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Alfonsino growth, length and maturity estimates from fish sampled Cook Island trawl vessels in SIOFA

Relates to agenda item: 3.2 **Working paper X** **Info paper**

Delegation of The Cook Islands

Abstract

Alfonsino (*Beryx splendens*) aggregate in large numbers and are a major fishery in the Southern Indian Ocean Fisheries Agreement (SIOFA) area where they are fished using bentho-pelagic trawl gear by the Cook Islands fleet in the SIOFA area. Between 2009 to 2020 45,062 fish were sampled for length and maturity across all months of the year. The samples were collected from a wide area in the south central Indian Ocean and were obtained from five broad regions. This analysis provides updated age and growth information for alfonsino, a detailed description of the length samples by year, month and marine feature as well as updating the maturity schedule for alfonsino.

Gonad mass increases substantially with fish length. The monthly gonado-somatic index (GSI) trends show that alfonsino have a distinct spawning season through the Austral summer with the bulk of spawning taking place from December to February. The estimated size-at-maturity was 38cm for both males and females which coincides with an age of 9 years. The size-at-maturity coincides with a change in the growth of the fish as well a change in the relationship between fish age and otolith weight. For fish below the size-at-50% maturity the sex ratio is approximately balanced, however, after the onset of maturity the sex ratio becomes skewed in favour of females which may be related to differential mortality of male and female fish.

Recommendations

- The SERAWG note that the otolith samples are reflective of the length sample of the tows from which they came.
- Future assessments:
  - Use the updated maturity schedule.
  - Use the revised growth curve.
  - Consider estimating size/age specific natural mortality.
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- The current alfonsino maturity classification tables should continue to be used, but SIOFA should update the gonad maturity classification scheme for consideration by SERAGW4, ensuring that GSI is not used to allocate a maturity stage to a gonad, when finalised, the new classification tables should be use by all SIOFA fleets catching alfonsino.

Ministry *of* Marine Resources

GOVERNMENT OF THE COOK ISLANDS

Alfonsino growth, length and maturity estimates from fish sampled Cook Island trawl vessels in SIOFA

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Contents

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Gonad mass increases substantially with fish length. The monthly gonado-somatic index (GSI) trends show that alfonsino have a distinct spawning season through the Austral summer with the bulk of spawning taking place from December to February. The estimated size-at-maturity was 38cm for both males and females which coincides with an age of 9 years. The size-at-maturity coincides with a change in the growth of the fish as well a change in the relationship between fish age and otolith weight. For fish below the size-at-50% maturity the sex ratio is approximately balanced, however, after the onset of maturity the sex ratio becomes skewed in favour of females which may be related to differential mortality of male and female fish.

The following recommendations are presented for the considerations of the Scientific Committee Stock Assessment and Ecological Risk Assessment Working Group:

- The SERAWG note that the otolith samples are reflective of the length sample of the tows from which they came.
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  - Use the updated maturity schedule.
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- The current alfonsino maturity classification tables should continue to be used, but SIOFA should update the gonad maturity classification scheme for consideration by SERAGW4, ensuring that GSI is not used to allocate a maturity stage to a gonad, when finalised, the new classification tables should be use by all SIOFA fleets catching alfonsino.

1 Introduction

Alfonsino (*Beryx splendens*) inhabit waters from 25-1,300m, but are most commonly found at depths of 200-800m, where they are found in association with marine features such as hills, ridges and seamounts (Shotton, 2016). They aggregate in large numbers and are a major fishery in the Southern Indian Ocean Fisheries Agreement (SIOFA) area where they are fished using bentho-pelagic trawl gear. They are targeted with both bottom and mid-water trawl gear. The Cook Islands vessels uses mid-water (bentho-pelagic) trawl gear which is designed to fish close to the bottom and may occasionally contact the sea floor and mid-water trawl gear that is designed to fish without bottom contact. The historic Australian alfonsino fleet fished with similar gear to the Cook Islands fleet in the SIOFA area, while the Japanese vessels tend to use mid-water gear. It is believed that the mid-water gear fishing away from marine features targets mainly smaller fish while the bentho-pelagic sets which are focused around marine features like seamounts target larger individuals.

A number of biological investigations of alfonsino have been undertaken including investigations into age growth (Adachi et al. 2000; Brouwer et al. 2020; Lehodey and Grandperrin 1996; Massey and Horn 1990; Santamaria et al. 2006; Tanuchi et al. 2004) and reproduction (Flores et al. 2012; Gonzalez et al. 2003; Lehodey et al. 1997). These studies found that alfonsino to be a relatively slow growing iteroparous gonochoristic species. Levy-Hartmann et al. (2011) found an extremely high intra-specific genetic diversity which lead them to suggest that alfonsino have a wide and uniform stock distribution with a high degree of mixing between areas within and between Oceans. Some morphometric data have been collected, however, at this stage the stock structure of Indian Ocean alfonsino is unknown and it is not clear if the genetic structure is occurring through adult or larval mixing. The stock distribution of Indian Ocean alfonsino is therefore currently unresolved.

In 2020 the SIOFA undertook a stock assessment of alfonsino in the Agreement Area (Brandao et al., 2020). That assessment included age and growth information from the Cook Islands trawl fishery as well as limited length information from a single year. The Cook Islands, Australia and Japan provided alfonsino otoliths from key fishing grounds in the East and West of the Agreement area to the Fish Ageing Services (FAS), Victoria, Australia, to carry out age estimations. Brouwer et al. (2020) estimated the growth parameters using samples collected from the Cook Islands fleet. However, length information was missing from many of the female fish. In addition, length and maturity information from this fishery was not incorporated into the assessment.

This paper updated the growth information to include more female fish in the analysis; provides information on the representivity of the otoliths collected for the age and growth study; provides information on the length composition of the catch as well as updating the maturity schedule for alfonsino in SIOFA.

2 Methods

Observers on Cook Islands flagged vessels fishing in the SIOFA are required to collect length, sex, maturity and age material. One hundred randomly selected fish are weighed whole, measured (fork length cm) and sexed. For each fish the gonad was weighed and maturity stage estimated visually. 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.

Otoliths were stored dry. Otoliths were read whole and assigned an age, edge type and readability score by two readers independently. The von Bertalanffy growth function was used to describe growth. The growth parameters were estimated in R (R Core Team, 2020) using non-linear least-squares estimation (nls) which uses the methods described by Bates and Watts (1988) and Bates and Chambers (1992). Growth was estimated using all the data and only otoliths with good readability (readability scores 1-3 [R1-R3]). For more details on the methods see Brouwer et al. (2020); Massey and Horn (1990); Lehodey and Grandperrin (1996).

To assess age sample representivity, 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.

Male and female gonads were assigned to a six-stage maturity scale based on the seven stage scale used by FAO (2015). In this analysis female stages 6 and 7 were combined into a single spent state (Table 1). Gonad mass and stage was summarised by length class. Fish with gonads in stages 1 and 2 were considered immature while those at stages 3-6 were considered mature. The gonado-somatic index (GSI) was calculated by dividing the gonad mass by fish mass for female alfonsino and then summarised by month.

Size-at-maturity was estimated. The proportion of mature fish in each size class in the sample was estimated during the spawning season only and a maturity ogive was fitted in R (R Core Team, 2020) using a binomial General Linear Model. The length-at-50% maturity was then derived and the age-at-50% maturity was then estimated from the growth curves.

3 Results and Discussion

Sampling occurred from 2009 to 2020 with 45,062 fish being sampled across all months of the year. The samples were collected from a wide area in the south central Indian Ocean and were spread across five broad regions (Figure 1). Brouwer et al. (2020) noted that the age sample used in that analysis was missing female length information from length classes 35cm - 50cm, as a result those samples were rejected. These length records have been found and added to the previous analysis (Figure 2). Their inclusion resulted in a more realistic female growth estimate which is now similar to that of the males (Figure 3). There is no difference between the male, female and both sexes combined curves (Figure 4). The updated combined growth parameters are shown in Figure 5. These revised growth parameters are slightly different from those used in Brandao et al. (2020) and these revised values should be used in future.

In addition to the age-length relationship, there is a relatively consistent relationship between fish age and otolith weight (Figure 6). However, like the age-length relationship the data become more varied and less predictable for fish over 8 years of age.

At the second meeting of the SIOFA Scientific Committee Stock Assessment and Ecological Risk Assessment Working Group in 2020 the group discussed Brouwer et al. (2020). During that discussion a question was raised as to whether the sample of aged fish was representative of the catch. To investigate this the length sample form the random sample of the catch was compared to fish from the otolith sample. There is broad similarity between the otolith sample and all length samples, all length samples from sets where otoliths were collected and for sets where no otoliths were sampled (Figure 7). A two-sample Kolmogorov-Smirnov test was used to compare the length sample to the length of fish in the otolith sample. This test revealed no statistical difference between the two samples (D = 0.042975, p-value = 0.1271), indicating that the otolith sample was not biased and is representative of the sampled catch. The otolith sample represented about 10% of the sampled catch in each length class from the length sample. However, small fish that are caught infrequently were under represented as were the very large fish over 54cm in length and some large size samples were over sampled (Figure 8). These trends result from the infrequent catch of fish at the very low and very high end of the scale. It is therefore recommended that attempts be made to deliberately target otolith sample collection from very small and very large fish, but excluding these targeted samples from the overall length sample to avoid creating a bias in the random length sample (Perreault et al., In Press). The assumption here is that the random sample is representative of the catch. Nevertheless, the overall sample densities are very similar and the sample shows no directional bias (Figure 9). There is no strong evidence that the mean length of alfonsino in the Cook Islands fishery has changed substantially over time (Figure 10). There is some interannual variation which is could be result of changes in the proportion of mid-water and bentho-pelagic sets. Lastly, there is some variation in the mean length between features, however, this does not seem to be substantial (Figure 11).

Gonad mass increases substantially with fish length, the gonad mass for fish below 38cm is negligible it increases with fish length after that and large fish have very large gonads during the spawning season but not outside of it (Figure 12). As gonads outside of the spawning season can be difficult to stage accurately, only fish sampled during the spawning season were used to estimate size-at-maturity. Fish with gonads stages 1 and 2 were deemed immature (Table 1). This classification indicated that females below 38cm were mostly immature and for females the onset of maturity is slightly earlier than that for the males (Figure 13). For male fish large gonads are common in species that are group spawners where sperm competition is strong (Brouwer and Griffiths, 2005). Noting the issues mentioned above with respect to staging gonads outside of the spawning season, the monthly proportions of each gonad stage was assessed along with changes in fish size through the year (Figure 14). These data show that, broadly speaking, fish length does not change substantially over the course of the year, but it appears the small male fish join the schools during the spawning season. In addition, it appears that fish are under staged outside of the spawning season where many fish (particularly the male fish) are classed as having a gonad maturity stage 1. This is likely caused by the poor gonad classification system in FAO 2015 that relies on GSI as well as gonad appearance to assign a maturity stage, this can result in inexperienced samplers relying on the GSI for staging rather than the gonad appearance.

