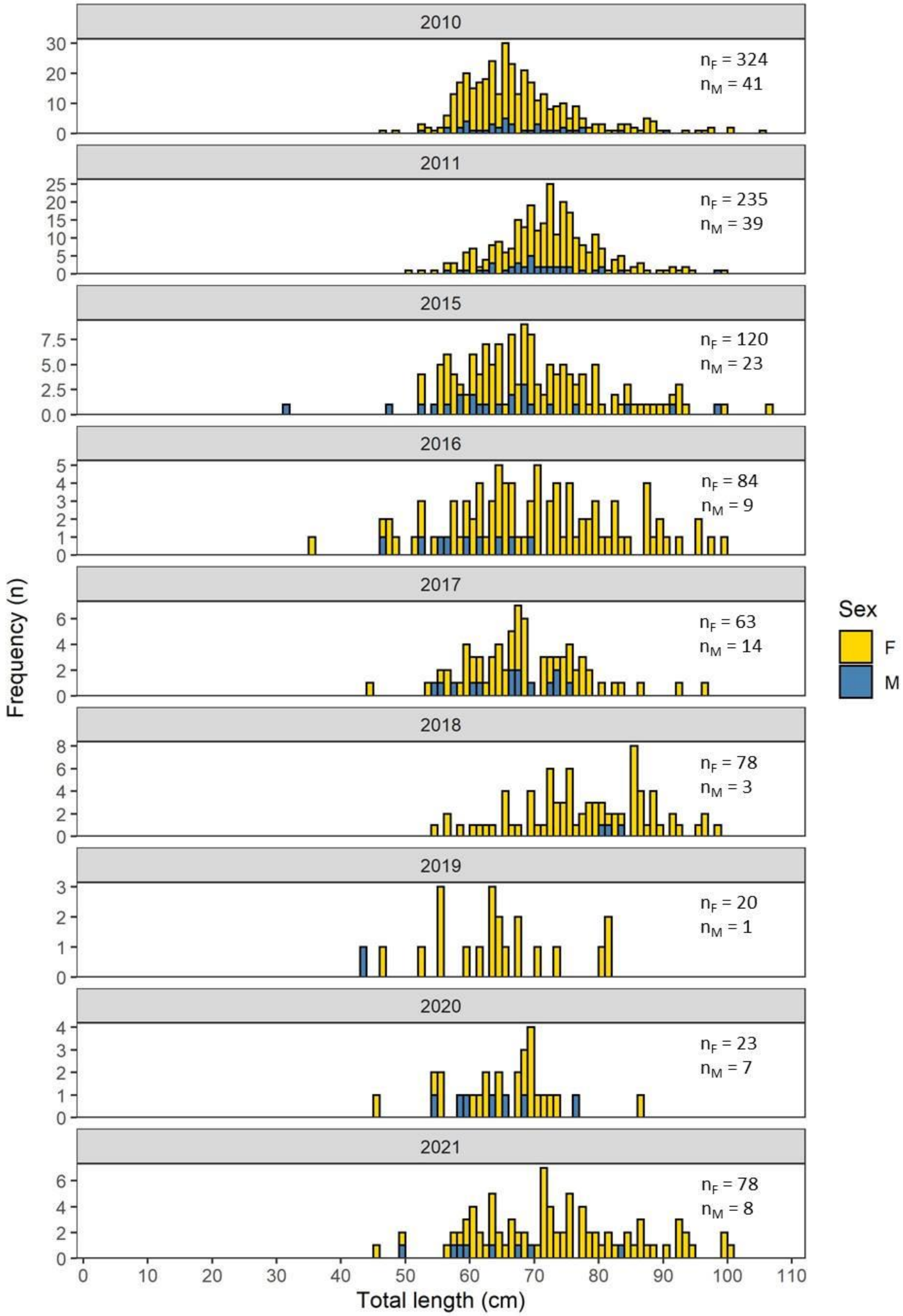


Fig. 31. Length frequency of southern hake (*Merluccius australis*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

4.2.11. 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.

CPUE of toothfish was < 13 kg/h across years, with the highest CPUEs estimated in 2011 and in 2017 (12 kg/h each); the second lowest CPUE in the time series was estimated for 2021 at 4 kg/h (Fig. 32). Catch and biomass estimates were consistent with CPUE patterns through time. The proportion of toothfish catches between groundfish and calamari pre-seasons surveys was variable across years. The maximum catch was reported in 2017 (2.5 t) followed by 2011 (2.4 t); the lowest catch was reported in 2020 (0.5 t), whereas 0.7 t were caught in 2021 (Fig. 32; Appendix II). The survey biomass estimate of toothfish has remained below 12,000 t pear year since 2010, with the lowest biomass estimated in 2020 (3,191 t). In 2021, the biomass of toothfish was estimated at 4,646 t (Fig. 32; Appendix III). There was a statistically significant decrease in biomass from 2010 to 2021 ($p = 0.04$; Appendix IV).

In 2021, the highest densities of toothfish were detected across the south-west of West Falkland (233 kg/km^2; Fig. 33). Toothfish had a patchy distribution around the Falkland Islands throughout the time series, with the highest density reported in 2018 (902 kg/km^2; Appendix XV).

Length frequency histograms show that toothfish had a range of sizes from 5 cm to 115 cm throughout the time series. Several cohorts were present but size overlap prevented identifying each cohort in some years. A small cohort had modal length at 30–36 cm; recruitment was low in recent years (Fig. 34).

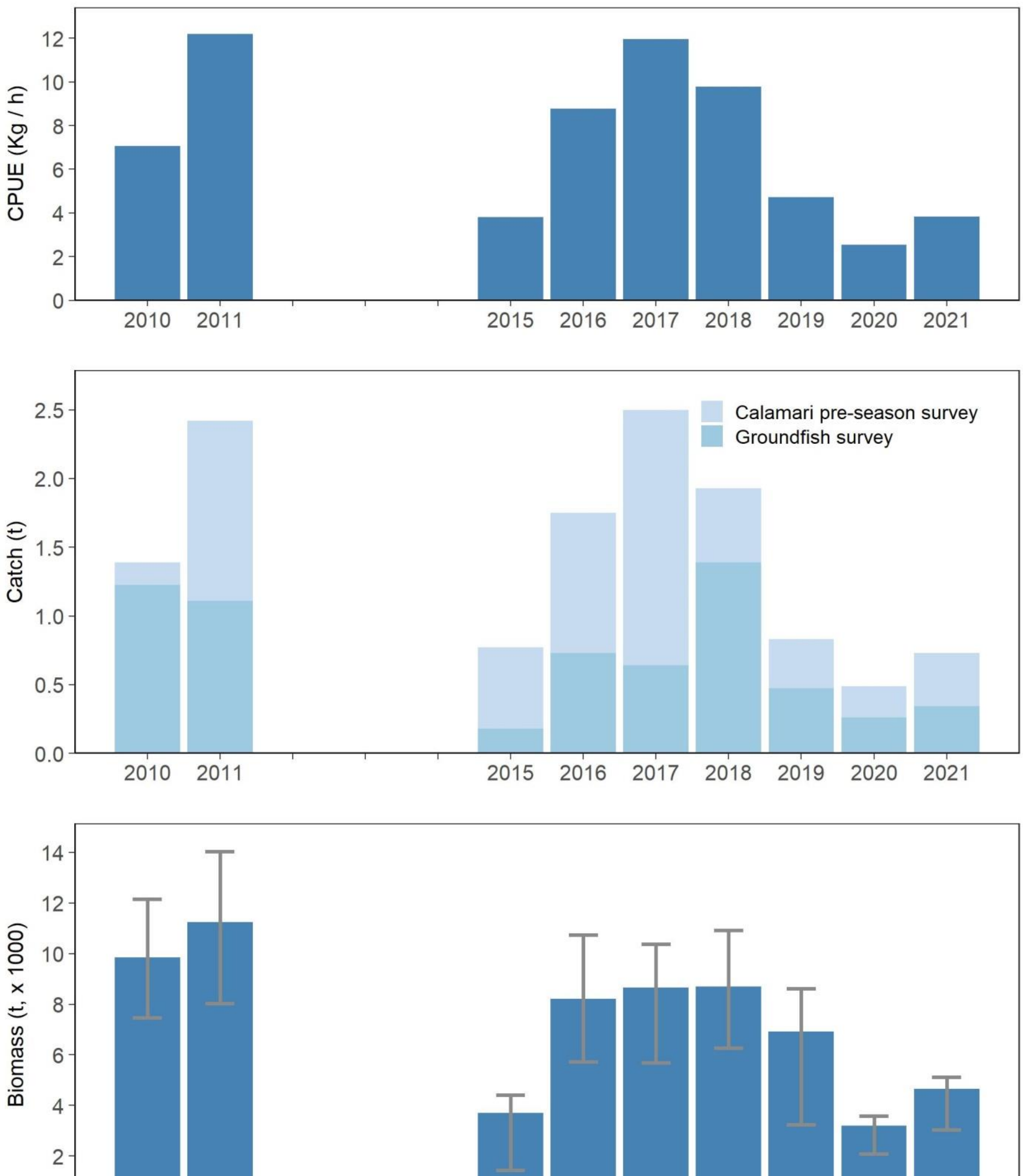


Fig. 32. CPUE (kg/h), catch (t) and mean biomass (t) ± 95% confidence intervals of toothfish (*Dissostichus eleginoides*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

