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Orange Roughy Age and Growth

Relate to agenda item: 4.1

Working paper ☒ Info paper ☐ Restricted ☐

Delegation of Cook Islands

Abstract

This report provides an assessment of the length-at-age data for orange roughy Hoplostethus atlanticus collected in the SIOFA area from three regions. We provide estimates of growth and length-at-age that inform age-based stock assessment models and to inform estimates of mortality, age-at-maturity, longevity and production.
Orange roughy saggital otoliths were collected by fishery observers from fish caught in the Southern Indian Ocean from 2011 to 2020 throughout the year. Each fish was measured (fork length mm) and otoliths were stored dry and sent to the National Institute of Water and Atmospheric Research Ltd. (NIWA) (New Zealand) for processing. Otoliths were sectioned and assigned an age, edge type and readability score by a single reader. Seven hundred and forty four fish were aged at three locations; of these 427 were male and 317 female. Fish length ranged from 20-60 cm for all fish; 20-58 cm for males and 20-61cm for females. Age estimates in this study ranged from 10 to 183 years old. The von Bertalanffy growth parameters are provided for both sexes combined and for males and females separately.
In addition, maturity estimates were derived for each of three regions as well as the SIOFA area as a whole.

Recommendations

1. The estimates from Walters Shoal should be used in the 2022 SIOFA orange roughy assessment of that region;
2. In future a stratified sampling selection be employed for otolith collection to ensure more representatives samples are collected across the size range of fish and between areas;
3. Recommend revision of the sampling protocols to prioritise biological data collection in tows made on the Southern Rise, Western Rise and areas to the East within the SIOFA area; and
4. If the assessment is sex separated, consider estimating age specific mortality.

Ministry *of* Marine Resources

GOVERNMENT OF THE COOK ISLANDS

Orange roughy age and growth in SIOFA from the Cook Island fishery

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1 Introduction

Orange roughy (*Hoplostethus atlanticus*) have a worldwide distribution in temperate regions and are found at depths of 450–1800m (Branch, 2001). Trawl fisheries have been developed in Australia, Namibia, New Zealand, the North-east Atlantic, Chile and in the Southern Indian Ocean Fisheries Agreement (SIOFA) area (Branch, 2001).

Orange roughy has been a major fishery in the SIOFA area targeted with trawl gear and also caught as bycatch in bottom trawl sets targeting alfonsino (*Beryx splendens*) (Brouwer et al., 2020). The growth estimates provide information on, growth rate and length-at-age that inform age-based stock assessment models and can be used to estimate mortality, age-at-maturity, longevity and production (Brouwer and Griffiths, 2004).

The Cook Islands, provided orange roughy otoliths from key fishing grounds in the SIOFA area to National Institute of Water and Atmospheric Research Ltd. (NIWA) (New Zealand) to carry out age estimations (Saunders, 2021). Saggitus Limited was contracted on behalf of the Ministry of Marine Resources Cook Islands (MMR) to estimate the growth parameters using these fish and fish previously aged by Horn et al. (2019). In addition the analysis will provide maturity estimates from three sub-regions in the SIOFA area.

This report provides an estimate of the length-at-age data for orange roughy samples within the SIOFA area, and are intended for use by the SIOFA orange roughy assessment team.

2 Methods

Orange roughy otoliths along with associated biological measurements were collected on two Cook Island vessels from 2011 to 2020 from three broad regions in the SIOFA area (Figure 1). Observers on board vessels fishing in the SIOFA area are required to collect length (fork length cm), sex, maturity and age material. One hundred randomly selected fish are weighed whole, measured and sexed. For each fish the gonad was weighed and maturity stage estimated visually and assigned to a 9-stage maturity scale set out in Cook Islands (2015). Saggital otoliths are collected from every 10^{th} fish. Recently the otolith collection has been rationalised and otoliths are collected in a stratified manner. The protocol now requires collection of otoliths from three fish per sex and 1cm size class to be taken per set. In addition, all information about the fishing set were also recorded. The Walter's Shoal sample was aged by Horn et al. (2019), after that analysis, an additional sample of small fish was obtained and these estimates were also included here. For the purposes of this report samples from North Walter's, Walter's Shoal and Seamounts were pooled and referred to as Walter's Shoal; and North Ridge and Middle Ridge are collectively referred to as the Western Rise (Figure 1).

Otoliths were prepared according to the methods set out in Horn et al. (2016) and Saunders (2021) and read once by a single reader using the otolith interpretation and reading protocols described in Horn et al. (2016). The von Bertalanffy growth function (von Bertalanffy, 1938) was used to describe fish growth. The growth parameters were estimated in R (R Core Team, 2020) using non-linear least-squares estimates function (nls) which uses the methods described by Bates and Watts (1988) and Bates and Chambers (1992). However, due to the low sample numbers in some regions the estimation failed for some region/sex combinations. As a result the estimates from combined areas and sexes from that model were used as priors and the von Bertalanffy parameters were estimates by region and sex and for combined sexes and regions using a Bayesian approach.

Data were used to estimate the growth curve parameters using maximum likelihood estimation (MLE). The von Bertalanffy growth curve was fitted assuming normally distributed errors with a constant coefficient of variation (CV) (c) parametrised as a function of mean length. Here, the length-at-age data are assumed to consist of length L and age t observations for n fish of sex i, i.e.,

$$\bar{L}_i = L_i^{\infty}\ (1\text{-}\exp(\text{-}k_i(t\text{-}t_i^0)) + \varepsilon\ where\ \varepsilon \sim N(0,c\bar{L}_i)$$

To assess age sample representatively, data from the random length sample and otolith sample were were compared using a Kolmogorov-Smirnov Test in R (R Core Team, 2020). This compares the similarities between distributions of unequal length by comparing the cumulative distribution functions (CDF). The test considers both the shape and location of the distributions. The null hypothesis being that the two samples are from the same distribution.

Gonad mass and stage were summarised by length class. Fish with gonads in stages 1 and 2 were considered immature while those at stages 3 and up were considered mature. The gonado-somatic index (GSI) was calculated by dividing the gonad mass by fish mass and then summarised by month and gonad stage to assess the gonad staging accuracy and spawning seasonality.

Size-at-maturity was estimated. The proportion of mature fish in each size class in the sample was estimated and a maturity ogive was fitted in R (R Core Team, 2020) using a binomial General Linear Model (GLM). The length-at-50% maturity was then derived and the age-at-50% (L_{50}) maturity was then estimated from the growth curves. Gonad stages 7-9 were dropped (0.5% of samples) from the analysis due to problems accurately staging spent gonads.

3 Results and Discussion

3.1 Length

Figure 2 to Figure 5 summarise the length data collected from 2011 to 2020 for orange roughy in the three areas samples. For Walter's shoal the length distributions are similar for all years. However, the samples from 2011 are particularly sparse and the 2020 sample is biased as there are a large number of very small fish (<35 cm) collected from a directed sample (Figure 2). These small fish were selected to collect very young fish to age and as a result the 2020 sample is biased by the presence of these samples.

The length samples from South Ridge are relatively uniform from year to year (Figure 3), as are those from the Western Rise (Figure 4). Both the Western Rise sample and that of the South Ridge have low sample rates with very small samples in some years.

Overall, however, the length patterns are broadly similar between regions (Figure 5). In all areas the peak fish density was in the length classes 45-50 cm, with no fish below the 25 cm length class or above 65 cm. Most length classes below 45 cm on South Ridge had a 50:50 sex ratio with a few male dominated. At Walters Shoal and Western Ridge the small size classes are male dominated. In all areas the large size classes are female dominated (Figure 6). This pattern can arise for a number of reason such as protandrous hermaphroditism, differential growth, selectivity or mortality. In the case of orange roughy, there is no evidence to suggest hermaphroditism either in the gonads that have been examined or from the presence of large male fish in the population. There slight evidence for differential growth and no evidence of differential selectivity. Differential natural mortality is therefore the most likely reason for the change in sex ratio with fish size. This pattern has been observed in other species such as alfonsino and can be associated with spawning stress (Brouwer et al., 2021). The relatively large size of orange roughy testes implies a high degree of sperm competition and possibly competition for mates. A mating strategy that requires a lot of energy can leave males exhausted and vulnerable to predation thereby increasing their natural mortality rate (M). This result suggest that the stock assessment could consider estimating size specific mortality, particularly if the assessment is sex separated.

3.2 Age and Growth

Seven hundred and forty four fish were aged at three locations; of these 427 were male and 317 female (Table 1). Fish length ranged from 20-60 cm for all fish; 20-58 cm for males and 20-61cm for females. Age estimates in this study included fish from 21–140 from Horn et al. (2019), a sample of young fish (<20 years old) also aged by Peter Horn as well as fish from 19–183 years old from Saunders, 2021.

The length and age frequencies of the orange roughy samples in the Cook Islands trawl catch are presented in Figures 7 to 10 and Table 2. These data show that at Walter's Shoal the data are skewed towards fish between 40-50 cm, this corresponds to fish between 30-70 years old, but with a rather long tail out to 140 years old. The small number of small fish (less than 30 cm) was from a deliberate collection of small fish specifically collected with the aim of improving the growth curves for this area. Similar trends are apparent for the South Ridge area, but with a small peak in small young fish in that area. While the fish from the Western Rise tend to be smaller to those at Walter's Shoal. Overall the SIOFA area combined data the fish size was centred around 35-55 cm and ages around 30-70 year old again with a long tail out to beyond 150 years old and with a small sample of small young fish (less than 20 cm and 10 years old). Generally speaking, these data provide a relatively good spread of data overall but the number of samples in some of the smaller regions like South Ridge may be small and increased sampling in that area would be beneficial.

The raw age and length data along with the von Bertalanffy fitted curves are presented in Figure 11. The data from the South Ridge are most sparse and Walters Shoal most abundant. The model managed to fit these data well and in all areas male growth was estimated to reach a smaller asymptote compared to the females. The group of small fish at Walter's Shoal were immature and the sex was not determined as a result these length and ages estimates were replicated in both males and females to assist with the curve fitting.

Residual distributions for the estimated length-at-age estimates are relatively good but less so for the South Ridge (Figure 12). Overall the residual distributions were relatively even through the middle age classes between 30-70 years old, but unevenly distributed for the younger fish and tend to be negatively distributed for the older age classes (>100 years old). The poor fits at the extremes are not unexpected and probably related to poor sampling of those age classes.

Figure 13 to Figure 16 show the distribution of the length-at-age data for each area, showing the data distribution and outlier estimates. The Walters Shoal data show relatively good fits to the data for both male and female fish (Figure 13). However, for both, the samples are lacking for older fish as a result the asymptote is largely influenced by the medium aged fish. This could result in a slightly lower estimate of L_∞ but its effect is likely to be minor and only a very large number of samples over 100 years old would change that part of the curve.

The data for the South Ridge are sparse particularly for males (Figure 14). The low number of samples in this region result in two data points for younger fish are very influential and result in a sharp down turn of the growth curve and a very high estimate of t_0 (Table 2). In contrast in the Western Rise, there are few samples of young male fish (Figure 15) as a result t_0 is underestimated (Table 2). Overall, however, the data data are well represented across most age classes between 20 and 100 years old and the curves fit the data well (Figure 12 and Figure 16 and Figure 17).

Figure 18 presents a comparison of the male, female and combined growth curves and the parameters are presented in Table 2. The curves are similar for Walter's Shoal and the Western Rise, with the South Ridge being different from the other two and the combined SIOFA curve laying between that of Western Rise and Walter's Shoal.

Figure 19 presents the length data from the otolith sample compared to that of the length sample when otoliths were collected. These data were also compared using a Two-sample Kolmogorov-Smirnov test and the results are presented in Table 3. These data show that the length data for the otolith samples from Walters Shoal was not different from the overall sample. The Western Rise age sample was slightly different from the overall sample while the Southern Rise sample was significantly different. This was likely due to the small number of samples collected from the Southern Rise and collecting additional samples from that area could be prioritised in that area to resolve this in future.

Orange roughy growth has been investigated over a number of years, and in a numerous or regions, including Australia (Fenton et al., 1991); Namibia (Branch, 2001), North Atlantic (Allain and Lorance, 2000); New Zealand (Mace et al., 1990; Tracey and Horn, 1999, (Horn et al., 2016); and growth estimates have been provided in the SIOFA area (Horn et al., 2019 and Saunders, 2021). These studies have demonstrated that there is considerable variation in growth both between and within regions. Direct comparisons with other areas of the world were not undertaken due to the differences in length measurements. However, the variation in growth between regions in SIOFA require further investigation. Moreover the areas beyond Walter's Shoal should be prioritised for biological data collection to clarify the regional differences in growth. In addition, the areas within SIOFA further to the east (Taylors, 90-East and Broken Ridge) where no samples have been aged should also be investigated and the collection of samples from those areas should also be considered a priority.

3.3 Maturity

Comparing the GSI and the gonad stages assigned by observers indicates that the staging definitions set out in Cook Islands (2015) seems appropriate and the macroscopic staging is probably a useful indicator of maturity (Figure 20). This showed that GSI was low for gonad stages 1 and 2 and increased with gonad stage 3-5 declining again when fish are staged as spent. This is in contrast to the definitions in Cook Islands (2015) for alfonsino which were showed to be inaccurate and require clarification (Brouwer et al., 2021). However, there may still be some issues with gonad macroscopic staging of orange roughy as Figure 21 shows while there are stage 3, 4 and 5 gonads (mature, ripe and ripe running) all year round, suggesting prolonged spawning, peaks in juvenile stages 1 and 2 appear later in the year. This can occur if juvenile and post spawning gonads are miss-classified (Brouwer and Griffiths, 2005), or if "young of the year" arrive on the spawning grounds at a specific time of year. However, reviewing the gonad staging by fish size, suggests that the latter may be more likely than miss-classification of gonad stages (Figure 22).

Reviewing the GSI by size shows that the GSI increases above 40 cm for females and remains high for all large size classes (Figure 23). GSI is also generally higher for females than males, but male GSI is still relatively large. GSI by size is difficult to compare between areas due to the relatively low samples sizes from the South Ridge and to some extent the Western Rise. Some of this variation may be due to the time of year the different areas were fished with a wider range of months being sampled at Waiters Shoal and the Western Rise compared to the South Ridge (Figure 24). Generally speaking, GSI values for both males and females are higher in the Austral Winter. The high values in the Spring at Walter's Shoal may be biased by a few samples from those months (Figure 24). Combining the data from all areas (Figure 25) and assessing the gonad stages by month (Figure 21) suggests that the spawning season is relatively prolonged.

The size-at-maturity varied between regions and sexes (Figure 26). The combined curves can be found in Figure 27 and the L_{50} values in Table 4. Male and female L_{50} was similar at Walter's Shoal at 39 cm, and was most different at South Ridge with female L_{50} estimated at 35 cm and male at 40 cm, but it should be noted that South Ridge also had the fewest samples (n=280) of all the areas. At the Western Rise female L_{50} was also lower (35 cm) than males (38 cm) as was the overall SIOFA sample. However, the data at Western Rise are hampered by low sample numbers of small fish which may result in skewing the maturity curve to the left.

