Stock structure of alfonsino and orange roughy in the SIOFA area

Final report for SER2022-BYS1 and SER2022-ORY1

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Funded by
the European Union

To be cited as:

Middleton, D. A. J., Hill-Moana, T., and Neubauer, P. (2023). Stock structure of alfonsino and orange roughy in the SIOFA area. Final report for SER2022-BYS1 and SER2022-ORY1. 49 p.

ABSTRACT

Density-based clustering was successfully applied to elucidate patterns in the trawl fishing effort for alfonsino and orange roughy in the SIOFA area.

Two broad areas of trawl fishery activity were identified: one in the western part of the SIOFA area associated with the Madagascar Plateau and the Southwest Indian Ridge, and an eastern area, associated with the Ninety east Ridge, the Diamantina Escarpment, and adjacent seamount areas. Haul by haul catch data indicated that the eastern area was almost exclusively an alfonsino fishery, whereas the western area supported both alfonsino and orange roughy fisheries, with the latter typically fishing deeper.

These patterns are generally in line with the recent, two-area, approach for orange roughy assessment. Finer scale divisions, such as those used in the 2018 assessments, are potentially justified if fish movement is limited and there is genuine affinity to fine scale features.

For alfonsino, there is evidence that smaller fish are generally more prevalent in the western fishery area, with adult fish present in both areas. At present, the two region assessment approach would appear to be a pragmatic choice.

Resolving stock structure in fisheries is seldom straightforward; as a result it is advisable that stock assessments routinely assess the sensitivity of results to alternative stock hypothesis, in order to provide information that allows robust management in the face of these uncertainties.

CONTENTS

1. INTRODUCTION

The Southern Indian Ocean Fisheries Agreement (SIOFA) entered into force in June 2012 and currently has thirteen Contracting Parties, Cooperating non Contracting Parties, and Participating Fishing Entities. Its objectives include ensuring the long-term conservation and sustainable use of the fishery resources in the high seas areas of the southern Indian Ocean, and promoting the sustainable development of fisheries in the area.

Alfonsino (*Beryx* spp.) and orange roughy (*Hoplostethus atlanticus*) are key targeted species of trawl fisheries in the SIOFA area (SIOFA Secretariat, 2022). In 2020, the SIOFA Scientific Committee conducted the first alfonsino stock assessments in the SIOFA region (Brandão et al., 2020). Initial assessments for orange roughy were undertaken in 2018 (Cordue, 2018a, 2018b) with an updated assessment completed in 2022 (Roa-Ureta et al., 2022). Interim reference points for orange roughy and alfonsino, specifically a target of $40\% B_0$ and a limit of $20\% B_0$, were recommended by the SIOFA Scientific Committee in 2021, following a review by Butterworth et al. (2021).

With funding support from the European Union, the SIOFA Scientific Committee established two projects, SER2022-BYS1 and SER2022-ORY1, to investigate and review the stock structure of alfonsino and orange roughy in the SIOFA area, with the aim of supporting the assessment of key target stocks.

These projects have the objective of providing advice on:

- the life history and stock structure of the species in the SIOFA area;
- the appropriate management units for SIOFA to use in future monitoring and stock assessments; and
- the feasibility of a genetic stock discrimination project for alfonsino (*Beryx splendens* in the SIOFA area.)

Density-based clustering of fine-scale fishing effort data has recently been employed to identify areas that are appropriate for describing patterns in catch and effort, and to assist in assessing the biological structure of the population for alfonsino fisheries in New Zealand. Here we have employed a similar approach to assist in investigating stock structure of alfonsino and orange roughy in the SIOFA area, and consider the resulting spatial patterns in the context of observer sampling data, and bathymetric and oceanographic features. We discuss other approaches to identify stock structure, including the potential use of modern genetic approaches.

The density-based clustering approach was applied to haul-by-haul data from the SIOFA region that caught alfonsino and/or orange roughy. Because this common analysis was the central basis of our investigations for both species, the reporting from the two projects has been combined into a single report.

2. METHODS

2.1 Data

The SIOFA secretariat provided an extract of catch-effort and observer data in spreadsheet format. The catch-effort data were provided as a single spreadsheet consisting of fishing effort records joined to associated catch records. Data were provided where the species reported caught was *Beryx decadactylus*, *Beryx splendens*, *Beryx* spp., *Hoplostethus atlanticus* or *Hoplostethus mediterraneus*.

2.2 Identifying spatial clusters of fishing effort

Density based clustering (dbscan; Hahsler et al., 2019) of tow locations was used to identify spatial clusters in the haul-by-haul data for trawling (bottom, midwater or unspecified) in the SIOFA area. The dbscan algorithm uses the concept of the ϵ-neighbourhood (epsilon neighbourhood) of a data point, to identify the set of points within a specified radius, ϵ, around a data point p.