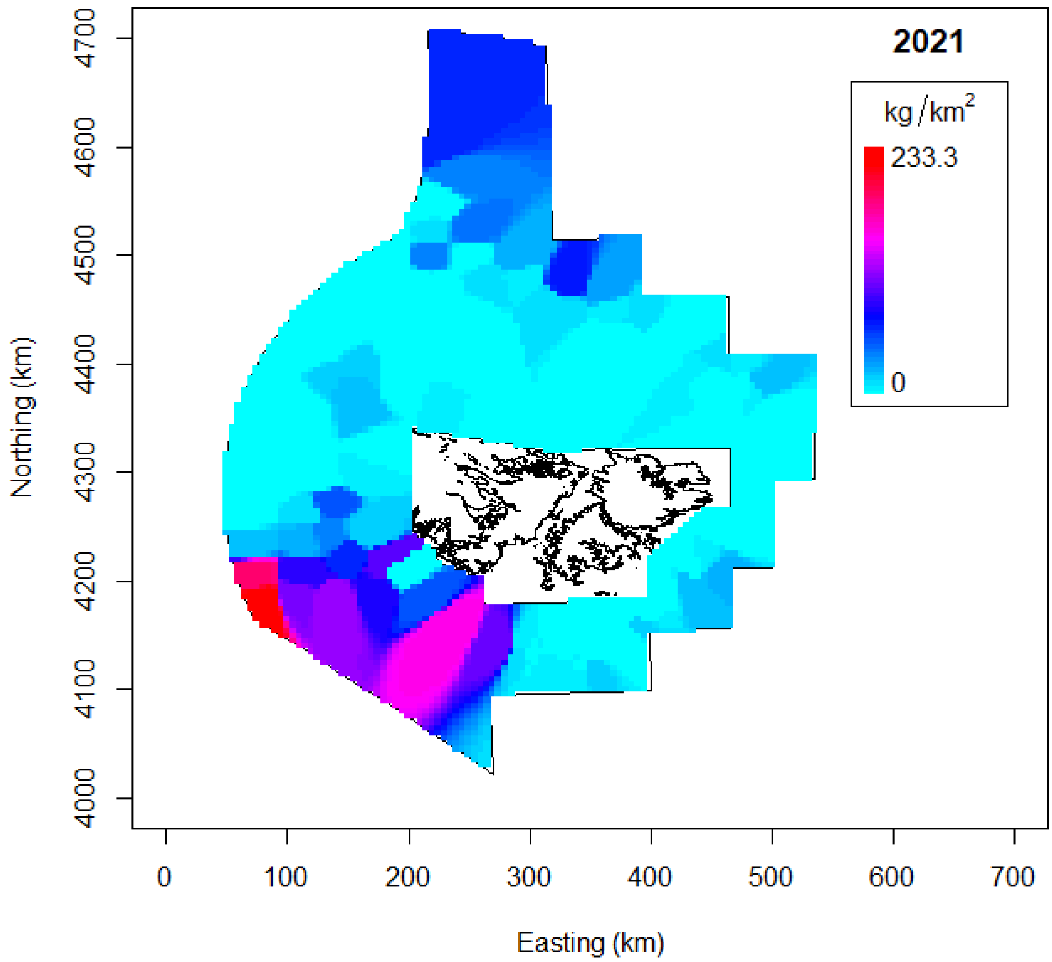


Fig. 33. Density of toothfish (*Dissostichus eleginoides*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters.

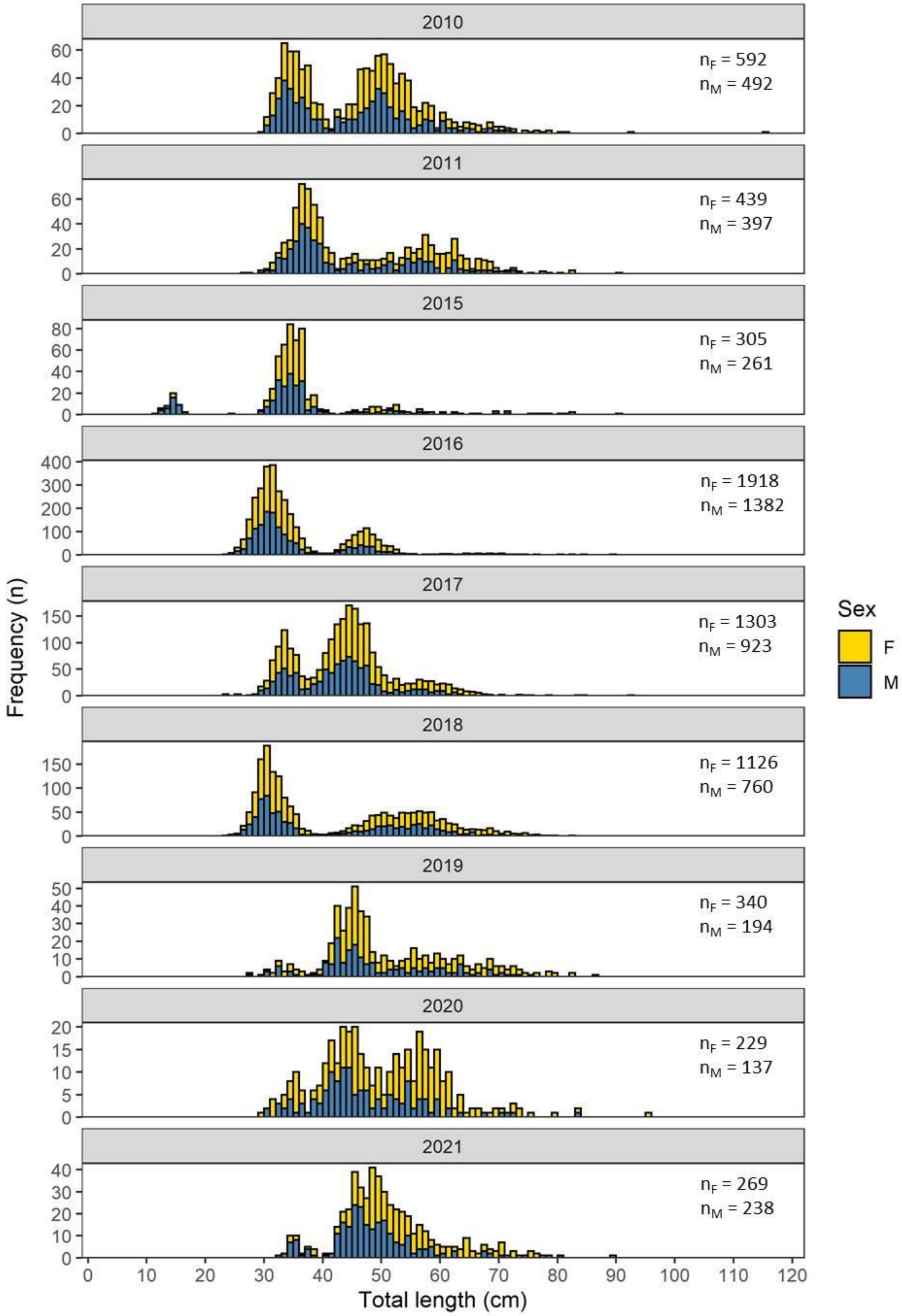


Fig. 34. Length frequency of toothfish (*Dissostichus eleginoides*) during the February 2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.

5. Discussion

The biomass for four commercial species from the February bottom trawl research surveys declined from 2010 to 2021. Rock cod had the greatest decrease in biomass; it was estimated that its biomass in 2021 (59,109 t) was only 8% of its biomass in 2010 (709,536 t). Red cod biomass in 2021 (34,341 t) was 37% of its biomass in 2010 (93,195 t). Southern hake biomass in 2021 (2,286 t) was 41% of its biomass in 2010 (5,541 t). Toothfish biomass in 2021 (4,646 t) was 47% of its biomass in 2010 (9,846 t). Banded whiptail grenadier, hoki, kingclip, southern blue whiting, common hake, and the Argentine shortfin squid had no statistically significant biomass trends.

The year 2015 had peaks in biomass for a number of species, including the Argentine shortfin squid, banded whiptail grenadier, common hake, and kingclip. A total of 6.4 t of Argentine shortfin squid were caught in a valid 30 minutes trawl (station 1709) during the February 2015 groundfish survey; this trawl may have inflated the biomass estimate for *I. argentinus* for that year. However, the high abundance of Argentine shortfin squid is consistent with high commercial catches during 2015, which has been partially examined (Winter 2015) and requires further research.

All species, except for Argentine shortfin squid had greater biomasses in 2021 compared with 2020. In particular, common hake had the greatest increase in biomass of all species from 2020 (3,346 t) to 2021 (33,688 t). It is important to note that common hake start migrating into Falkland Islands waters during February or later (Arkhipkin et al. 2012, 2015). Therefore, comparison of February biomass estimates for this species is affected by variations in the timing of its migration. The high abundance of common hake during February 2021 may be due to early migration into Falkland Islands waters and not due to high catches in a few trawls (< 750 kg per trawl; Trevizan et al. *in prep*).

The declining biomass trend of rock cod estimated in February surveys is consistent with the declining biomass trend estimated from 2005 to 2019 based on commercial data (Winter 2020). The decrease in rock cod abundance is concurrent with high proportions of rock cod discard, that in 2019 were 16% in the *Illex* squid and restricted finfish fishery (i.e. rock cod, southern blue whiting, and hoki), 45% in the restricted finfish fishery, and 99.8% in the Patagonian squid fishery (Falkland Islands Government 2020). Rock cod are discarded because of their small size and most of these small individuals have not reproduced during their lifetime, which can affect recruitment to the fishery (Gilman et al. 2020). An apparent change in its geographic distribution inferred from increasing out-of-zone catches may also have contributed to the decrease in abundance of this species in Falkland Islands waters from 2016 to 2018 (estimated from Winter 2021, Table A1). The relatively high biomass of rock cod in February 2021 was mainly due to high catches of this species in three trawls during the calamari pre-season survey (stations 723, 740 and 763).

Low biomasses for hoki and southern blue whiting estimated from research surveys are supported by stock assessments based on commercial catch data and data-poor methods such as LBB, OCOM and CMSY, that have also found declining biomass trends with stabilization over the past few years (Ramos & Winter 2019a; Ramos et al. 2020a). The recent biomass stabilization may be a delayed consequence of the establishment of a 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 hoki and southern blue whiting stocks (Falkland Islands Government 2020). Both stocks may be further benefited by reduced fishing pressure because of the S-licence not being used since 2017.

In February 2021 hoki was characterized by particularly high biomass. This high biomass was mainly due to the exceptionally high catch of this species in a single trawl in the groundfish survey (station 3362), which had to be completed at minute 20 of bottom time to avoid overloading the net (Trevizan et al. *in prep*). This trawl was considered valid due to the schooling behaviour of hoki making high localized densities realistic, but resulted in a wide 95% confidence interval for biomass. The biomass estimate for hoki in February 2021 was considered comparable with biomass estimates for previous years because the same computation was implemented consistently every year, including valid shorter trawls with high catches. Nevertheless, future assessments will incorporate an adjustment of the algorithm to take into account possible inflation of biomass estimates.

Toothfish biomass estimated in research surveys has remained below 12,000 t since 2010, with the lowest biomass estimate in 2020 (3,191 t). However, these findings represent only a portion of the population given that trawlers rarely catch adult toothfish. A shift in fishing behaviour, i.e. vessels fishing deeper and further south in the FICZ to capture ridge scaled rattail *Macrourus carinatus*, has led the finfish fishery to catch more toothfish since 2016 compared with previous years (Falkland Islands Government 2019). The marginal statistically significant decrease in biomass of toothfish found from the February surveys data is consistent with the negative trends in biomass detected using CASAL and CMSY+ on commercial data, with JABBA showing stabilization over the last decade (Skeljo & Winter 2020a,b).