The monthly GSI data shows that alfonsino have a distinct spawning season through the Austral summer (Figure 15). As with many other fish species the male gonads develop first before the females are ready to spawn. A few females may be ready to spawn as

early as August, but the bulk of spawning takes place from December to February. In the South Pacific Ocean Lehodey et al. (1997) also noted that spawning was truncated and occurred primarily in December and January while Flores et al. (2012) noted that in the south eastern Pacific spawning occurred from June to November but with a peak in July and August. As noted above it was noted in FAO 2015 that the gonad staging descriptions use GSI as a means to classify the gonads, given the large change in GSI between the spawning season and the rest if the year, GSI should never be used to classify gonads and these should be removed from the maturity scale.

The estimated size-at-maturity was about 38cm for both males and females which coincides with an age of 9 years (Figure 16). The age-at-maturity is older than that use in the previous stock assessment (6 years) (Brandao et al., 2020). A revised assessment should use this updated maturity schedule. This maturity schedule could result in a slightly more pessimistic stock status than previously estimated, although the overall impact of a revised maturity schedule, growth curve and additional length information is difficult to predict. Lehodey et al. (1997) found that alfonsino in the Pacific Ocean attain maturity at a smaller size (33 cm - female and 34cm - male). Gonzalez et al. (2003) obtained similar estimates of size-at-maturity in the north Atlantic, but also noted regional variation that is believed to be caused by varying levels of exploitation, with smaller fish and lower size-at-maturity in areas with higher levels of exploitation. The large size-at-maturity observed here could be indicative of a relatively lightly exploited stock compared to others, this premiss is consistent with the results observed from the sock assessment which estimated low levels of exploitation for southern Indian Ocean alfonsino (Brandao et al., 2020).

The size-at-maturity coincides with a change in the growth of the fish as well as the relationship between fish age and otolith weight. At maturity, growth slows and individual variation in length-at-age increases, otolith weight-at-age and the relationship between length and gonad mass all show a relatively marked change at the onset of maturity. This pattern where the growth characteristics of a fish changes with the onset of maturity is common in fish, as when they mature fish allocate more energy to reproduction and less to somatic growth (Brouwer and Griffiths 2004; Brouwer and Griffiths 2005).

The sex ratio of alfonsino in the Southern Indian ocean is skewed as has been observed in other alfonsino populations (Shotton, 2016). For fish below the size-at-50% maturity the sex ratio is approximately balanced, however, after the onset of maturity the sex ratio becomes skewed in favour of females (Figure 17). This pattern can arise for a number of reason such as protandrous hermaphroditism, differential growth, selectivity or mortality. In the case of alfonsino, 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 is no evidence for differential growth or 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 and can be associated with spawning stress. Given that very large size of alfonsino 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 an updated assessment could consider estimating size specific mortality as the 2020 assessment fixed M at 0.2 for all age classes (Brandao et al., 2020). Finally, the sex ratio does not change seasonally (Figure 18), and that along with the relatively stable length distribution through the year suggests a relatively stable stock that,

while individual fish may move large distances, there is no definitive seasonal movement pattern.

4 Recommendations

- The SERAWG note that the otolith samples are reflective of the length sample of the tows from which they came.
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5 Acknowledgements

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Tables

Table 1: Maturity scale used to assign gonad maturity state.

Stage	Female sate	Definition (Female)	Male state	Definition (Male)
1	Immature	Ovary small, firm, with no eggs visible to the naked eye.	Immature	Testis small, translucent, whitish, long, thin strips lying close to the vertebral column.
2	Maturing virgin or resting	Ovary more extended, firm, small oocytes visible, giving ovary a grainy appearance.	Developing or resting	Testis white, flat, convoluted, easily visible to the naked eye, about 1/4 length of the body cavity.
3	Developing	Ovary large, starting to swell the body cavity, contains oocytes of two sizes. Well-developed blood vessels. No hyaline oocytes present.	Developed	Testis large, white and convoluted, no milt produced when pressed or cut.
4	Mature	Ovary large, filling or swelling the body cavity. Hyaline oocytes present.	Ripe	Testis large, opalescent white, drops of milt produced when pressed or cut.
5	Running ripe	Ovulated oocytes present which flow freely with light pressure on abdomen or free in cavity when ovary cut.	Partially spent	Testes are multilobed, but thin, and some milt is extruded with pressure.
6	Spent	Ovary shrunken and bloodshot, some hyaline or ovulated oocytes present.	Spent	Testis shrunk, flabby, dirty white in colour.

Figures

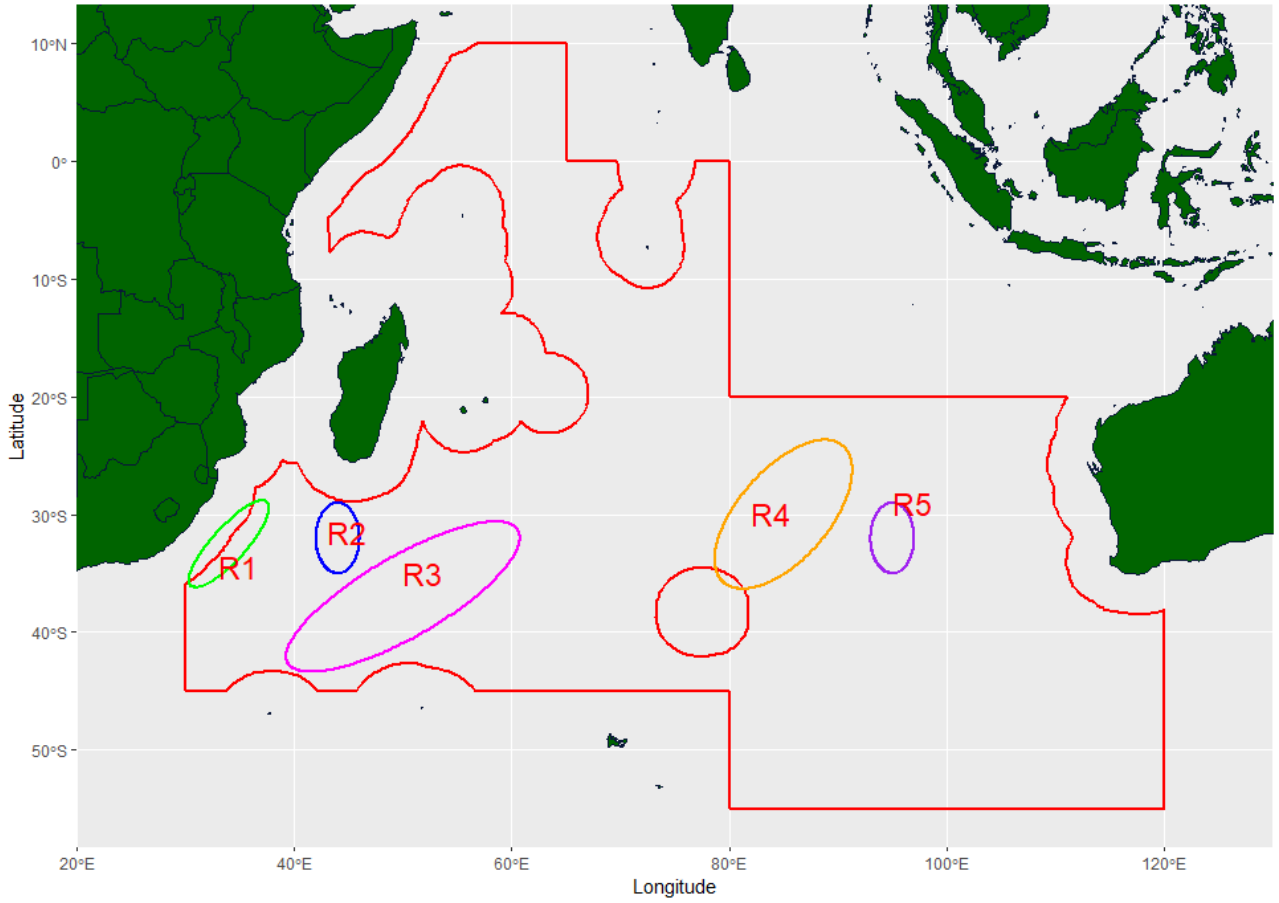


Figure 1: Location of alfonsino samples collected from the from the Cook Islands trawl fleet showing the five different regions (R1-R5), the red line is the SIOFA boundary.