Orange roughy are synchronous spawners forming dense spawning aggregations (Branch, 2001). The large size of the male gonads suggest that there is a high degree of sperm competition (Brouwer and Griffiths, 2005), which is often synonymous with groups spawning. The winter spawning period noticed here is consistent with other observations in the Southern Hemisphere. The size-at-maturity presented here is not directly comparable to other studies as we measured fork length while other studies use standard length. Despite this the size-at-maturity estimated here is within the range recorded in other areas and most similar to the estimates derived for New Zealand (Horn et al., 1988).

Horn et al. (1988) speculated that between-area differences in age or size-at-maturity may be indicative of separate stocks, and noted these differences for different stocks around New Zealand, where stock separation was confirmed through genetic analyses. The differences found in this study between age and maturity estimates between areas could be indicative of a structured stock through the SIOFA area. However, the sample sizes from two regions were low and have resulted in less robust estimates of these parameters form areas beyond Walter's Shoal, and at this stage suggesting that separate stocks exist in the SIOFA area may be premature, but is worth further investigation.

4 Conclusions

In conclusion, as with all orange roughy populations, orange roughy in the SIOFA area are slow growing and very long lived, maturing late in life at about 30 years old. Due to the low level of fishing effort in this fishery, sampling overall has been uneven both between sub-regions within SIOFA and also through time, which will complicate analyses. As a result, as with the previous assessment (Cordue, 2018), the 2022 stock assessments should be treated as relatively data poor, and will rely more on abundance trends from acoustic biomass estimates than biological changes through time.

While these data provided here should be used for the Walters Shoal stock assessment, they are not sufficient to comment on the stock structure within the SIOFA area. However, with additional sampling from areas that have been historically under sampled or using alternative techniques stock structure could be explored in future if the SIOFA believes this to be necessary.

5 Recommendations

1. The estimates from Walters Shoal should be used in the 2022 SIOFA orange roughy assessment of that region;
2. In future a stratified sampling selection be employed for otolith collection to ensure more representatives samples are collected across the size range of fish and between areas;
3. Recommend revision of the sampling protocols to prioritise biological data collection in tows made on the Southern Rise, Western Rise and areas to the East within the SIOFA area; and
4. If the assessment is sex separated, consider estimating age specific mortality.

6 Acknowledgements

The authors would like to thank the vessel operators and observers for collecting the data, Charles Heaphy and Brian Flanagan for getting the otoliths to us, as well as Tiare-Renee Nicholas from MMR for collating the recent biological data. We would also like to thank Pamela Maru and Kerry Robertson for helpful editorial comments.

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Tables

Table 1: Orange roughy number of age samples for each sex by region area.

Area	Female	Male
South Ridge	30	16
Walters Shoal	148	271
Western Rise	139	140
Total	317	427

Table 2: Orange roughy von Bertalanffy growth parameters for each sex and combined sexes estimated for each area and combined SIOFA area. Values in parentheses are the 95% CI calculated from the Hessian, the CVs at length are within each area for both sexes and between areas for combined sex model.

Parameters	Combined	Male	Female
Walters Shoal			
L_∞	46.6 (45.98 , 47.22)	45.09 (44.5 , 45.68)	48.61 (47.78 , 49.44)
k	0.07 (0.07 , 0.08)	0.08 (0.07 , 0.09)	0.07 (0.06 , 0.07)
t_0	3.49 (2.49 , 4.49)	4.1 (3.07 , 5.13)	3.31 (4.48 , 2.14)
CV	0.08	0.06	
South			
L_∞	54.99 (52.88 , 57.1)	53.38 (51.18 , 55.59)	57.13 (53.77 , 60.48)
k	0.05 (0.03 , 0.07)	0.13 (0.02 , 0.23)	0.04 (0.02 , 0.06)
t_0	7.65 (-1.77 , 17.07)	18.35 (10.85 , 25.85)	4.44 (18.94 , 10.05)
CV	0.08	0.07	
West			
L_∞	50.7 (49.34 , 52.06)	50.53 (48.5 , 52.55)	51.51 (49.8 , 53.23)
k	0.04 (0.03 , 0.06)	0.03 (0.02 , 0.04)	0.06 (0.04 , 0.08)
t_0	-7.91 (-16.46 , 0.64)	-29.93 (-47.01 , -12.86)	4.18 (10.39 , 2.03)
CV	0.08	0.08	
SIOFA			
L_∞	48.78 (48.23 , 49.32)	47.03 (46.32 , 47.75)	50.83 (49.95 , 51.71)
k	0.06 (0.06 , 0.07)	0.07 (0.06 , 0.08)	0.06 (0.05 , 0.06)
t_0	2.6 (1.49 , 3.71)	2.17 (0.14 , 4.2)	2.66 (1.23 , 4.08)
CV	0.08	0.08	

Table 3: Orange roughy Two-sample Kolmogorov-Smirnov test results comparing the age sample to the length sample for the tows where otoliths were collected. Note these results removed the specific directed age sample from very small fish which were an exception to the usual sampling protocols.

Area	D-statistic	p-value
South Ridge	0.70173	<0.001
Walters Shoal	0.01159	0.86
Western Rise	0.15583	0.01

Table 4: Orange roughy length-at-50% maturity sex by region area.

Area	Female	Male
South Ridge	35.3	40.45
Walters Shoal	39.15	39.55
Western Rise	34.97	38.08
SIOFA	33.08	36.85

Figures

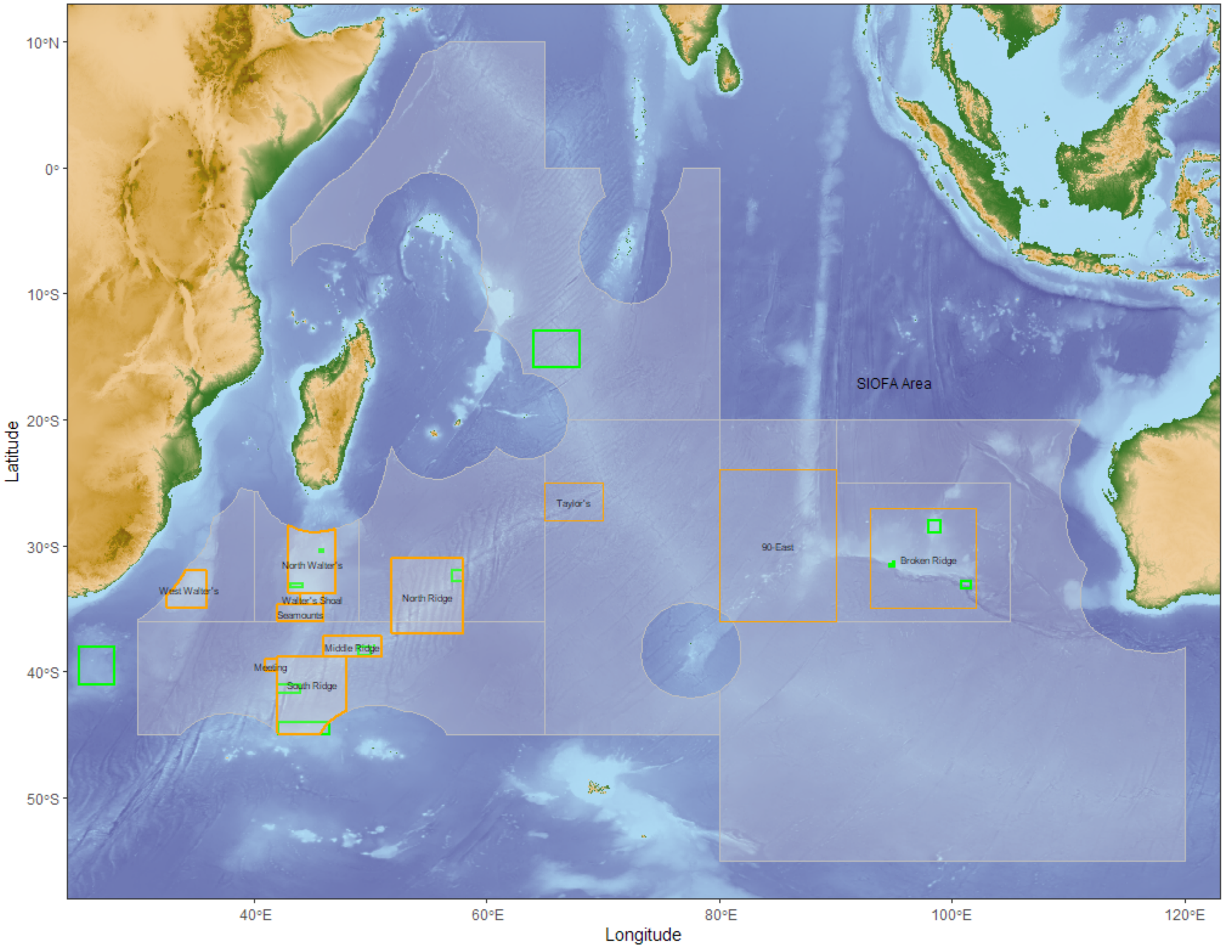

Figure 1: Map of the SIOFA area showing the regions where samples of orange roughy were derived. The green boxes are Benthic Protected Areas. For the purposes of this report samples from North Walter's, Walter's Shoal and Seamounts are referred to as Walter's Shoal; and North Ridge and Middle Ridge are collectively referred to as the Western Rise.

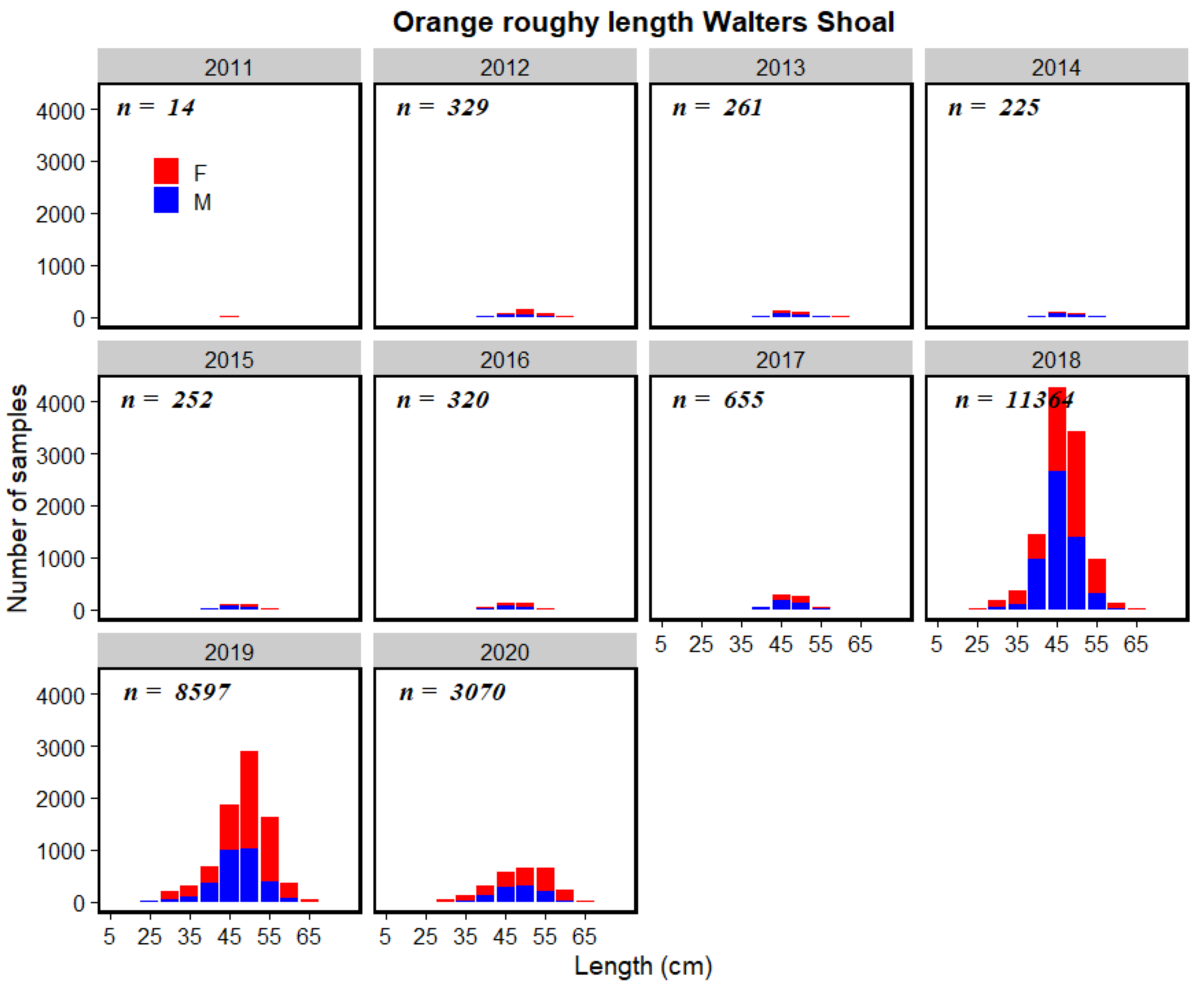

Figure 2: Length distributions by year for the total sample of orange roughy sampled from Walter's Shoal.

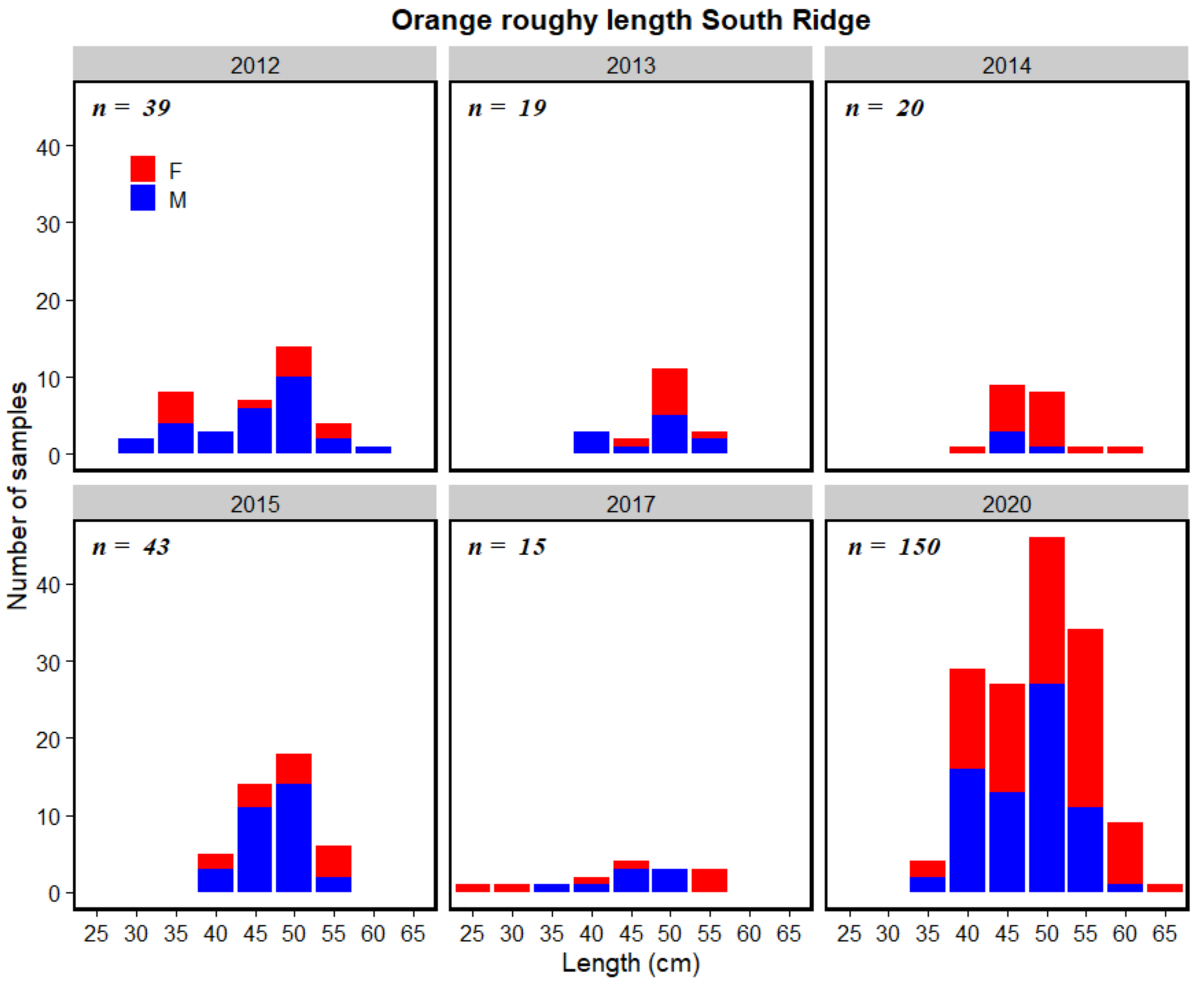

Figure 3: Length distributions by year for the total sample of orange roughy sampled from South Ridge.

