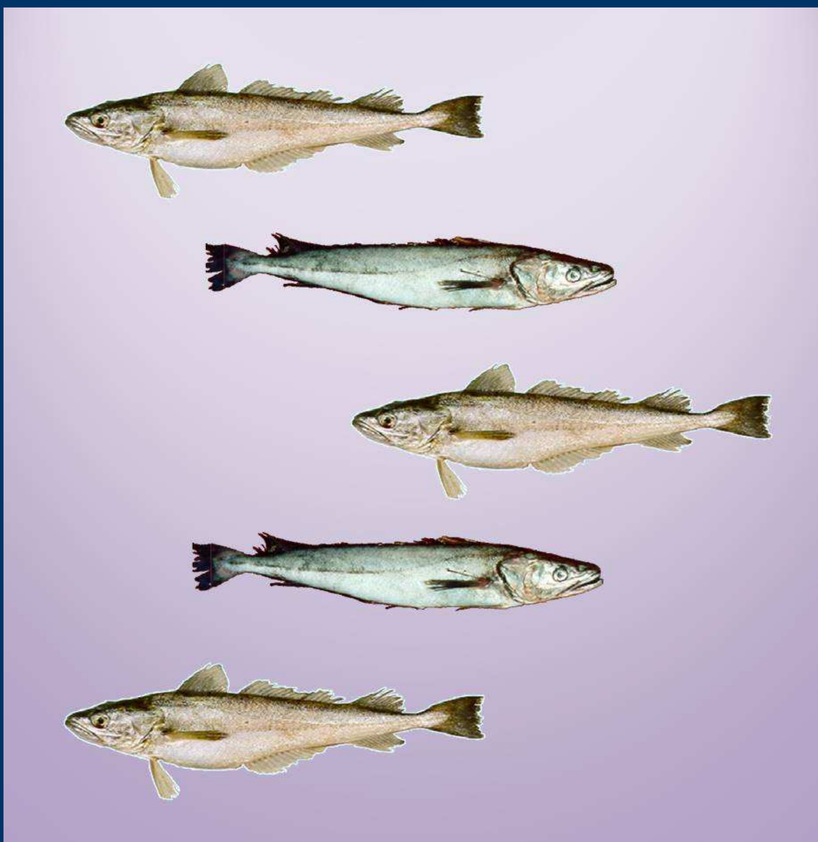
Stock Assessment
Hake

Merluccius hubbsi

Merluccius australis



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Index

Abstract

Hake biomass in 2019 was estimated at 2,526,756 tonnes *Merluccius hubbsi* and 20,526 tonnes *Merluccius australis*, using the CMSY method for data limited stocks and annual reported catches from Argentina and the Falkland Islands. The biomass estimate of *M. hubbsi* showed an increasing trend since 2008, and in 2019 reached its highest estimate since 1995, whereas the biomass estimate of *M. australis* showed an increasing trend since 2017 but was lower than any year before 2015. Both species' estimates produced high margins of uncertainty. Maximum sustainable yield (MSY) from the CMSY method was estimated at 352,409 tonnes for *M. hubbsi* and 4,617 tonnes for *M. australis*; both MSYs were higher than the combined Argentine and Falkland Islands catches of these species in 2019. Lengths at 50% adulthood (50% dichotomous juvenile / adult maturity classification) of both species have shown significant variation since their earliest calculable year (1988/1991), but were currently lower than in 1991 only for male *M. australis*. The recent high commercial catches of *M. hubbsi* in Argentina and the Falkland Islands, together with high proportions of mature individuals in catches indicate that the population is robust.

Introduction

Two species of hake *Merluccius* (Merluccidae) are taken in the commercial trawl fisheries of Argentina and the Falkland Islands: common hake *Merluccius hubbsi* and southern hake *Merluccius australis* (Sánchez et al. 2012, Navarro et al. 2014; 2019, FIG 2019). Both species are migratory (Podestá 1990, Bezzi et al. 1995, Arkhipkin et al. 2012, Arkhipkin et al. 2015), and their migration patterns indicate that some of the same stocks are taken in the fisheries of Argentina and the Falkland Islands. *M. australis* is economically more valuable (Tingley et al. 1995, Arkhipkin et al. 2015), but *M. hubbsi* yields higher volume production, representing 98.8% of Argentine hake catch south of 41°S latitude from 1987 to 2019, and 99.8% of Falklands hake catch from 1987 to 2019 (Figures 1 and 2)[1]. *M. australis*, but not *M. hubbsi*, is included in the most recent data exchange program between Argentina and the Falkland Islands (SSC 2018).

In Falkland Islands waters, both species occur over the shelf and upper continental slope but are spatially separated, with *M. hubbsi* mainly present to the north of 52°S at 100–250 m depth and *M. australis* to the south of 52°S at 150–500 m depth in colder waters (Arkhipkin et al. 2015). Data analyses around Falkland waters have shown that the two hake species can occupy the same feeding grounds by segregating spatially, temporally, and possibly in their diets (Arkhipkin et al. 2003). *M. hubbsi* migrate into western Falkland Islands waters in February, large numbers are then found to the west and north from March to May. In May, *M. hubbsi* is also found to the south and southeast, and its widest distribution occurs from July to September. The migration from the southeast occurs in September; individuals are found to the northwest in October, and leave Falkland Islands waters in November (Arkhipkin et al. 2012, 2015). Falkland Islands waters have been identified mainly as a feeding ground for this species (Arkhipkin et al. 2003), where post-spawning individuals occur mostly from March to June, and resting individuals from July to November (Arkhipkin et al. 2015). Females are larger than males, with maximum sizes in the Falkland Islands fishery at 102 cm total length (TL) for females and 90 cm TL for males; maximum age has been estimated at 18 years old (Arkhipkin et al. 2015). The von Bertalanffy length-at-age

[1] Whereby *Merluccius australis* may be underreported in commercial catches, given the difficulty of visually distinguishing between *M. australis* and *M. hubbsi* (Cousseau and Cotrina 1980).

equation estimated during periods of low (2000–2006) and high (2007–2012) abundance of *M. hubbsi* in Falkland Islands waters obtained parameters of L_∞ = 122.0 cm TL, k = 0.087, and t_0 = -1.55, and L_∞ = 111.5 cm TL, k = 0.097, and t_0 = -0.68, respectively (Arkhipkin et al. 2015).

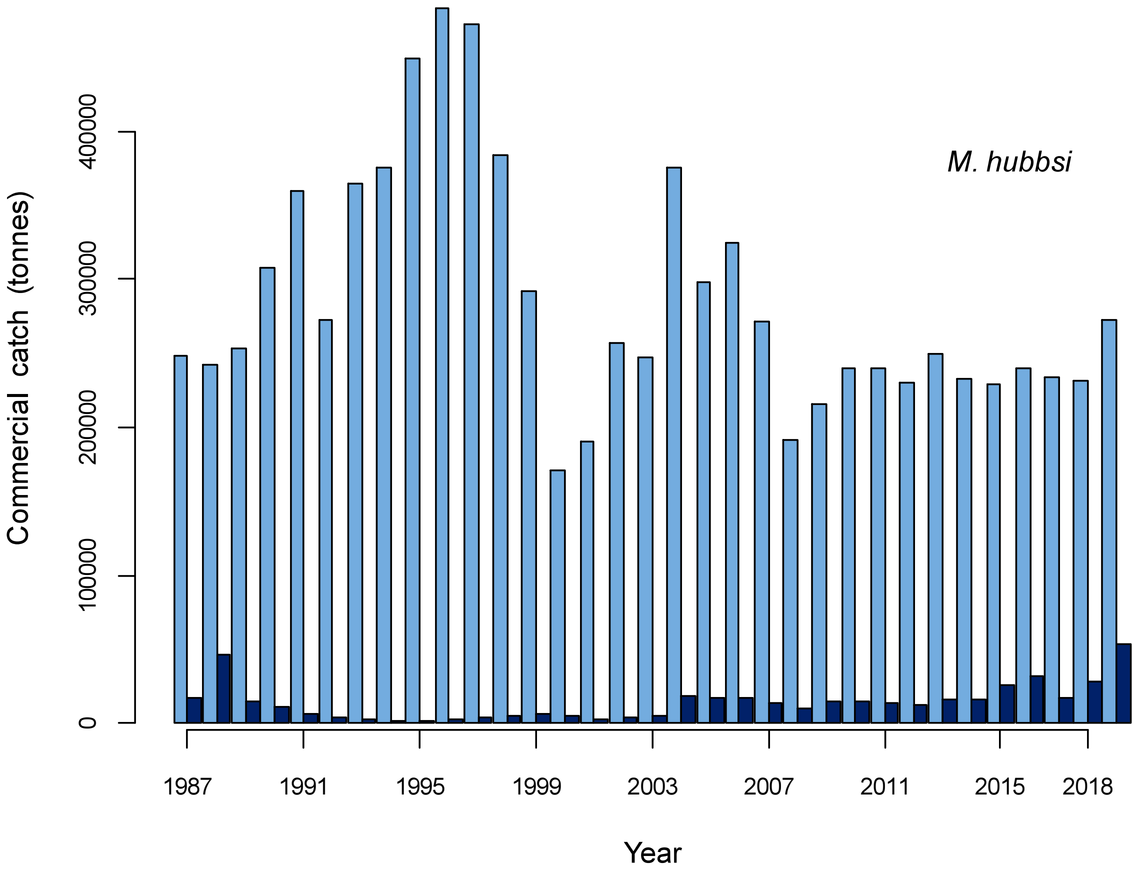


Figure 1. Commercial catches of *M. hubbsi* reported in Argentine south of 41°S latitude (light blue) and Falkland Islands (dark blue) fisheries, 1987 to 2019.

Post-spawning *M. australis* arrive to the southwest of Falkland Islands waters in spring[2]. In summer most individuals are in resting condition and located to the southwest and along the north (at ~ 200 m depth). In autumn *M. australis* occurs more commonly to the west; from May it is found mainly at the western limit of the Falkland Interim Conservation Zone and then migrates to spawning grounds out of Falkland Islands waters (Arkhipkin et al. 2015). Females are larger than males, with maximum sizes in the Falkland Islands fishery at 106 cm TL for females and 101 cm TL for males; maximum age has been estimated at 19 years old (Arkhipkin et al. 2015). The von Bertalanffy equation estimated for *M. australis* during the same periods of low (2000–2006) and high (2007–2012) abundance obtained parameters of L_∞ = 94.3 cm TL, k = 0.203, and t_0 = -0.53, and L_∞ = 136.0 cm TL, k = 0.0442, and t_0 = -7.96, respectively (Arkhipkin et al. 2015).

[2] Austral seasons are referenced throughout this report: summer (January to March); autumn (April to June); winter (July to September); spring (October to December).

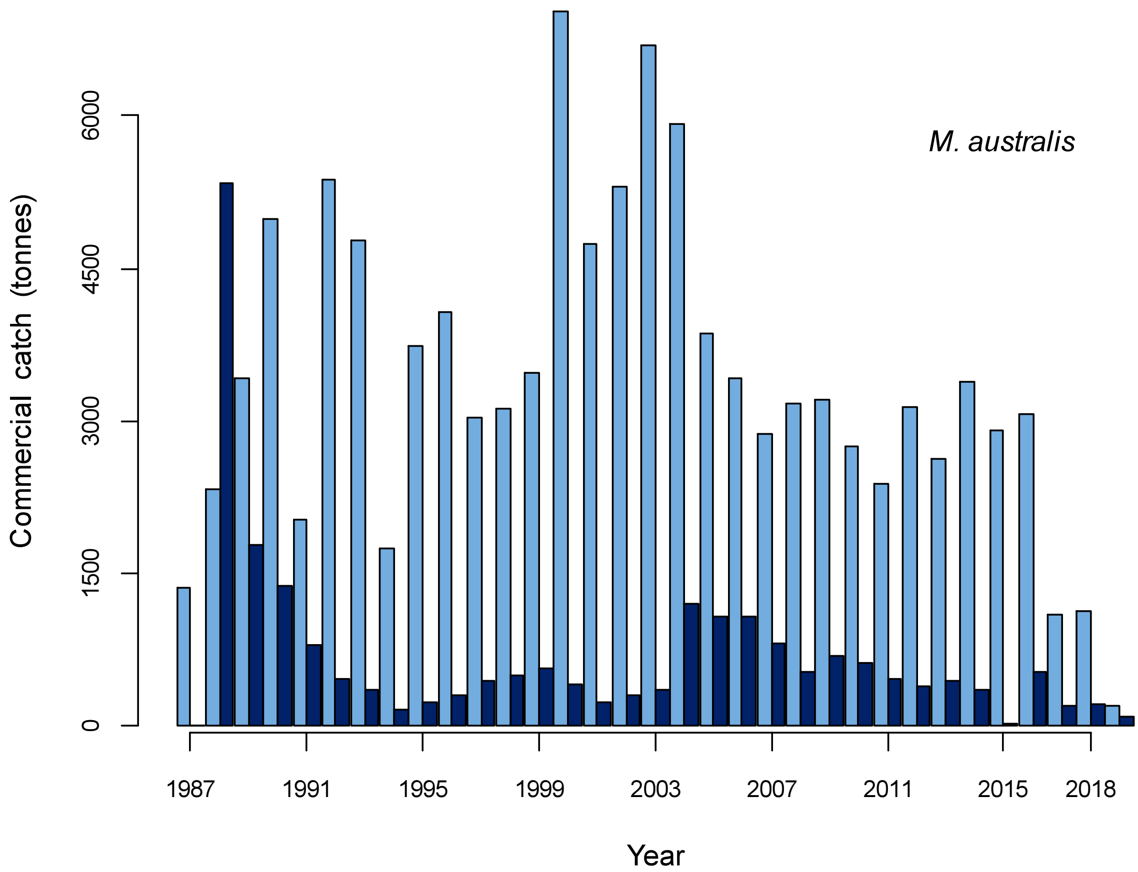


Figure 2. Commercial catches of *M. australis* reported in Argentine (light blue) and Falkland Islands (dark blue) fisheries, 1987 to 2019.

In Argentina, three stocks of *M. hubbsi* are recognized: the northern stock that occurs at 34°S–41°S, the San Matías Gulf stock at 41°S–42°S, 63°W, and the southern or Patagonian stock at 41°S–55°S (Irusta et al. 2016); the latter being the stock that migrates into Falkland Islands waters (Arkhipkin et al. 2015). Examination of spatial and temporal patterns of *M. hubbsi* CPUE in Argentine waters (34°S–47°S) suggests offshore and northwards migrations to feeding grounds during late summer and early autumn; and inshore and southward migrations to spawning grounds in early spring (Podestá 1990). Mature individuals can be found all year round, although the main reproductive peaks occur in spring and summer at three different areas: 36°S–39°S and 42°S–44°S in early spring, and 42°S–47°S in late spring-early summer (Ciechomski et al. 1979). In particular, the Patagonian stock reproduces mainly between December and January (Macchi et al. 2004). Length at 50% maturity ranges between 32 and 34 cm TL (Pájaro et al. 2005), at about 2.6 years of age. Females have longer life span and greater maximum size (15 years, 92 cm TL) compared to males (13 years, 64 cm TL). The von Bertalanffy equation based on Argentine research data of the Patagonian stock obtained L_∞ = 94.89 cm TL, k = 0.17, t_0 = -0.18 for females, and L_∞ = 53.69 cm TL, k = 0.38, t_0 = -0.10 for males (Renzi et al. 2009). Annual natural mortality has been estimated at a mean of 0.32 (D'Atri 2012). The biomass of the Patagonian stock has been variable, with a declining trend from 1996 to 2000, followed by an overall increase from 2001 to 2011 (Irusta et al. 2016). The total biomass of the Patagonian stock was estimated at variously 885,210 t and 1,143,880 t in 2018 (Santos et al. 2019). The total biomass of the northern stock declined about 79% from 1986 to 2013 (Irusta 2014).

Merluccius australis in Argentine waters is more abundant to the south of 52°S and at >150 m depth, and some level of connectivity with the Pacific Ocean stock has been suggested (Giussi et al. 2016 and references therein). Spawning appears to occur during winter on the continental shelf (Cotrina 1981). Length at 50% maturity was estimated at 59.5 cm TL, at about 4.5 years of age (Gorini et al. 2012). Females have longer life spans (18 years) compared to males (14 years); the von Bertalanffy equation obtained L_∞ = 100.19 cm TL, k = 0.137, t_0 = -1.137 for females, and L_∞ = 82.05 cm TL, k = 0.277, t_0 = 0.992 for males (Gorini et al. 2010). Annual natural mortality has been estimated at a mean of 0.19 (Giussi et al. 2016). Most individuals caught by the fishery are 60–70 cm TL, although individuals >100 cm TL are also caught (Giussi et al. 2016). In Argentine waters, the biomass of *M. australis* had a declining trend prior to 1991, followed by a period of stabilization until 2007, and a slight increase from 2012 (Giussi & Zavatteri 2018).