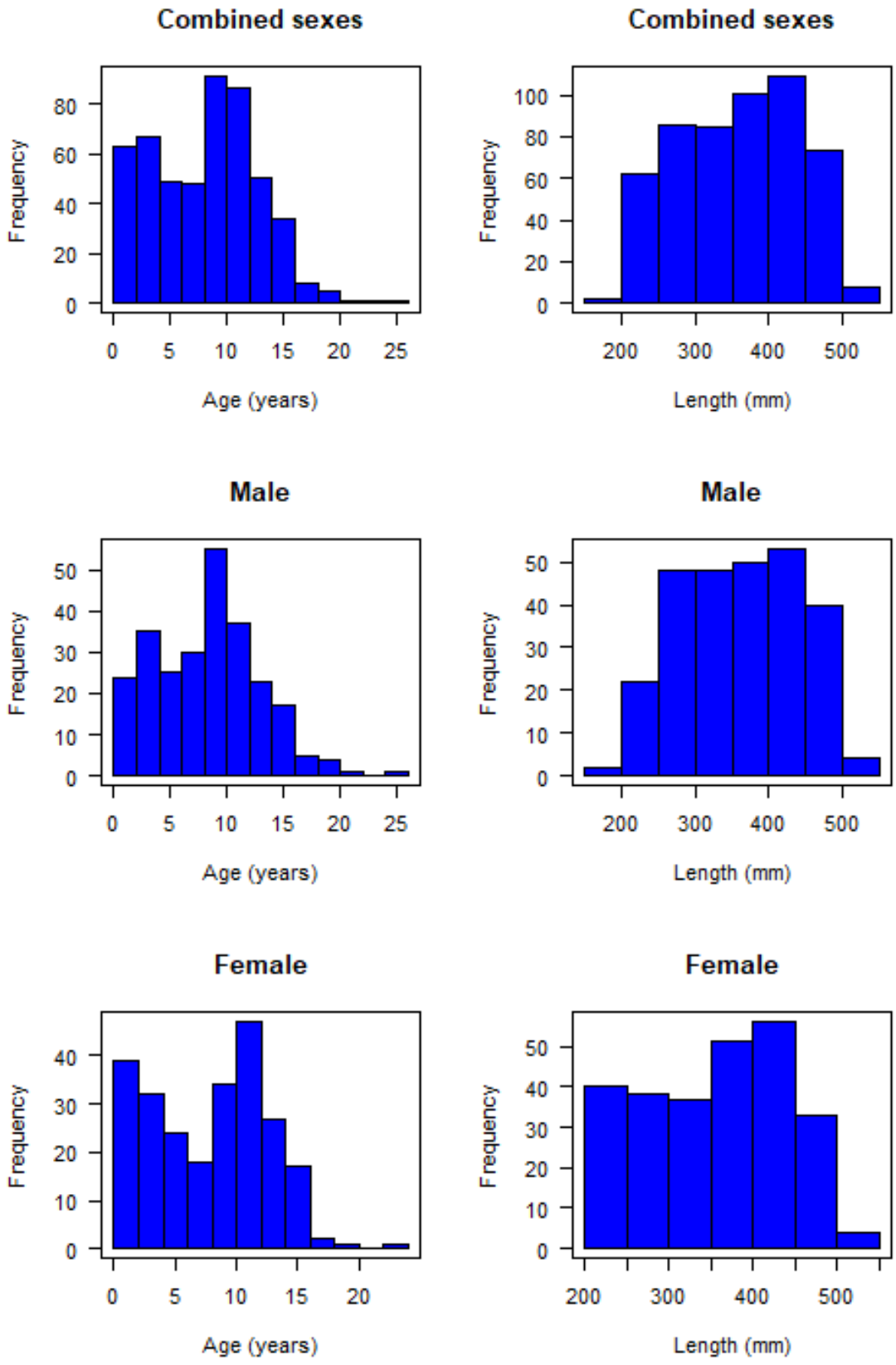


Figure 2: Age and length sample distribution of alfonsino collected from the Cook Islands trawl fleet.

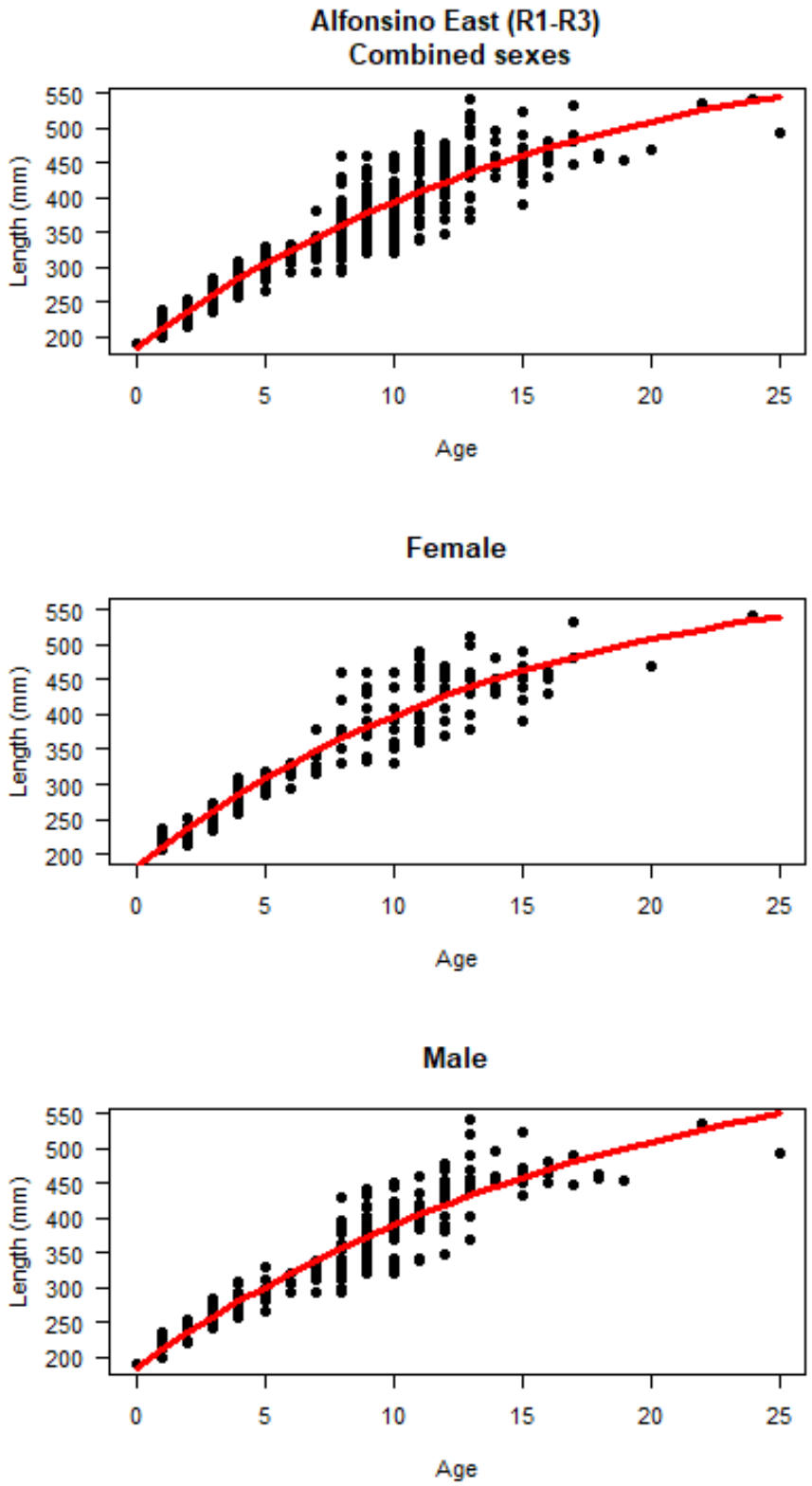


Figure 3: Length-at-age of alfonsino samples in the Indian Ocean showing samples with readability scores of 3 or less and the fitted von Bertalanffy growth curve for both sexes combined (top), females (middle) and males (bottom).

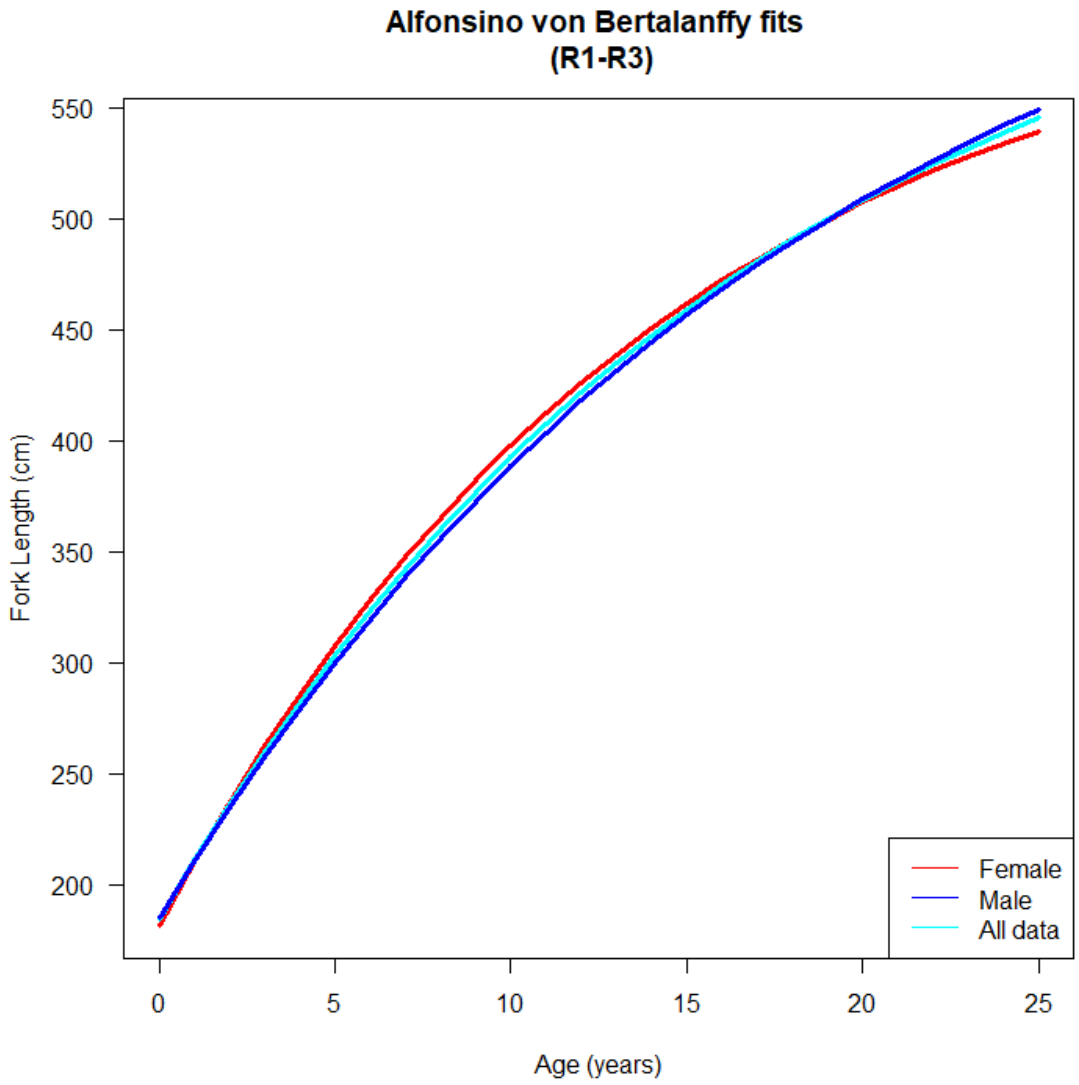


Figure 4: The von Bertalanffy growth curve for both sexes combined, female and male alfonsino sampled in the Indian Ocean with readability scores of 1-3.