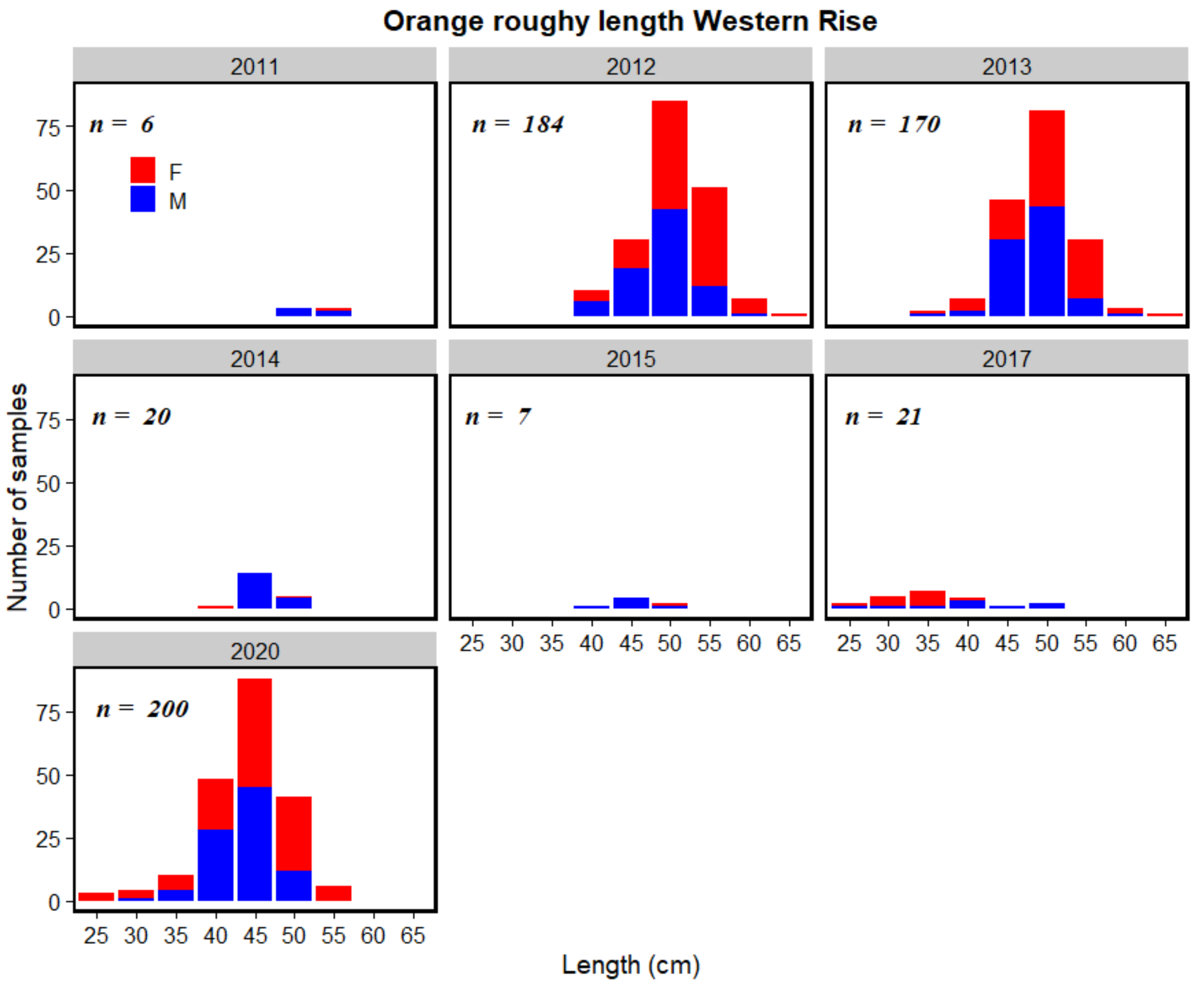

Figure 4: Length distributions by year for the total sample of orange roughy sampled from Western Rise.

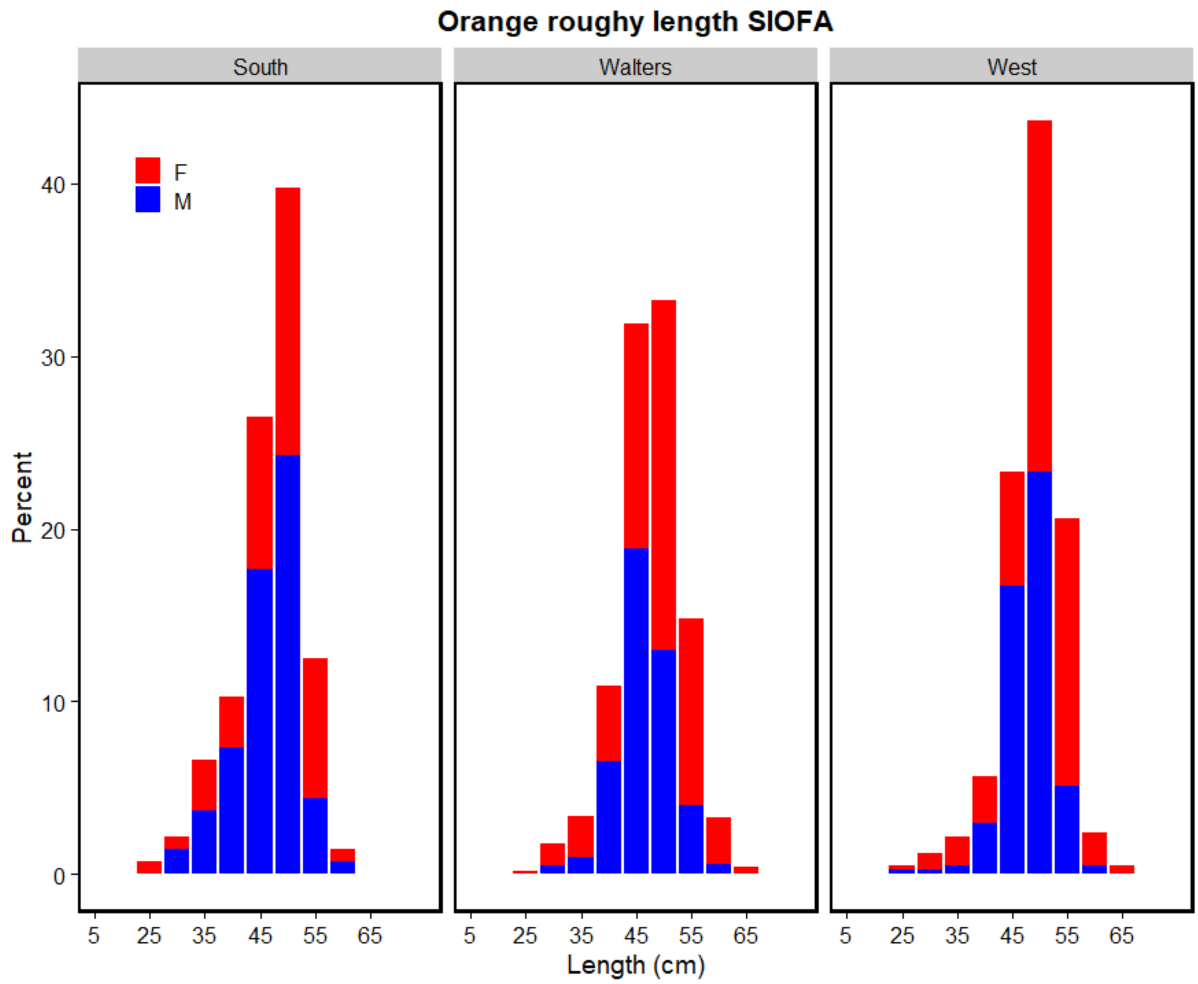

Figure 5: Length distributions by area for all years of orange roughy sampled from the SIOFA area.

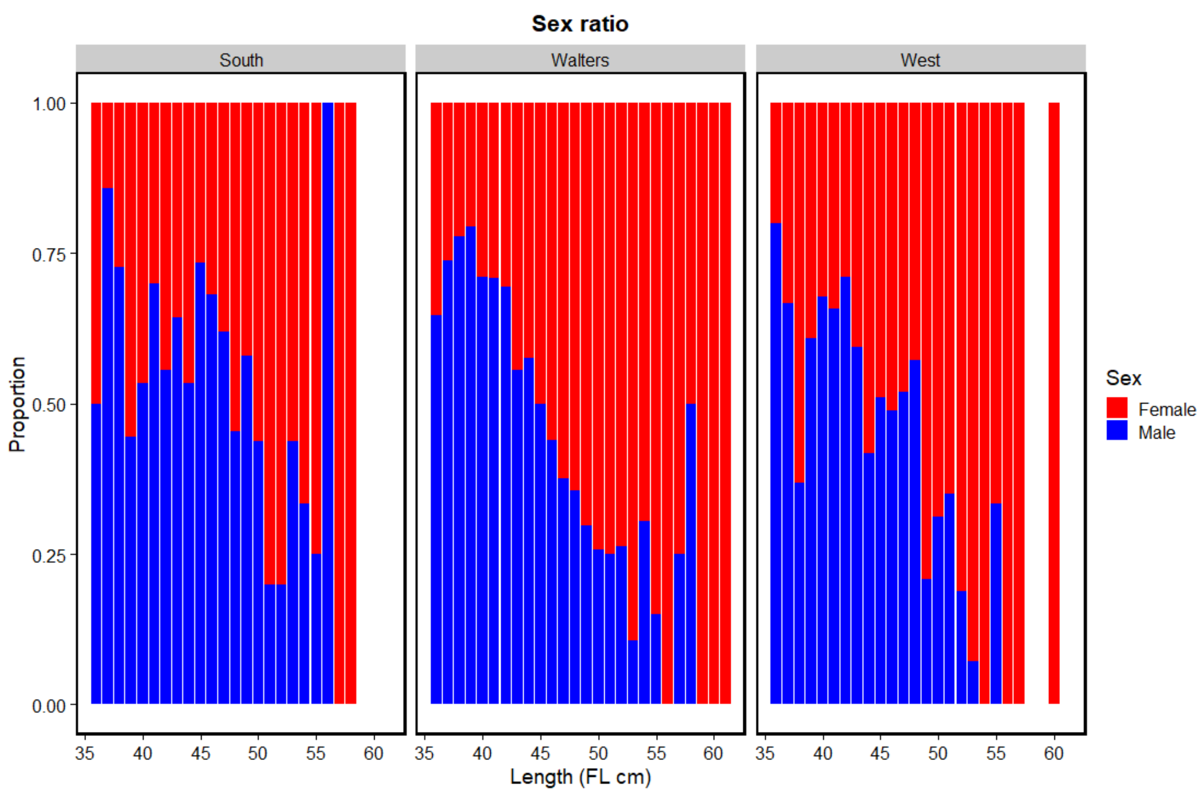

Figure 6: The orange roughy sex ratio by size and region from all regions in the SIOFA area.

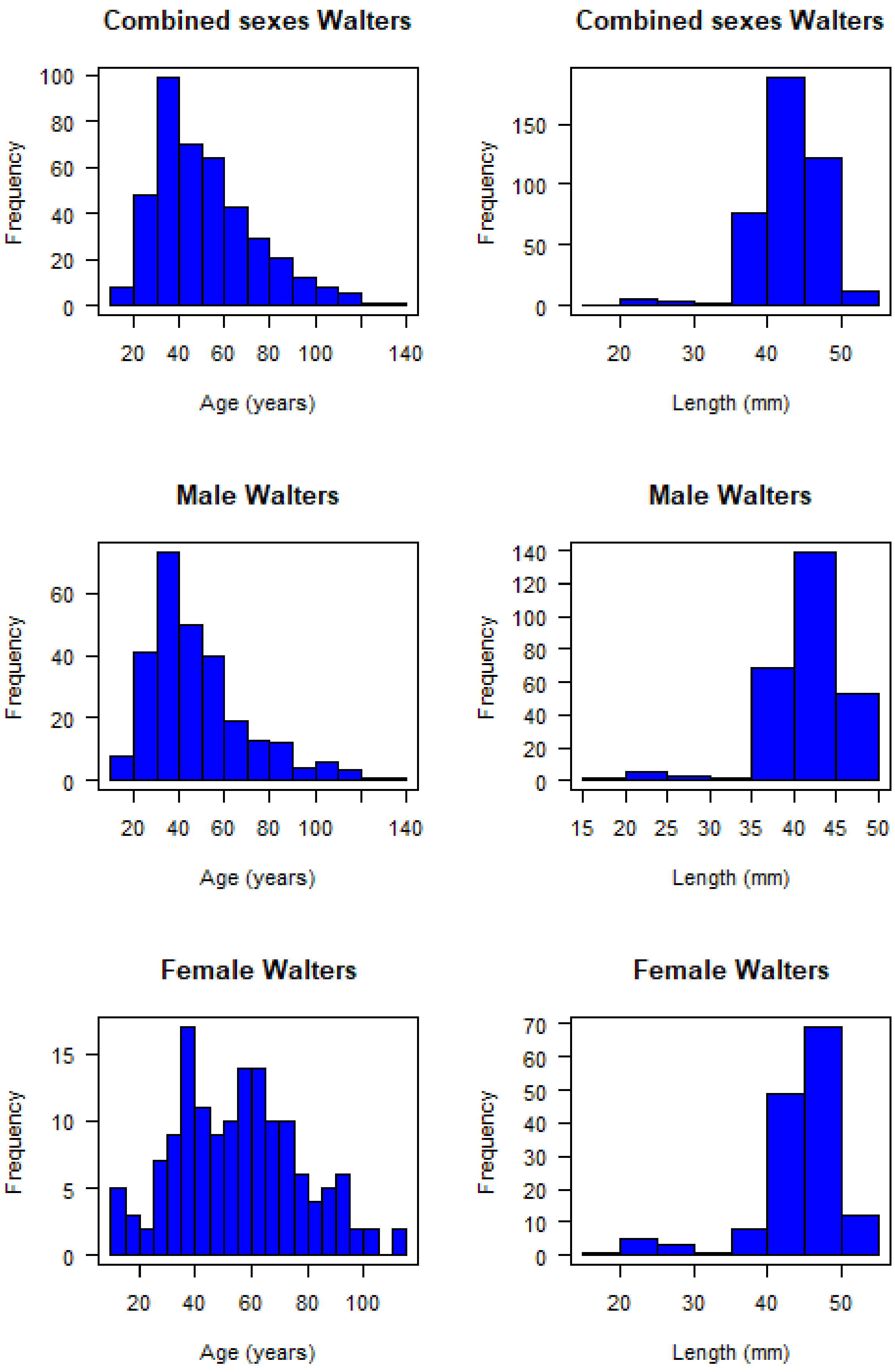

Figure 7: Age and length distributions in the sample data set of orange roughy sampled from Walter's Shoal.