Annual fishery catches during 1987–2019 have a variable positive and significant negative correlation between Argentina and the Falkland Islands for *M. hubbsi*, but not significant for *M. australis* (Figure 3), according to the criterion that a horizontal line can be drawn between the 95% confidence intervals without intersection (Swartzman et al. 1992).

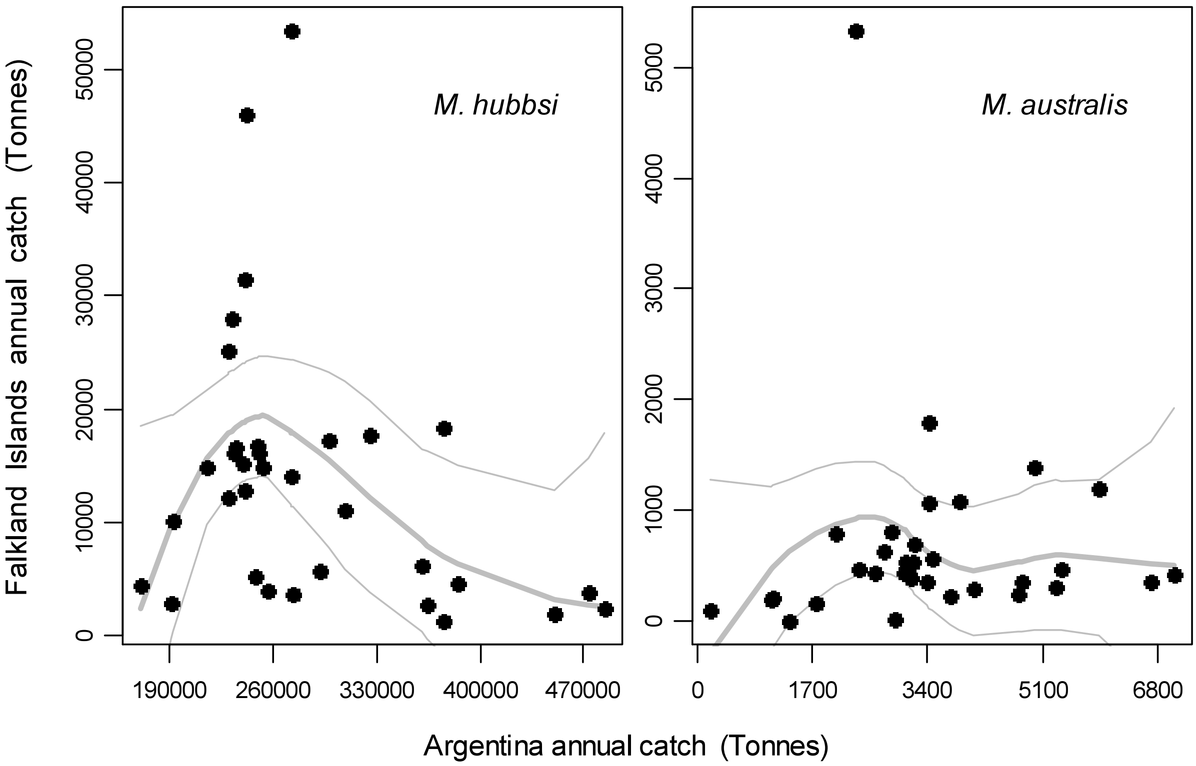


Figure 3. Annual commercial hake catches of Argentina vs. the Falkland Islands, 1987 to 2019, with LOESS smooth 95% confidence interval (grey bands; degree = 2, span = 0.90).

Methods

Assessment modelling

With effort data unavailable for Argentine hake fisheries, current assessment was based on the CMSY method designed for data-limited stocks (Froese et al. 2017). CMSY (catch –

maximum sustainable yield) uses catch time series and parameter priors to estimate fish stock abundance on a Schaefer surplus production model (Froese et al. 2017).

Hake catch time series were compiled from the national fisheries databases of Argentina and the Falkland Islands. However, Falkland Islands commercial fisheries were not required to separately report *M. hubbsi* and *M. australis* catches before 2015 (A. Blake, Falkland Islands Fisheries Department [FIFD], pers. comm.), with most years reporting zero or near-zero *M. australis*. For years before 2015, Falkland Islands hake catches were therefore proportioned between the two species according to their average ratio in observer composition samples[3]. To mitigate random variation, the yearly average proportions were smoothed by LOESS (local polynomial regression).

The CMSY prior for carrying capacity K is based on the ratio of highest total catch in the time series over growth rate r. The prior for growth rate r is based on approximate ranges of species' resilience (Martell and Froese 2013, Froese et al. 2017). Resilience is defined by the spawning stock biomass per recruit that corresponds to replacement fishing mortality, and is affected by productivity factors including fecundity, age at maturity, and longevity (Musick 1999). Stocks with greater growth rate r, carrying capacity K, greater fecundity, younger age at maturity, and shorter life cycles may have greater resilience. CMSY runs a Monte Carlo algorithm to search pairs of r and K that do not crash the stock or exceed projected maximum biomass levels in relation to depletion criteria shown by the catch time series. The median of the biomass values for each year predicted from the validated r and K pairs is then used as the most probable biomass, and the 2.5th and 97.5th percentiles are used as indicators of the range that contains 95% of the biomass predictions (Froese et al. 2017).

Both *M. hubbsi* and *M. australis* are classified as species of low resilience (Froese and Pauly 2018), and were assigned the prior range of growth parameter r 0.05 to 0.5 (Froese et al. 2017). The Monte Carlo algorithms were run to 30,000 iterations. Stock status time series of *M. hubbsi* and *M. australis* were visualized as Kobe plots of B/B_{MSY} on the x-axis vs. F/F_{MSY} on the y-axis (Maunder and Aires-da-Silva 2011), and as biomass trends by year.

The current assessment was simplified from last year's assessment, which included analyses using abundance indices to tune surplus production models in the JABBA model framework (Winker et al. 2018). The JABBA models were then composited with the CMSY models (Winter 2019). However, results of that approach were not found to give stock estimates with appreciably higher precision, and are therefore not reprised.

Total Allowable Catch

Total Allowable Catch (TAC) was defined as equivalent to the maximum sustainable yield.

Criteria that have been proposed to partition shared international fish stocks include economic dependence, proportional coastline or EEZ area, equity, and perhaps most commonly; historical catches (FAO 2002, Van Dyke 2010, Henriksen and Hoel 2011). For this assessment, the respective proportions of Argentine / Falkland Islands hake catches are calculated as a hypothetical partition in three ways: a) as the end-point of the LOESS smooth trend (degree = 2, span = 0.90) of hake catch proportions over the 1987 to 2019 time series (Figures 1 and 2), b) as the average of the last three years (2017 - 2019), and c) as the average of the last 10 ten years (2010 - 2019). However, catch trend as a criterion remains subjective. Unilateral conservation measures may decrease a catch proportion that would otherwise be higher. For example, the Falkland Islands have implemented both area and licence restrictions on the catch of hake (FIG 2018). Conversely, overfishing may inflate a catch

[3] Using observer identification remains subject to limited accuracy, given the difficulty in distinguishing between the two species (A. Blake, FIFD, pers. comm.).

proportion, and overfishing has been reported for hake (Mercopress 2010). Therefore, partitions presented in this report are exemplary only[4], and actual catch sharing (which could include simple 50-50% allocation of a TAC) remains a matter of agreement.

Lengths at maturity

For comparative evaluation, lengths at maturity were calculated from binomial logistic regressions of hake length vs. adulthood in each year. Gonadal maturity is cyclical as fish pass through pre- to post-spawning phases, and definitive maturity assignments can only be made that stages ≤1 are always juvenile and stages ≥3 are always adult (B. Lee and H. Randhawa, FIFD, pers. comm.). Therefore, maturity assignment was simplified to a dichotomous classification of juvenile (0 and 1) or adult (3+), omitting stage 2. The aggregates of 50% adulthood lengths were plotted against years and trends examined with LOESS smooths (degree = 2, span = 0.90), and weighted by the inverse average variance of each year's binomial logistic coefficients. Years were excluded if the 50% adulthood length calculation did not intercept on a positive slope, or obtained an impossible length result[5]; either <0 cm or >97 cm (*M. hubbsi*) or >155 cm (*M. australis*); the recorded maximum lengths for either species (Froese and Pauly 2018)[6]. Males and females were analysed separately as hake are sexually dimorphic (Lorenzo and Defeo 2015).

Overfishing indicators

The three overfishing indicators proposed by Froese (2004) were examined for 2019 hake catches from the available FIFD age, length, and maturity measurements: (1) % mature fish in catch (using the adulthood criteria above), (2) % optimum-length fish in catch, and (3) % 'mega-spawners' in catch. Optimum length (L_{opt}) was calculated by the empirical equation:

$$\log(L_{opt}) = 1.0421 \cdot \log(L_{\infty}) - 0.2742$$

(Froese and Binohlan 2000), where L_{∞} is asymptotic length according to the von Bertalanffy growth function, or derived from maximum reported length L_{max} by the additional empirical equation:

$$\log(L_{\infty}) = 0.044 + 0.9841 \cdot \log(L_{max})$$

(Froese and Binohlan 2000). L_{opt} represents the length where the number of fish in a given unfished year-class × their mean individual weight is maximum; thus obtaining max. yield and potential revenue. Mega-spawners are defined as fish 10% larger than L_{opt} (Froese 2004).

[4] Actual TACs of Argentine commercial fisheries are listed on the website www.agroindustria.gob.ar/sitio/areas/pesca_maritima/desembarques/, zip files Capturas Máximas Permisibles per year. For example the 2019 TAC of *M. australis* was 3400 tonnes, the 2020 TAC of *M. hubbsi* south of 41° S is 290,000 tonnes (accessed 07/05/2020). Actual allocations of Falkland Islands commercial fisheries are published annually in the licensing advice document, e.g., FIFD (2019).

[5] Results that were implausible but not categorically impossible were not excluded, to avoid subjectivity.

[6] In fact, Froese and Pauly (2018) give the maximum length for *M. hubbsi* as 95 rather than 97 cm. 13 (out of 306598) available *M. hubbsi* length measurements in the FIFD database were longer than 95 cm. To ensure reliably identified lengths, only >95 cm *M. hubbsi* measurements were accepted from observer stations that concurrently reported *M. australis* lengths, which provided a solid indication that the observer would have known to correctly distinguish the two species. Two *M. hubbsi* lengths, one of 96 cm and one of 97 cm, were thus accepted. No *M. australis* length measurements in the FIFD database were >155 cm, the maximum published by Froese and Pauly (2018).

Results
Falkland Islands 2019 catches

During 2019 a total of 53,522 tonnes *M. hubbsi* and 91 t *M. australis* were reported caught in the Falkland Islands zone, with catch by licence distributions shown in Table 1. *M. hubbsi* was the highest Falkland Islands finfish catch species in 2019 (FIG 2020 in prep.). About half of all Falklands *M. hubbsi* catch was under A licence; the designated target licence for this species. Together, the finfish licences A, G and W accounted for 98.4% of *M. hubbsi* catch and 99.4% of *M. australis* catch. Among 804 A-licence catch reports in 2019, *M. hubbsi* was the highest catch species on 765 and the second-highest on 12 catch reports. *M. australis* was fourth-highest on 1 catch report. Among 604 G licence catch reports in 2019, *M. hubbsi* was the highest catch species on 419 catch reports and the second highest catch species on 61 catch reports. *M. australis* was highest on 1 catch report. Among 754 W-licence catch reports in 2019, *M. hubbsi* was the highest catch species on 447 catch reports and the second-highest on 26 catch reports, whereas *M. australis* was third-highest on 4 catch reports.

Table 1. Falkland Islands hake catches by licence in 2019.

Licence		*M. hubbsi* catch		*M. australis* catch	
Code	Type	Tonnes	%	Tonnes	%
A	Unrestricted finfish	27162.8	50.8	8.0	8.7
G	Restricted finfish + *Illex*	11214.6	21.0	16.8	18.4
W	Restricted finfish	14238.3	26.6	66.0	72.3
F	Skate	213.6	0.4	0.0	0.0
C	Calamari 1st season	124.4	0.2	0.5	0.6
X	Calamari 2nd season	90.3	0.2	0.0	0.0
B	*Illex* squid	25.2	0.0	0.0	0.0
S	Surimi	0.0	0.0	0.0	0.0
L	Toothfish longline	0.0	0.0	0.0	0.0
E	Experimental	91.6	0.2	0.0	0.0
O	Other (outside)	354.9	0.7	0.0	0.0
Total		*53522.4	100.0	91.3	100.0

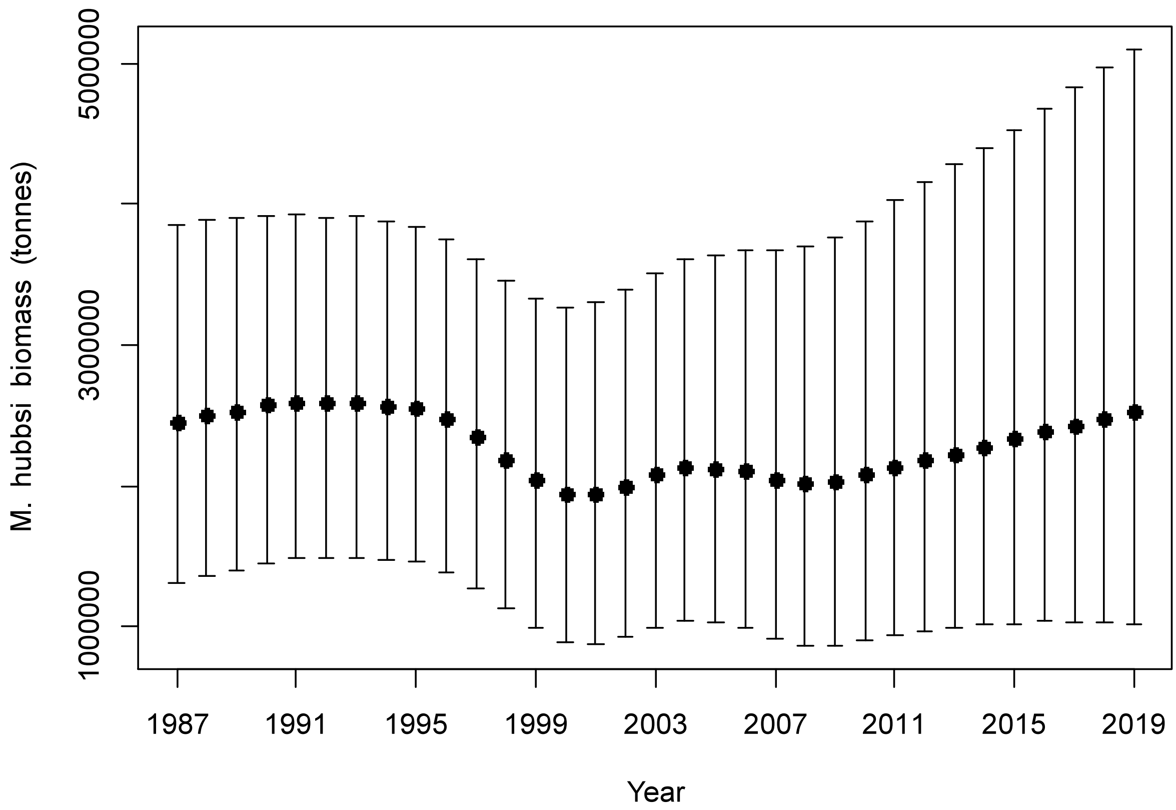
* Slightly higher than the sum of licenced catches, as a few reports were missing licence designations.

Merluccius hubbsi

CMSY for *M. hubbsi* obtained 3,522 validated parameter combinations (of the 30,000 Monte Carlo iterations), giving the median and 95% confidence interval values in Table 2. In particular, maximum sustainable yield for the whole stock was estimated at 352,409 tonnes.

Table 2. Parameter values of the CMSY surplus production model for *M. hubbsi*.