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 contributed nearly 11% of the 10-year average catch of hoki and southern blue whiting each, shared with Argentina and Chile (Ramos & Winter 2019a; Ramos et al. 2020a), whereas the Falkland Islands kingclip production accounted for 28% of the combined production (Ramos & Winter 2019b). Declines in biomass of some stocks may also be in part due to high fishing pressure outside Falkland Islands waters.

Overlap of lengths in the length frequency histograms presented in this report does not allow identifying the several cohorts for each species, and prevent analyses of length trends through time. In previous stock assessments, length data have been examined in the form of length at 50% maturity or modal length, from which trends through years were also presented; those trends are discussed here as a reference. Length at 50% maturity of rock cod declined from 2003 to 2019 (Winter 2020), and modal length of hoki had a statistically significant decline from 2002 to 2018 (Ramos & Winter 2019a). Southern blue whiting had a statistically significant decline in modal length from 2002 to 2018 (Ramos & Winter 2019c).

The February surveys provide an opportunity to search for juvenile individuals in Falkland Islands waters. In addition to low abundance, southern blue whiting individuals smaller than 20 cm total length have been scarce through the time series (n_{2010} = 1; n_{2011} = 36; n_{2015} = 446; n_{2016} = 37; n_{2017} = 238; n_{2018} = 47; n_{2019} = 0; n_{2020} = 1; n_{2021} = 4), likely an indication of poor recruitment to the fishery. Individuals in the range between 20 cm and 30 cm total length were sampled every year in larger numbers (n_{2010} = 1,610; n_{2011} = 389; n_{2015} = 664; n_{2016} = 413; n_{2017} = 262; n_{2018} = 1,781; n_{2019} = 115; n_{2020} = 17; n_{2021} = 618).

The FIFD has made efforts to search for juvenile toothfish during austral spring or summer over the last few years, by juvenile toothfish surveys (e.g. Pompert et al. 2015; Arkhipkin et al. 2017) or by including four inshore stations in groundfish surveys (e.g. see Arkhipkin et al. 2019; Randhawa et al. 2020; Trevizan et al. *in prep*). Juvenile toothfish smaller than 20 cm total length have also been scarce in groundfish surveys through the time series (n_{2010} = 0; n_{2011} = 60; n_{2015} = 237; n_{2016} = 57; n_{2017} = 109; n_{2018} = 0; n_{2019} = 1; n_{2020} = 2; n_{2021} = 26).

6. References

Agnew DJ (2002) Critical aspects of the Falkland Islands pelagic ecosystem: distribution, spawning and migration of pelagic animals in relation to oil exploration. Aquatic Conservation 12: 39–50.

Arkhipkin A, Bakanev S, Laptikhovsky V (2011) Rock cod Biomass Survey - 2011. Report number ZDLT1-02-2011. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 37 pp.

Arkhipkin A, Brickle P, Laptikhovsky V, Winter A (2012) Dining hall at sea: feeding migrations of nektonic predators to the eastern Patagonian Shelf. Journal of Fish Biology 81: 882–902. doi:10.1111/j.1095-8649.2012.03359.x

Arkhipkin A, Herrera D, Lee B, Boag T, Bradley K, Cockcroft K (2017) Scientific Report, Fisheries Cruise ZDLT1-01-2017. Stanley, Fisheries Department, Directorate of Natural Resources, Falkland Islands Government. 34 pp.

Arkhipkin A, Lee B, Goyot L, Ramos JE, Chemshirova I, Roberts G, Costa M, Blake A (2019) Demersal biomass survey. Report number ZDLM3-02-2019. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 44 pp.

Arkhipkin AI, Laptikhovsky VV, Barton AJ (2015) Biology and fishery of common hake (*Merluccius hubbsi*) and southern hake (*Merluccius australis*) around the Falkland/Malvinas Islands on the Patagonian shelf of the Southwest Atlantic Ocean. In H. Arancibia (Ed.), Hakes, Biology and Exploitation (pp. 154–184). Oxford: Wiley.

Arkhipkin A, Winter A, May T (2010) Loligo gahi Stock Assessment Survey, First Season 2010. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 13 pp.

Arkhipkin AI, Laptikhovsky VV (2010) Convergence in life-history traits in migratory deep-water squid and fish. ICES Journal of Marine Science 67: 1444–1451.

Barabanov AV (1982) Influence of hydrometeorological conditions of the Southwest Atlantic on migrations of southern blue whiting in Scotia Sea. *In:* Arkhipkin AI, Schuchert PC, Danyushevsky L (2009) Otolith chemistry reveals fine population structure and close affinity to the Pacific and Atlantic oceanic spawning grounds in the migratory southern blue whiting (*Micromesistius australis australis*). Fisheries Research 96: 188–194. doi: 10.1016/j.fishres.2008.11.002

Bianchi A, Massonneau M, Olevera RM (1982) Análisis estadístico de las características T–S del sector austral de la Plataforma Continental Argentina. Acta Oceanolica Argentina 3: 93–118. *In:* Arkhipkin A, Brickle P, Laptikhovsky V, Winter A (2012) Dining hall at sea: feeding migrations of nektonic predators to the eastern Patagonian Shelf. Journal of Fish Biology 81: 882–902. doi:10.1111/j.1095-8649.2012.03359.x

Boltovskoy D (Ed.) (1999) South Atlantic Zooplankton. *In:* Arkhipkin A, Brickle P, Laptikhovsky V, Winter A (2012) Dining hall at sea: feeding migrations of nektonic predators to the eastern Patagonian Shelf. Journal of Fish Biology 81: 882–902. doi:10.1111/j.1095-8649.2012.03359.x

Brickle P, Laptikhovsky V (2010) Rock cod Biomass Survey. Report number ZDLT1-02-2010. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 31 pp.

Falkland Islands Government (1989) Fisheries Report, FIG Stanley, Fisheries Department. 45 pp.

Falkland Islands Government (2019) Fisheries Department Fisheries Statistics, Vol. 23, FIG Stanley, Fisheries Department. 102 pp.

Falkland Islands Government (2020) Fisheries Department Fisheries Statistics, Vol. 24, FIG Stanley, Fisheries Department. 68 pp.

Gilman E, Perez-Roda A, Huntington T, Kennelly SJ, Suuronen P, Chaloupka M, Medley PAH (2020) Benchmarking global fisheries discards. Scientific Reports 10: 14017. doi:10.1038/s41598-020-71021-x

Gras M, Blake A, Pompert J, Jürgens L, Visauta E, Busbridge T, Rushton H, Zawadowski T (2015) Rock cod Biomass Survey. Report number ZDLT1-02-2015. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 45 pp.

Gras M, Pompert J, Blake A, Boag T, Grimmer A, Iriarte V, Sánchez B (2016) Finfish and Rock cod Biomass Survey. Report number ZDLT1-02-2016. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 72 pp.

Gras M, Pompert J, Blake A, Busbridge T, Derbyshire C, Keningale B, Thomas O (2017) Groundfish survey. Report number ZDLT1-02-2017. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 83 pp.

Gras M, Randhawa H, Blake A, Busbridge T, Chemshirova I, Guest A (2018) Groundfish survey. Report number ZDLM3-02-2018. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 81 pp.

Laptikhovsky VV, Arkhipkin AI, Brickle P (2008) Life history, fishery and stock conservation of the Patagonian toothfish around the Falkland Islands. American Fisheries Society Symposium 49: 1357–1363. *In:* Arkhipkin A, Brickle P, Laptikhovsky V, Winter A (2012) Dining hall at sea: feeding migrations of nektonic predators to the eastern Patagonian Shelf. Journal of Fish Biology 81: 882–902. doi:10.1111/j.1095-8649.2012.03359.x

Payá I, Brickle P, Laptikhovsky V, Winter A (2010) Vessel Units, Allowable Effort, and Allowable Catch 2011. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 53 pp.

Peterson RG, Whitworth III T (1989) The Subantarctic and Polar fronts in relation to deep water masses through the Southwestern Atlantic. Journal of Geophysical Research 94: 10817–10838. *In:* Arkhipkin A, Brickle P, Laptikhovsky V, Winter A (2012) Dining hall at sea: feeding migrations of nektonic predators to the eastern Patagonian Shelf. Journal of Fish Biology 81: 882–902. doi:10.1111/j.1095-8649.2012.03359.x

Pompert J, Blake A, Lee B, Jones J, Zawadowski T (2015) Scientific Report, Fisheries Cruise ZDLT1-11-2015. Stanley, Fisheries Department, Directorate of Natural Resources, Falkland Islands Government. 39 pp.

Ramos JE, Skeljo F, Winter A (2020a) Stock assessment of southern blue whiting (*Micromesistius australis australis*) in the Falkland Islands. SA–2020–BLU. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 38 pp.

Ramos JE, Winter A (2019a) Stock assessment of hoki (*Macruronus magellanicus*) in the Falkland Islands. SA–2019–WHI. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government. Stanley, Falkland Islands. 47 pp.

Ramos JE, Winter A (2019b) Stock assessment of Kingclip (*Genypterus blacodes*) in the Falkland Islands, 2017–2018. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government. Stanley, Falkland Islands. 31 pp.

Ramos JE, Winter A (2019c) Stock assessment of Southern blue whiting (*Micromesistius australis*) in the Falkland Islands. SA–2019–BLU. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government. Stanley, Falkland Islands. 51 pp.

Randhawa HS, Goyot L, Blake A, Ramos JE, Roberts G, Brewin J, Evans D (2020) Cruise Report ZDLT1-02-2020: 2020 Demersal Biomass Survey. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 97 pp.

Seafish (2010) Bridle angle and wing end spread calculations. Research and development catching sector fact sheet. Available at: www.seafish.org

Skeljo F, Winter A (2020a) 2019 Alternative Stock Assessments for Patagonian toothfish (*Dissostichus eleginoides*). SA-2019-TOO. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 22 p.

Skeljo F, Winter A (2020b) 2019 Stock assessment report for Patagonian toothfish (*Dissostichus eleginoides*). SA-2019-TOO. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 36 p.

Trevizan T, Ramos JE, Blake A, Brewin J, Büring T, Claes J, Evans D (*in prep*) Demersal biomass survey. Report number ZDLT1-02-2021. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands.

Winter A (2015) Loligo Stock Assessment, First Season 2015. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 28 pp.