The dbscan algorithm requires two parameters:

- ϵ, the size (radius) of the ϵ-neighbourhood (here measured in metres); and
- *minPts*, the minimum number of points required in the ϵ-neighbourhood for a point to qualify as a core point.

Points are then classified as:

- **core points**, if the number of points, $N_\epsilon(p)$, in their ϵ-neighbourhood is greater than or equal to the minimum threshold, *minPts*;
- **border points**, if they are in the neighbourhood of a core point but do not meet the definition of a core point; or
- **noise points** otherwise.

Points are assigned to a cluster if they qualify as core or border points; noise points are not assigned to a cluster.

The parameters used for the dbscan algorithm were selected after inspecting the resulting spatial clustering for a range of parameter choices. Different values were chosen for the eastern and western parts of the SIOFA area (east and west of 70°E), after considering the clustering of tows in relation to bathymetric features. These exploratory analyses required visualising the data at a tow by tow level and are omitted from this report. For reporting purposes, we plot the concave hull that encloses the tow locations assigned to a cluster, using a concavity parameter of 0.8 to limit the detail of the polygon border. An anonymised example is show in Figure 1.

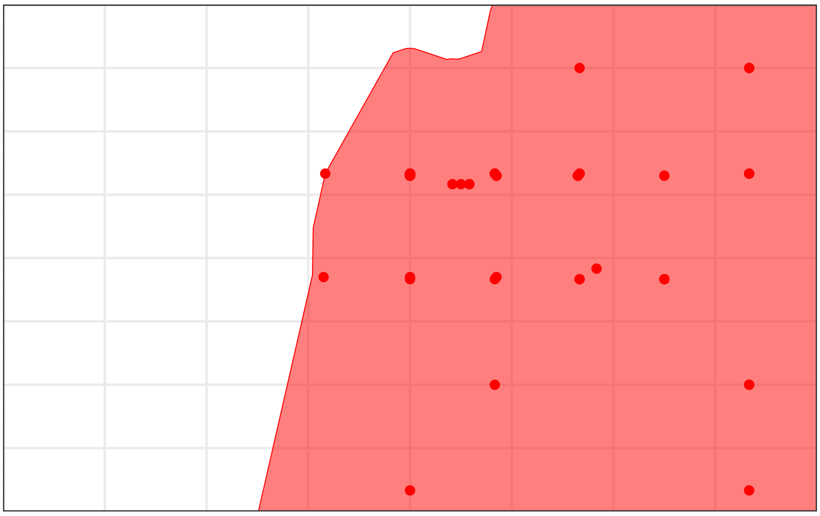

Figure 1: Anonymised example of tow start positions, all assigned to the same effort cluster, and the concave hull cluster polygon boundary.

2.3 Investigating patterns in length data

Patterns in the observer length sampling data were investigated using regression trees. For each sampled tow, the mean length of the sampled fish was calculated and a regression tree (Therneau & Atkinson, 2022) was used to partition the samples into groups on the basis of mean length and the available explanatory variables: region (east or west), dbscan cluster, and year.

The observer data extract did not provide sample weights, or the full catch weight of a species in the sampled tows, so samples were combined at the cluster level without scaling of composition data. Cluster level length-frequency distributions were prepared as proportions at length to compensate for the different sample sizes between locations and years.

2.4 Oceanographic data

Patterns in ocean surface currents were explored using two sources of data. Major ocean current pathways, depicted as polygon arrows, were obtained from data layers compiled by the NOAA National Weather Service and the US Army[1]. Ocean Surface Current Analysis (OSCAR) data were obtained from the Jet Propulsion Laboratory (JPL) Physical Oceanography Distributed Active Archive Center (DAAC). These products contain global near-surface current estimates (Dohan, 2021), with individual files cataloguing a full calendar year of data including zonal and meridional velocities at a third of a degree resolution and an approximately five-day interval. Data from 1993 to 2022 were processed to determine the average surface current speed in metres per second, and the average surface current direction.

[1] https://hub.arcgis.com/maps/beyondmaps::major-ocean-currents/about

3. RESULTS

3.1 Catch-effort dataset characterisation

The catch-effort data were derived from two source databases: aggregated data (AGG) where a record represents multiple fishing events, and haul-by-haul data (HBH) where each effort record is a single fishing event. For both data types, there were instances where multiple catch records for a species were associated with the same effort record. After inspecting examples of both data types, it was concluded that cases where an effort record had multiple records for a species with identical catch weights probably represented data errors, and these duplicates were dropped. However, where an effort record had multiple records for a species with different catch weights, these were potentially legitimate and were retained.

The original extract contained 20 456 catch-effort records; after removing duplicate rows, this was reduced to 18 313 records. Annual effort records in the two formats are tabulated in Table 1.

The records in the aggregated catch-effort data were exclusively for trawling (Table 2). The haul-by-haul format data included records from a broader range of gear types, but were dominated by trawling records using both bottom and mid-water gear (Table 3). This confirms that it is primarily trawl fisheries that catch alfonsino in the SIOFA area, but also suggests that the aggregated data may omit a small amount of bycatch from non-trawl methods.