Parameter		Median	95% CI
2019 biomass (t)	B_{2019}	2526756	1014197 – 5096377
Carrying capacity (t)	K	4994476	2346476 – 10630750
Population growth rate (yr^{-1})	r	0.282	0.163 – 0.487
Maximum sustainable yield (t)	MSY	352409	233884 – 531000


M. hubbsi biomass (tonnes)
5000000
3000000
1000000
1987
1991
1995
1999
2003
2007
2011
2015
2019
Year

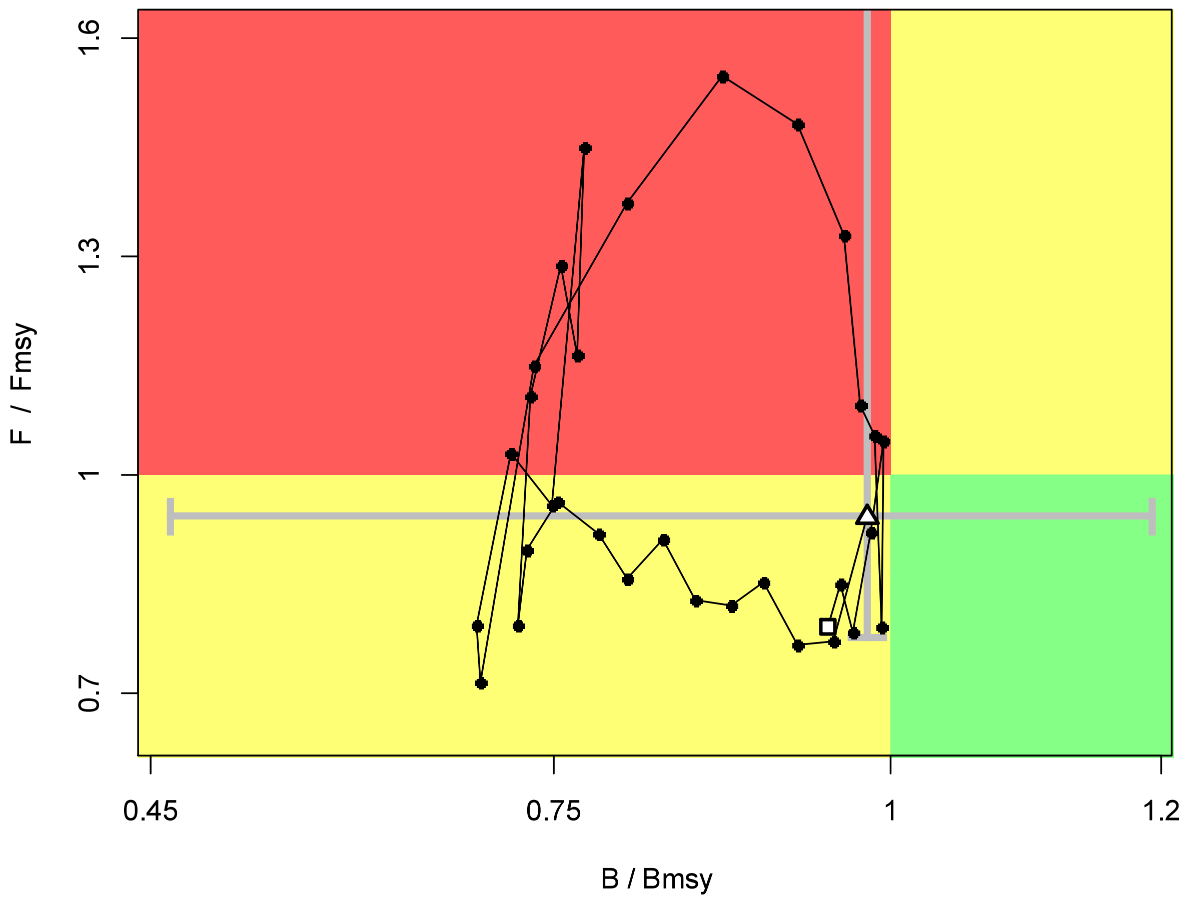

F / Fmsy
1.6
1.3
1
0.7
0.45
0.75
1
1.2
B / Bmsy

Figure 4 [previous page – top]. Time series of the *M. hubbsi* CMSY annual biomass estimates, ±95% confidence bars.

Figure 5 [previous page – bottom]. Kobe plot of the *M. hubbsi* time series calculated with CMSY, B / B_{MSY} vs. F / F_{MSY}. Square symbol: start of the time series – 1987. Triangle symbol: end of the time series – 2019. Grey bars: 95% confidence intervals in 2019.

The biomass time series ranged from a median estimate maximum of 2,596,650 tonnes in 1991 to a minimum of 1,942,816 tonnes in 2001 (Figure 4). The median estimate has been continually increasing since 2008; however, variation of the *M. hubbsi* biomass since 1987 is not statistically significantly (according to the horizontal intersection criterion).

The Kobe plot for *M. hubbsi* showed the stock starting out at B/B_{MSY} = 0.952 and F/F_{MSY} = 0.790 in 1987, then subject to overfishing (F/F_{MSY} > 1) in most years from 1991 to 2007. Prominent exceptions were 1992, 2000, and 2001; these clearly show as years of lower catches on Figure 1. Since 2008 F/F_{MSY} has remained <1, and B/B_{MSY} increased again to give the time series a roughly counter-clockwise loop (Figure 5), with B/B_{MSY} in 2019 = 0.982 and F/F_{MSY} in 2019 = 0.942. Both B/B_{MSY} and F/F_{MSY} in 2019 were, however, subject to wide margins of uncertainty bracketing 1.

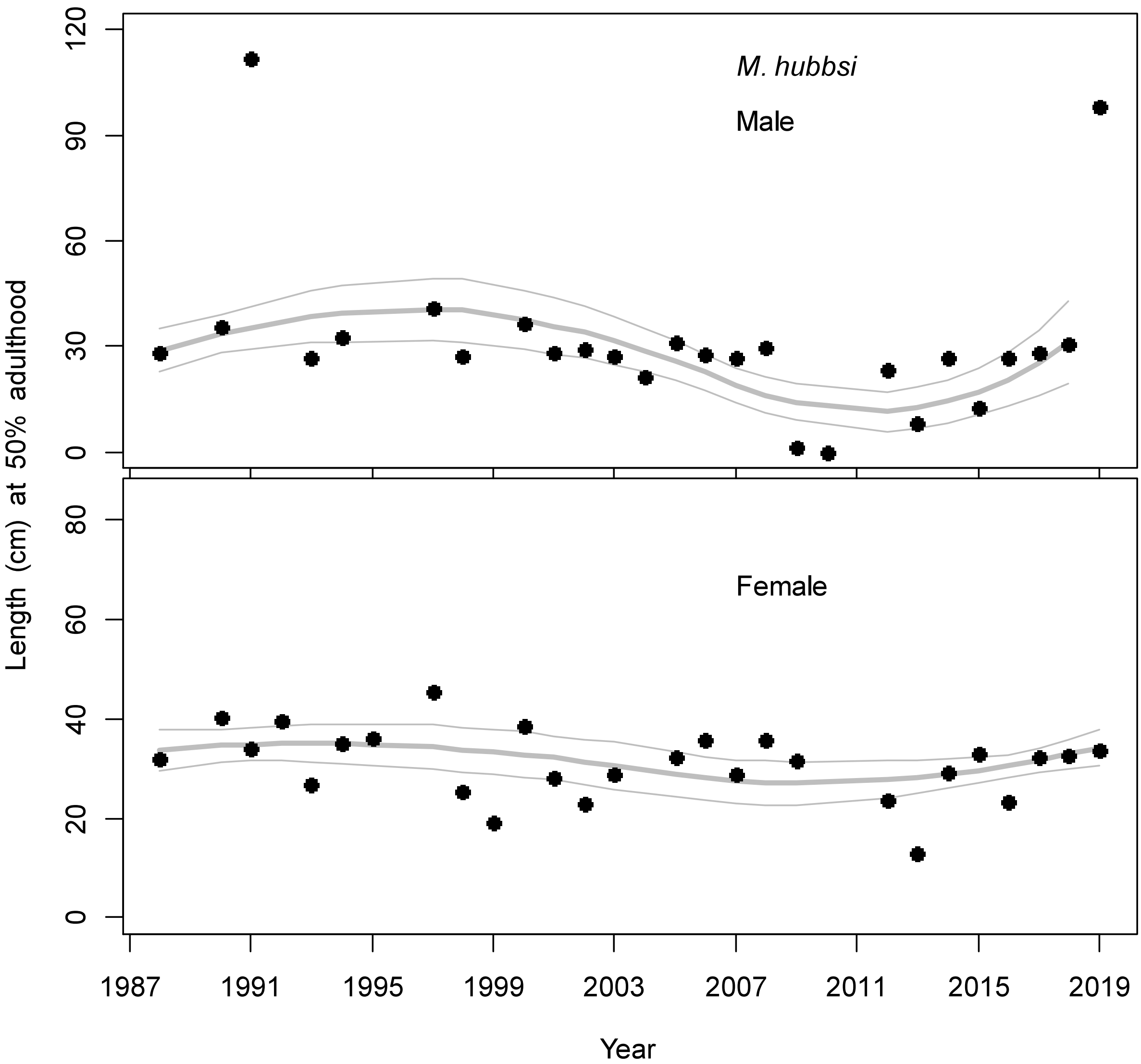


Figure 6 [previous page]. Lengths at 50% adulthood of male (top) and female (bottom) *M. hubbsi*, 1988 to 2019. Yearly data correspond to the 0.5 length intercepts in Figure A1. Grey lines are LOESS smooths ± 95% confidence intervals. LOESS calculations exclude years 1989, 1991, 1992, 1995, 1996, 1999, 2010, 2011, and 2019 for males, and years 1989, 1996, 2004, 2010, and 2011 for females.

Lengths at 50% adulthood were calculated from 43,907 male and 146,253 female measurements in the FIFD database. As Falkland Islands waters are mainly a feeding area, only 1,872 of the males and 4,336 of the females measured were juvenile (stages 0 and 1), resulting in poorly convergent binomial logistic regressions in multiple years and no regressions at all in years when no juvenile specimens were measured. Years 1989, 1991, 1992, 1995, 1996, 1999, 2010, 2011, and 2019 for males, and years 1989, 1996, 2004, 2010, and 2011 for females obtained impossible lengths (Figure A1) and were excluded from the time series trend smooths. Male lengths at 50% adulthood declined significantly between approximately 1997 and 2011, then trended upward again (Figure 6 – top). Female lengths at 50% adulthood also declined significantly over the same range of years, then levelled (Figure 6 – bottom).

The three overfishing indicators of Froese (2004) are summarized for *M. hubbsi* in Table 3 by finfish licence. For the 'mature' indicator, the target outcome would be 100% of fish caught (Froese 2004). All three finfish licences came close to this target. For the L_{opt} indicator, the target outcome would be all catch within ±10% of L_{opt}. L_{opt} = 86.8 cm was derived empirically from L_{max} = 97 cm, as the von Bertalanffy estimation produced a questionable L_∞ = 121.2 cm (Figure A2)[7]. Only very small proportions of *M. hubbsi* finfish catches were within ±10% of L_{opt} (Table 3). For the 'mega-spawner' indicator, the target outcome would be at least 20% catch consisting of mega-spawners in fisheries that are managed without individual length restrictions (which would demonstrate that these large individuals are present in the stock). No Falkland Islands finfish-licence fishery came close to this target (Table 3).

Table 3. By licence, proportions of sampled *M. hubbsi* that were mature, within 10% of L_{opt}, and mega-spawners; i.e., >110% of L_{opt}, from commercial Falkland Islands fisheries in 2019.

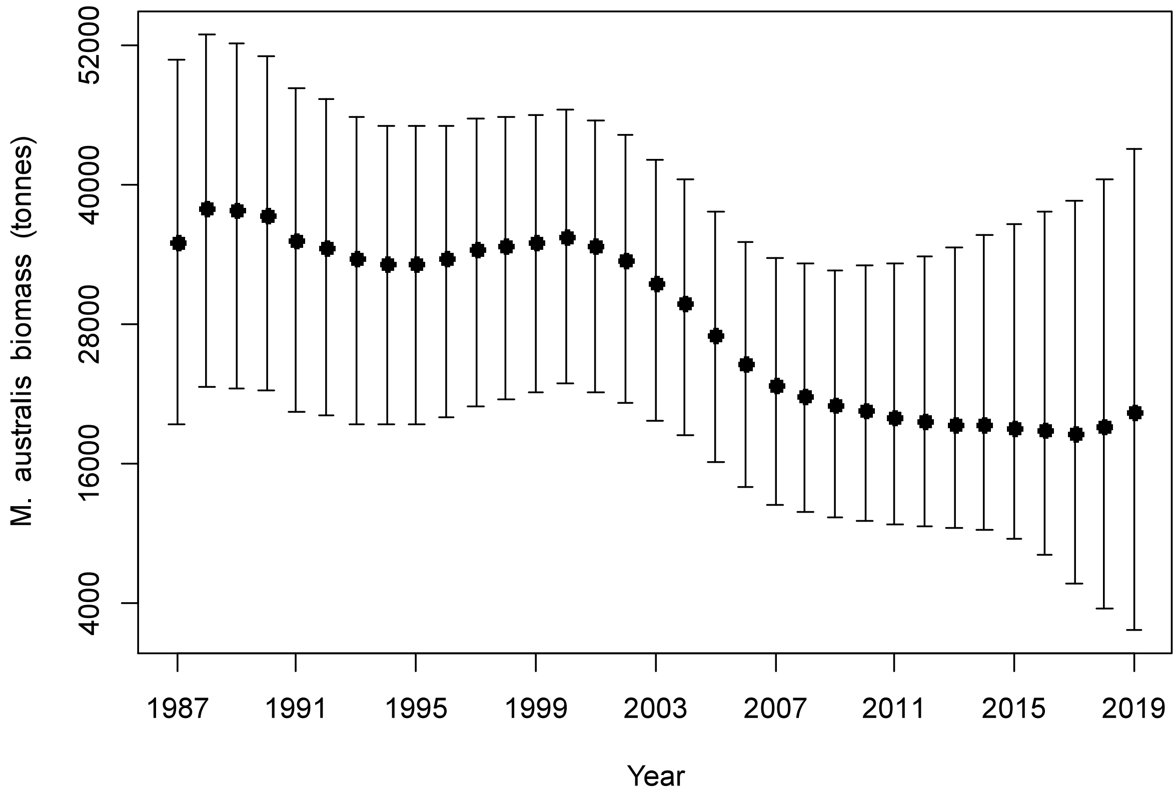
Licence		N	Overfishing indicators		
			Mature	L_{opt}	Mega-spawners
A	Unrestricted finfish	7623	0.9645	0.0007	0.0000
G	Restricted finfish + *Illex*	4303	0.9851	0.0009	0.0000
W	Restricted finfish	4060	0.9739	0.0007	0.0002

Merluccius australis

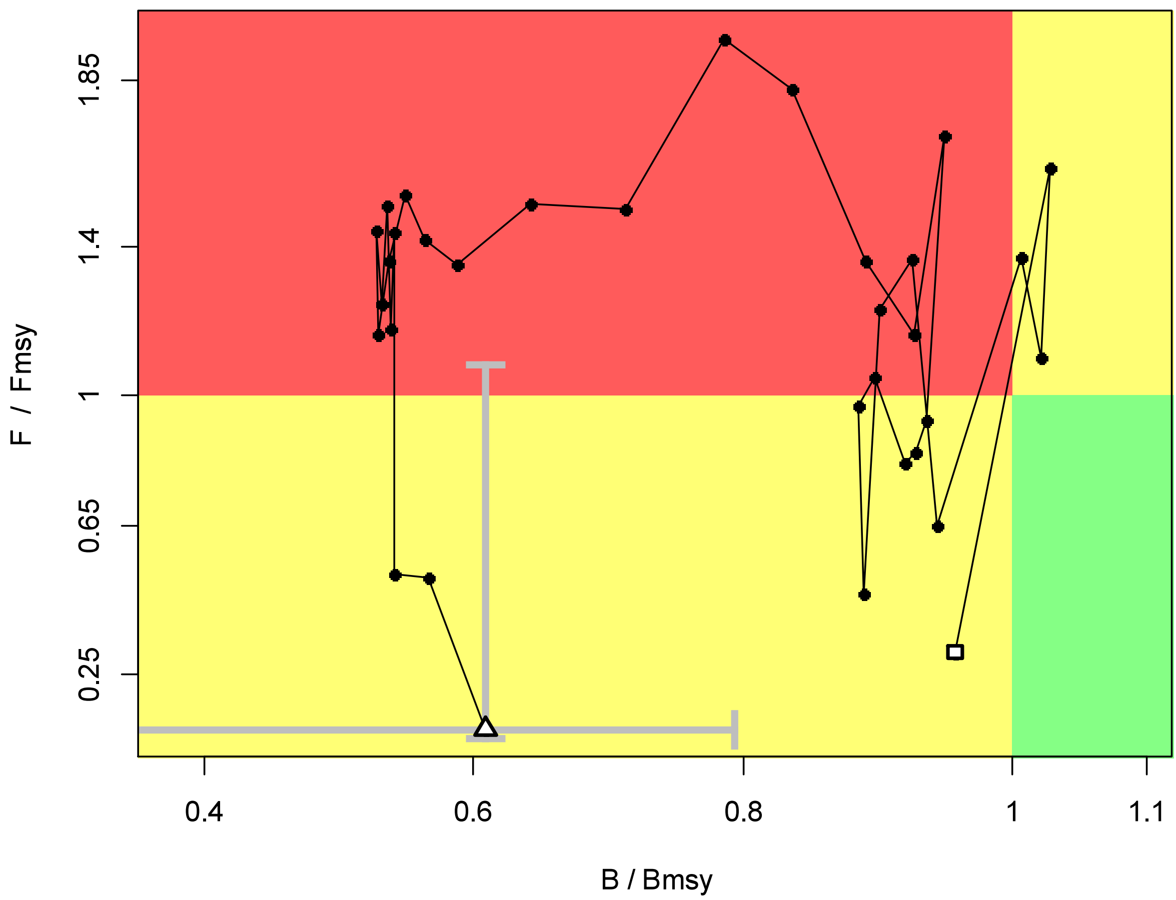
CMSY for *M. australis* obtained 1,592 validated parameter combinations (of the 30,000 Monte Carlo iterations), giving the median and 95% confidence interval values in Table 4. Maximum sustainable yield for the whole stock was estimated at 4,617 tonnes.