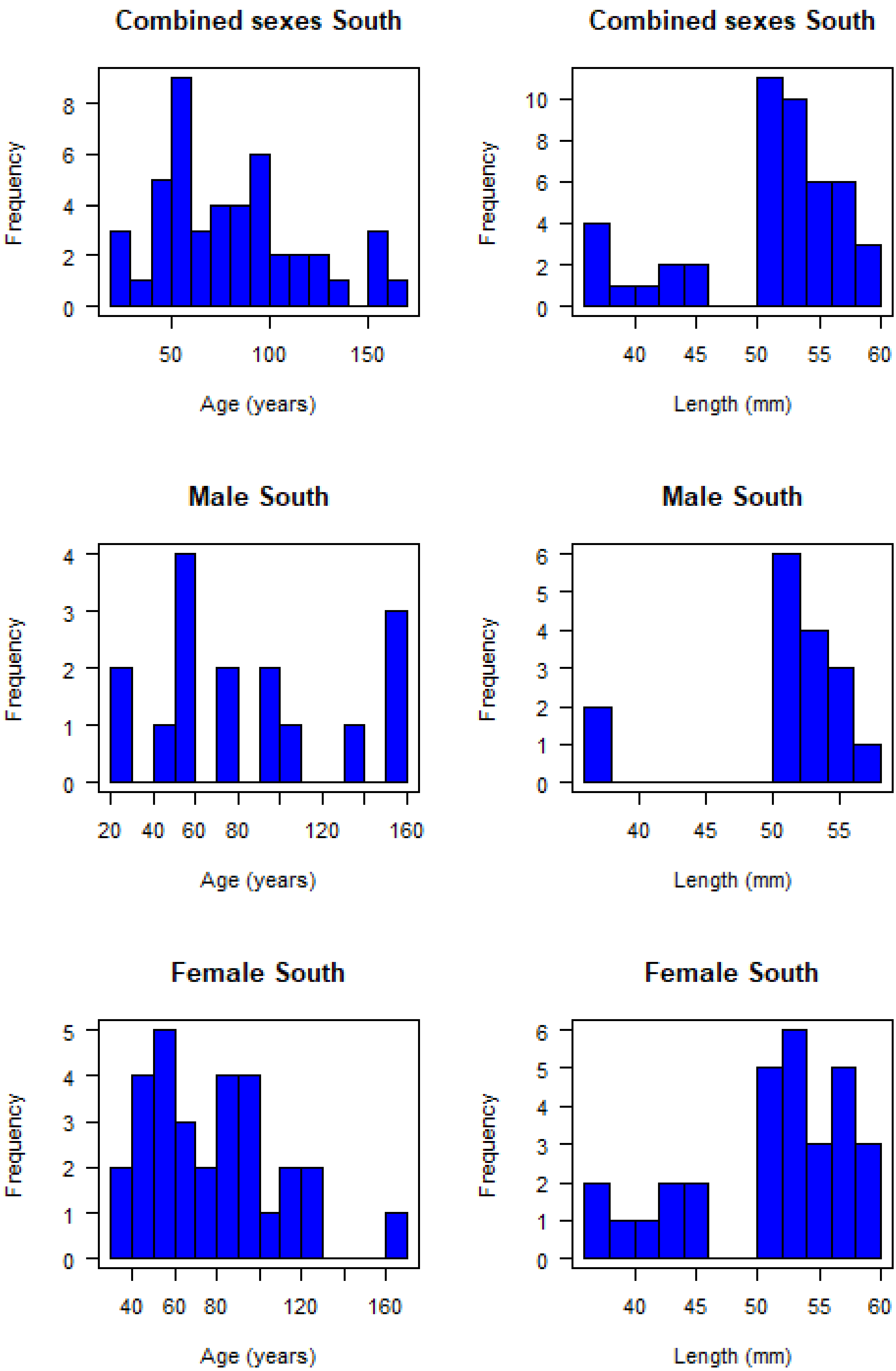

Figure 8: Age and length distributions in the sample data set of orange roughy sampled from South Ridge.

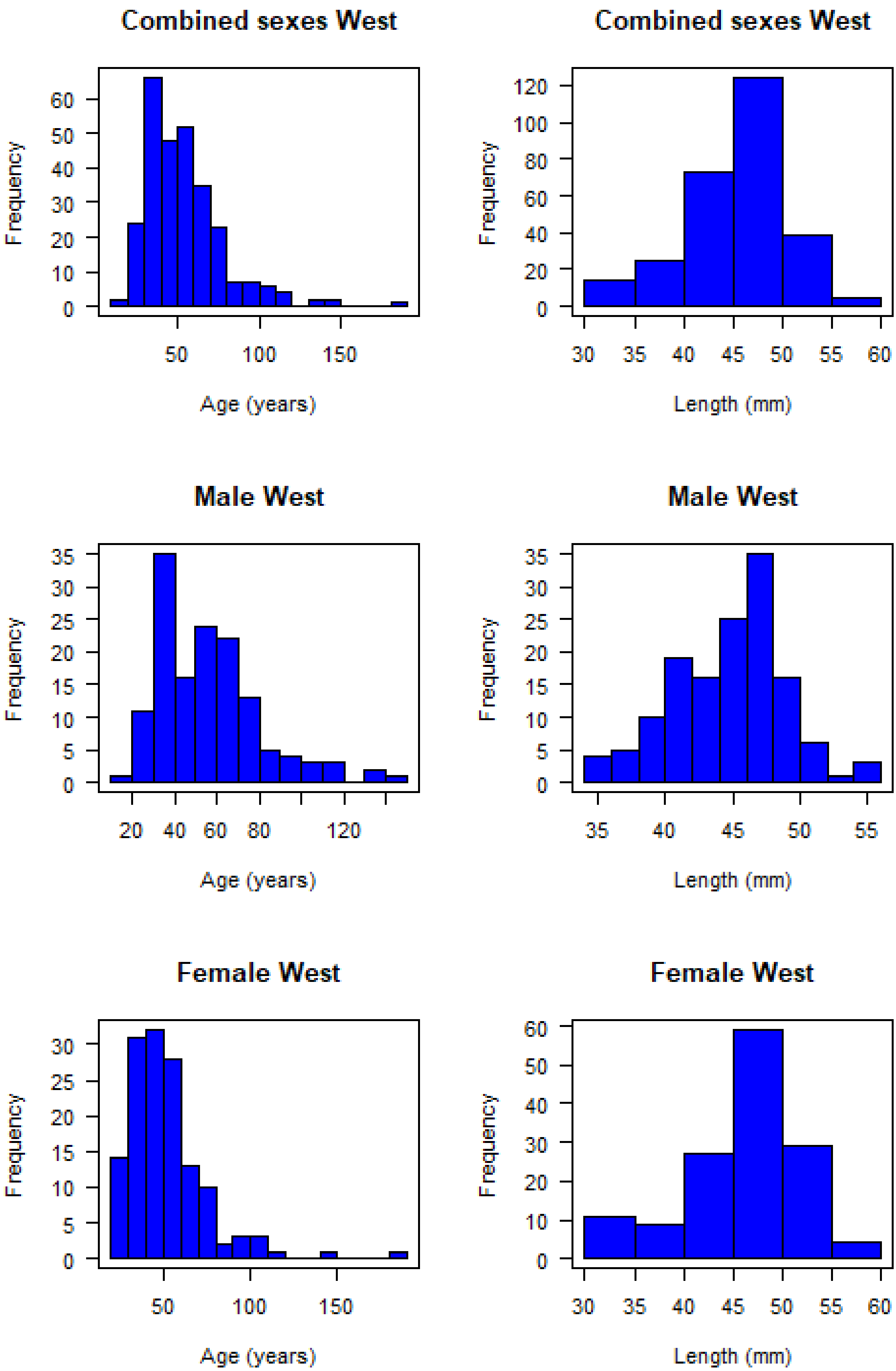

Figure 9: Age and length distributions in the sample data set of orange roughy sampled from Western Rise.

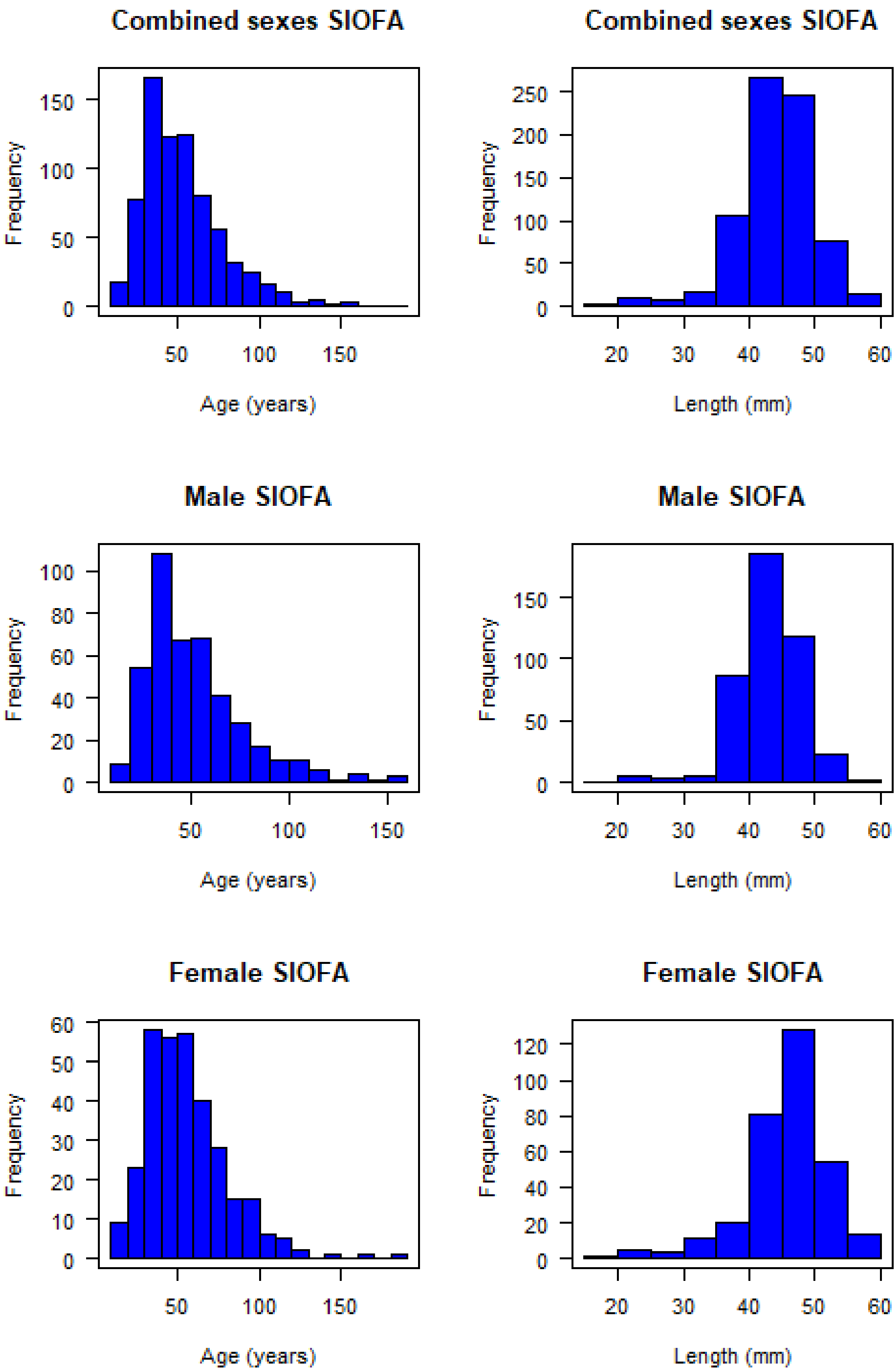

Figure 10: Age and length distributions in the sample data set of orange roughy in the SIOFA area all regions combined.

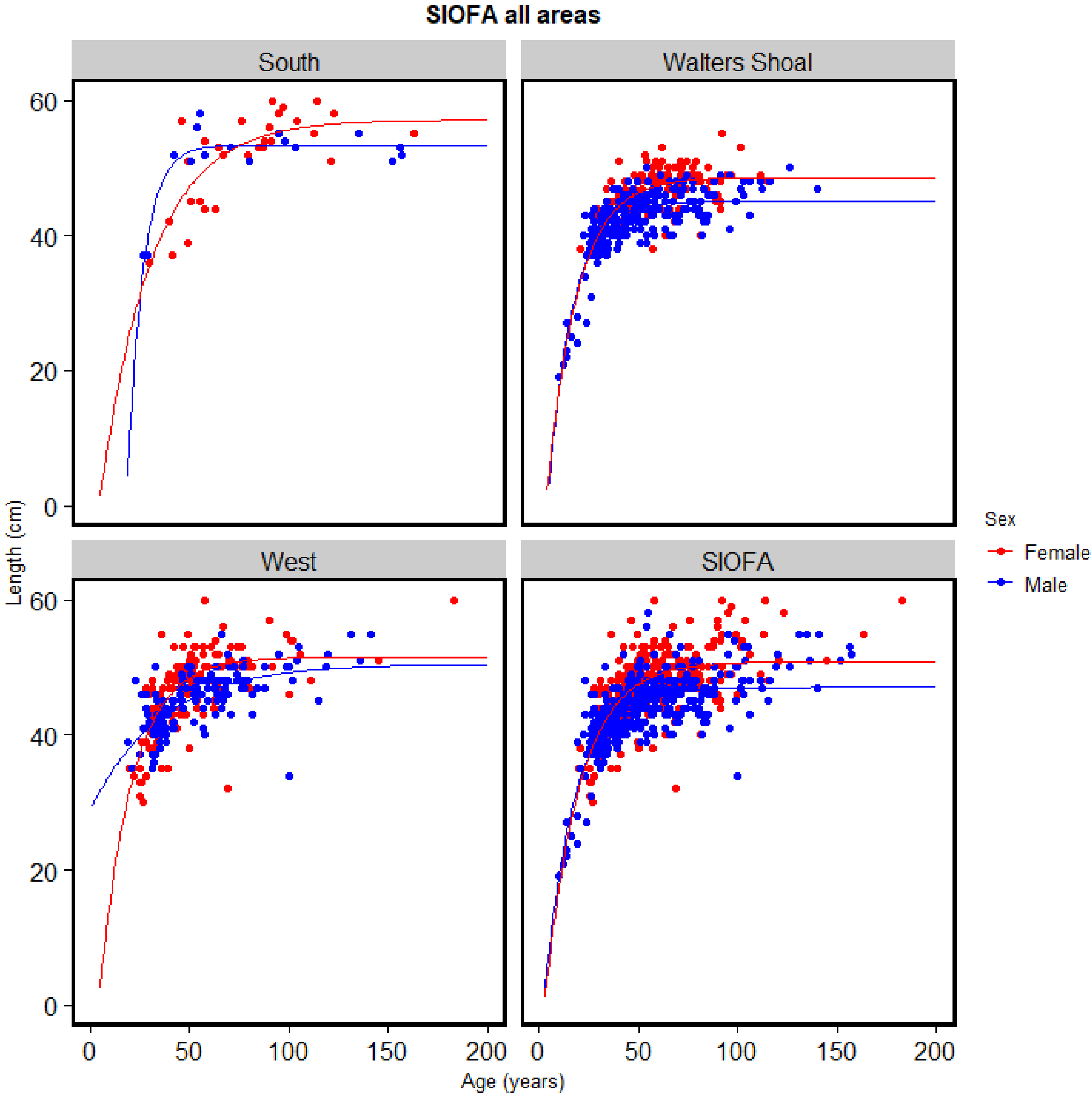

Figure 11: Age-at-length observations from all samples and the estimated von Bertalanffy curves of orange roughy in the SIOFA area, values for the curves can be found in Table 2. SIOFA refers to all areas combined.