Winter A (2019) Rock cod stock assessment (*Patagonotothen ramsayi*). Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 23 pp.

Winter A (2020) Rock cod stock assessment (*Patagonotothen ramsayi*). Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 33 pp.

Winter A (2021) Rock cod (*Patagonotothen ramsayi*) stock assessment. SA–2021–PAR. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 29 pp.

Winter A, Laptikhovsky V, Brickle P, Arkhipkin A (2010) Rock cod (*Patagonotothen ramsayi* (Regan, 1913)) stock assessment in the Falkland Islands. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 12 pp.

Winter A, Davidson D, Watson M (2011) *Loligo gahi* Stock Assessment Survey, 1st Season 2011. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 18 pp.

Winter A, Jones J, Shcherbich Z (2015) *Loligo* Stock Assessment Survey, 1st Season 2015. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 16 pp.

Winter A, Jones J, Shcherbich Z, Iriarte V (2017) Falkland calamari Stock Assessment Survey, 1st Season 2017. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 17 pp.

Winter A, Iriarte V, Zawadowski T (2018) *Doryteuthis gahi* Stock Assessment Survey, 1st Season 2018. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 20 pp.

Winter A, Lee B, Arkhipkin A, Tutjavi V, Büring T (2020) 2020 1st Season Assessment Survey Falkland calamari (*Doryteuthis gahi*). ZDLY-S1-2020. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 16 pp.

Winter A, Shcherbich Z, Matošević N (2021) 2021 1st Season Assessment Survey Falkland calamari (*Doryteuthis gahi*). ZDLY-S1-2021. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 18 pp.

Winter A, Zawadowski T, Shcherbich Z, Bradley K, Kuepfer A (2016) Falkland calamari Stock Assessment Survey, 1st Season 2016. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 19 pp.

Winter A, Zawadowski T, Tutjavi V (2019) *Doryteuthis gahi* Stock Assessment Survey, 1st Season 2019. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 18 pp.

Appendix I

February groundfish (gf) and calamari pre-season (pr) surveys information. Catches per survey and combined total include Argentine shortfin squid, banded whiptail 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	195.8	458.0	653.8
2011	Castelo (ZDLT1)	Venturer (ZDLP1)	88	58	146	NA	NA	196.7	257.4	454.1
2015	Castelo (ZDLT1)	Baffin Bay (MSPL9)	89	57	146	NA	NA	121.8	392.9	514.7
2016	Castelo (ZDLT1)	Sil (ZDLR1)	90	56	146	NA	638	87.7	206.7	294.4
2017	Castelo (ZDLT1)	Argos Vigo (ZDLU1)	90	58	148	2328	1002	48.1	254.3	302.5
2018	Monteferro (ZDLM3)	Castelo (ZDLT1)	97	59	156	143,144,156,164,183	NA	81.4	169.6	251.1
2019	Monteferro (ZDLM3)	Argos Cíes (ZDLS3)	79	52	135	240,242,244,246	25,29,37	47.0	418.7	465.6
2020	Castelo (ZDLT1)	Argos Cíes (ZDLS3)	80	59	139	NA	NA	49.9	283.9	333.8
2021	Castelo (ZDLT1)	Capricorn (ZDLY)	80	55	135	3388,3391,3392,3393	NA	76.4	348.0	424.4

Appendix II

Catches (t) of main commercial species during the February 2010–2011, and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters.

Year	Argentine shortfin squid	Banded whiptail grenadier	Common hake	Hoki	Kingclip	Patagonian squid	Red cod
2010	0.88	8.05	1.31	79.78	3.24	356.76	13.54
2011	1.95	6.20	1.67	56.00	8.59	50.51	23.54
2015	31.87	6.58	3.17	26.36	14.73	186.14	21.81
2016	0.10	3.28	0.69	38.91	5.45	66.89	19.95
2017	2.48	3.97	2.94	3.69	4.26	185.23	13.82
2018	10.70	7.54	1.73	30.02	3.59	115.84	13.30
2019	9.41	2.50	2.75	7.55	4.42	386.26	13.68
2020	17.91	2.62	0.72	14.38	3.62	272.08	3.71
2021	10.31	6.53	8.15	30.83	4.79	285.54	6.04
Total	85.61	47.27	23.13	287.52	52.69	1905.25	129.39
Mean	9.51	5.25	2.57	31.95	5.85	211.69	14.38

Table II. *continued*

Year	Rock cod	Southern blue whiting	Southern hake	Toothfish	Total	Mean
2010	164.59	21.87	0.82	1.39	652.23	59.29
2011	249.38	52.29	0.77	2.42	453.32	41.21
2015	198.27	24.12	0.36	0.77	514.18	46.74
2016	77.31	79.36	0.25	1.75	293.94	26.72
2017	76.13	6.41	0.20	2.50	301.63	27.42
2018	35.92	29.51	0.30	1.93	250.38	22.76
2019	27.94	8.38	0.05	0.83	463.77	42.16
2020	10.98	5.10	0.10	0.49	331.71	30.16
2021	57.16	12.17	0.26	0.73	422.51	38.41
Total	897.68	239.21	3.11	12.81		
Mean	99.74	26.58	0.35	1.42		

Appendix III

Estimated biomass (t) of main commercial species during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. The 95% confidence intervals are indicated in parentheses.

Year	Argentine shortfin squid	Banded whiptail grenadier	Common hake	Hoki
2010	8620.30 (3508.71–13828.03)	86113.09 (46234.37–110793.53)	9013.04 (6042.43–12604.24)	272080.22 (197644.96–472481.97)
2011	9288.09 (6719.00–12632.60)	49649.82 (23347.38–84631.86)	10334.29 (8472.85–12860.06)	225981.56 (173396.03–287362.59)
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 (7474.80–18341.05)	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	60112.28 (39782.78–95959.78)	22216.70 (10183.84–37239.19)	11100.21 (9412.62–14671.40)	41346.89 (6569.34–188598.04)
2020	148023.20 (90413.40–195436.03)	39100.03 (10577.14–46950.92)	3346.38 (2851.53–3972.17)	77727.54 (20133.68–165424.57)
2021	43309.68 (20207.65–69125.54)	66298.28 (31890.54–84287.54)	33687.59 (28103.10–41558.83)	312118.42 (93792.22–737156.05)

Appendix III. *continued*

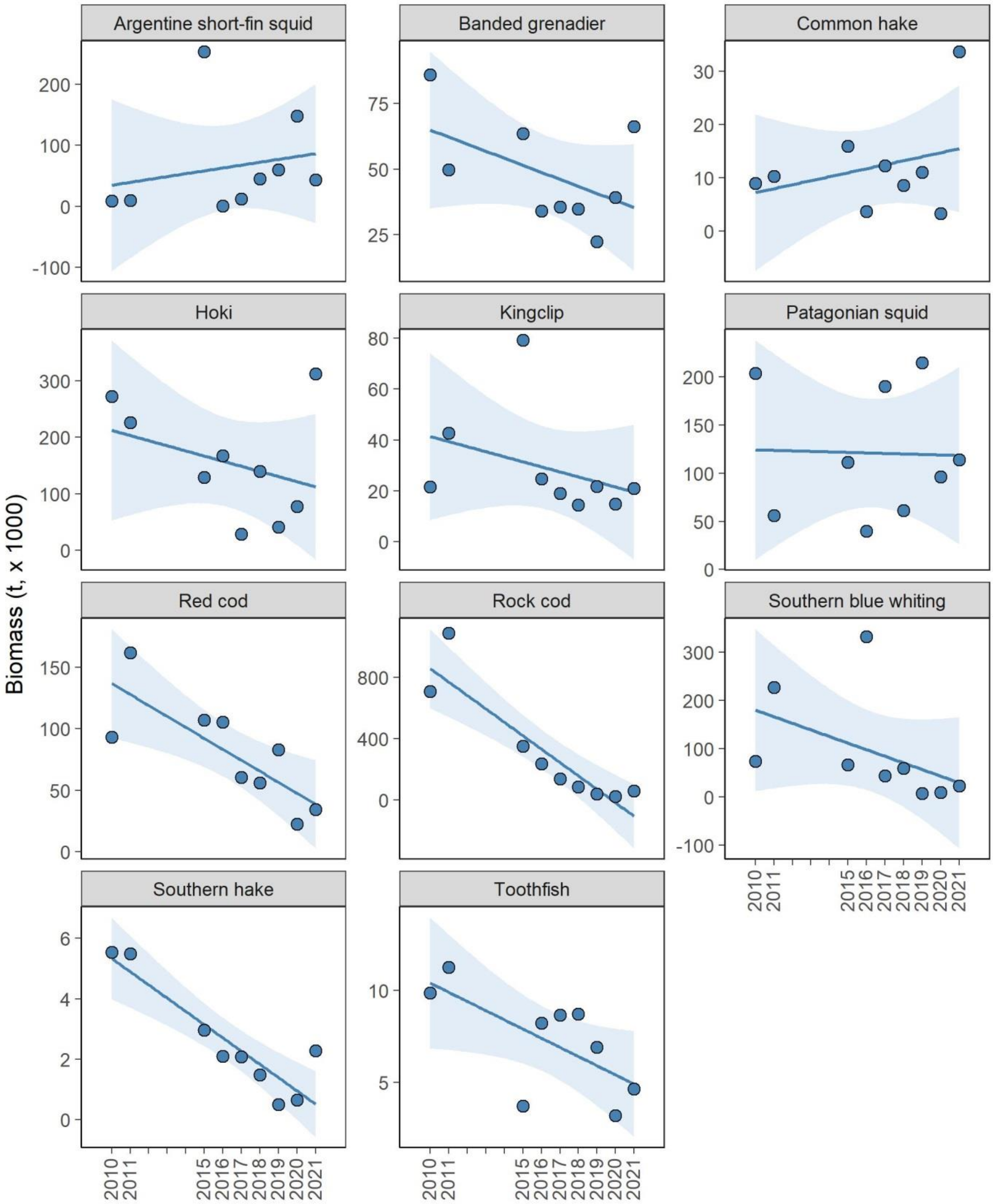
Year	Kingclip	Patagonian squid	Red cod	Rock cod
2010	21617.44 (13740.07–31108.56)	203558.43 (162047.16–250085.16)	93194.65 (19743.66–150576.55)	709535.66 (530503.55–1086153.89)
2011	42590.31 (29174.13–65043.77)	55768.45 (43073.71–78140.40)	161778.97 (41760.22–252434.63)	1089328.38 (722488.27–1750511.28)
2015	79128.92 (30842.99–130266.84)	111351.39 (80460.29–169743.16)	106878.11 (45428.59–160292.10)	352570.42 (268194.30–429993.32)
2016	24791.36 (13831.38–39084.50)	39946.94 (33264.42–53333.28)	105369.24 (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	21837.14 (14985.57–29227.05)	214660.51 (184179.62–263115.42)	82793.68 (36684.05–116442.72)	39605.16 (27855.34–54807.51)
2020	14883.58 (10351.98– 26525.09)	96135.68 (77679.89– 136705.30)	22661.17 (11566.08–34435.10)	22246.45 (13151.14–29258.84)
2021	20977.20 (12801.04–34022.91)	114109.97 (94290.93–159469.33)	34341.38 (22268.63–50967.64)	59109.16 (45570.64–66849.77)