The biomass time series reached its lowest median estimate at 18,611 tonnes in 2017; then increased modestly for the next two years. As for *M. hubbsi*, variation of the *M. australis* biomass time series since 1987 is not statistically significant (Figure 7).

[7] The von Bertalanffy curve was calculated from only 576 individuals aged by FIFD scientific staff and considered reliable. This data set was deficient in older individuals for a reliable estimate (Figure A2).



M. australis biomass (tonnes)
52000
40000
28000
16000
4000
1987
1991
1995
1999
2003
2007
2011
2015
2019
Year



F / Fmsy
1.85
1.4
1
0.65
0.25
0.4
0.6
0.8
1
1.1
B / Bmsy

Figure 7 [previous page – top]. Time series of the *M. australis* CMSY annual biomass estimates, ±95% confidence bars.

Figure 8 [previous page – bottom]. Kobe plot of the *M. australis* time series calculated with CMSY, B / B_{MSY} vs. F / F_{MSY}. Square symbol: start of the time series – 1987. Triangle symbol: end of the time series – 2019. Grey bars: 95% confidence intervals in 2019.

Table 4. Parameter values of the CMSY surplus production model for *M. australis*.

Parameter		Median	95% CI
2019 biomass (t)	B_{2019}	20526	1763 – 43146
Carrying capacity (t)	K	65427	31664 – 135191
Population growth rate (yr^{-1})	r	0.282	0.163 – 0.487
Maximum sustainable yield (t)	MSY	4617	3247 – 6563

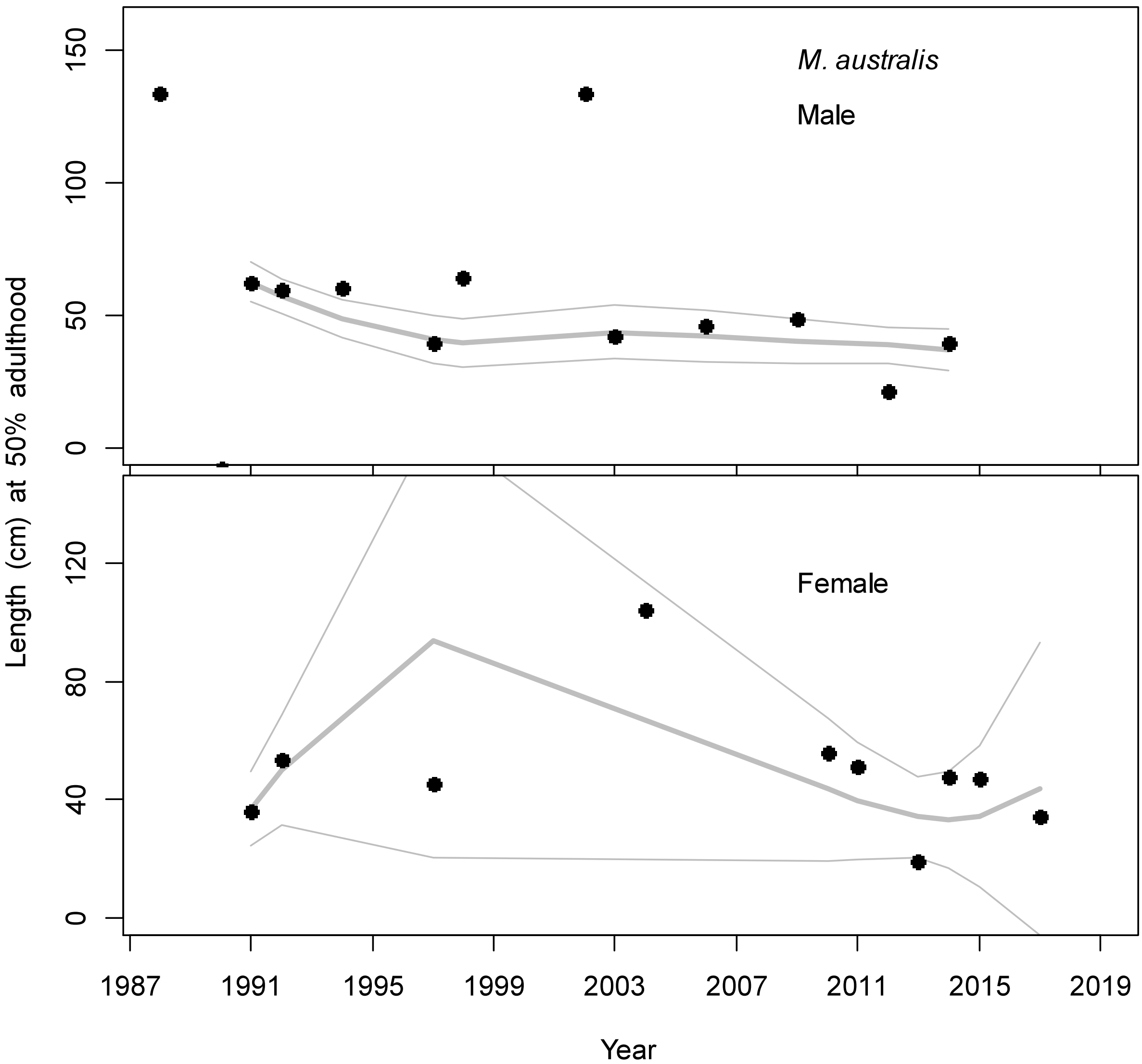


Figure 9. Lengths at 50% adulthood of male (top) and female (bottom) *M. australis*, 1988 to 2019. Yearly data correspond to the 0.5 length intercepts in Figure A3. Grey lines are LOESS smooths ± 95% confidence intervals. The LOESS calculations include years 1991, 1992, 1994, 1997, 1998,

2003, 2006, 2009, 2012, and 2014 for males, and years 1991, 1992, 1997, 2010, 2011, 2013, 2014, 2015, and 2017 for females.

The Kobe plot for *M. australis* showed the stock starting at B/B_{MSY} = 0.957 and F/F_{MSY} = 0.309 in 1987 (Figure 8). B/B_{MSY} then increased >1 for the next three years 1988 – 1990; visible as the highest points in Figure 7. For the next 10-12 years both B/B_{MSY} and F/F_{MSY} shifted erratically, corresponding to the biomass plateau until 2000 in Figure 7, followed by decreasing biomass as F/F_{MSY} stayed consistently >1 and B/B_{MSY} decreased. Overfishing (F/F_{MSY} > 1) has only ceased in the last 3 years (Figure 8) as the biomass time series showed the beginning of a slight increase (Figure 7). Like *M. hubbsi* (Figure 5), the stock status of *M. australis* thus followed a counter-clockwise loop, but unlike *M. hubbsi*, B/B_{MSY} of *M. australis* remained significantly <1 as of 2019 (Figure 8).

Lengths at 50% adulthood were calculated from 2,729 male and 7,550 female measurements in the FIFD database, of which respectively 41 and 41 juveniles. Time series trends of length at 50% adulthood were sparse as many years did not yield useable data (Figure A3). Notwithstanding, for males length at 50% adulthood declined significantly from 1991 to about 1998 (Figure 9 – top) according to the horizontal line intersection criterion. For females, length at 50% adulthood did not change significantly through the time series (Figure 9 – bottom).

Overfishing indicators were not examined for *M. australis*, as only 33 sampled individuals in 2019 had a maturity assignment.

Total Allowable Catch

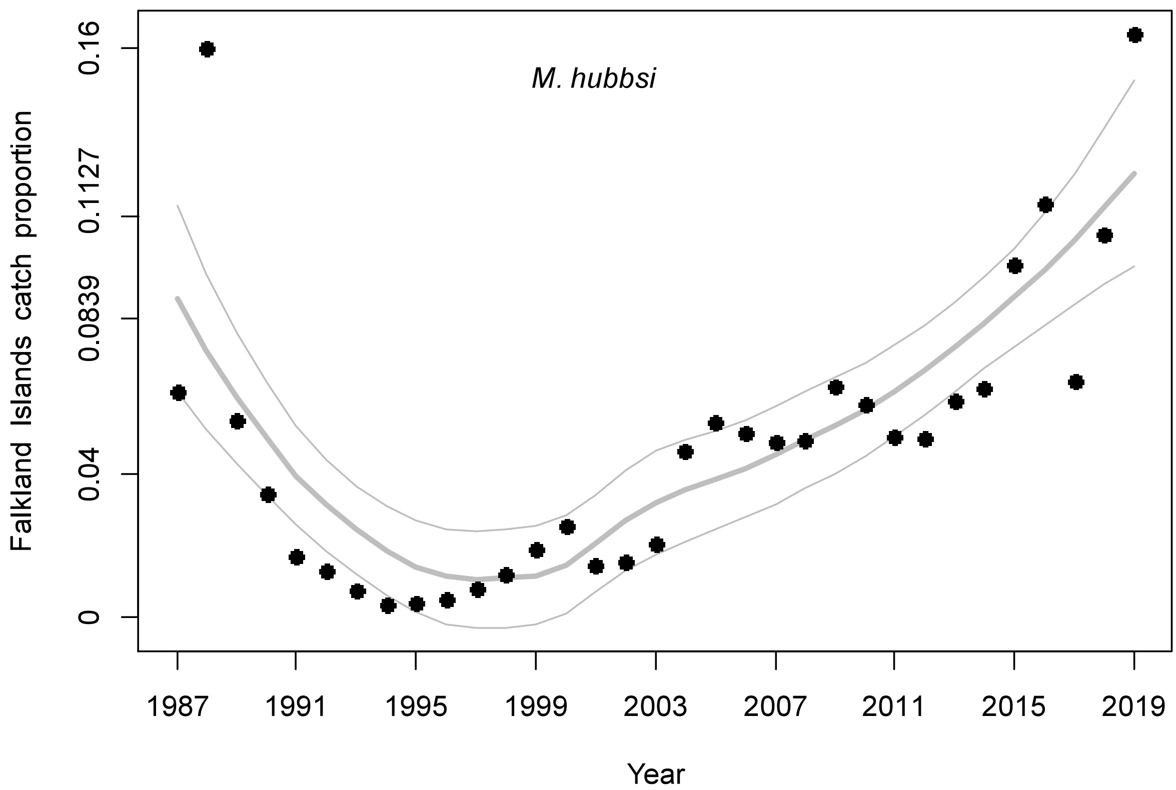


Figure 10. Time series trend of the proportion of total *M. hubbsi* catch that is taken by Falkland Islands fisheries. Lines: LOESS smooth and 95% confidence interval.

For *M. hubbsi*, the end-point of the LOESS smooth corresponded to a Falkland Islands catch proportion of 12.49% of the total (Figure 10). The average of 2017 – 2019 Falklands catch proportions was $\overline{6.62,\ 10.78,\ 16.42\%}$ = 11.27%, and the average of 2010 – 2019 Falklands catch proportions was $\overline{5.96, 5.09, 5.02, 6.07, 6.45, 9.89, 11.62, 6.62, 10.78, 16.42\%}$ = 8.39% (Figure 10). Thus, with a total MSY of 352,409 tonnes, the Falklands proportion equates to TAC options of a) 44,000 tonnes, b) 39,726 tonnes, or c) 29,574 tonnes.

For *M. australis*, the most recent year 2019 had the highest ever proportion of Falkland Islands catch: 32.82%, whereby, however, Argentina's 2019 catches were the lowest of the time series by a factor >5× (Figure 2). The end-point of the LOESS smooth corresponded to a Falklands catch proportion of 17.54% of the total (Figure 11). The average of 2017 – 2019 Falkland Islands catch proportions was $\overline{15.33, 15.74, 32.82\%}$ = 21.30%, and the average of 2010 – 2019 Falkland Islands catch proportions was $\overline{18.50, 16.36, 10.91, 14.17, 9.61, 0.51, 14.81, 15.33, 15.74, 32.82\%}$ = 14.88%. The zero proportion in 1987 (Figure 11) predates effective observer sampling, and the 0.6965 proportion in 1988 is likely an artefact of the exceptionally high (until recently) Falkland Islands hake catch that year (Figures 1 and 2). With a total MSY of 4,617 tonnes, the Falkland Islands proportion equates to TAC options of a) 810 tonnes, b) 983 tonnes, or c) 687 tonnes.

It is reiterated that these TAC options are exemplary proposals only, as both Argentina and the Falkland Islands set their fishery allocations separately of each other.

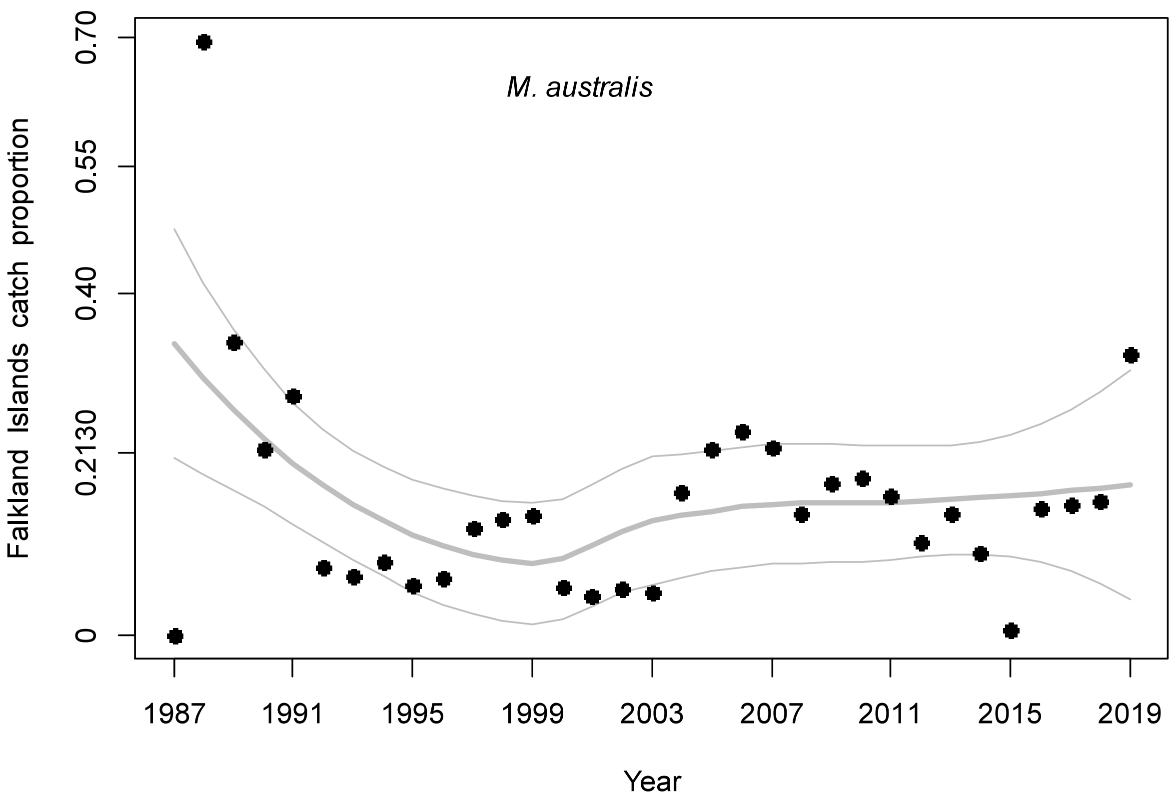


Figure 11. Time series trend of the proportion of total *M. australis* catch that is taken by Falkland Islands fisheries. Lines: LOESS smooth and 95% confidence interval.

Conclusion

Combined hake catches (*M. hubbsi* + *M. australis*) in 2019 were the highest on record (i.e., since 1987) in the Falkland Islands, and the highest since 2002 in Argentina (Figures 1 and 2). Catches of either species in 2019 (*M. hubbsi*: 53,522 t FK + 272,454 t AG, *M. australis*: 91 t FK + 187 t AG) were nevertheless below MSY calculated from the CMSY models. Modelled lengths at 50% adulthood showed some significant variation with the revised constraints on time series fitting; however, only for male *M. australis* was the modelled length at 50% adulthood lower in the most recent year than at the start of the time series (Figures 6 and 9).