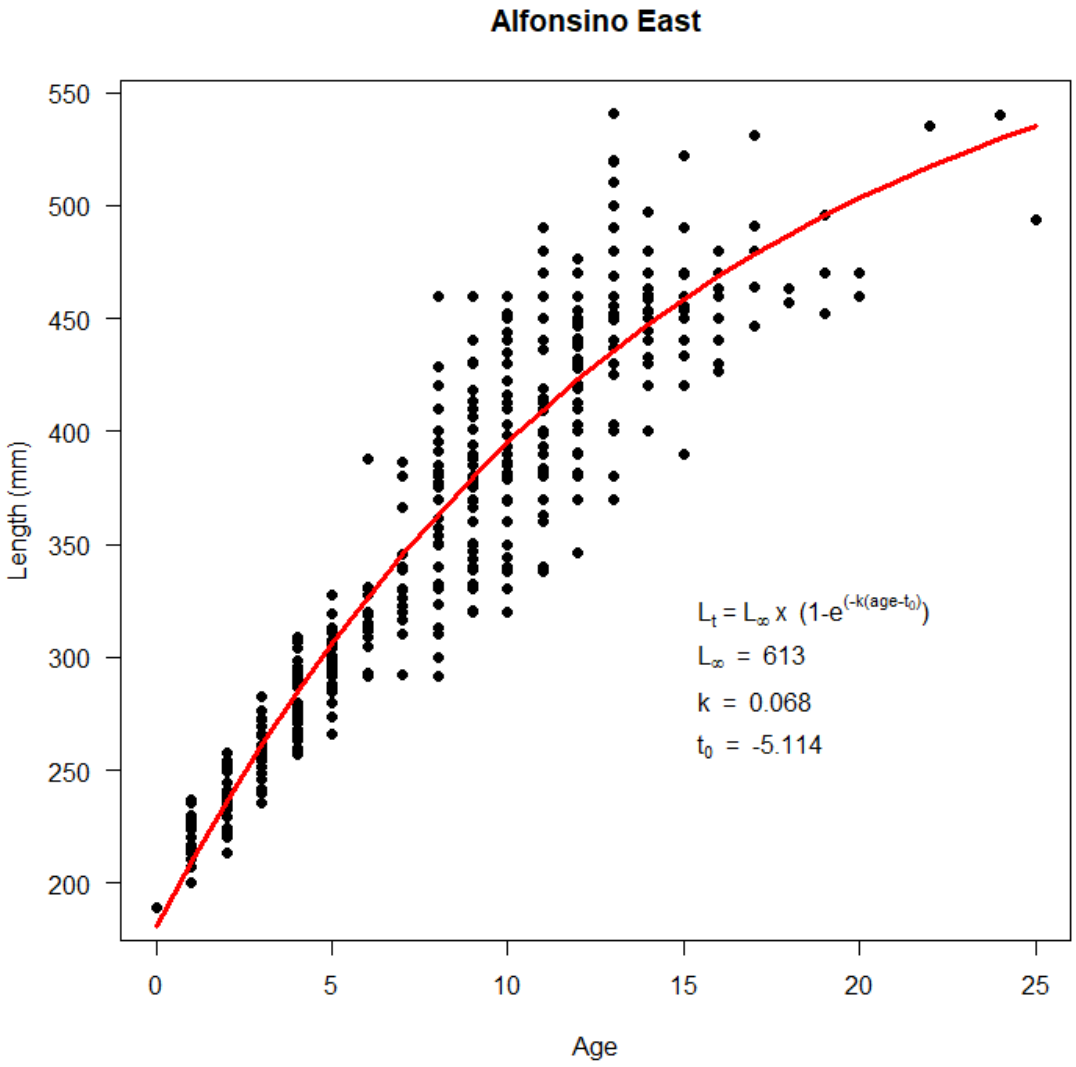


Figure 5: Length-at-age of alfonsino samples sexes combined in the Indian Ocean showing all samples with readability scores if 1-3 and the fitted von Bertalanffy growth curve along with the derived growth parameters.

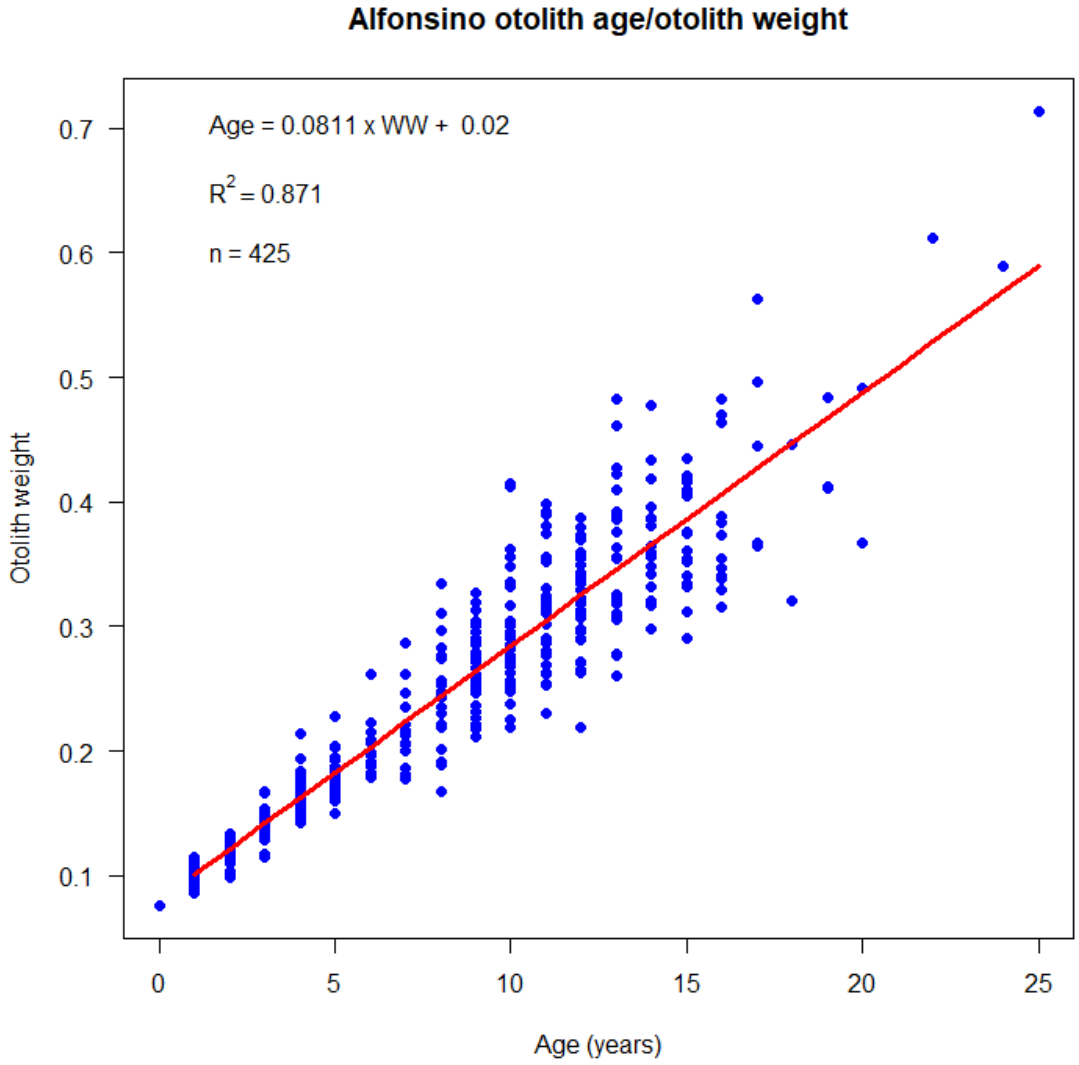


Figure 6: The otolith weight compared to estimated fish age for alfonsino sampled in the Indian Ocean from the Cook Islands trawl fleet.

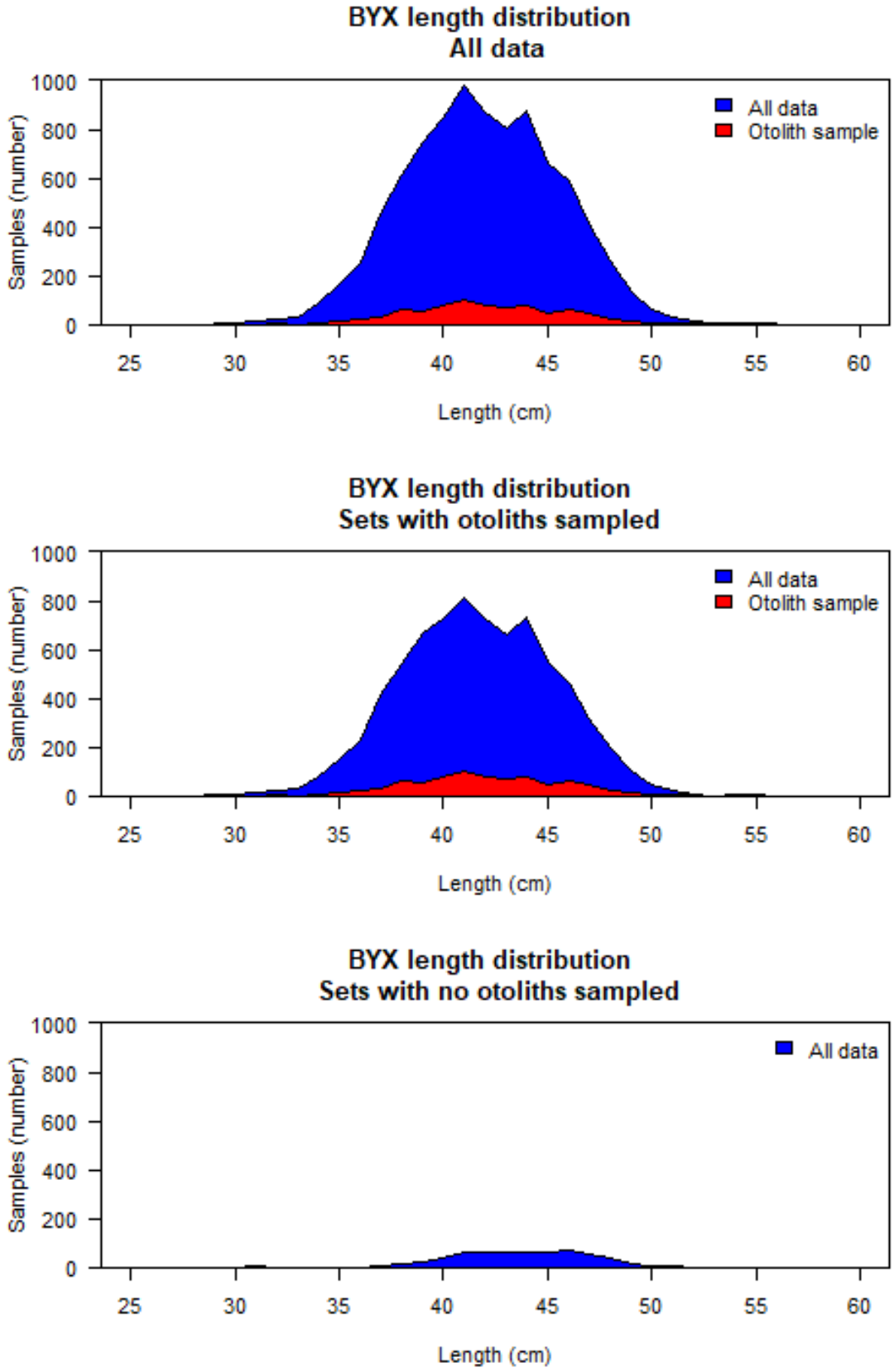


Figure 7: The length samples collected from alfonsino sampled in the Indian Ocean from the Cook Islands trawl fleet showing all length samples (top); the length distribution form samples where otoliths were samples (middle); and tows with no otoliths sampled (bottom).