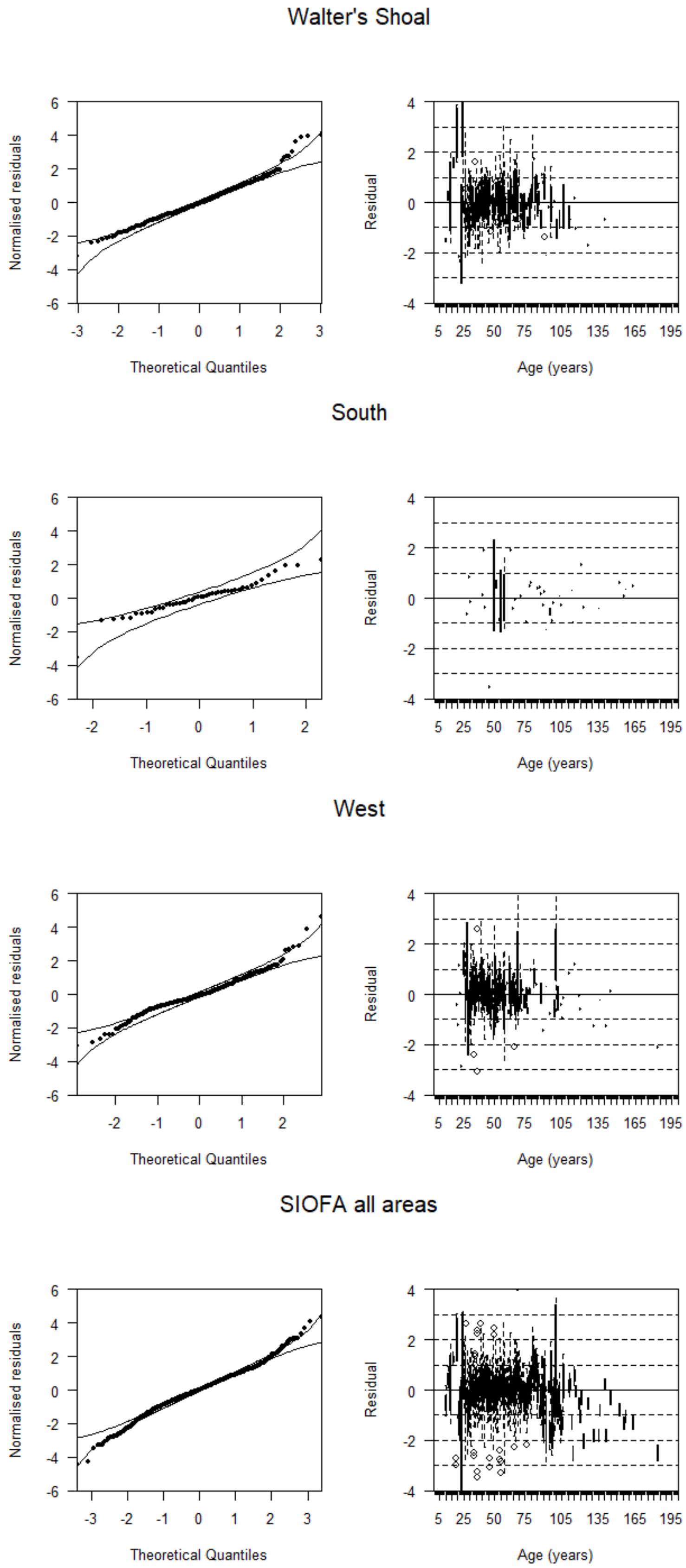

Figure 12: Residual distributions for the estimated length-at-age estimates of orange roughy in the SIOFA area.

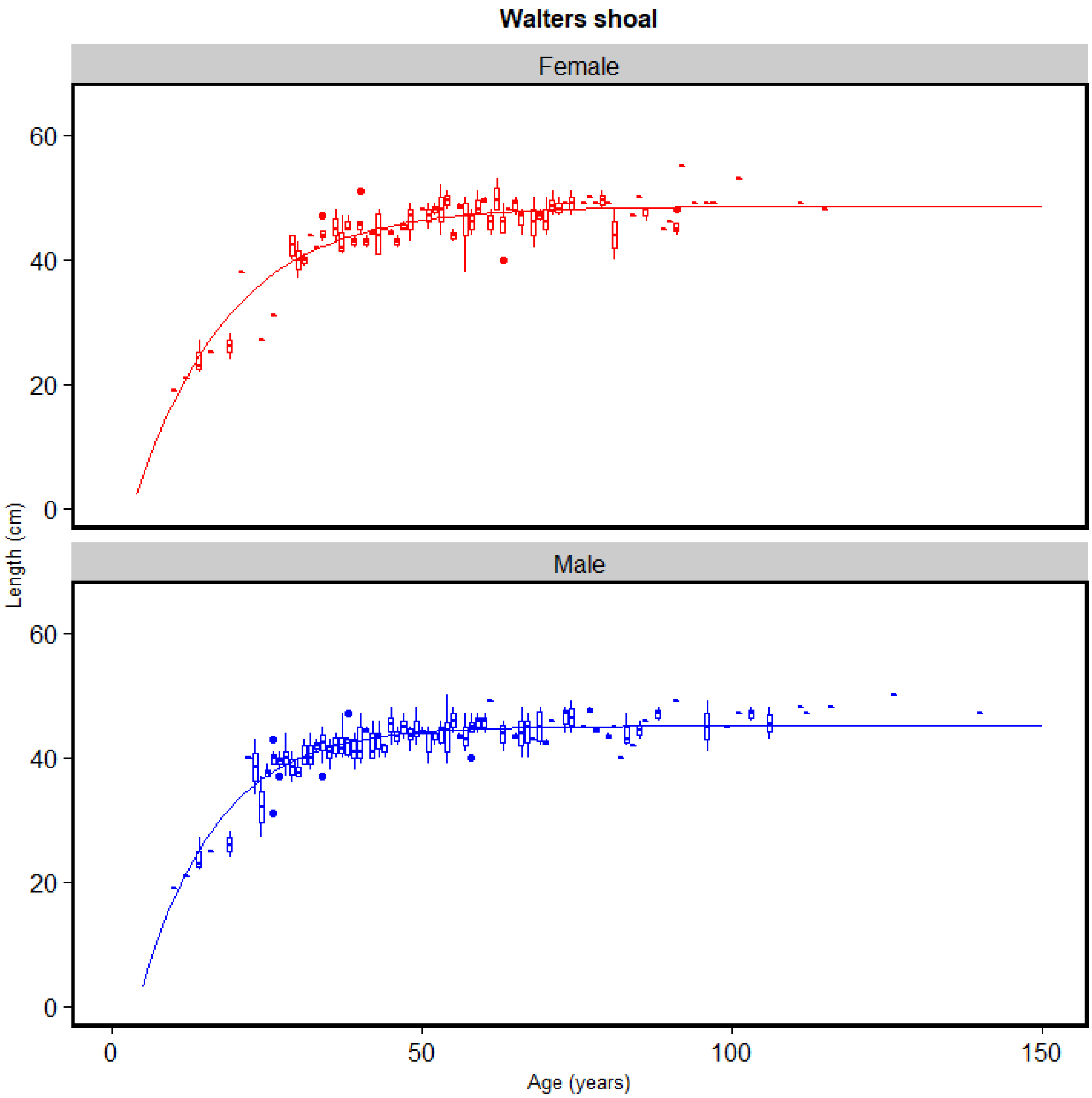

Figure 13: Estimated length-at-age distributions and the fitted von Bertalanffy growth curves of orange roughy at Walters Shoal, values for the curves can be found in Table 2.

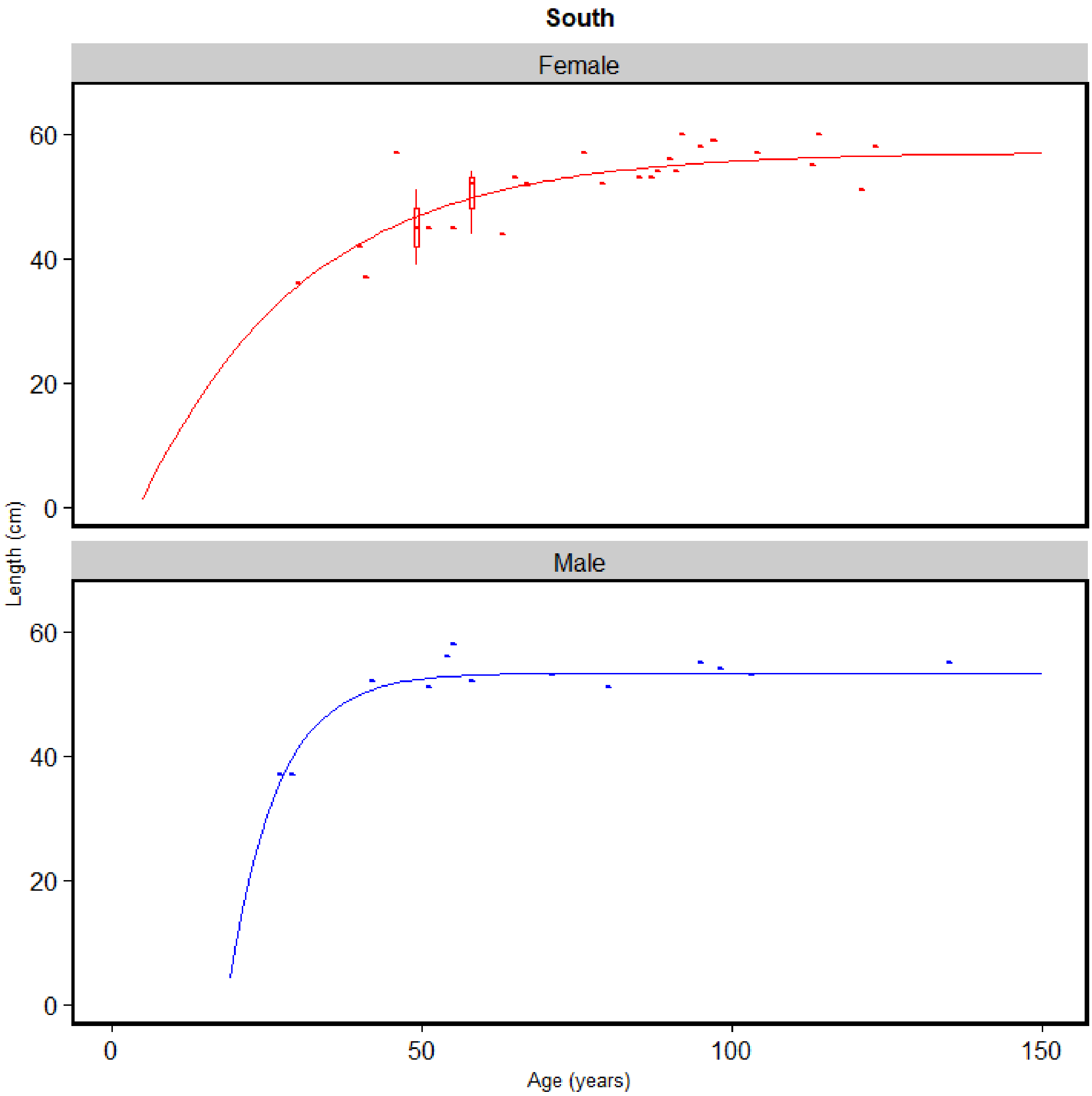

Figure 14: Estimated length-at-age distributions and the fitted von Bertalanffy growth curves of orange roughy at South Ridge, values for the curves can be found in Table 2.