The current hake stock assessment is conspicuous for its absence of statistically significant time series variation in *M. hubbsi* and *M. australis* biomass estimates (Figures 4 and 7), despite considerable inter-annual differences in commercial catches. For *M. australis*, the marginal occurrence of this species in Southwest Atlantic fisheries, and potential for misidentification, render a non-significant outcome expectable. For *M. hubbsi*, the outcome may reflect non-stationarity of the population. In Falkland Islands fisheries, hake catches from 2005 have had a statistically significant inverse correlation with rock cod (*Patagonotothen ramsayi*) catches, supporting the inference that carrying capacity of the marine environment has decreased for rock cod (Winter 2020). The corollary would be that carrying capacity has increased for hake, and that the fixed-carrying capacity CMSY method is correspondingly imprecise.

Opposite fates of hake and rock cod appear contradicted by their similar profiles of overfishing indicators: both *M. hubbsi* (Table 3, this report) and *P. ramsayi* (Table 12, Winter 2020) show predominantly mature fish being caught, but low proportions of 'optimum length' and 'mega-spawners'. However, 'optimum length' and 'mega-spawner' parameters are derivatives constructed from multiple regression across numerous taxa (Froese and Binohlan 2000), and are not certain to match Falkland Islands fisheries when only part of the hake stock's size / age distribution migrates to the Falklands zone. Likewise, the high catch proportions of mature *M. hubbsi* may primarily reflect that immature fish are not accessible anyway, but thereby imply that the Falkland Islands fishery is relatively safe for this species. Together with the current high overall catch levels of *M. hubbsi* – in mixed fisheries – the indications are of a robust population.

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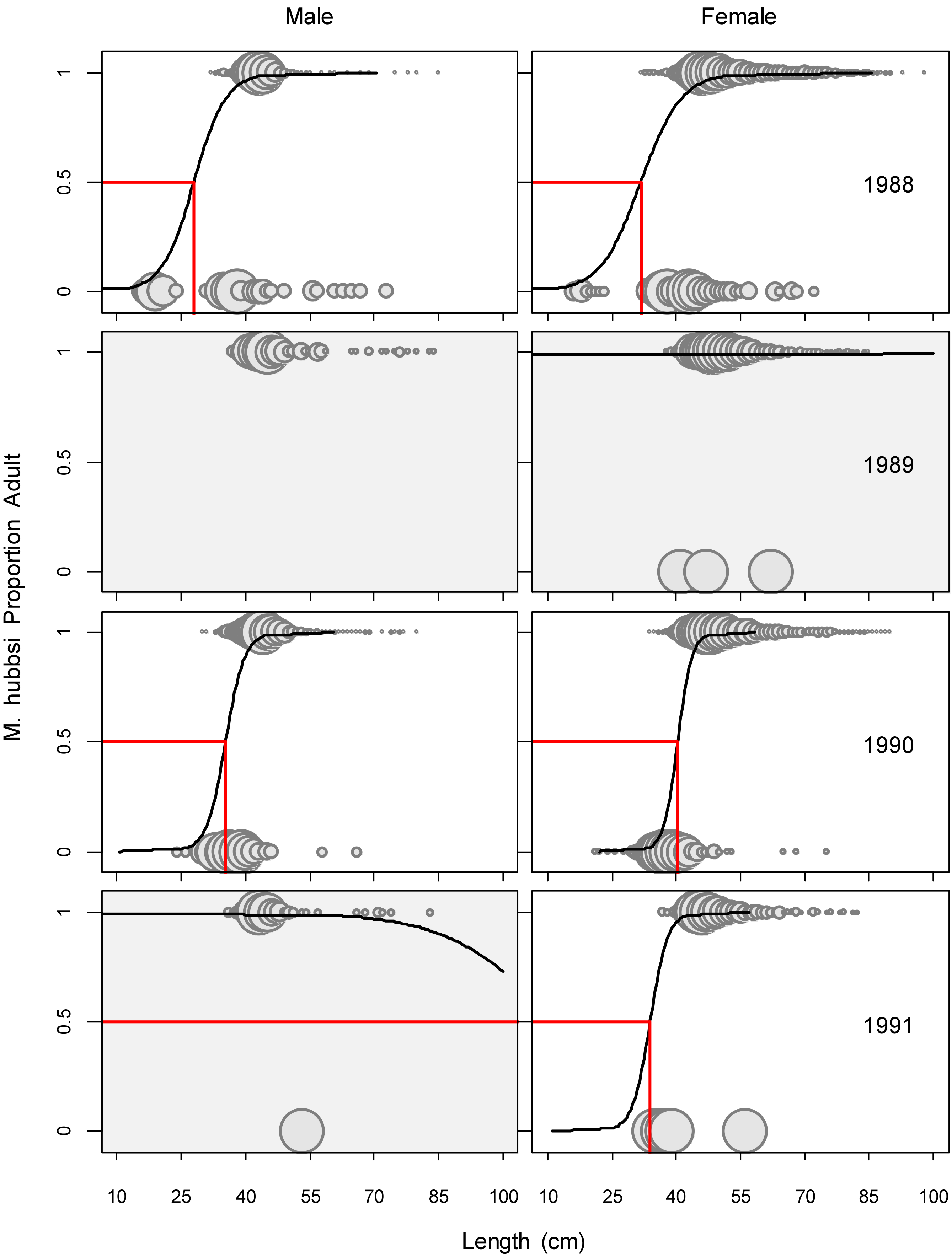
Appendix



Male
Female
1988
1989
1990
1991
1
0.5
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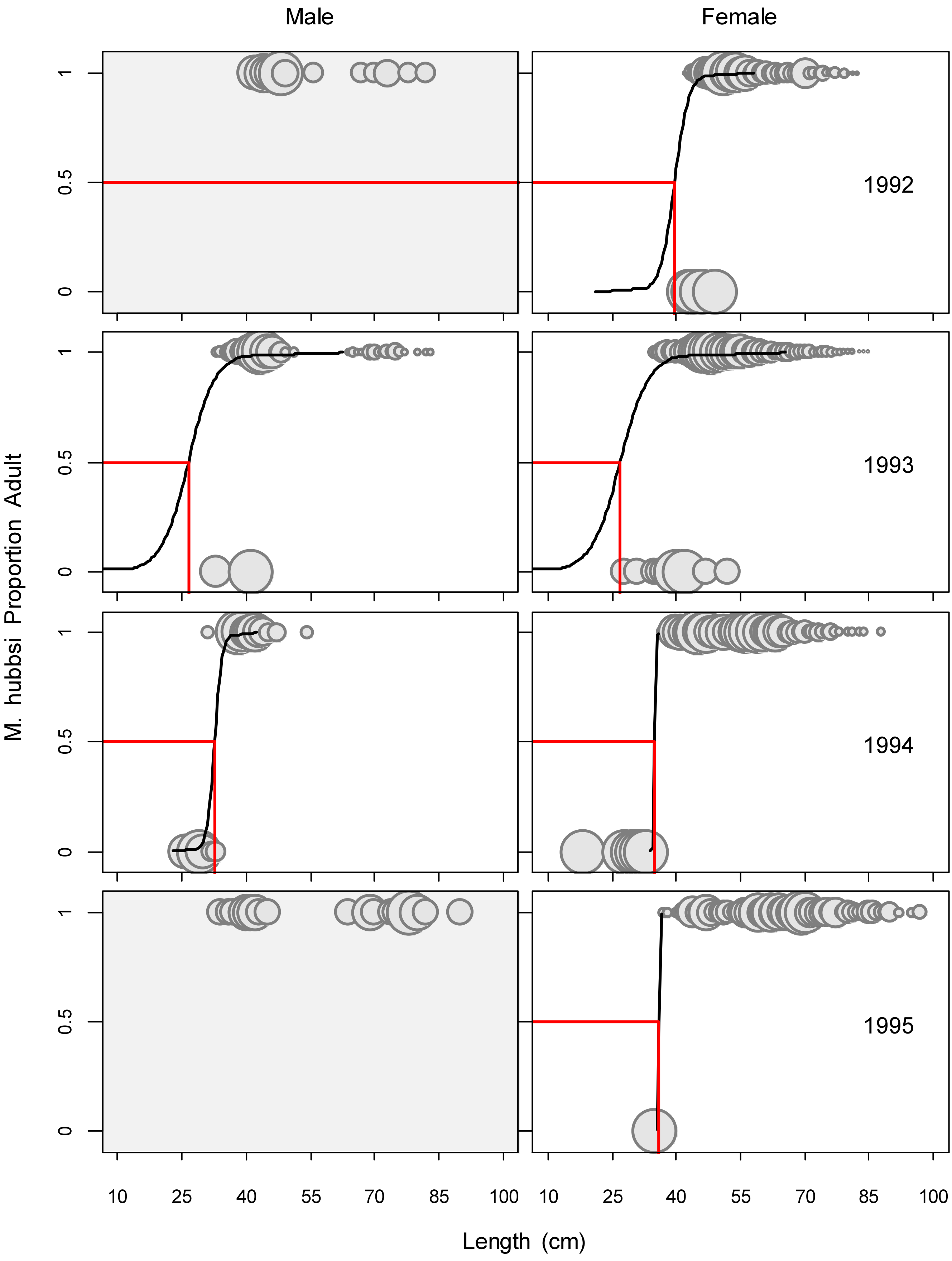
10
25
40
55
70
85
100
M. hubbsi Proportion Adult
Length (cm)



Male
Female
M. hubbsi Proportion Adult
1992
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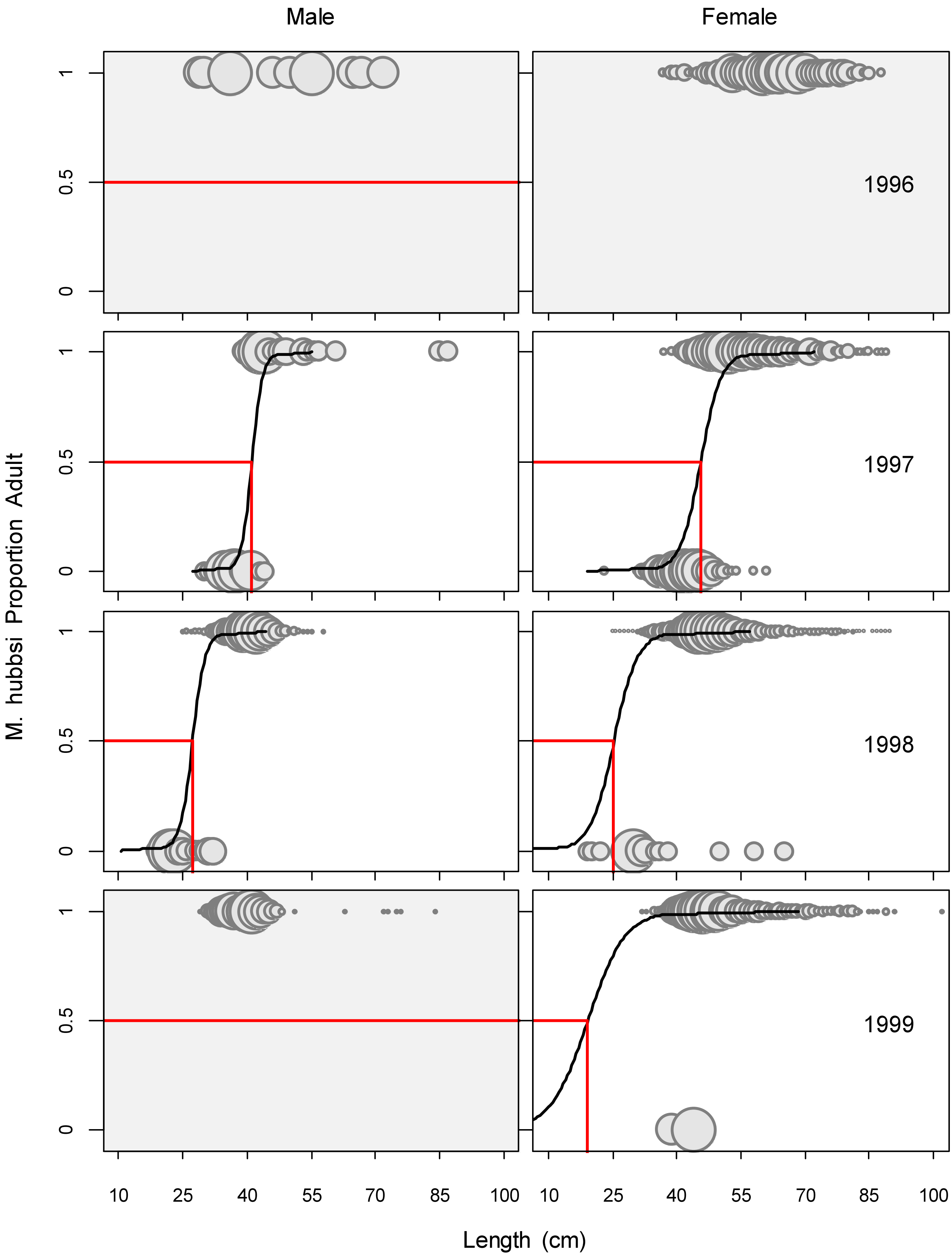
Length (cm)


Male
Female
1996
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M. hubbsi Proportion Adult
Length (cm)
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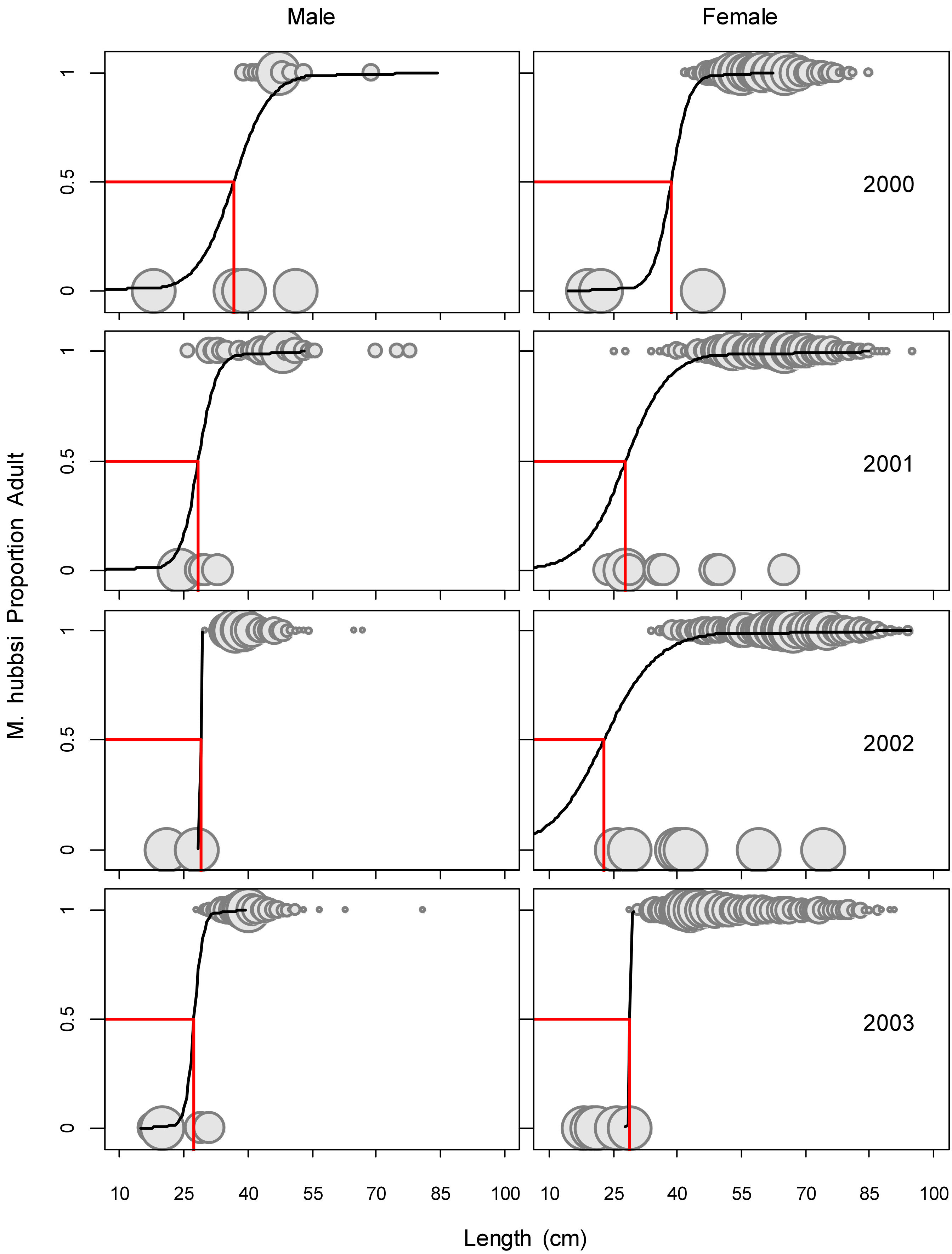