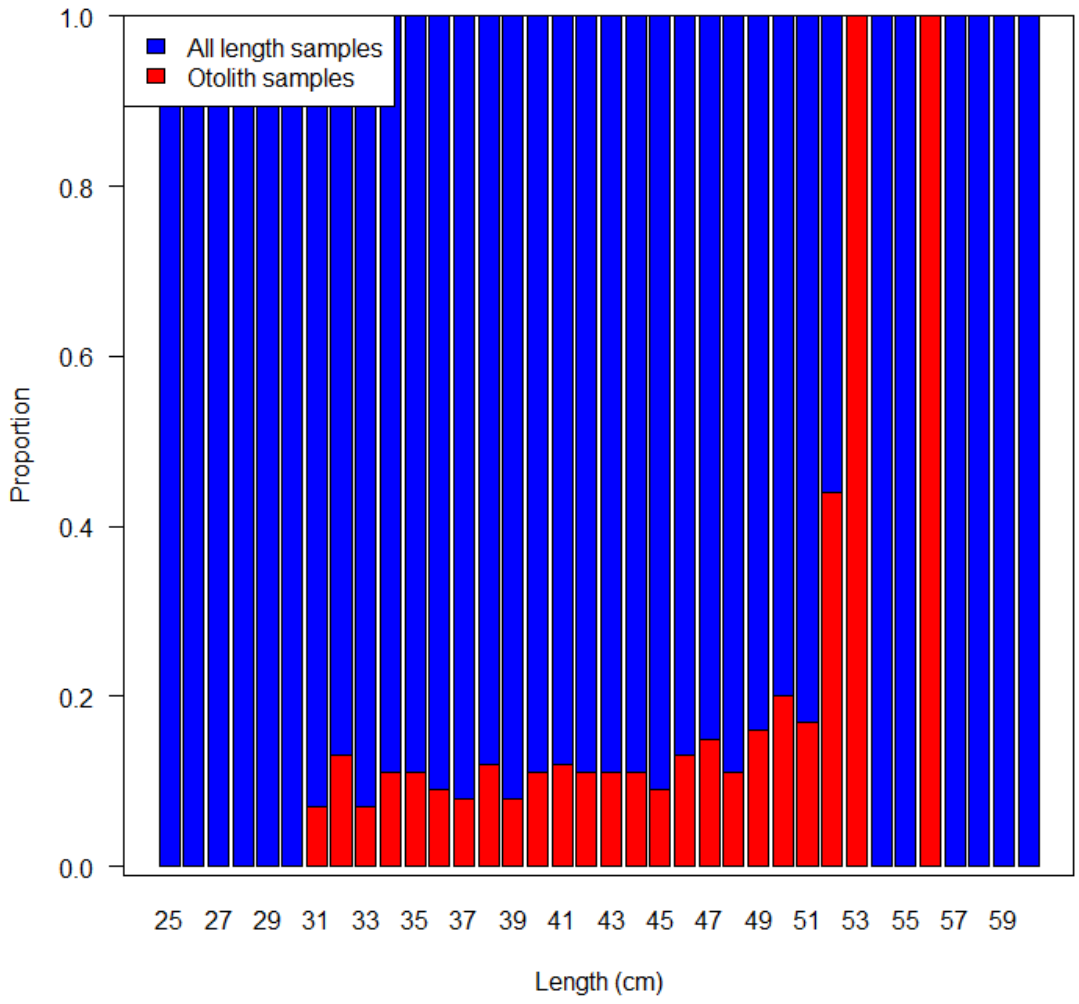


Figure 8: Alfonsino sampled in the Indian Ocean from the Cook Islands trawl fleet showing the proportion of otoliths samples collected by length class for sets where otoliths samples were collected.

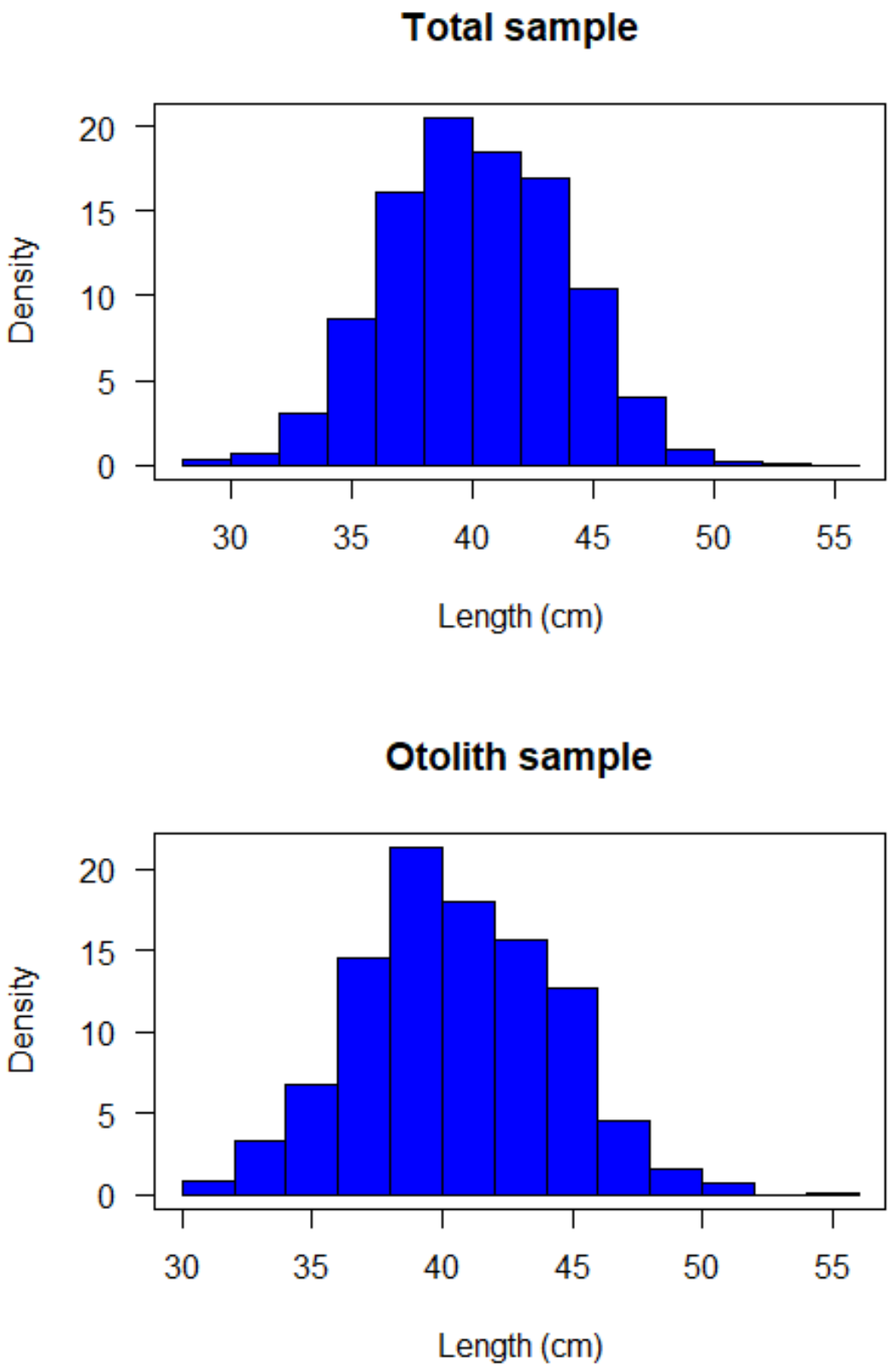


Figure 9: Sample densities of alfonsino from the random length sample (top) and the otolith sample (bottom).

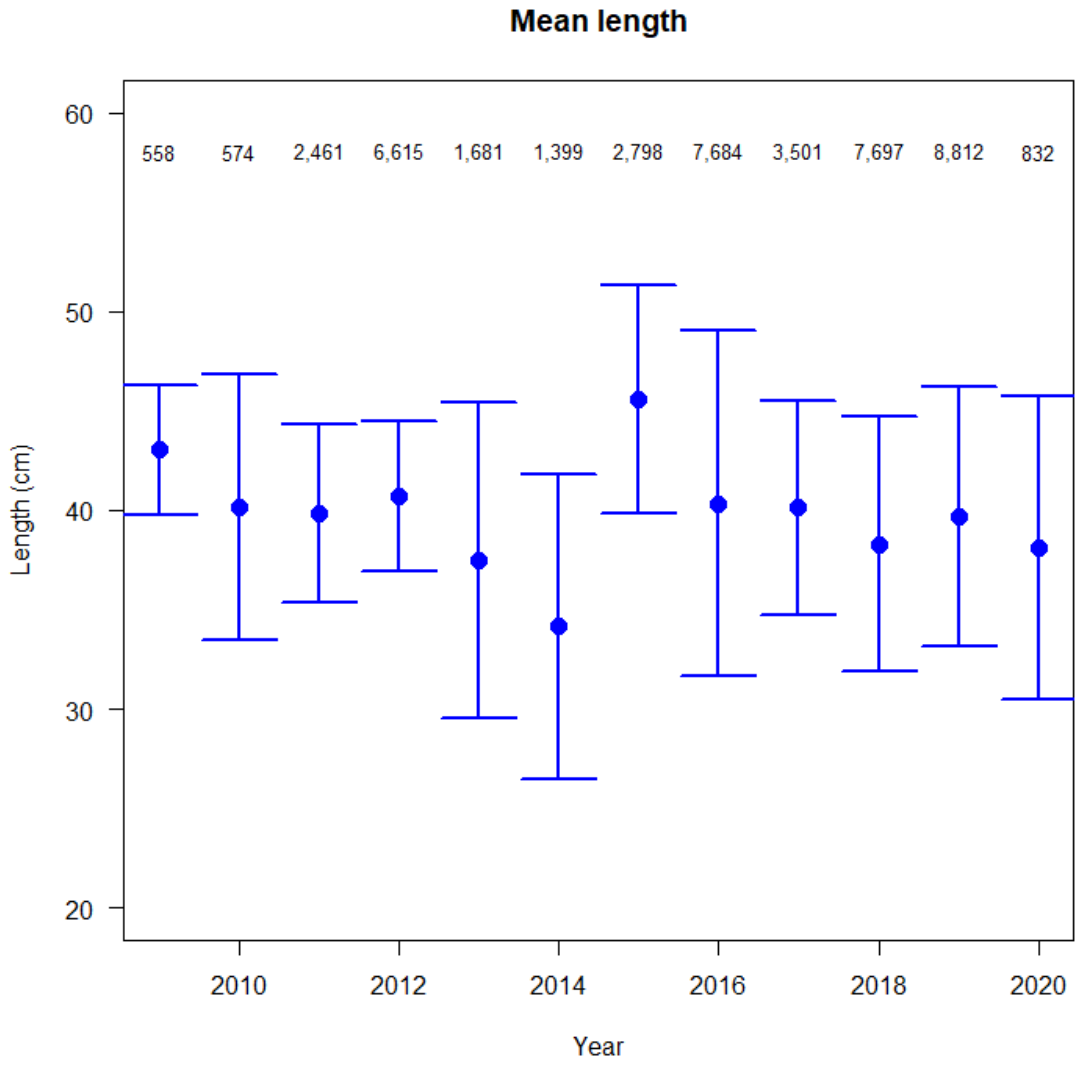


Figure 10: Mean length (points) and standard deviation (error bars) of alfonsino by year from the Cook Islands trawl fleet operating in the southern Indian Ocean. The numbers show the number of samples from each year.