Appendix III. *continued*

Year	Southern blue whiting	Southern hake	Toothfish
2010	73563.23 (27341.64–98431.47)	5540.86 (4196.15–6739.18)	9845.88 (7461.10–12152.61)
2011	226421.45 (45340.49–388061.75)	5495.37 (3692.86–9065.52)	11246.93 (8037.24–14037.05)
2015	66221.71 (13050.55–102946.05)	2955.72 (1645.37–4487.16)	3706.51 (1433.24–4408.06)
2016	332096.18 (26505.92–433238.55)	2091.94 (1144.92–3127.62)	8219.23 (5721.33–10734.75)
2017	43252.74 (1284.65–57549.59)	2076.28 (1014.90–2818.17)	8649.98 (5690.86–10369.9)
2018	58802.02 (17715.83–69838.20)	1482.37 (992.91–2012.70)	8704.55 (6261.69–10926.90)
2019	6670.33 (215.07–39035.01)	500.99 (104.97–663.63)	6910.38 (3243.16–8613.47)
2020	9551.28 (31.09–22890.97)	651.17 (256.75–984.81)	3191.16 (2079.74–3587.13)
2021	22808.66 (3239.03–43950.76)	2286.19 (928.58–4438.59)	4645.74 (3028.33–5113.28)

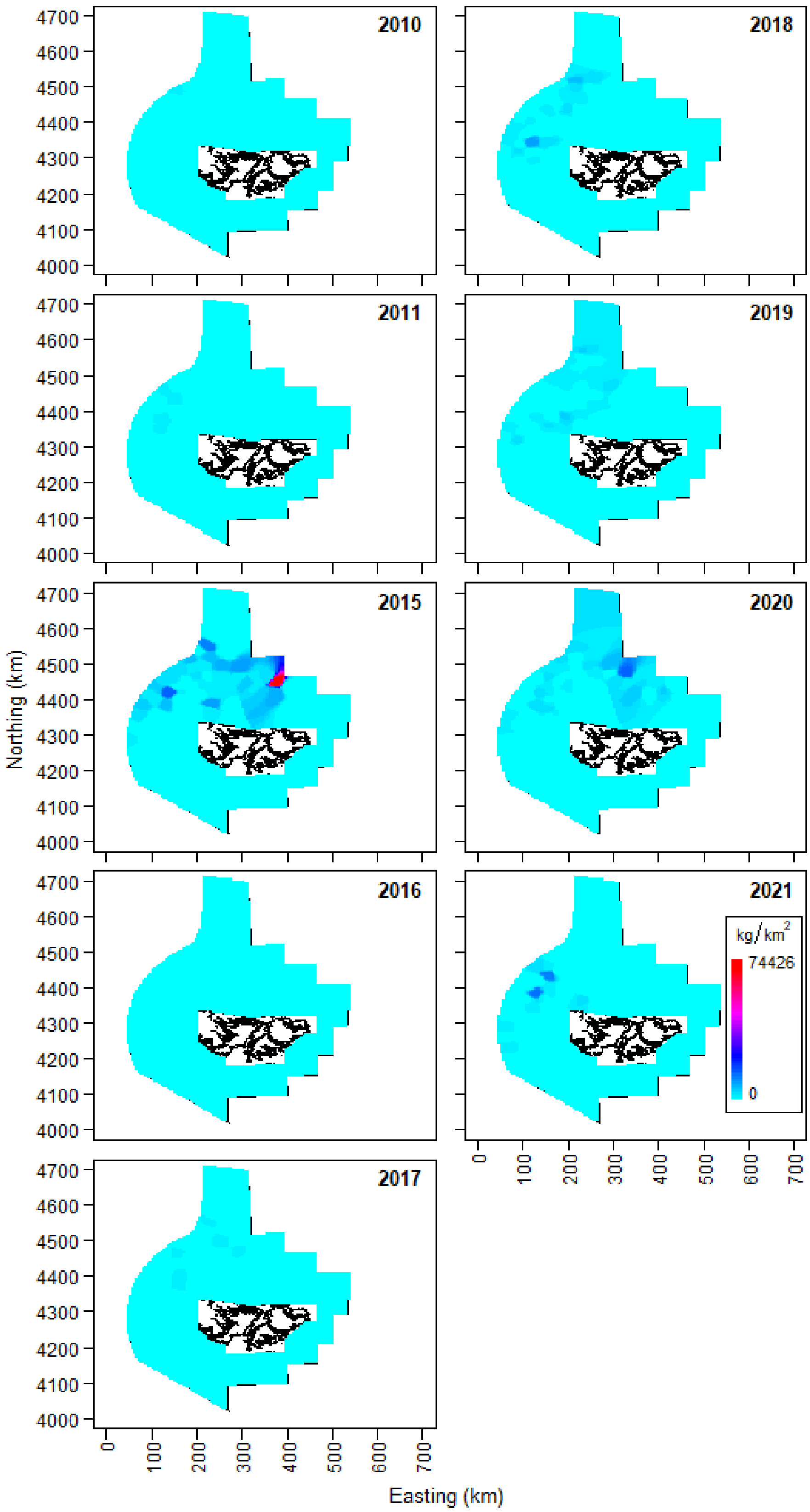
Appendix IV

Biomass (t) of commercial species in February groundfish and calamari pre-season surveys during 2010-2011 and 2015-2021. The linear model is indicated by the blue line and the 95% confidence intervals by the bluegray shade.



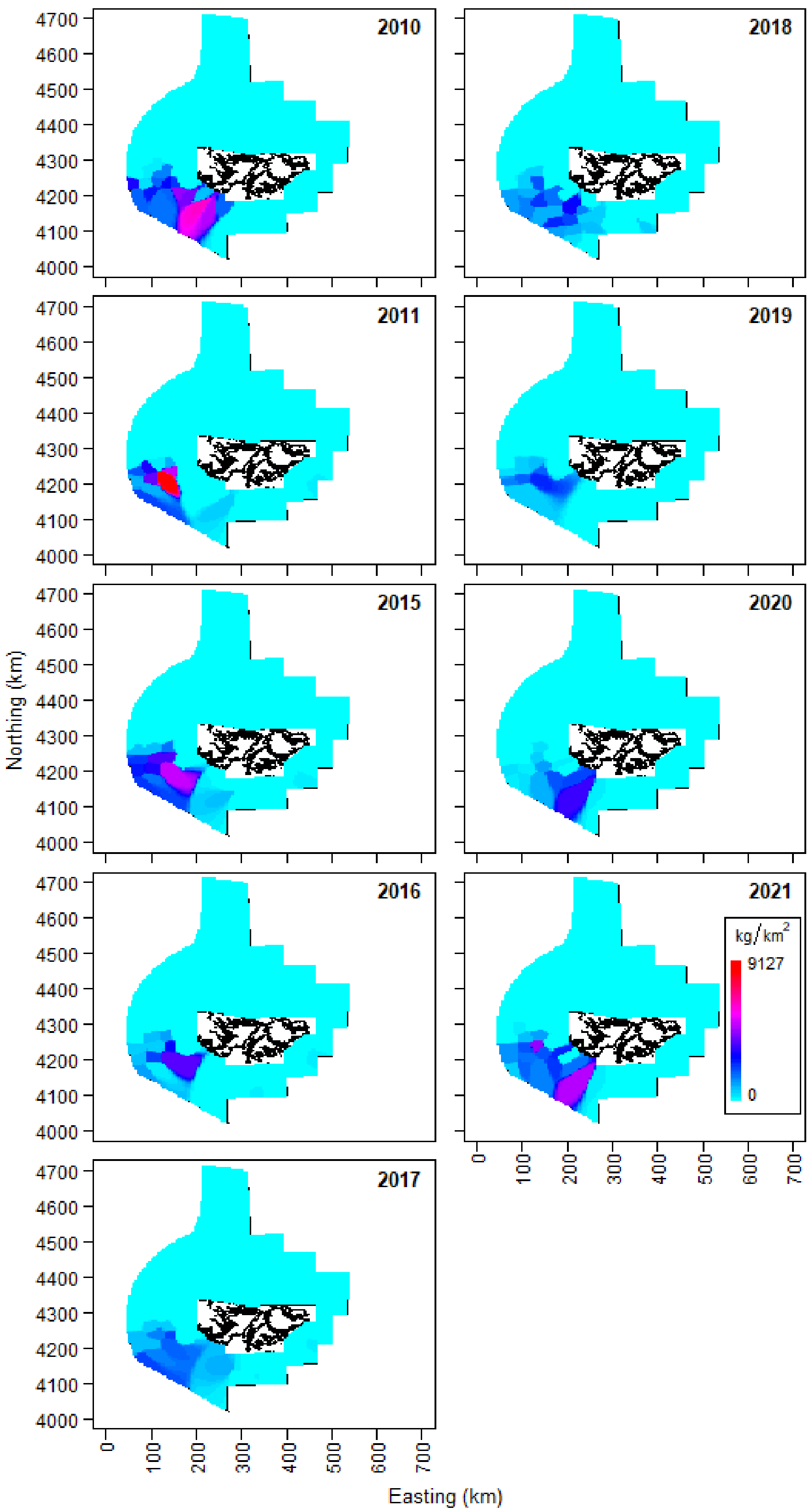
Appendix V

Comparative density of the Argentine shortfin squid (*Illex argentinus*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.