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2000
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M. hubbsi Proportion Adult
Length (cm)
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0.5
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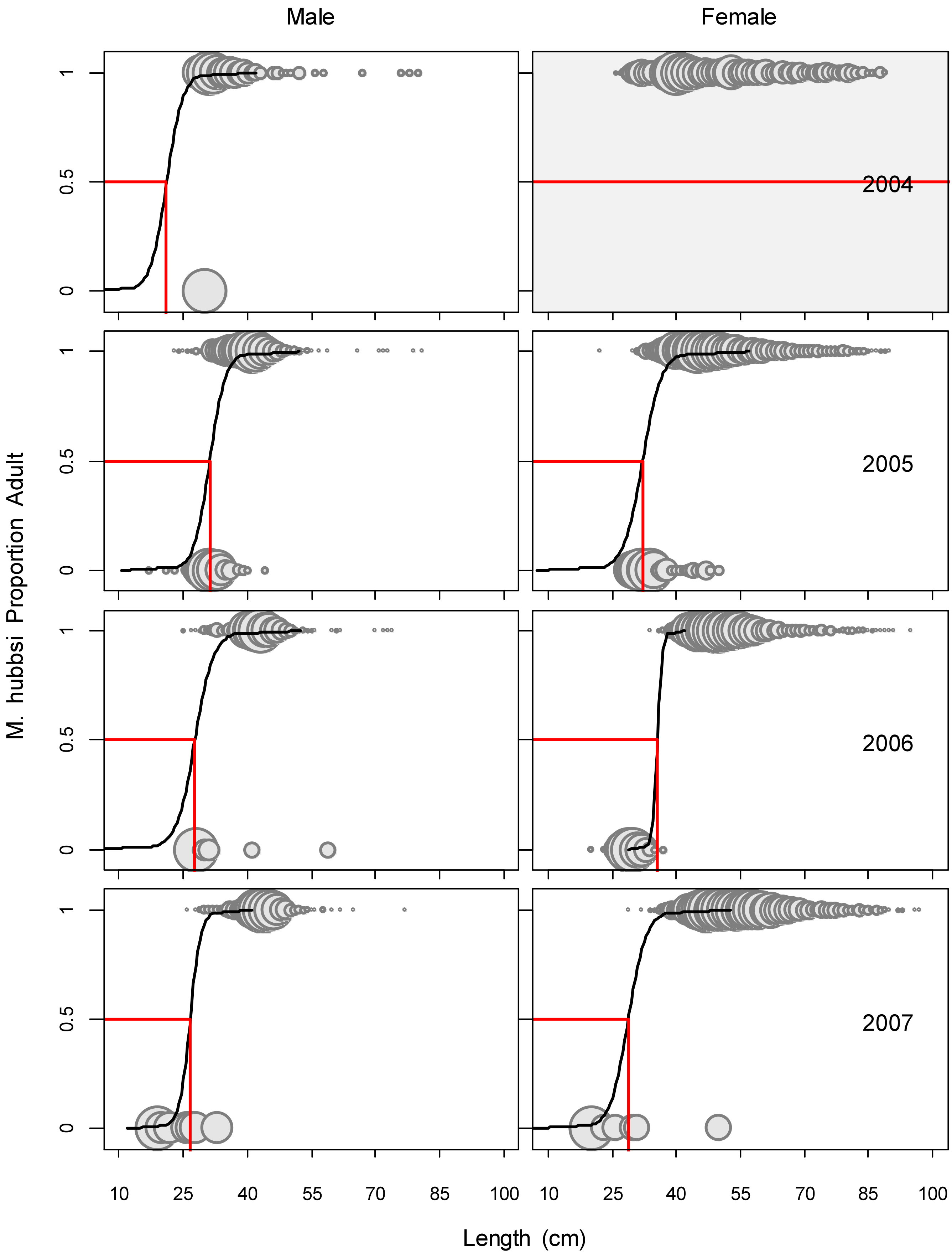
Male
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M. hubbsi Proportion Adult
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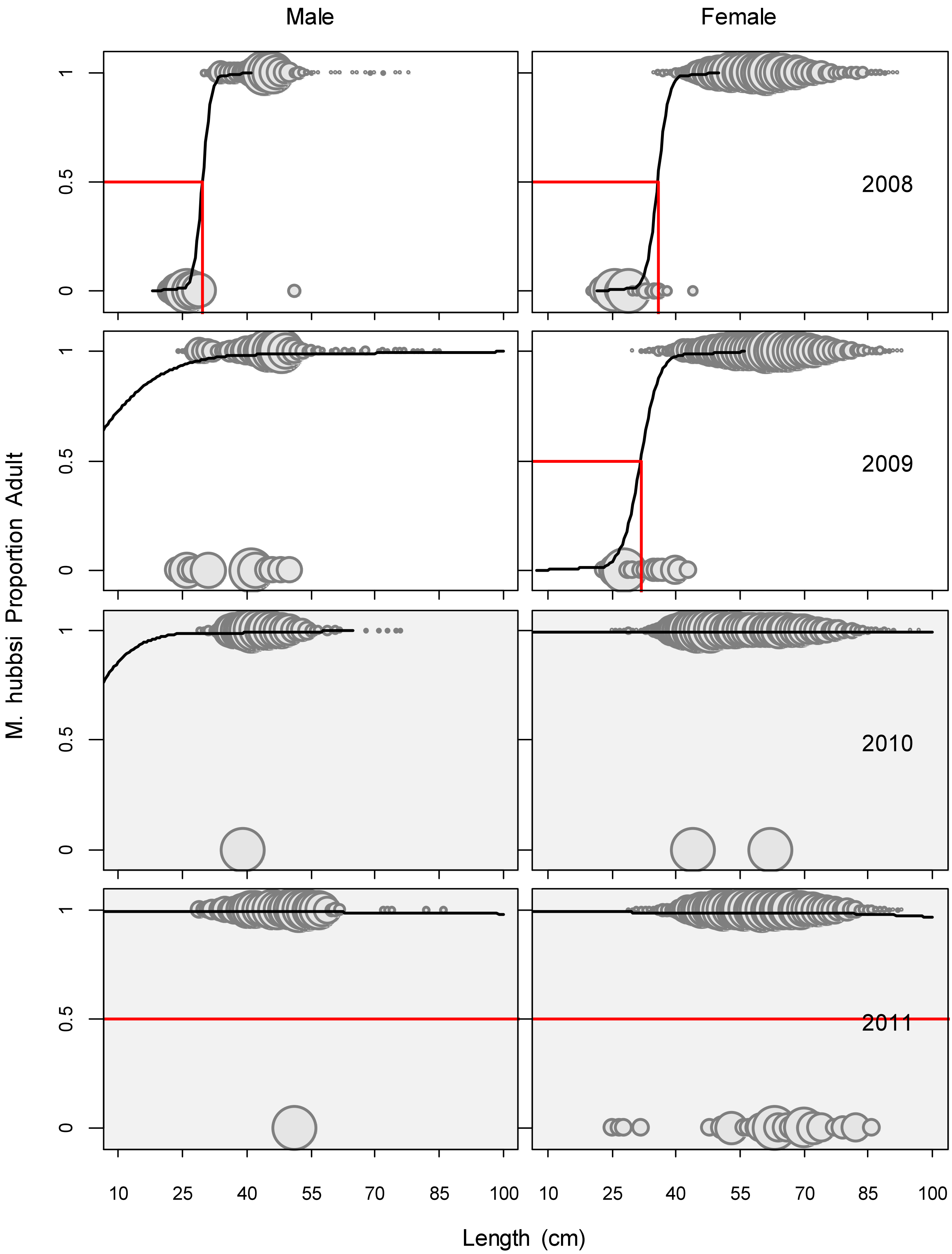
Length (cm)



Male
Female
M. hubbsi Proportion Adult
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2008
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85
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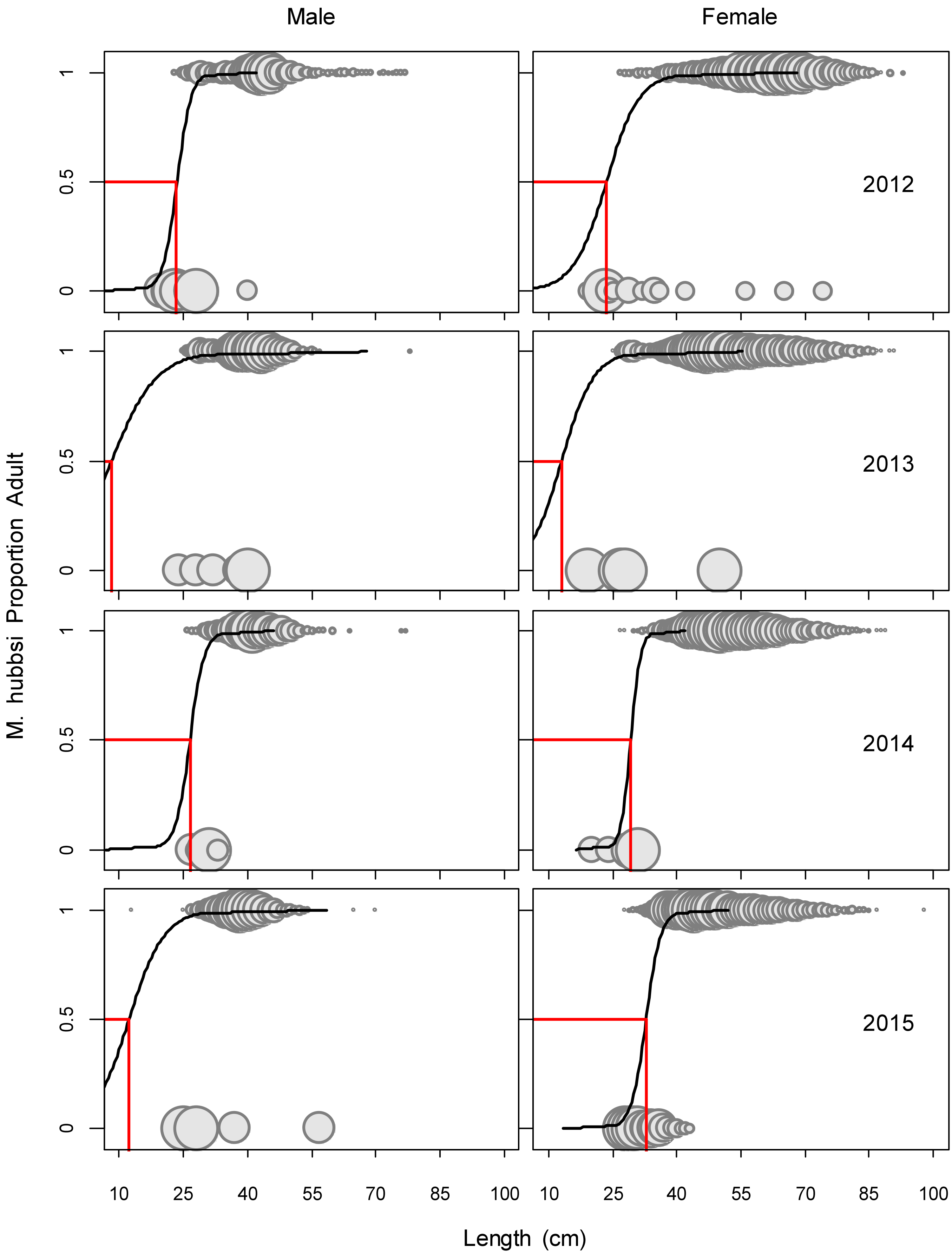
Length (cm)


Male
Female
M. hubbsi Proportion Adult
0
0.5
1
2012
2013
2014
2015
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25
40
55
70
85
100
Length (cm)

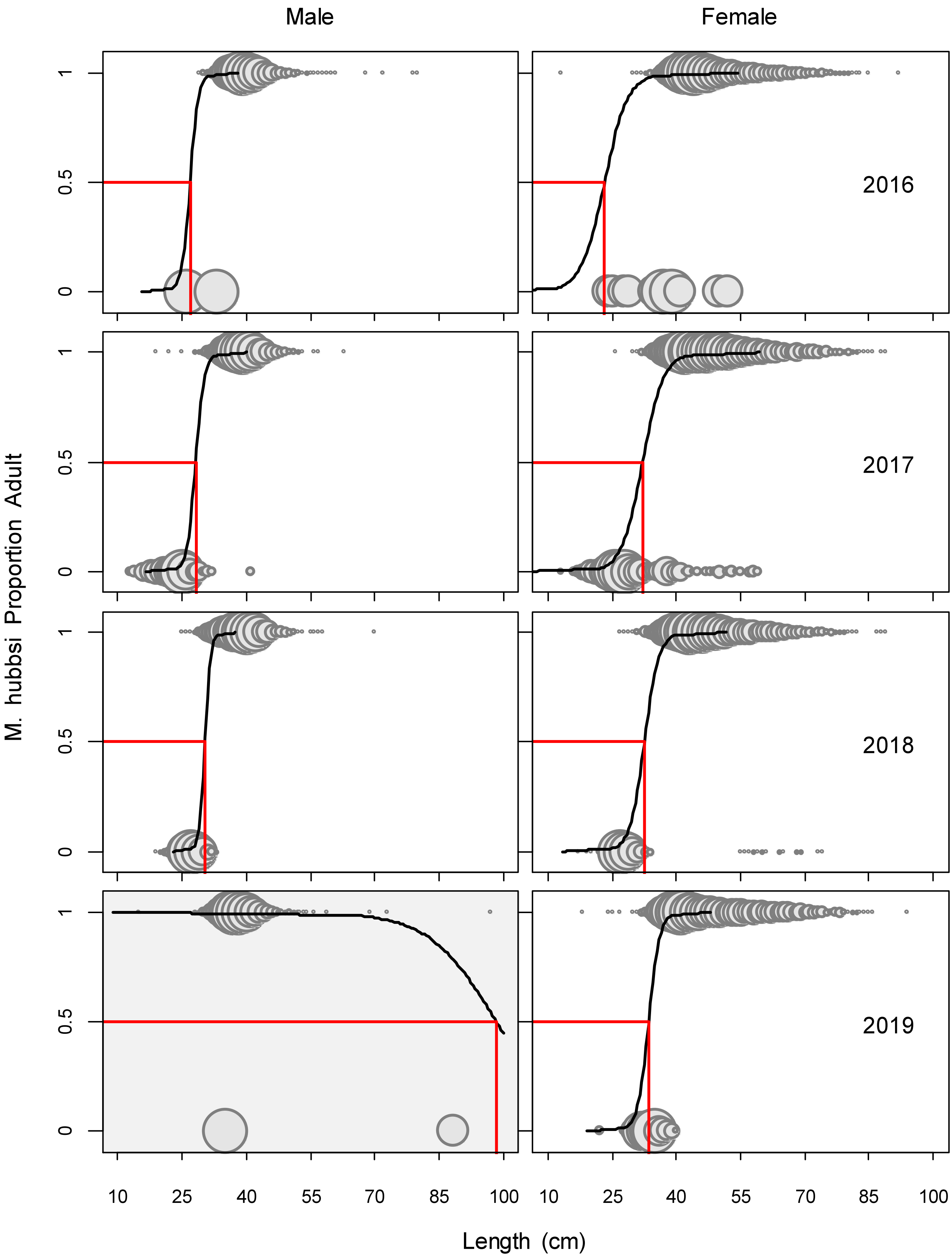
Male
Female
M. hubbsi Proportion Adult
1
0.5
0
2016
2017
2018
2019
10
25
40
55
70
85
100
Length (cm)

Figure A1. Binomial function GLMs of *M. hubbsi* juvenile (0) or adult (1) maturity vs. length. Grey circles: scaled to sample numbers. Red lines: Length intercept of 50% adulthood, corresponding to Figure 6. Plot fields that did not obtain possible length intercepts are shaded grey.