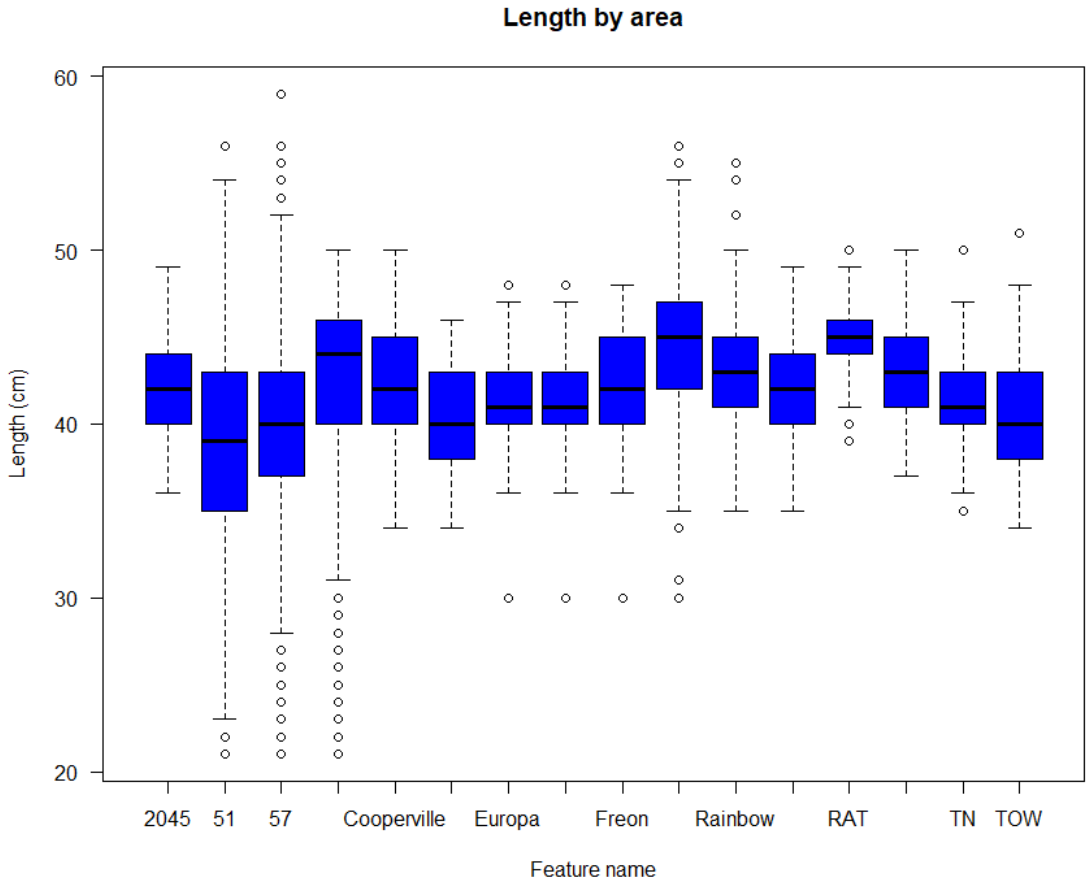


Figure 11: Median length (black lines) of alfonsino by marine feature from the Cook Islands trawl fleet operating in the southern Indian Ocean, the 25^{th} and 75^{th} percentiles (box), 1.5 x interquartile range (whiskers), and outlying data (points).

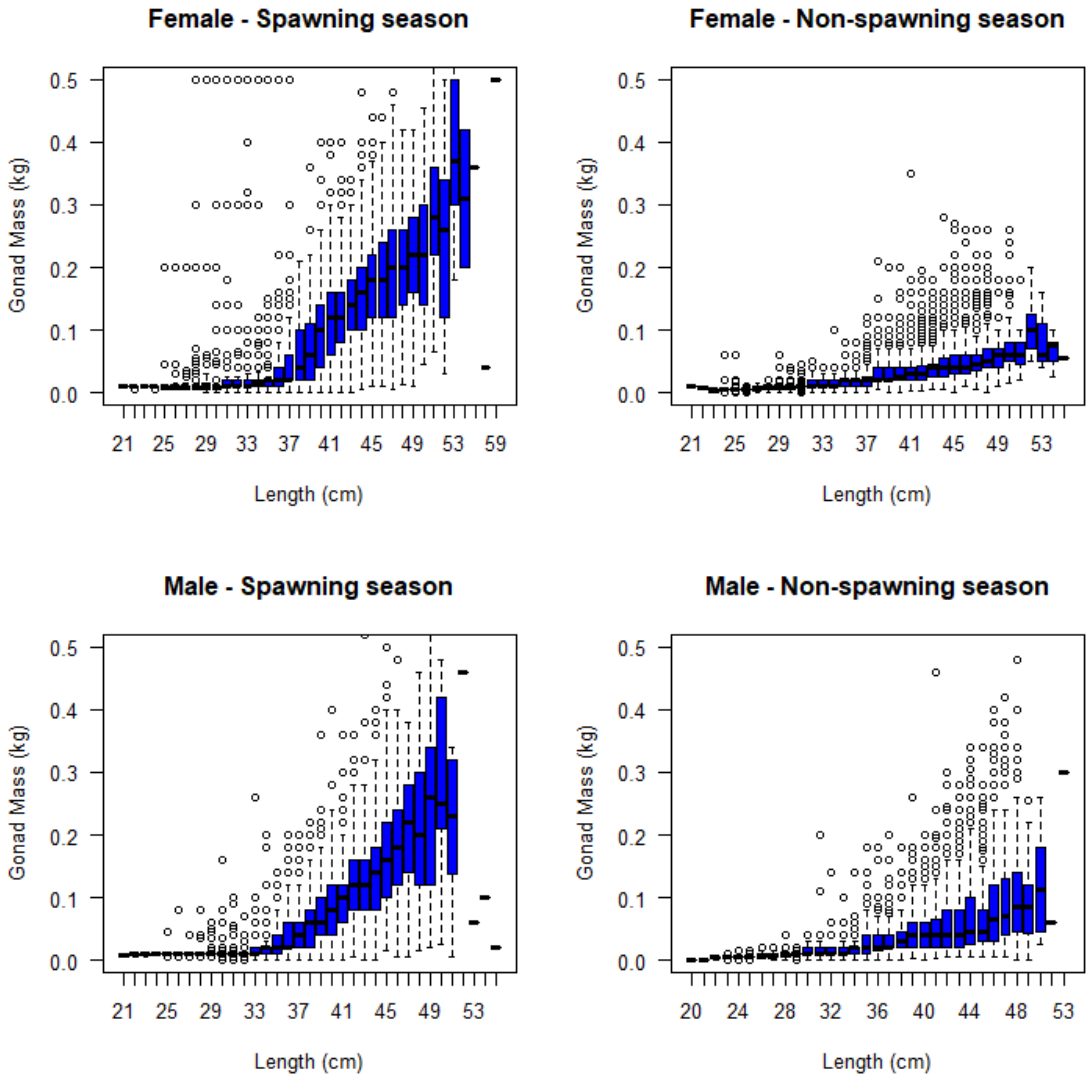


Figure 12: Alfonsino length and gonad weight from female (top) and male (bottom) fish sampled in the Indian Ocean from the Cook Islands trawl fleet during the spawning season (left) and outside of the spawning season (right).