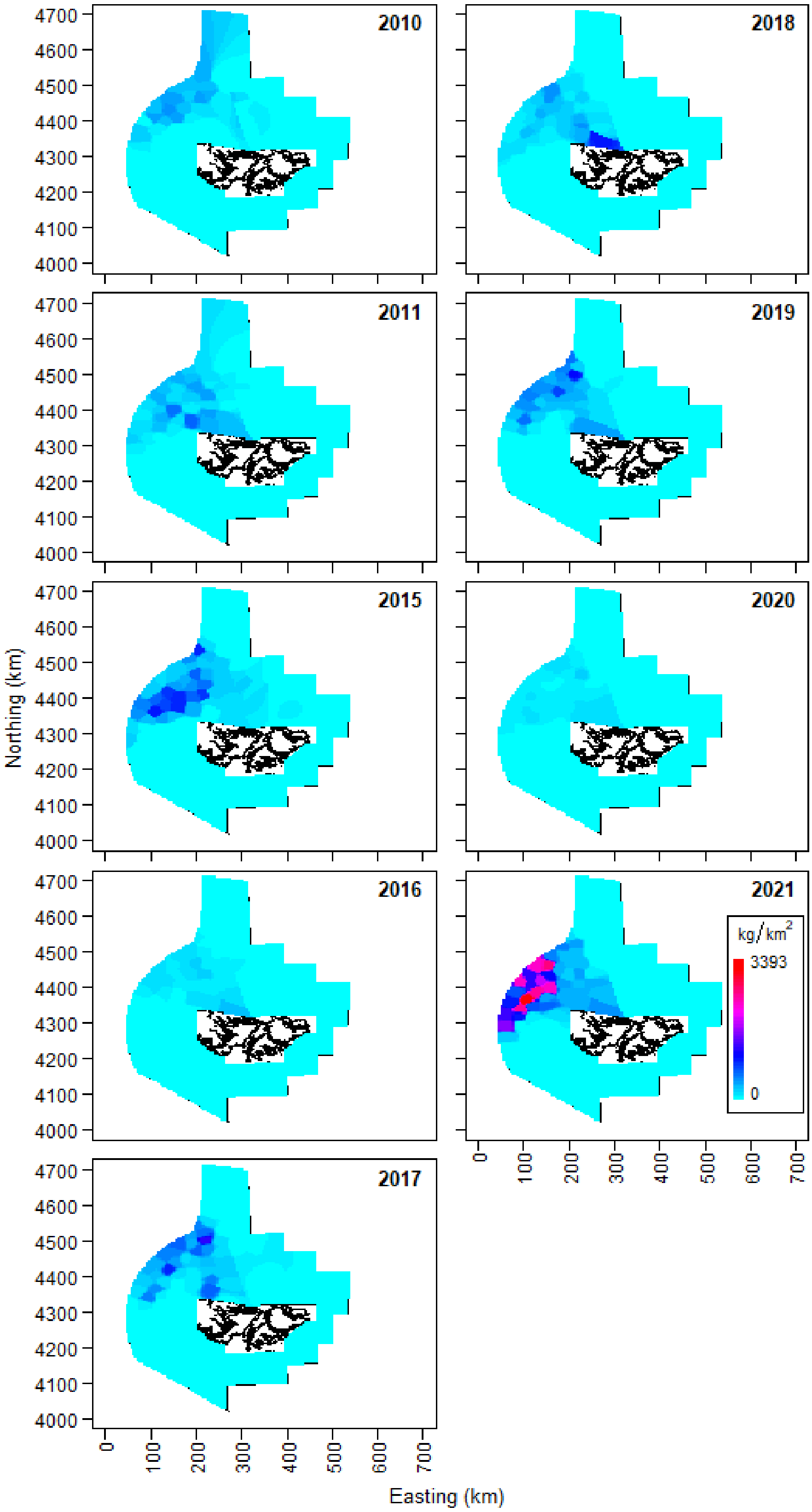
Appendix VI

Comparative density of banded whiptail grenadier (*Coelorinchus fasciatus*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.



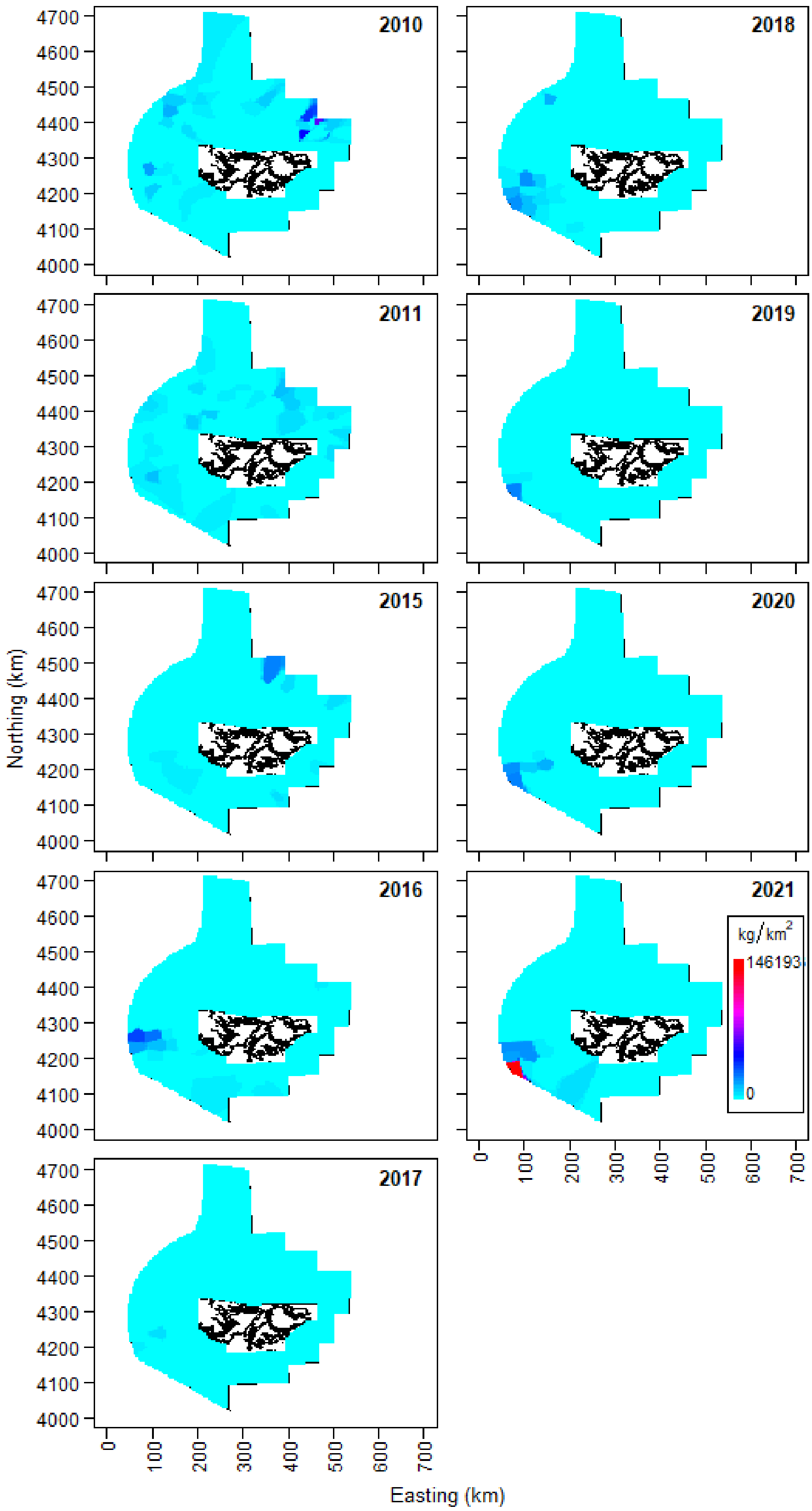
Appendix VII

Comparative density of common hake (*Merluccius hubbsi*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.



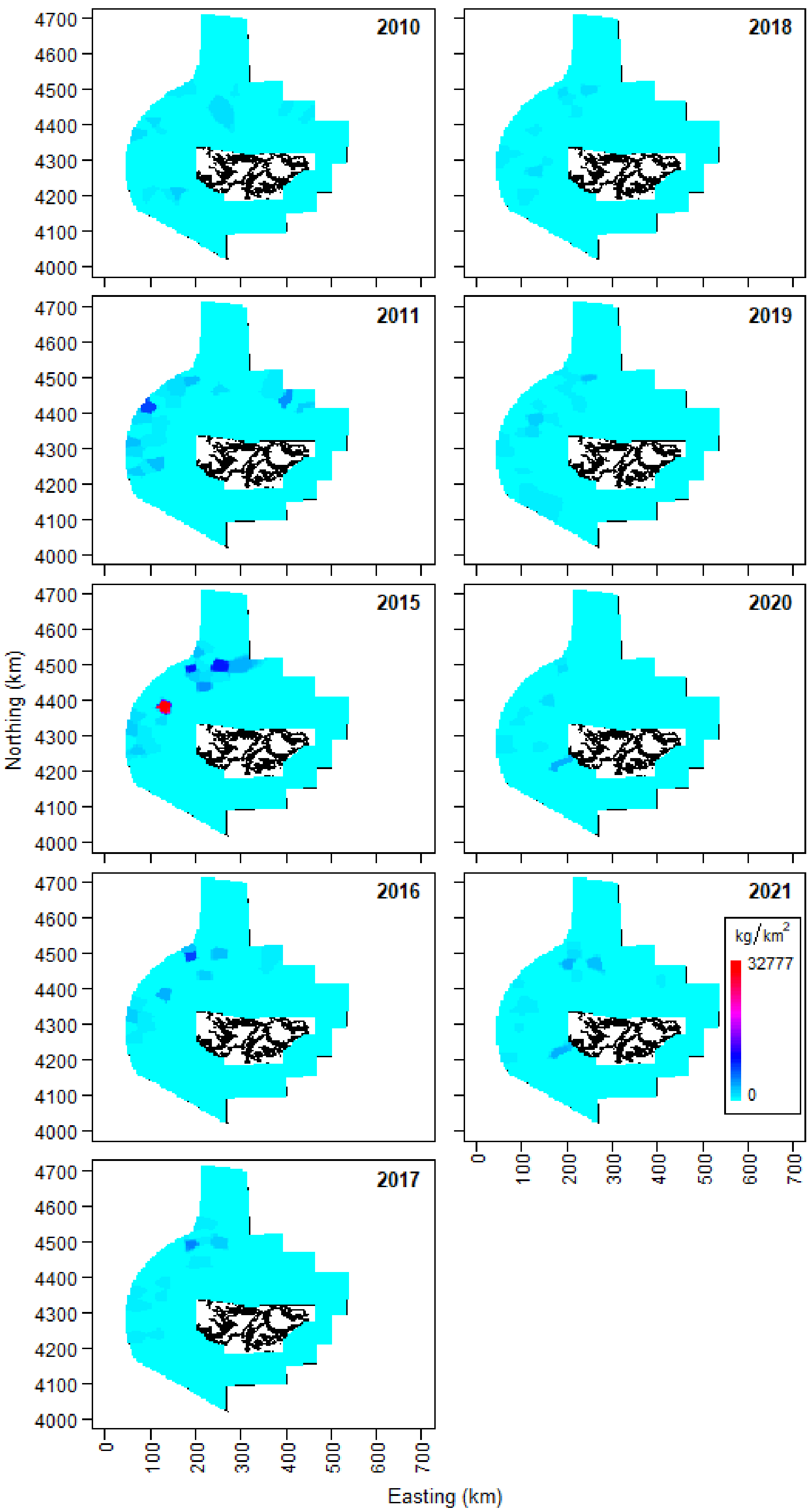
Appendix VIII

Comparative density of hoki (*Macruronus magellanicus*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.