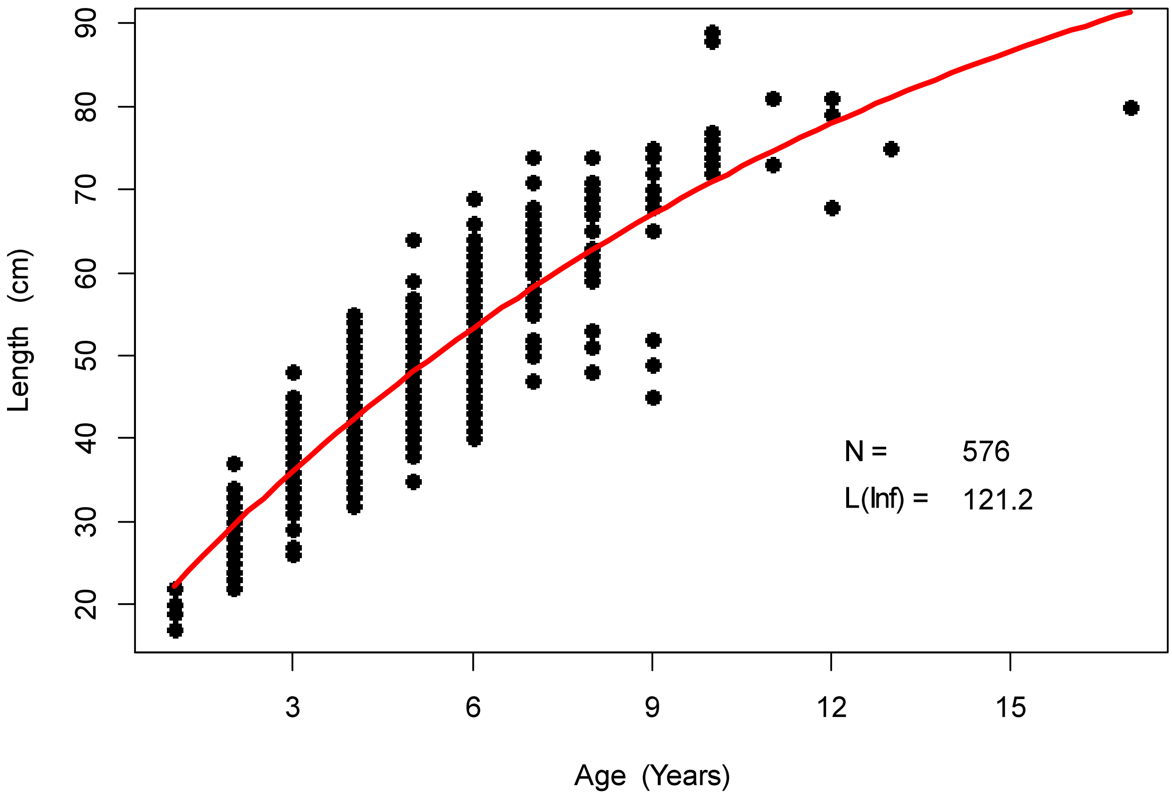

Figure A2. von Bertalanffy length-age relationship of *M. hubbsi* from FIFD-aged samples[8].

Figure A3 [next page]. Binomial function GLMs of *M. australis* juvenile (0) or adult (1) maturity vs. length. Grey circles: scaled to sample numbers. Red lines: Length intercept of 50% adulthood, corresponding to Figure 9. Plot fields that did not obtain possible length intercepts are shaded grey.

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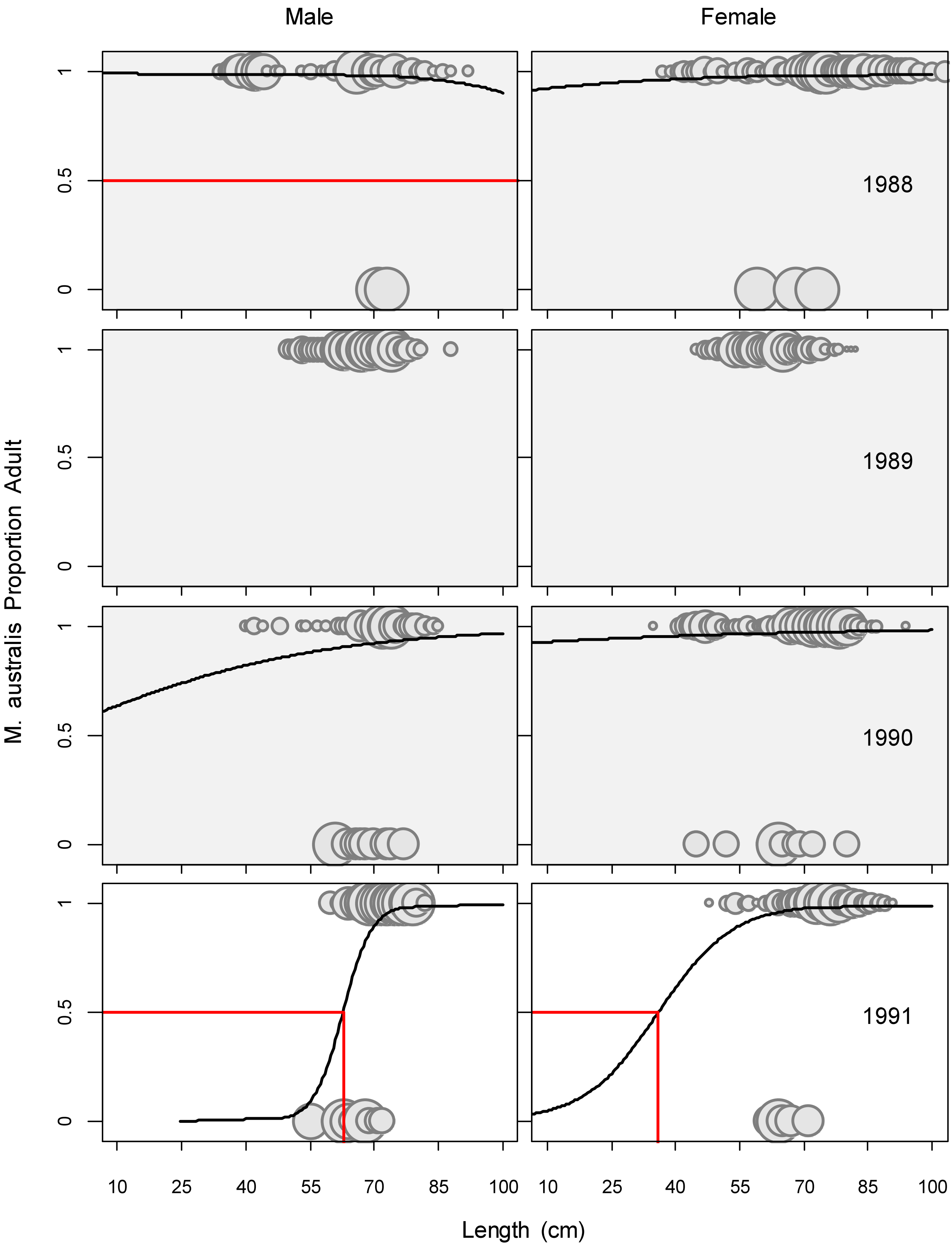
[8] Optimized in the 'fishmethods' R software package (Nelson 2015).



Male
Female
M. australis Proportion Adult
1
0.5
0
1988
1989
1990
1991
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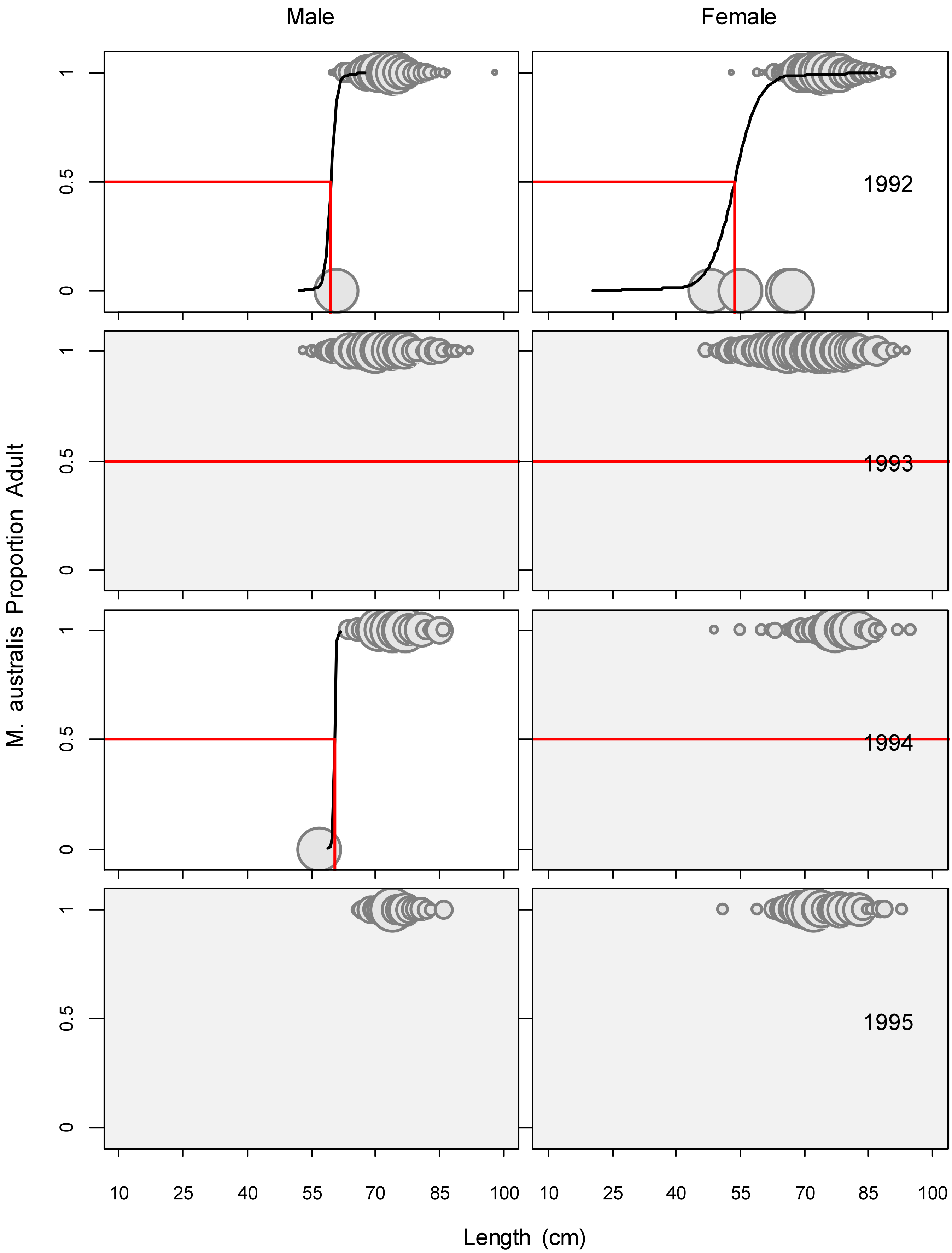
Length (cm)



Male
Female
M. australis Proportion Adult
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1992
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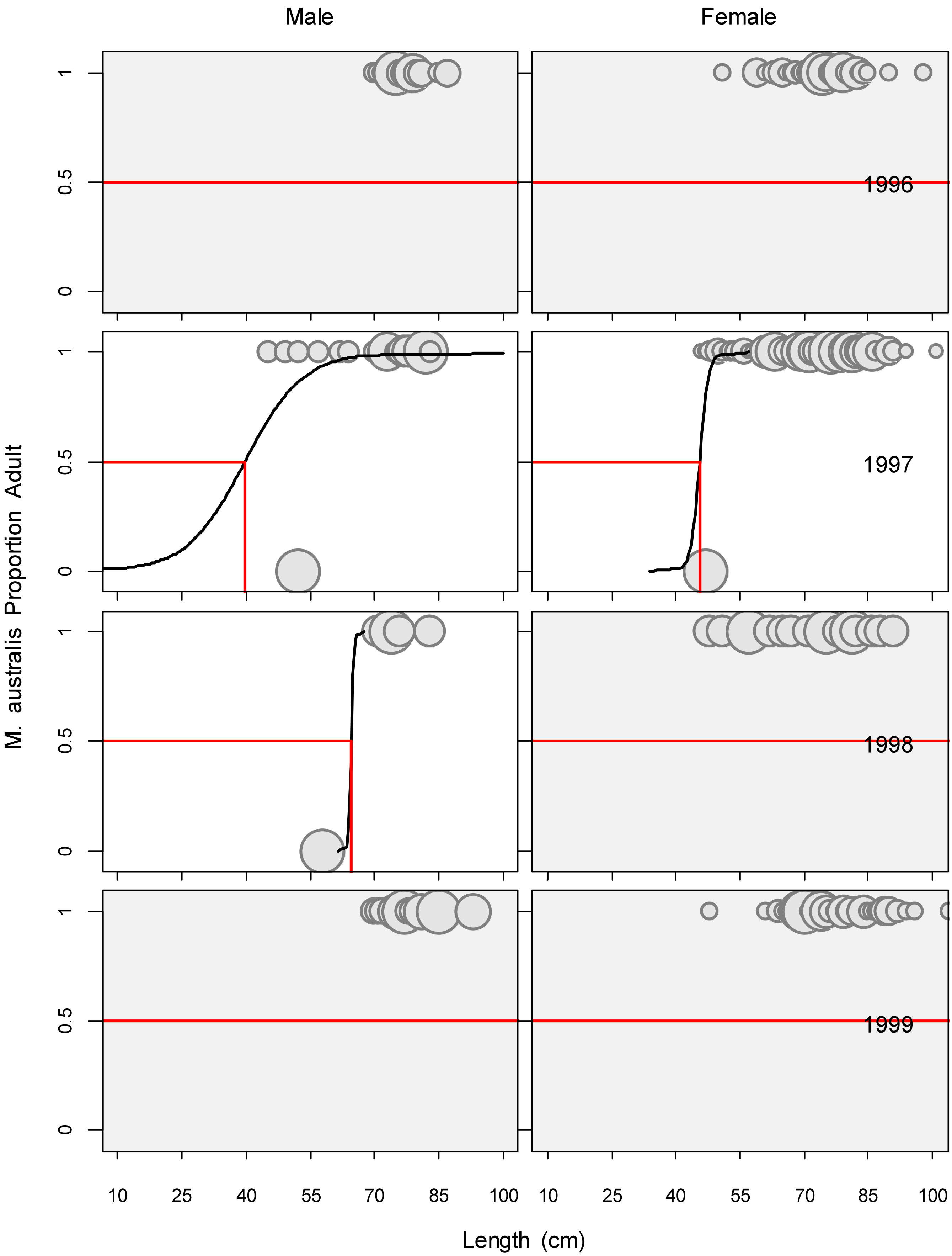
Length (cm)



Male
Female
M. australis Proportion Adult
1
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1996
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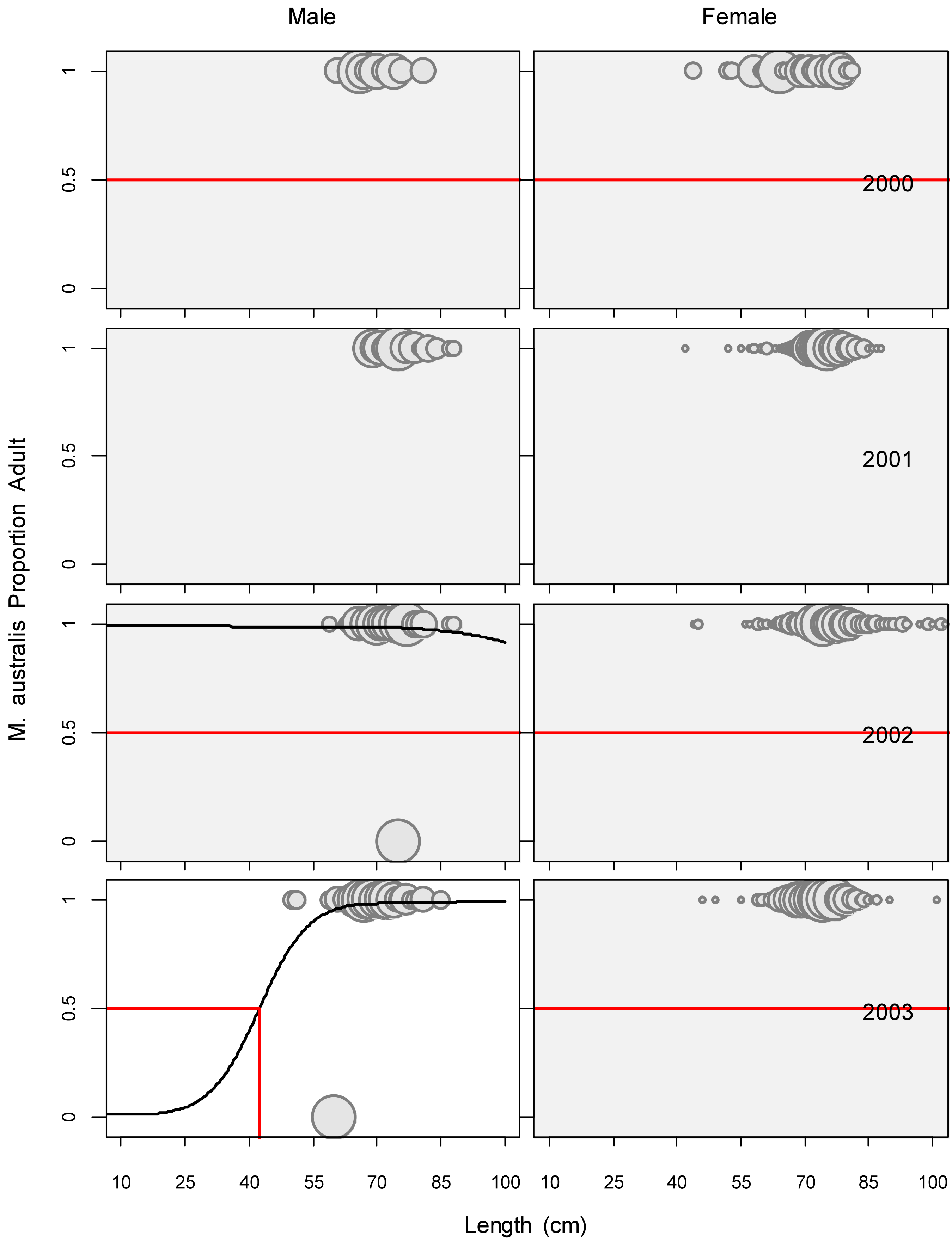
Length (cm)