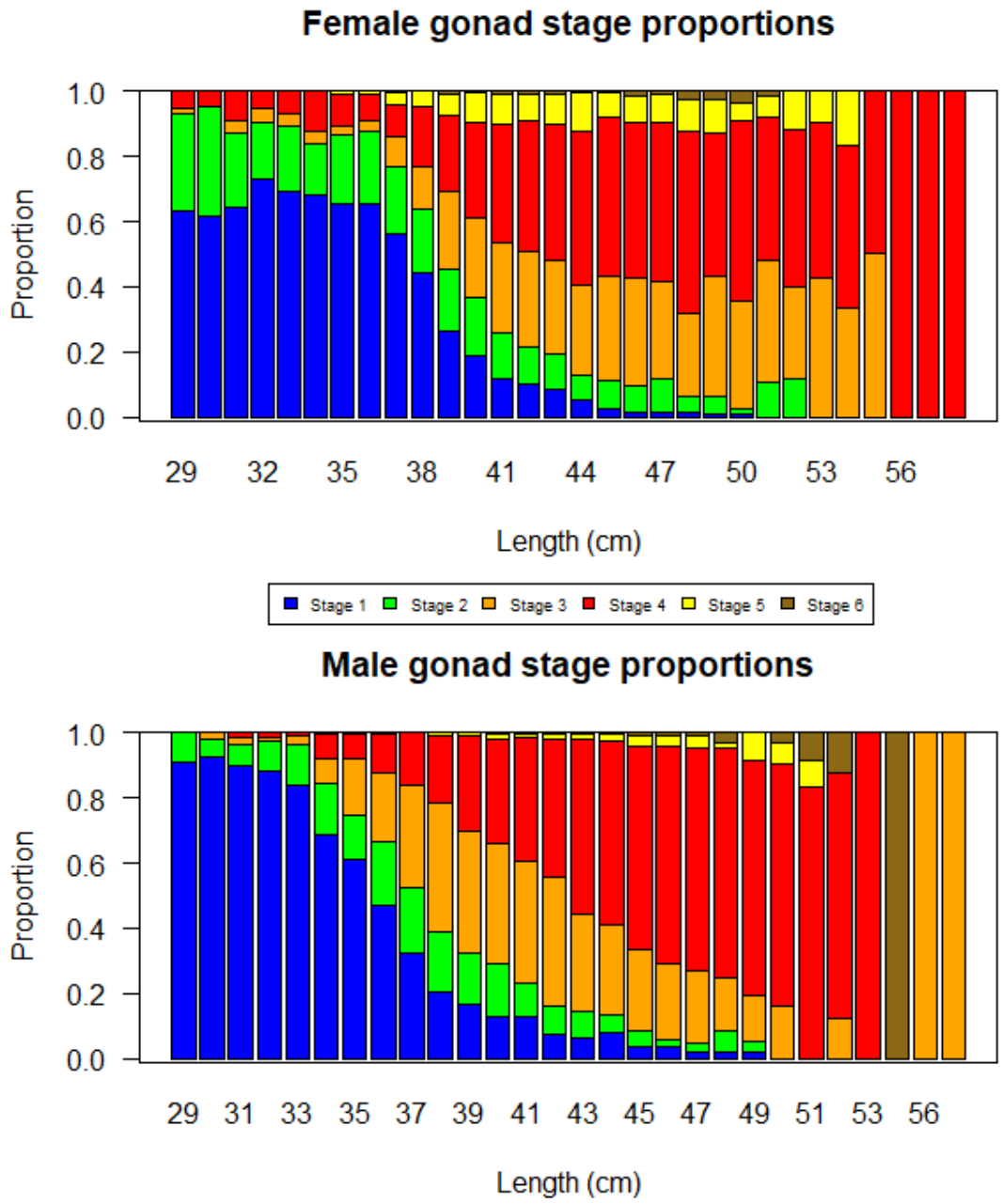


Figure 13: The proportions of each maturity stage from alfonsino sampled during the spawning season in the Indian Ocean from the Cook Islands trawl fleet showing the female (top) and male (bottom) fish separately.

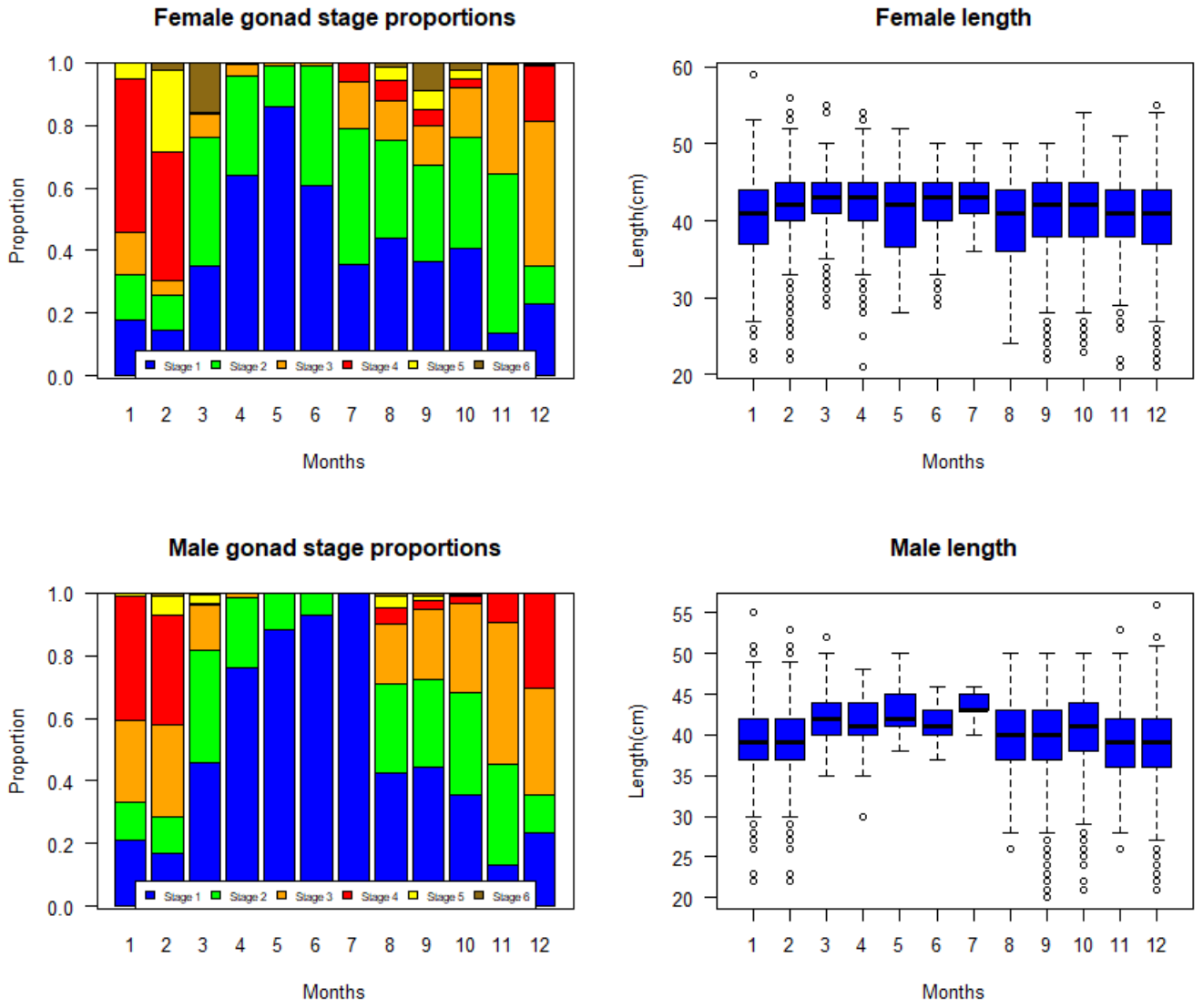


Figure 14: The proportions of each maturity stage from alfonsino sampled monthly in the Indian Ocean from the Cook Islands trawl fleet showing the female (top left) and male (bottom left) by month as well as the mean monthly length data (right).

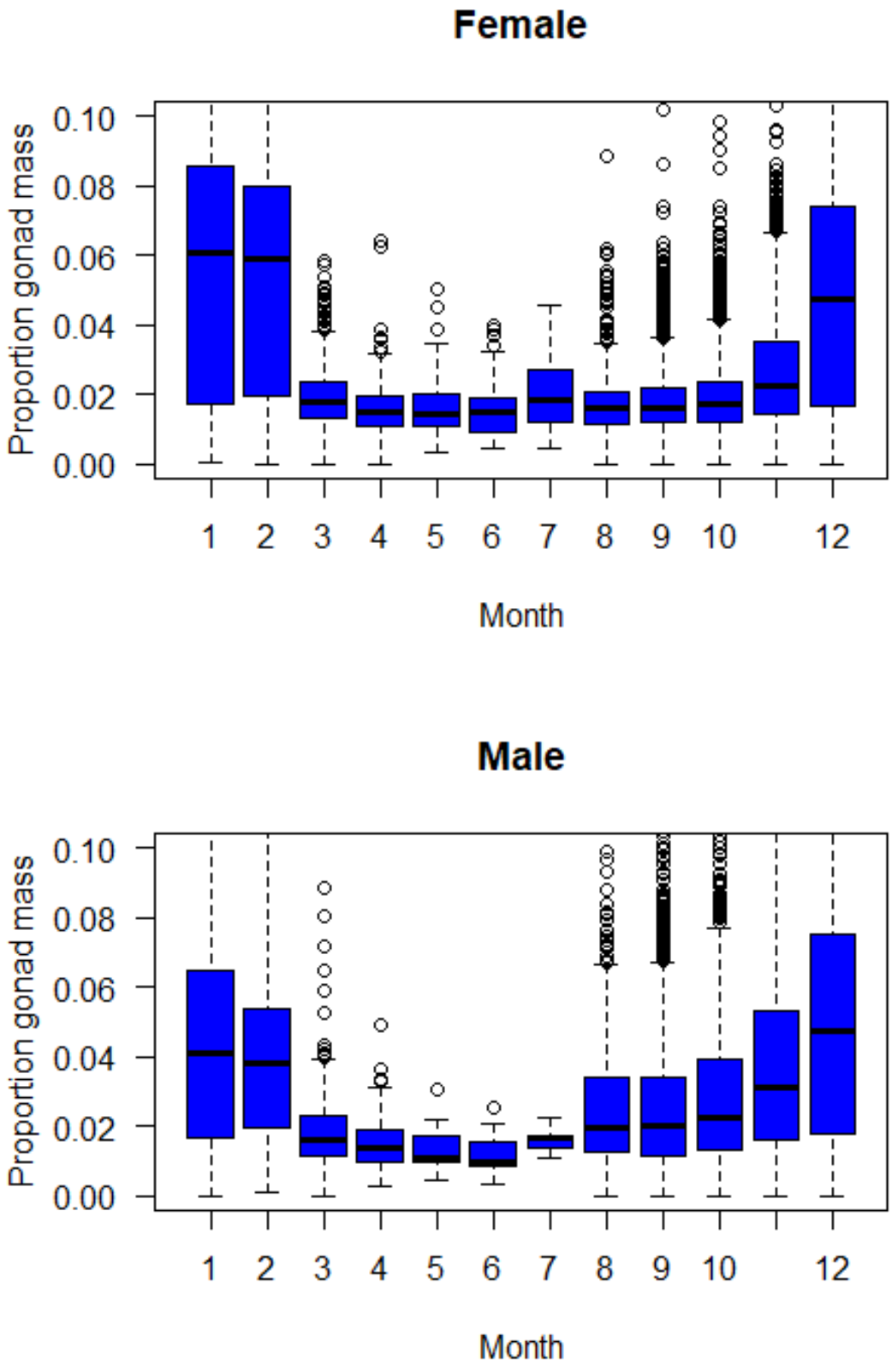
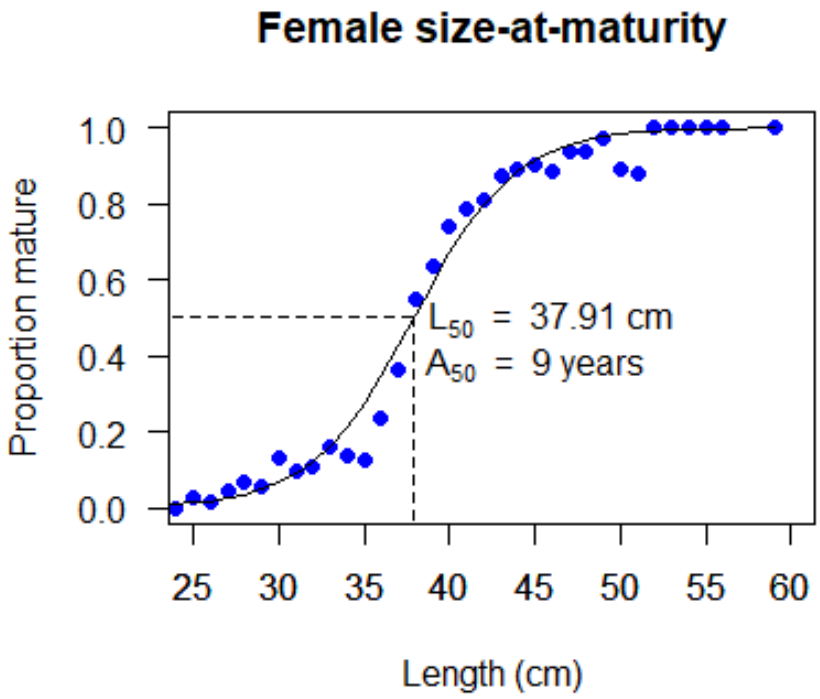


Figure 15: The female gonado-somatic index for alfonsino sampled in the Indian Ocean from the Cook Islands trawl fleet.