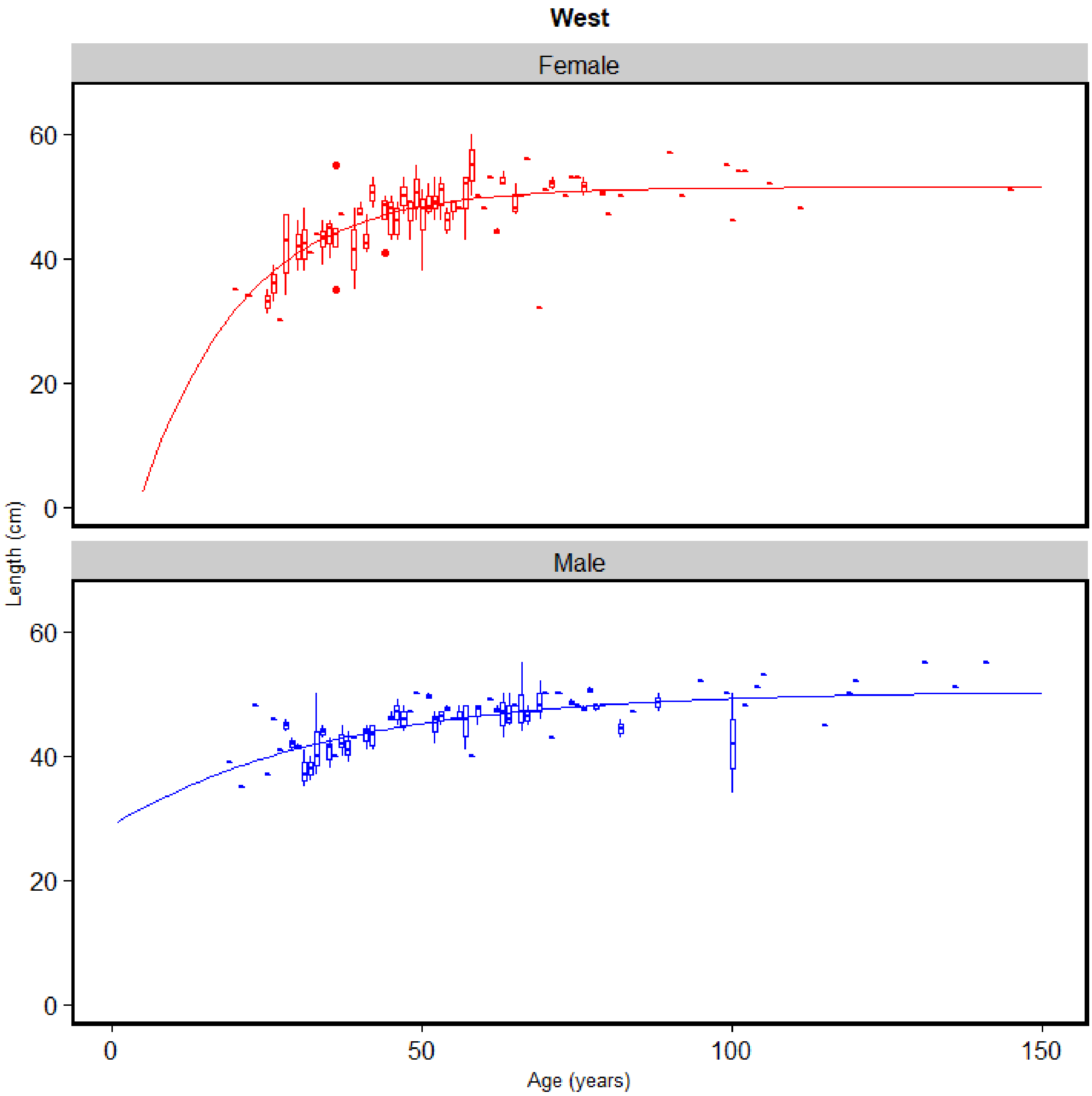

Figure 15: Estimated length-at-age distributions and the fitted von Bertalanffy growth curves of orange roughy at the Western Rise, values for the curves can be found in Table 2.

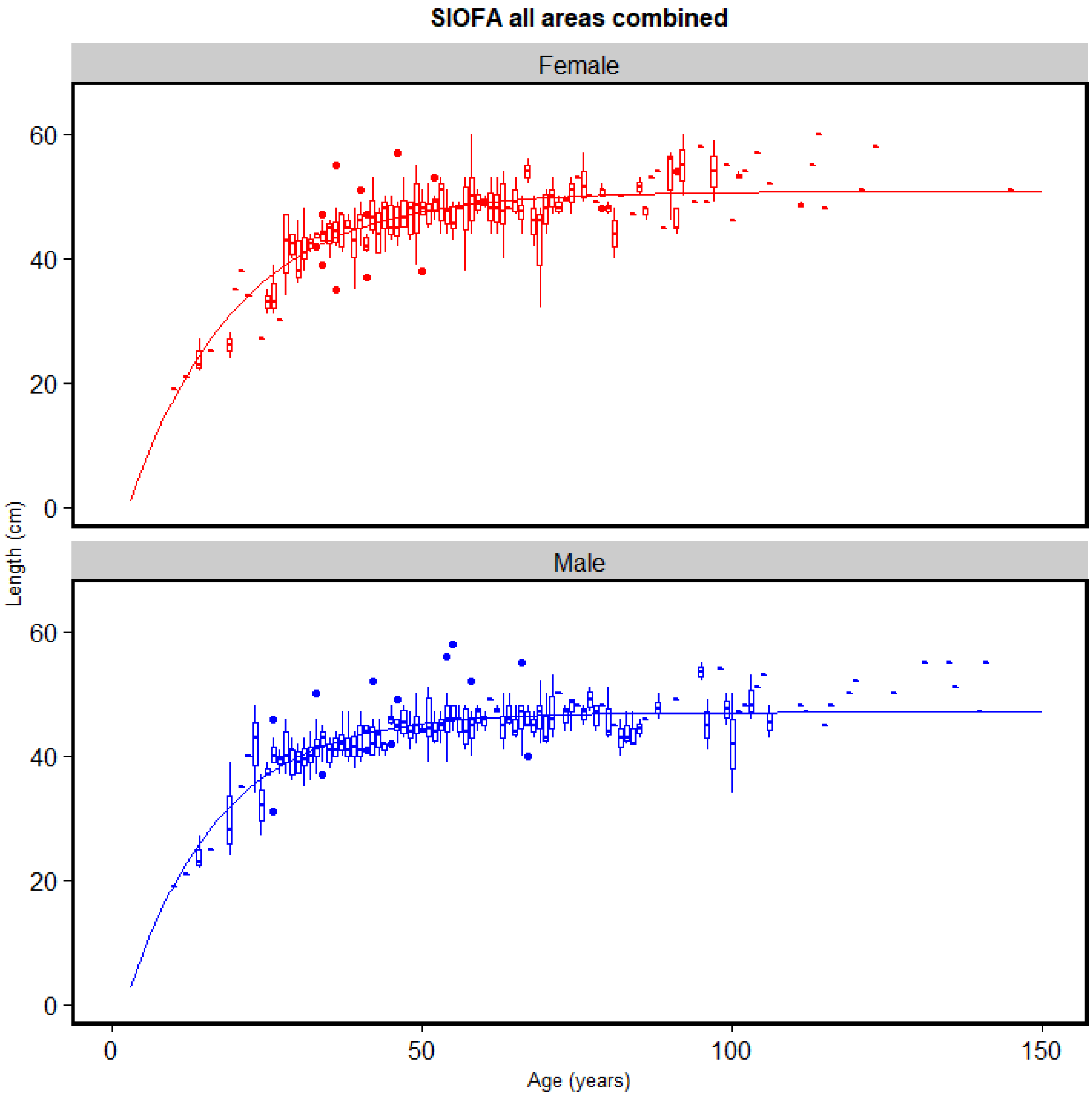

Figure 16: Estimated length-at-age distributions and the fitted von Bertalanffy growth curves of orange roughy in the SIOFA area, values for the curves can be found in Table 2.

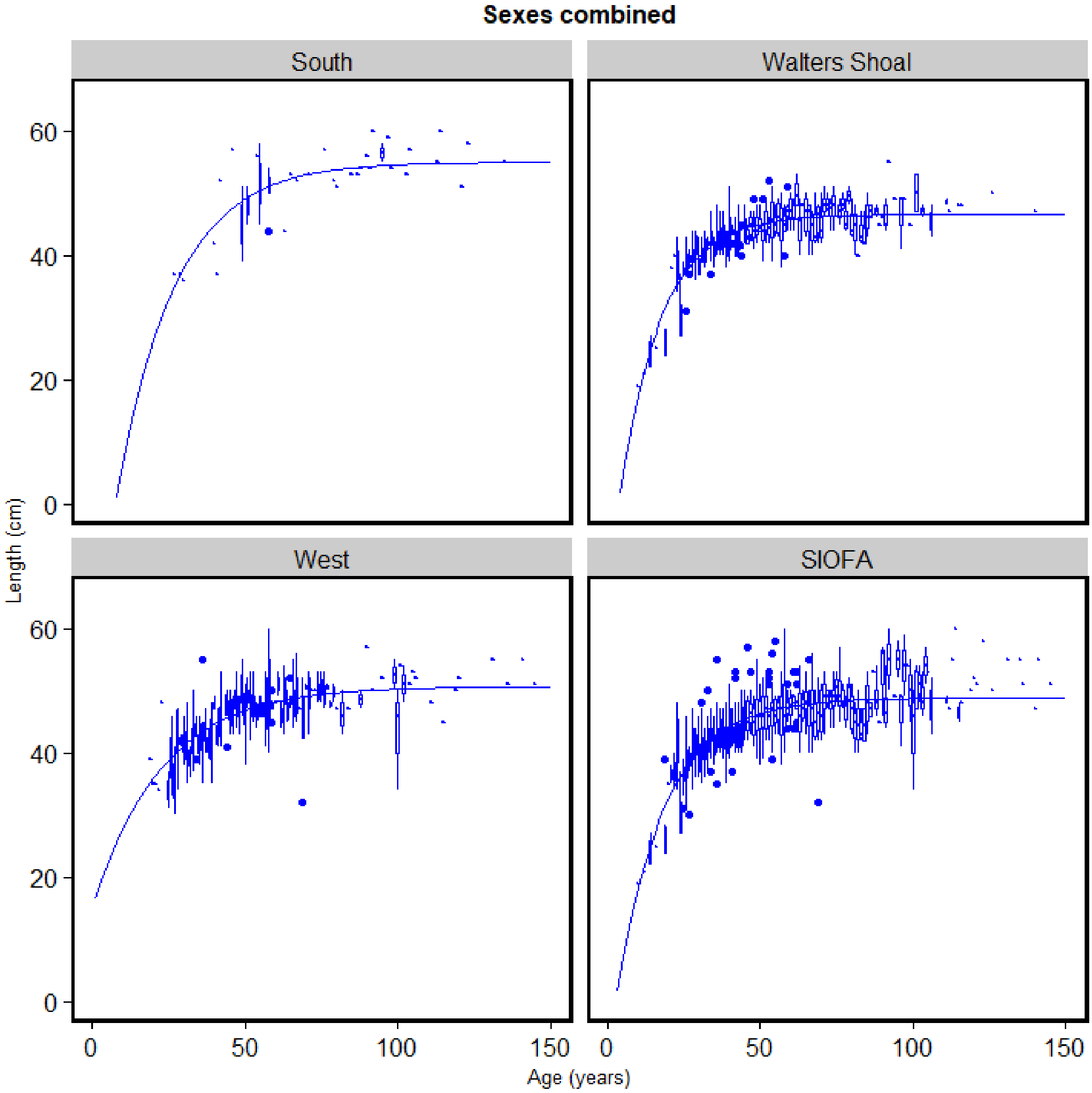

Figure 17: Estimated length-at-age distributions and the fitted von Bertalanffy growth curves of orange roughy where the sexes were combined in the SIOFA area, values for the curves can be found in Table 2. SIOFA refers to all areas combined.

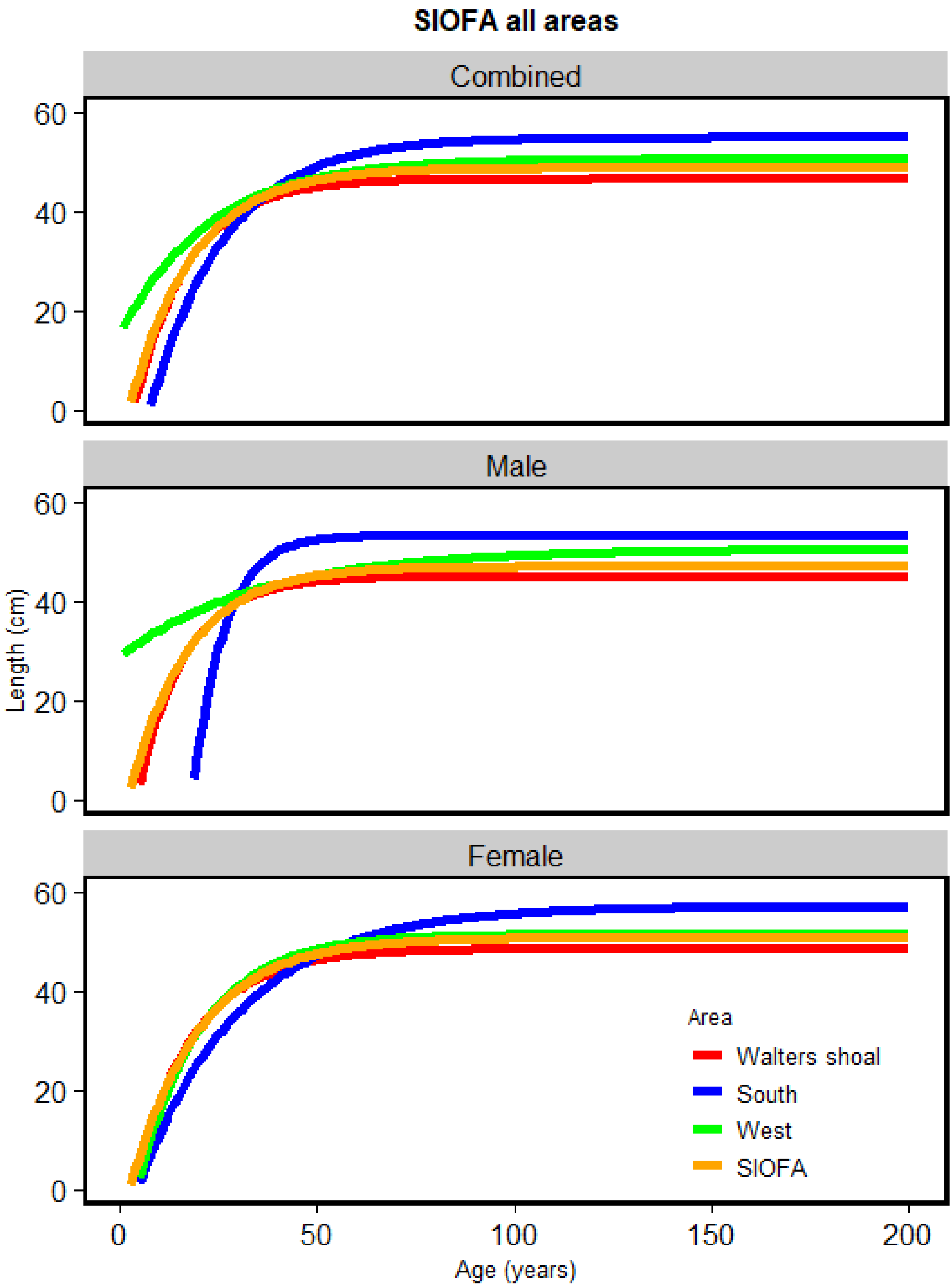

Figure 18: The von Bertalanffy growth curves of orange roughy from the regions sampled in the SIOFA area, values for the curves can be found in Table 2. SIOFA refers to all areas combined.