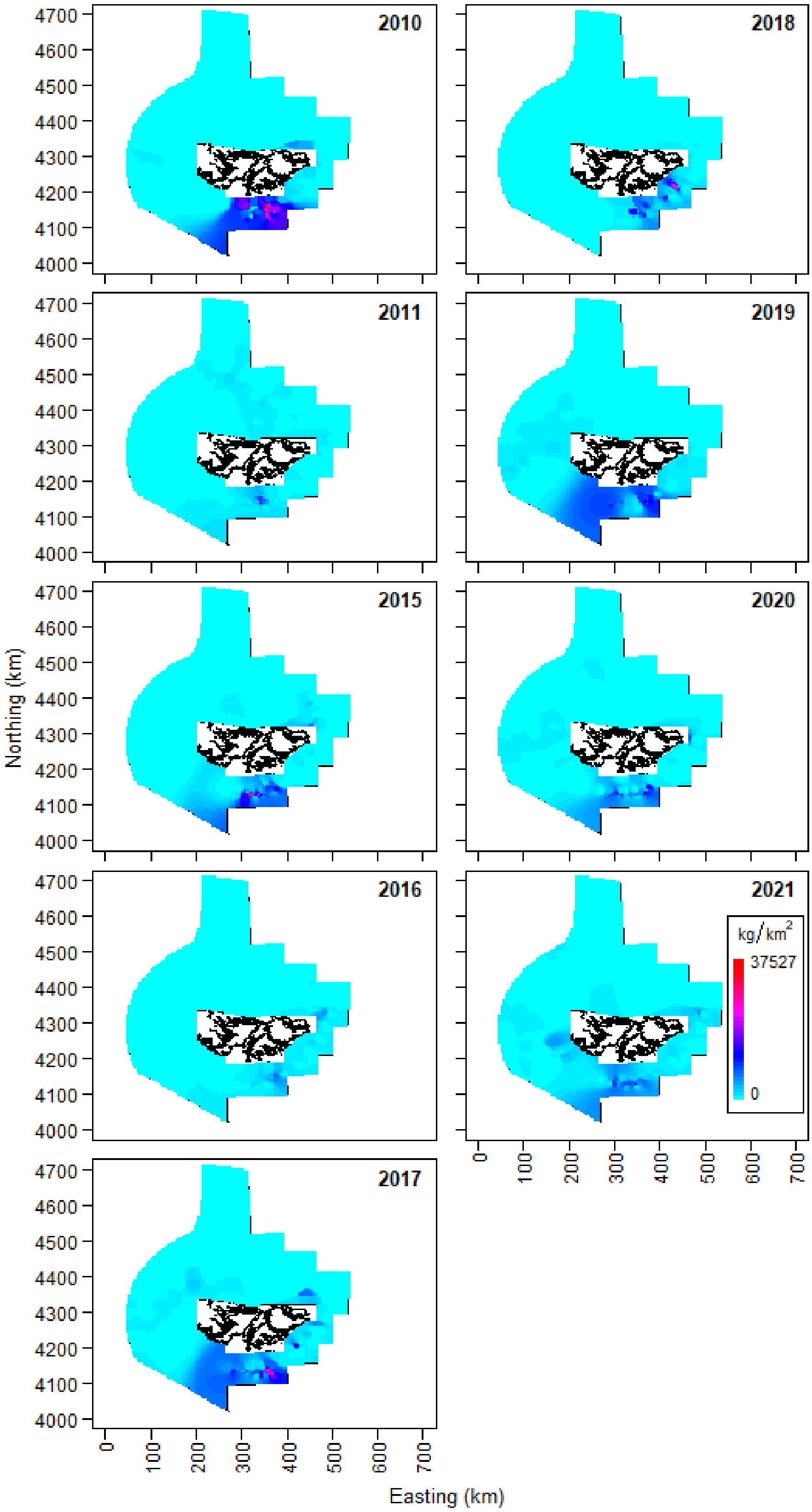
Appendix IX

Comparative density of kingclip (*Genypterus blacodes*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.



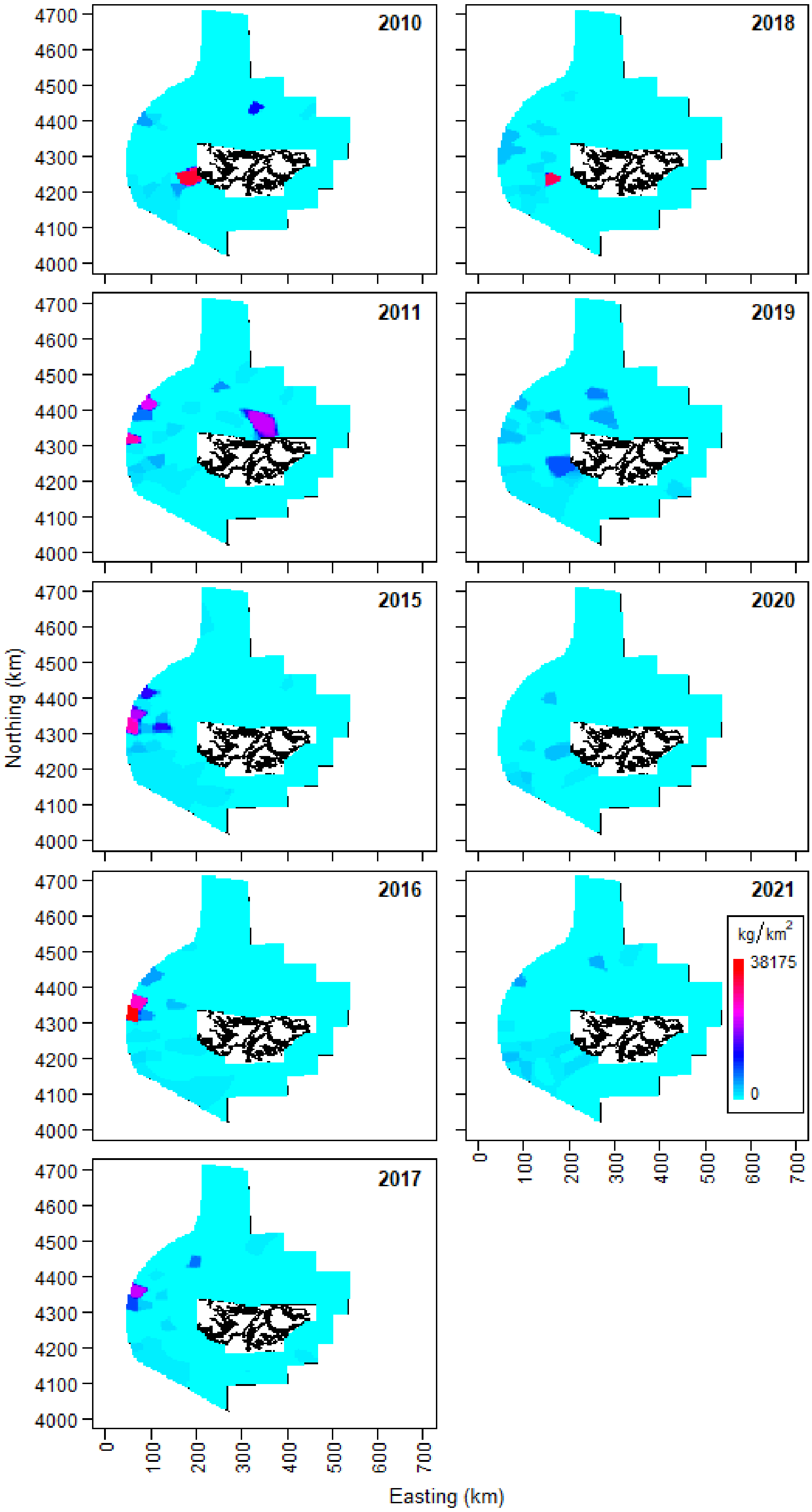
Appendix X

Comparative density of the Patagonian squid (*Doryteuthis gahi*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.