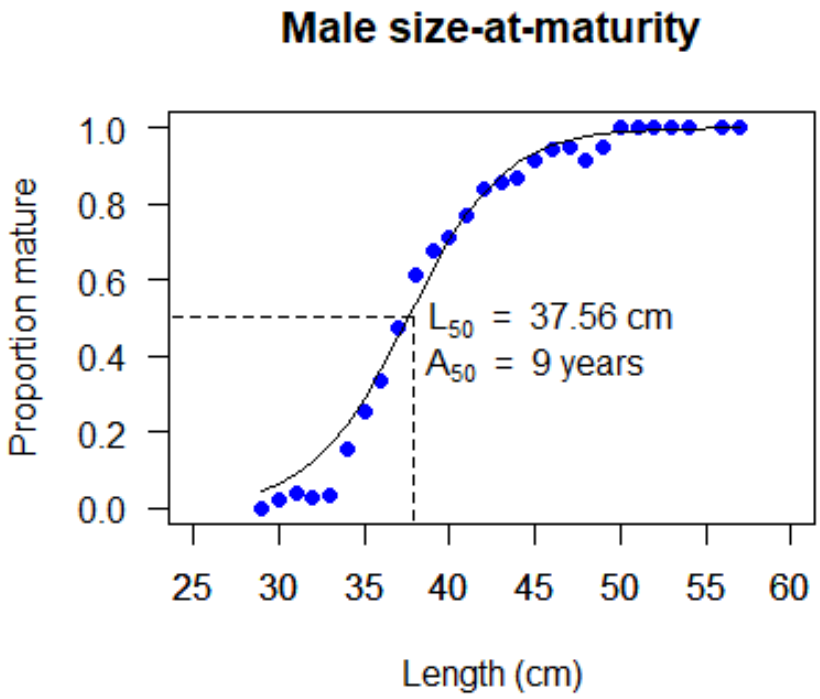


Figure 16: Alfonsino proportion mature-at-length from female (top) and male (bottom) fish sampled during the spawning season only in the Indian Ocean from the Cook Islands trawl fleet. The solid lines are the fitted maturity curve from the GLM. L_{50} is the length-at-50% maturity estimated from the fitted curve; A_{50} is the age-at-50% maturity estimated from the female and male growth curves respectively.

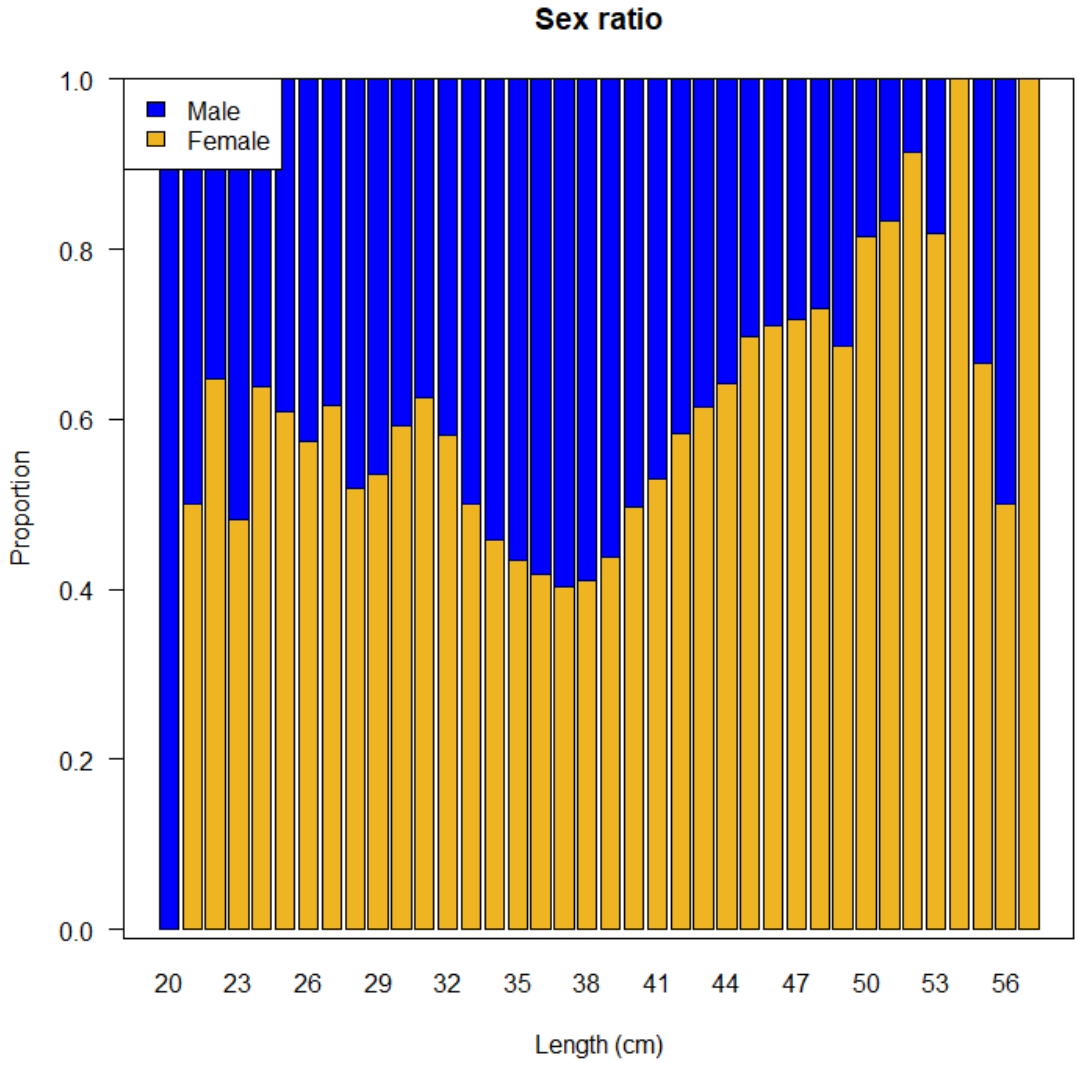


Figure 17: Alfonsino sex ratio-at-length from fish sampled in the Indian Ocean from the Cook Islands trawl fleet.

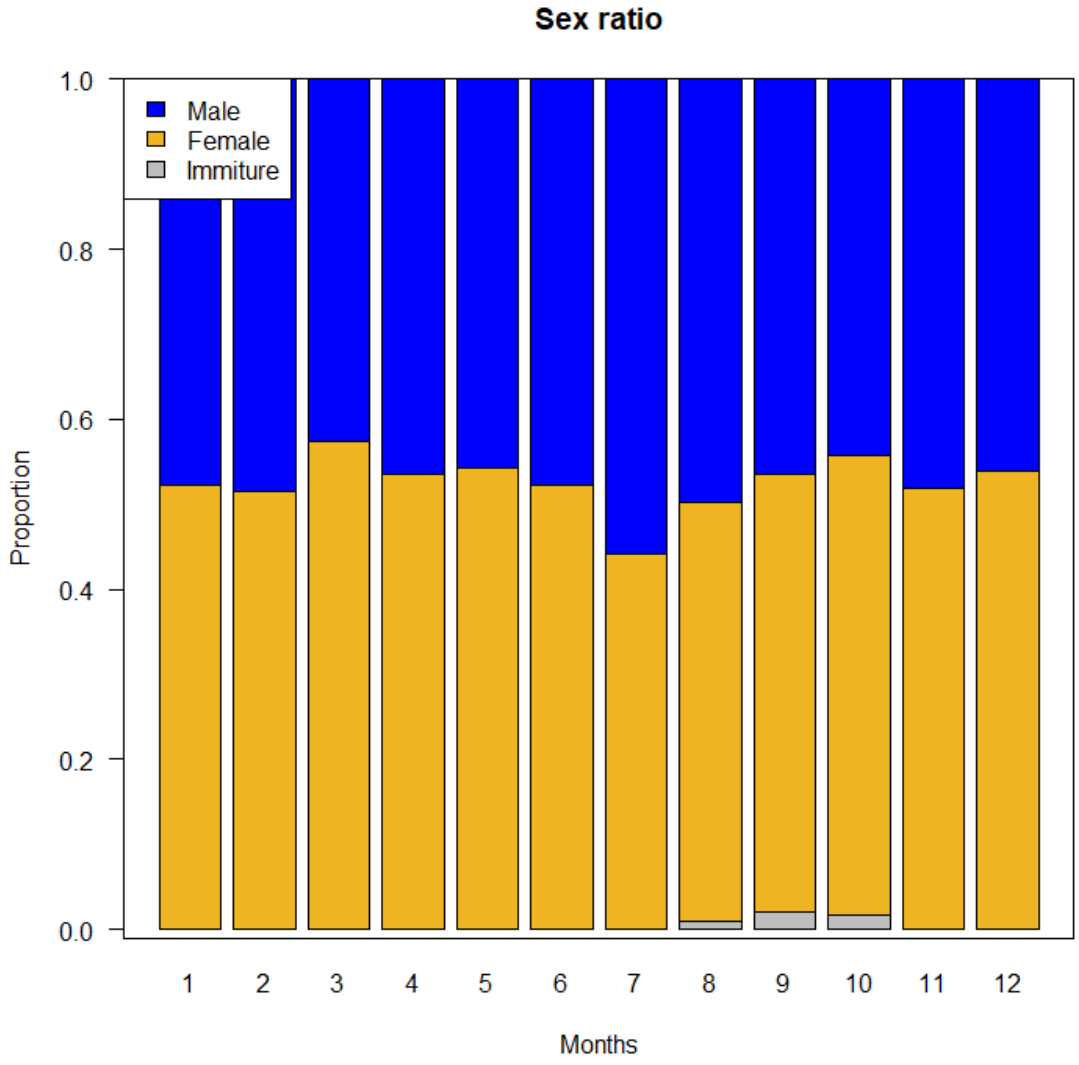


Figure 18: Alfonsino sex ratio by month from fish sampled in the Indian Ocean from the Cook Islands trawl fleet.