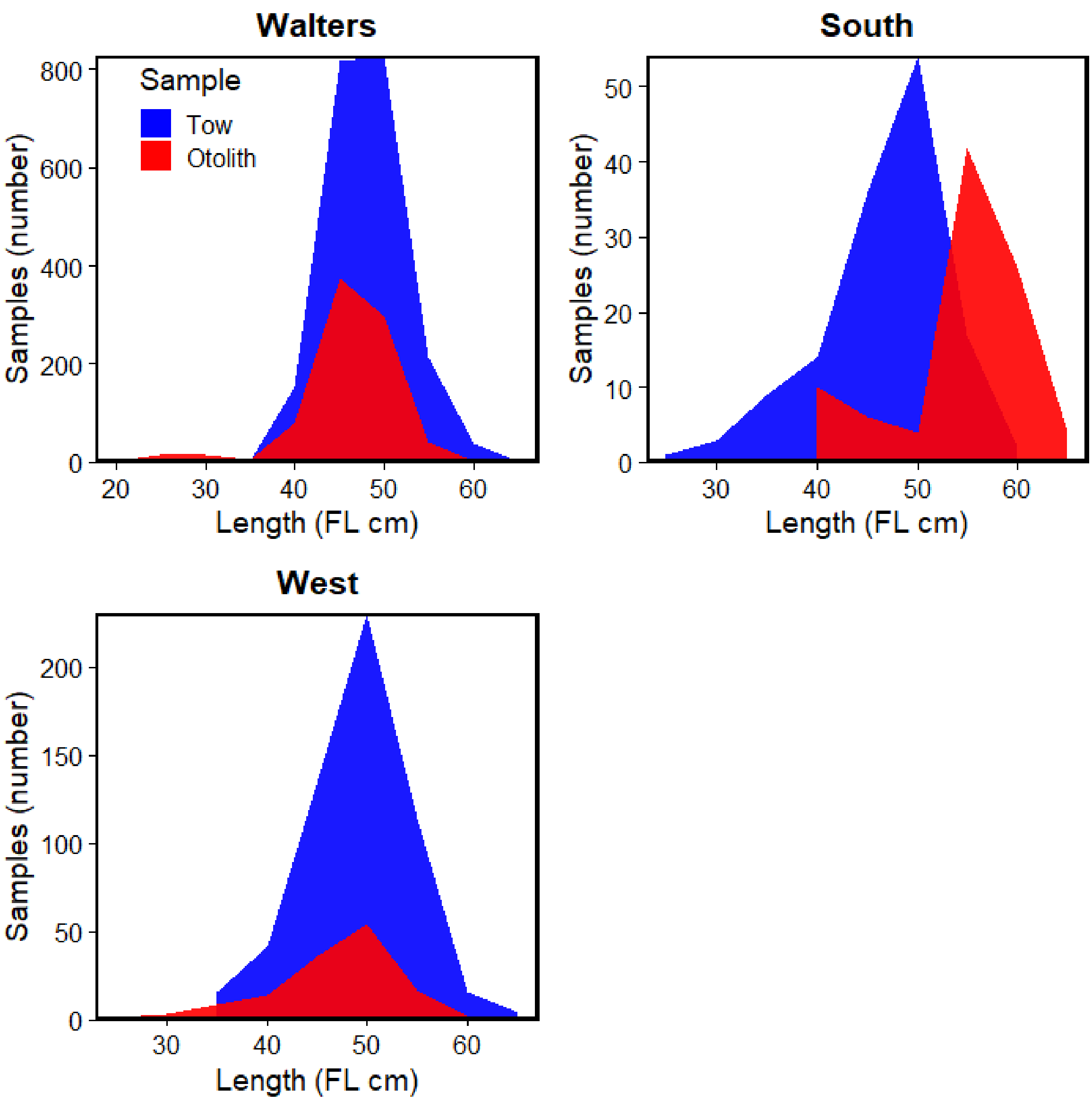

Figure 19: Comparisons of orange roughy length data form the age samples to the overall length sample in 5 cm length bins from each area from tows where otoliths were collected.

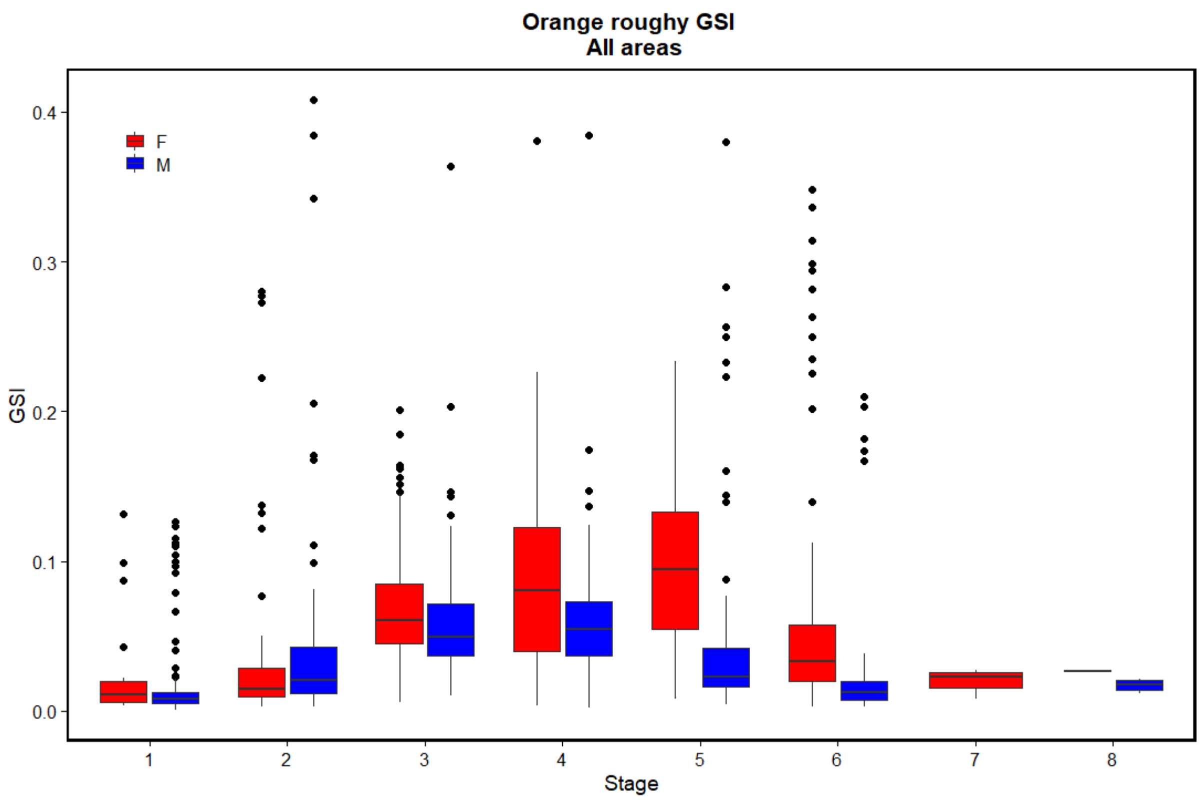

Figure 20: The gonado-somatic index for orange roughy by gonad stage from all regions sampled in the SIOFA area.

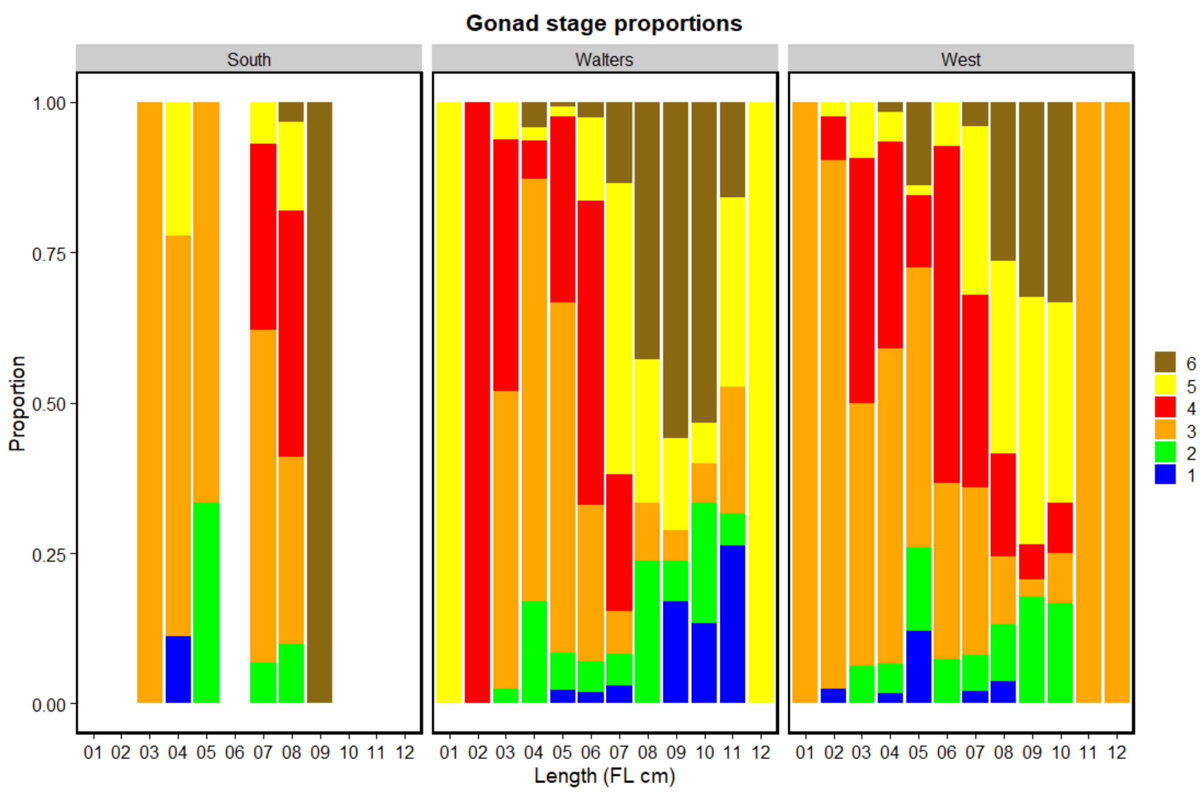

Figure 21: The gonad stages for orange roughy by month from each region sampled in the SIOFA area.

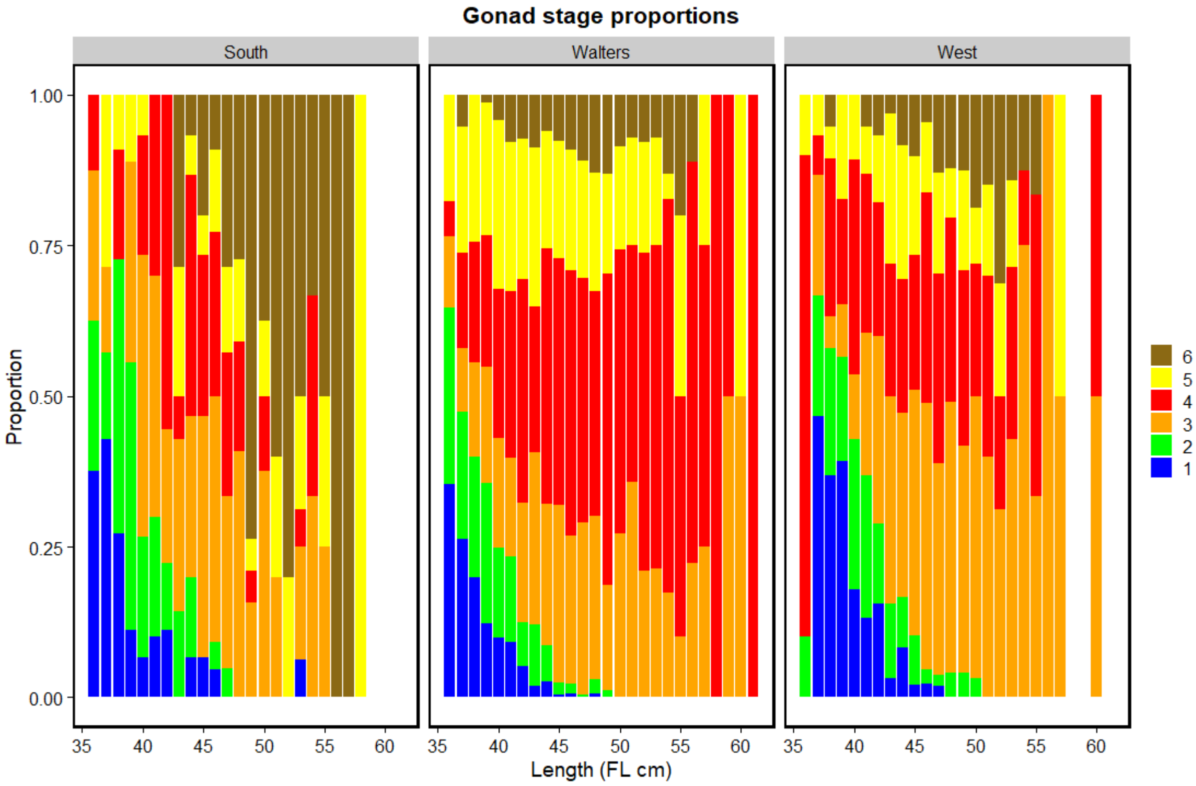

Figure 22: The gonad staging for orange roughy for gonad stages 1-6 from all regions in the SIOFA area. Stages 1 and 2 are considered immature with 3-6 being mature.

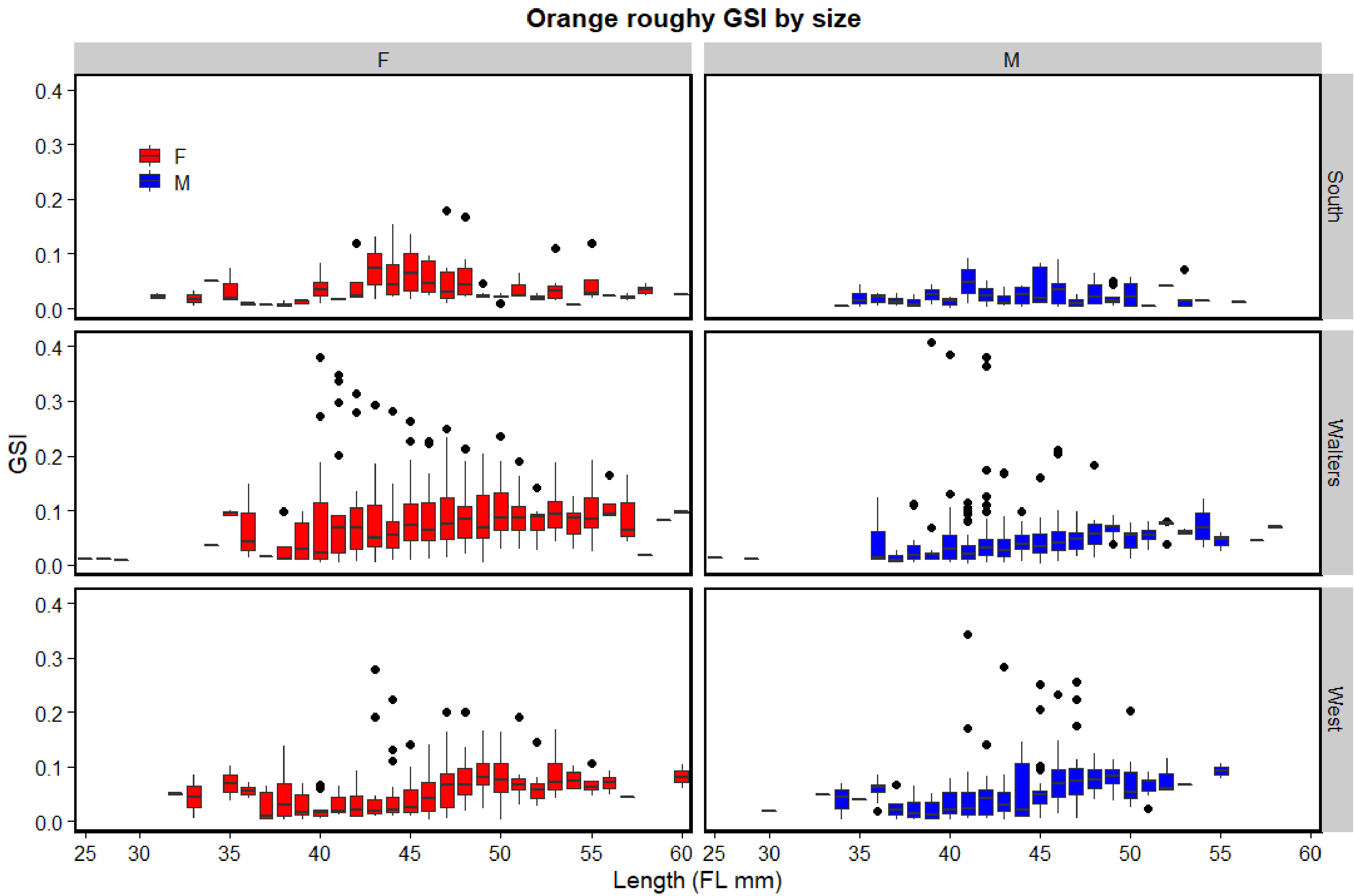

Figure 23: The gonado-somatic index for orange roughy by size from all regions in the SIOFA area combined.