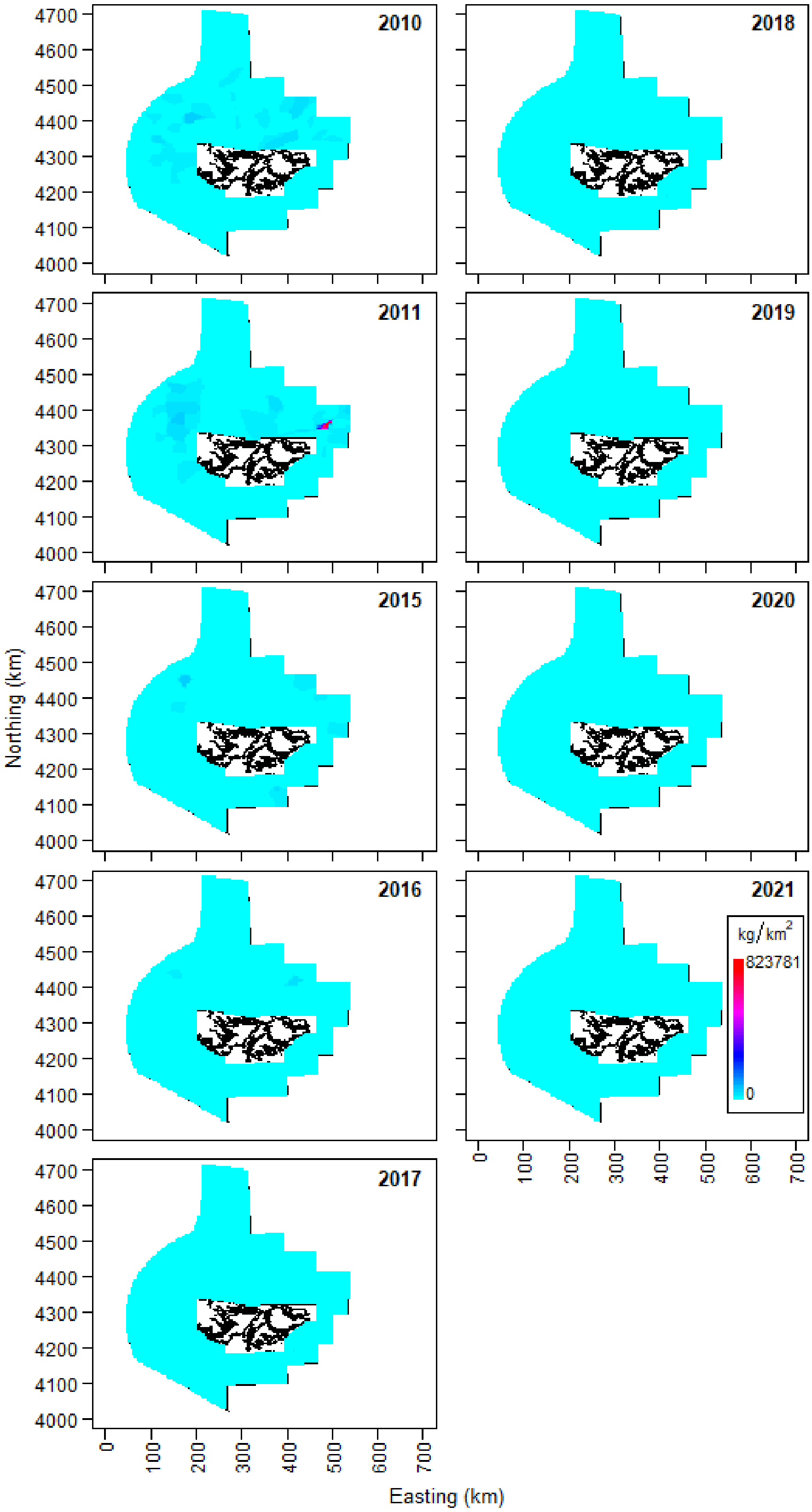
Appendix XI

Comparative density of red cod (*Salilota australis*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.



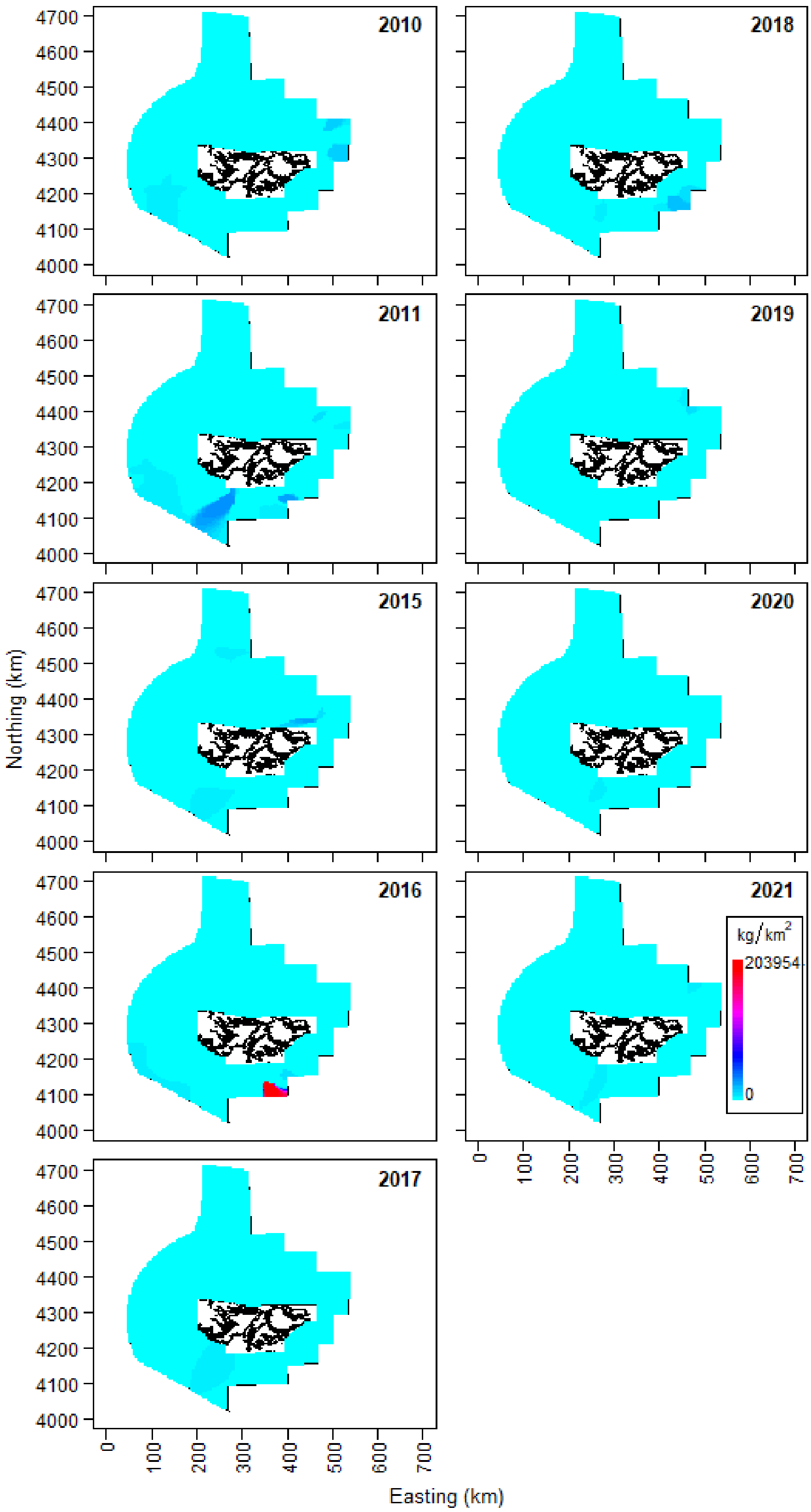
Appendix XII

Comparative density of rock cod (*Patagonotothen ramsayi*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.



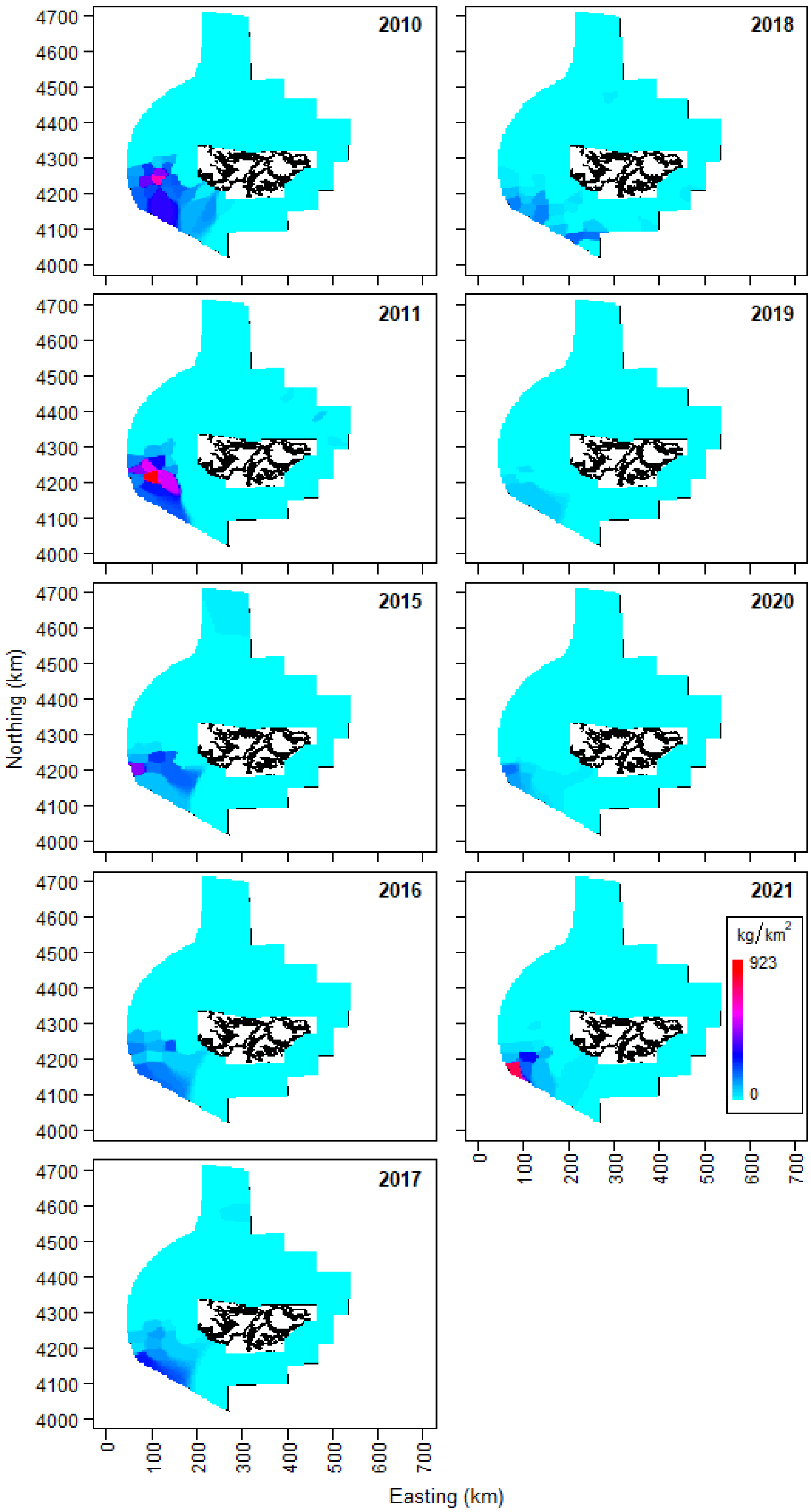
Appendix XIII

Comparative density of southern blue whiting (*Micromesistius australis australis*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.



Appendix XIV

Comparative density of southern hake (*Merluccius australis*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.



Appendix XV

Comparative density of toothfish (*Dissostichus eleginoides*) during the February 2010–2011 and 2015–2021 groundfish and calamari pre-season surveys in Falkland Islands waters. Note the data gap from 2012 to 2014.