Male
Female
2000
2001
2002
2003
M. australis Proportion Adult
Length (cm)
0
0.5
1
10
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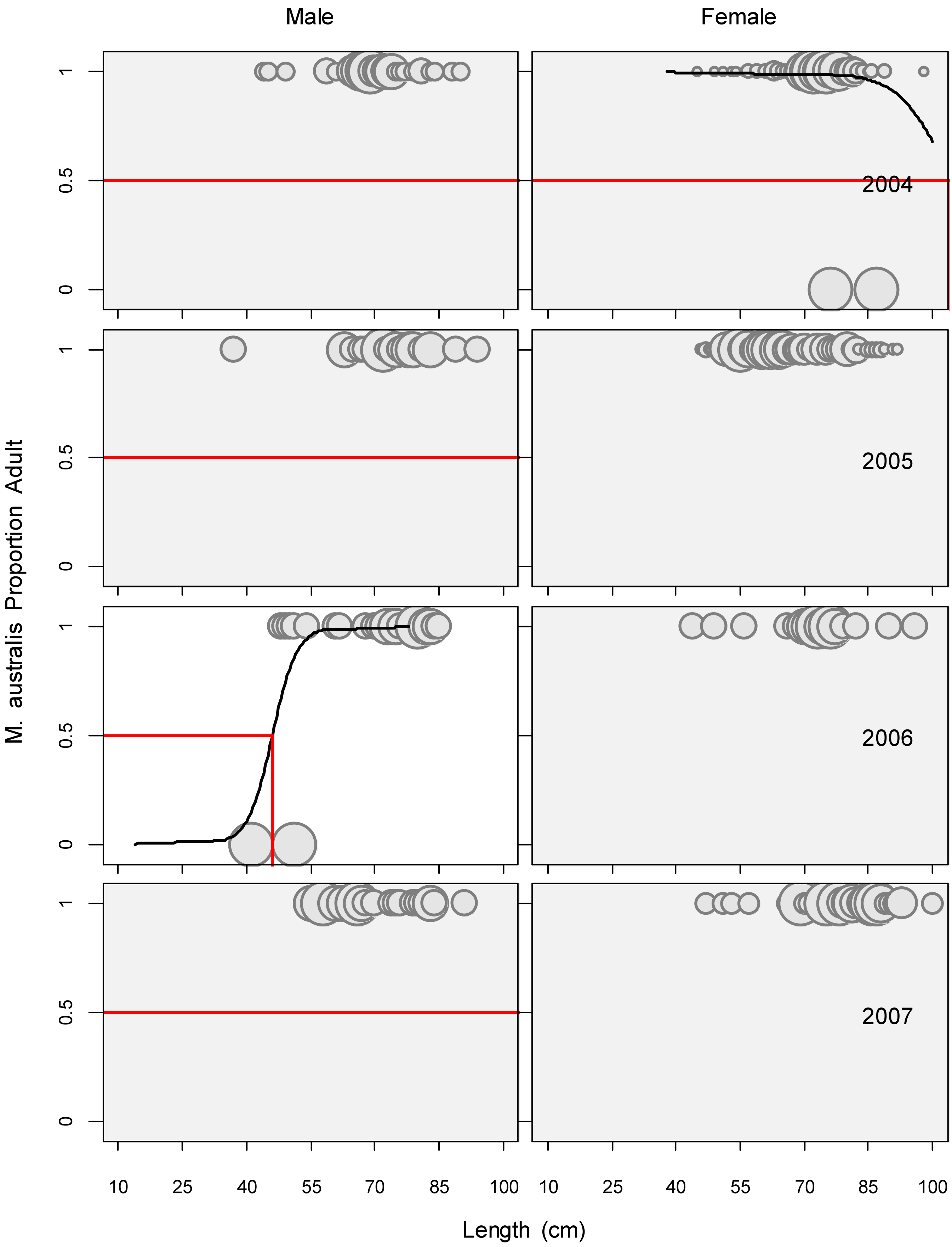
100


Male
Female
M. australis Proportion Adult
Length (cm)
2004
2005
2006
2007
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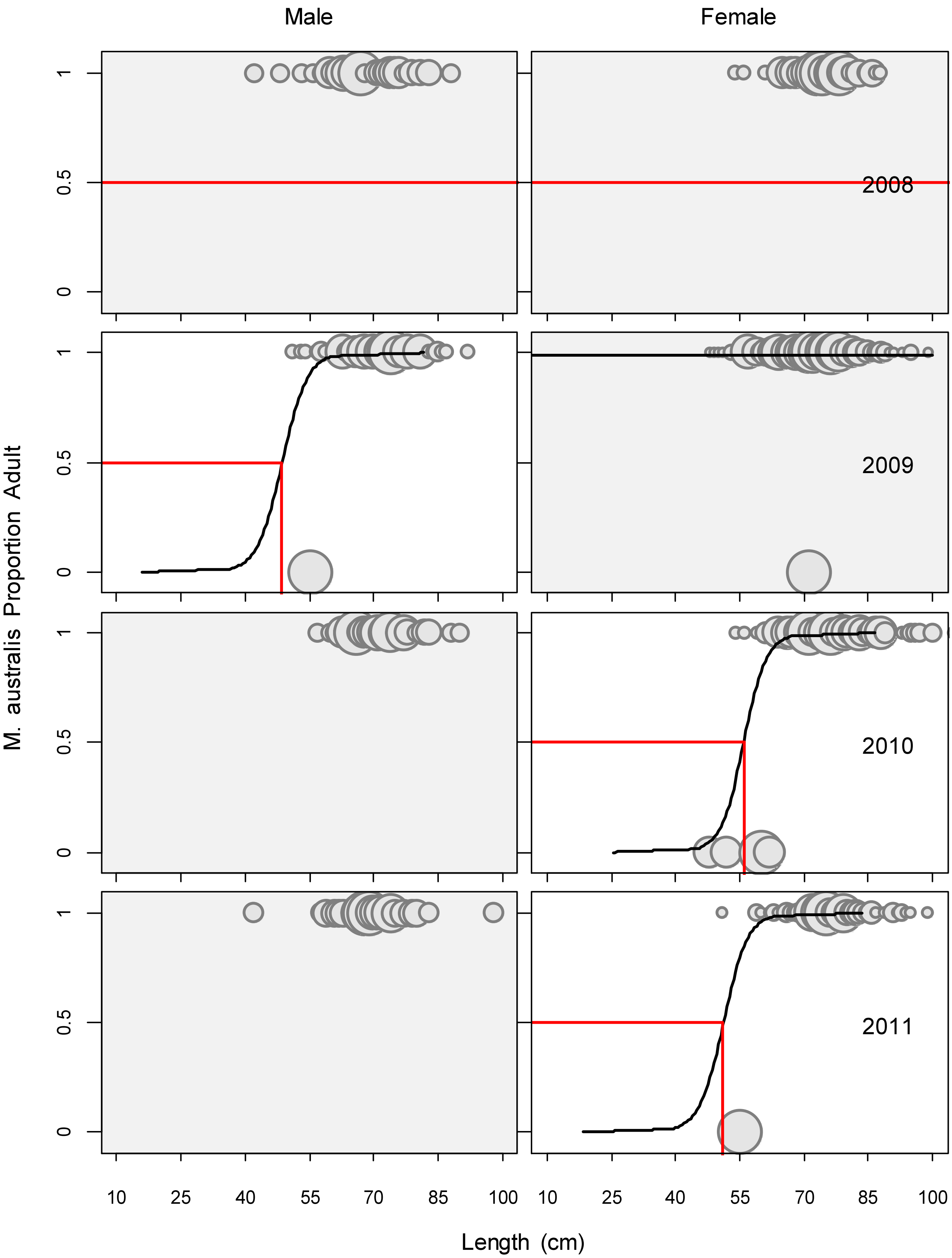

Male
Female
M. australis Proportion Adult
1
0.5
0
2008
2009
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2011
10
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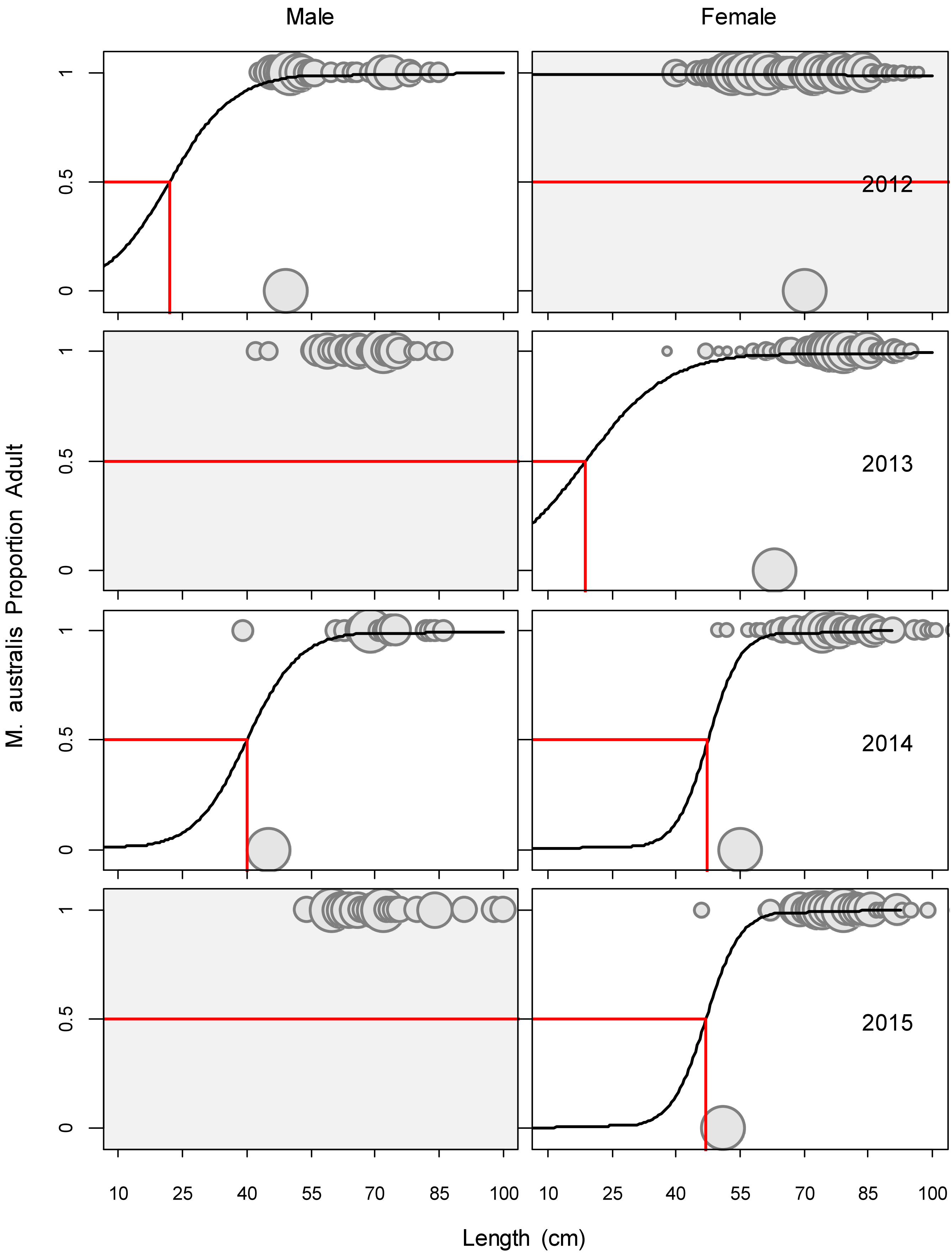
Length (cm)


Male
Female
M. australis Proportion Adult
Length (cm)
2012
2013
2014
2015
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0.5
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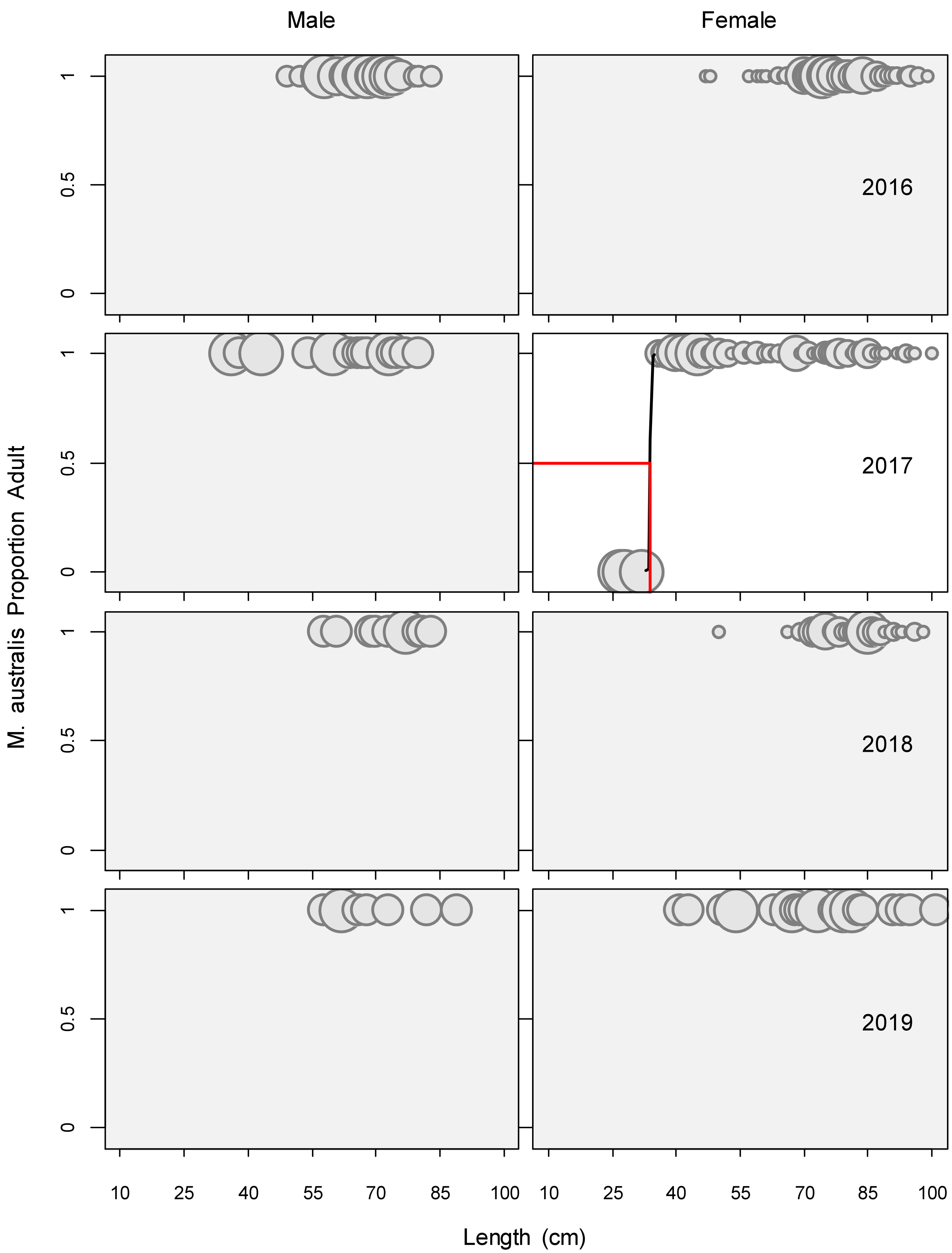
Male
Female
M. australis Proportion Adult
1
0.5
0
2016
2017
2018
2019
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Length (cm)