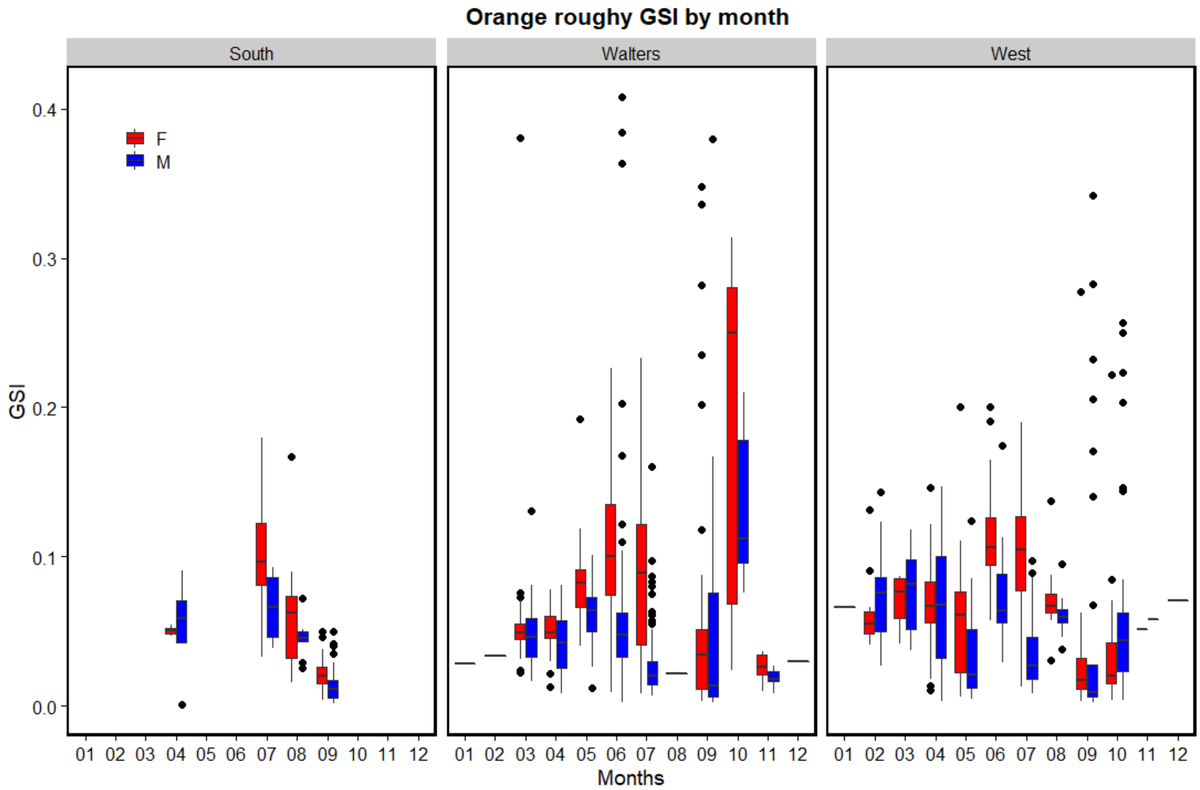

Figure 24: The gonado-somatic index for orange roughy by month from all regions sampled in the SIOFA area.

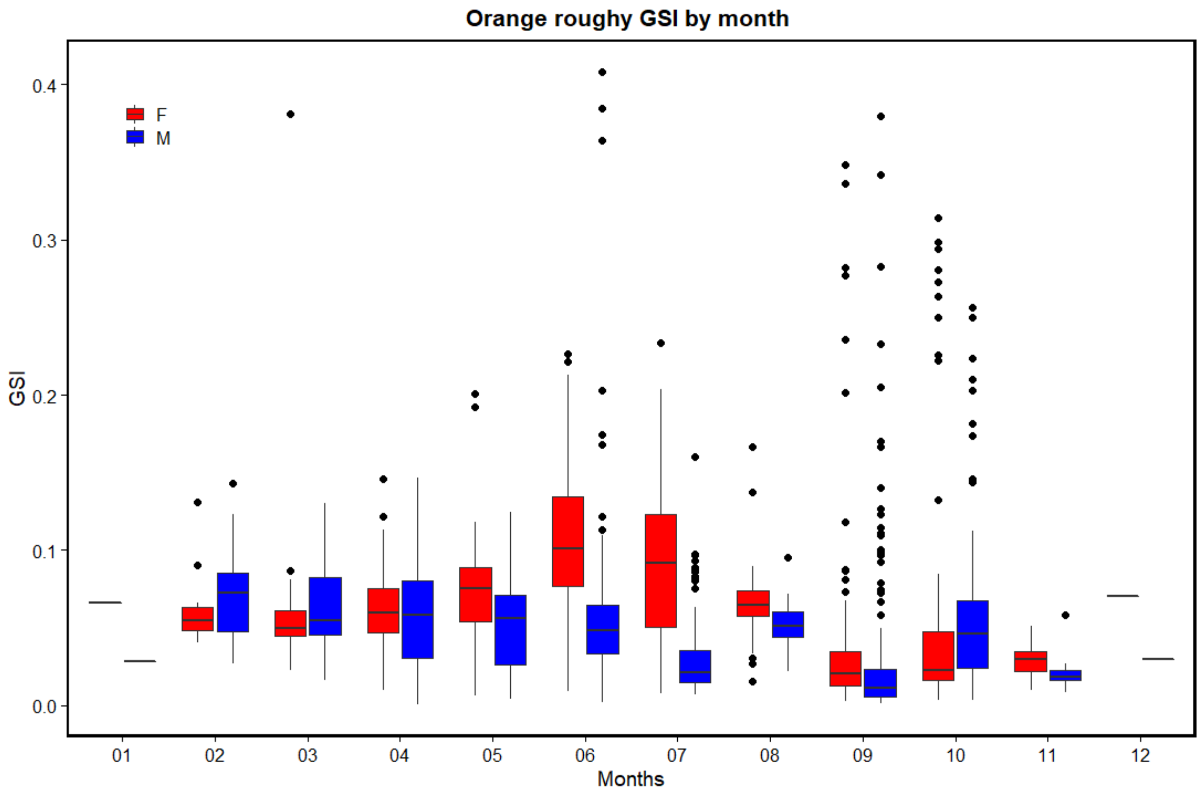

Figure 25: The gonado-somatic index for orange roughy by month from all regions in the SIOFA area combined.

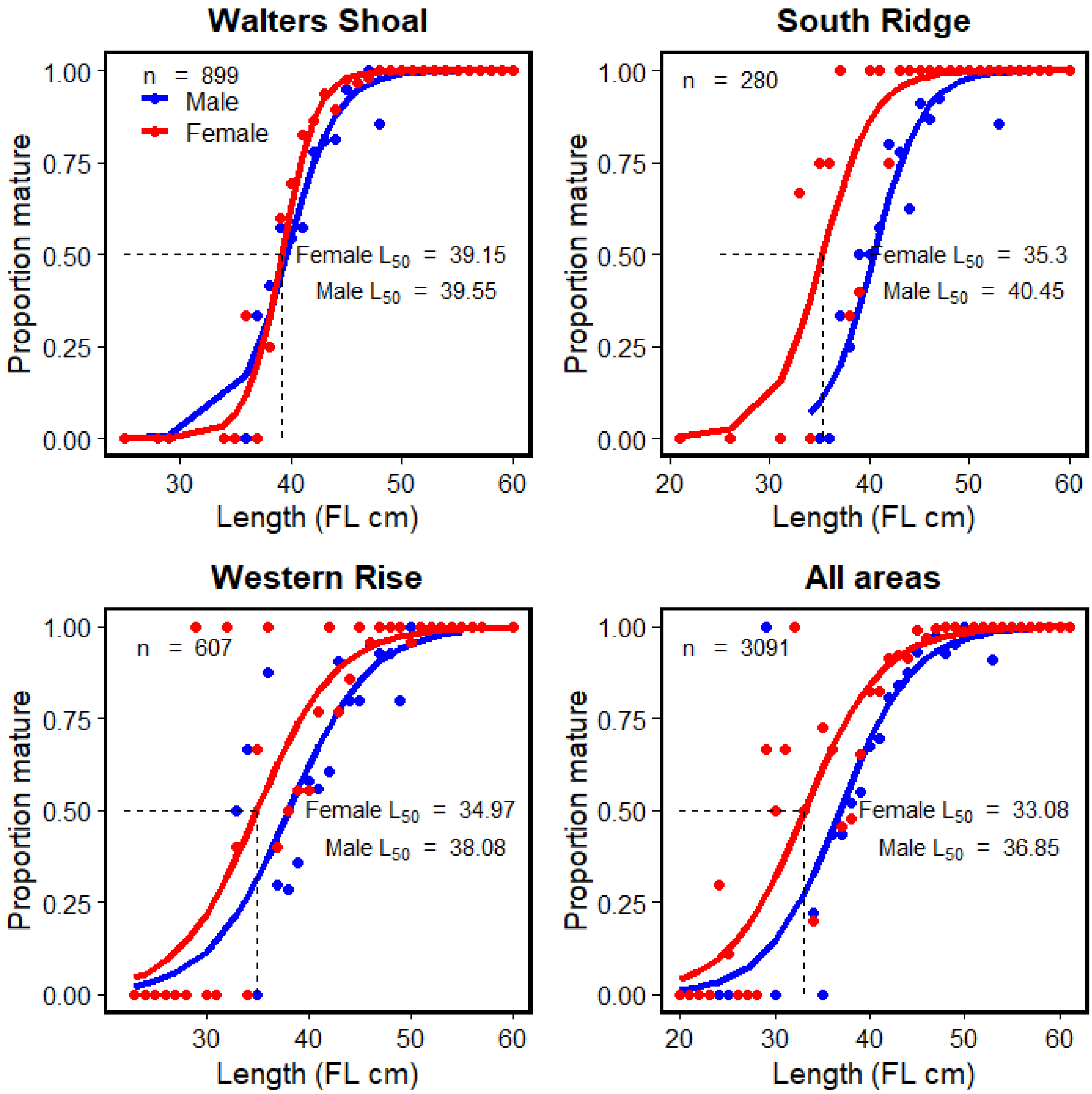

Figure 26: The orange roughy maturity curves showing the size-at-50% maturity (L_{50}) by sex for all regions in the SIOFA area and all regions combined (All areas). The dashed lines correspond to the female L_{50}.

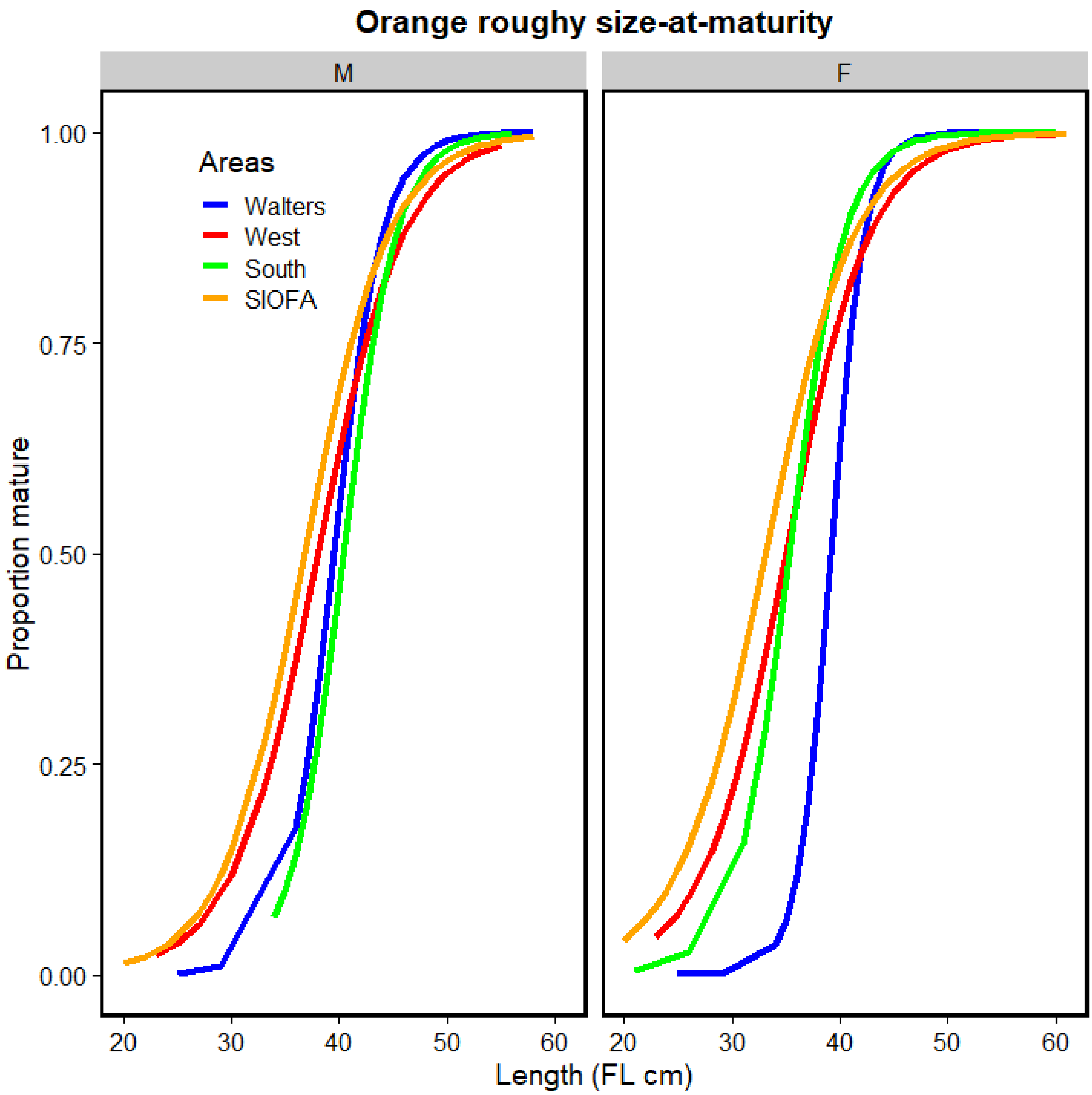

Figure 27: The orange roughy maturity curves by sex for all regions in the SIOFA area and all regions combined (SIOFA). The L_{50} values can be found in Table 4.