Mean fishing durations calculated from the haul-by-haul data indicated that tows catching alfonsino were longer (mean durations over an hour) than those catching orange roughy, which had a mean duration under half an hour (Table 4).

Table 1: Annual effort records in aggregated and haul-by-haul formats.

[redacted]

Table 2: Records in the aggregated data, by gear and year.

Year	Midwater trawl	Trawl (un-specified)
2001	310	
2002	58	
2003		163
2004		16
2005		155
2006		11
2009	169	202
2010	228	345
2011	58	414
2012	77	386
2013	116	419
2014	115	379
2015	345	427
2016	324	248
2017	396	348
2018	137	344
2019		101
Total	*2 333*	*3 958*

Table 3: Records (number of fishing events) in the haul-by-haul data, by gear and year.

Year	Bottom trawl	Demersal longline	Dropline	Gillnet	Longline	Midwater trawl	Set longline	Trawl (unspecified)
1999								172
2000								291
2001	114							406
2002						8		493
2003	152					76		45
2004	391				82	159		
2005	172				85	69		
2006	16					71		
2007					12	122		
2008	1			19		60		
2009	147					29		
2010	151					26		
2011	239					122		
2012	207					206		230
2013	4			37		341		73
2014	24			28		97		
2015					6	24		
2016					5	179		
2018		3	3			1		
2019		16				357		1 025
2020	204		2			972	102	361
2021	186					939	61	
2022	8					71		
Total	*2 016*	*19*	*5*	*84*	*190*	*3 929*	*163*	*3 096*

Table 4: Mean duration (hours) of tows catching alfonsino and orange roughy, from the haul-by-haul data.

Gear	BYS	ORY
Bottom trawl	1.05	0.40
Midwater trawl	1.59	0.36
Trawl (unspecified)	1.33	0.37

3.2 Spatial clustering of trawl effort

The haul-by-haul dataset comprised a total of 8987 records of individual trawl events, after eliminating a small number of records with positions recorded outside the SIOFA area. Most records were from the southern part of the SIOFA area (i.e., south of 25°S) and fell in two spatially distinct regions: a western area lying south of Madagascar, and an eastern area, lying west of Australia.

Density based clustering led to 24 clusters of trawl effort being identified, with 99 % of trawl events being assigned to one of these clusters. The general location of these clusters is illustrated in Figure 2, with more detailed maps of the western and eastern regions in Figure 3 and Figure 4, respectively.

In the western area, fishing effort is concentrated in areas at the north (W-01) and south (W-04) of the Madagascar Plateau, and in areas along the Southwest Indian Ridge. In the eastern area, most clusters of effort are along the Ninetyeast Ridge and on seamounts to the southwest of the ridge, with one area (E-07) further east on the Diamantina Escarpment.

Figure 2: Clusters of trawl fishing effort and baythmetry in the SIOFA area. Depth contours at 500, 1000 and 2000 m are illustrated, based on the GEBCO 2023 grid.

Figure 3: Clusters of trawl fishing effort and baythmetry in the south-western part of the SIOFA area. Depth contours at 500, 1000 and 2000 m are illustrated, based on the GEBCO 2023 grid.

Figure 4: Clusters of trawl fishing effort and baythmetry in eastern part of the SIOFA area. Depth contours at 500, 1000 and 2000 m are illustrated, based on the GEBCO 2023 grid.

3.3 Catch species composition

The haul by haul catch data were used to investigate patterns in the caches reported from the different clusters of effort Figure 5. Catches were predominantly of either splendid alfonsino, *Beryx splendens*, or orange roughy, *Hoplostethus atlanticus*. In the western area, some areas (W-02, W-03, W-05, W-07, W-15) had catches that were almost exclusively of alfonsino, others (W-10, W-13, W-14) were dominated by catches of orange roughy, and other areas had catches of both species. In the eastern area, catches in all areas were dominated by alfonsino.

Distributions of the depth of tows that caught alfonsino and orange roughy in the western area demonstrate that roughy is generally caught in deeper tows than alfonsino (Figure 6), although the fishing depths and depth differential between the species varies from cluster to cluster.

For alfonsino, the range of fishing depths across the SIOFA area is illustrated in Figure 7. Tows with alfonsino catches ranged from less than 200 m to more than 1500 m. Some areas (clusters E-08, W-01, W-05, W-12, W-15) had catches from a rather restricted depth range, while others (e.g., W-06) had catches over a broad depth range.

The majority of the fishing for both alfonsino and orange roughy appeared to be associated with the seabed, with the start depth of fishing (when available) recorded at a similar depth to the seabed depth (Figure 8). Although a number of tows that caught alfonsino had fishing start depths well above the seabed, this pattern did not dominate in any particular location.

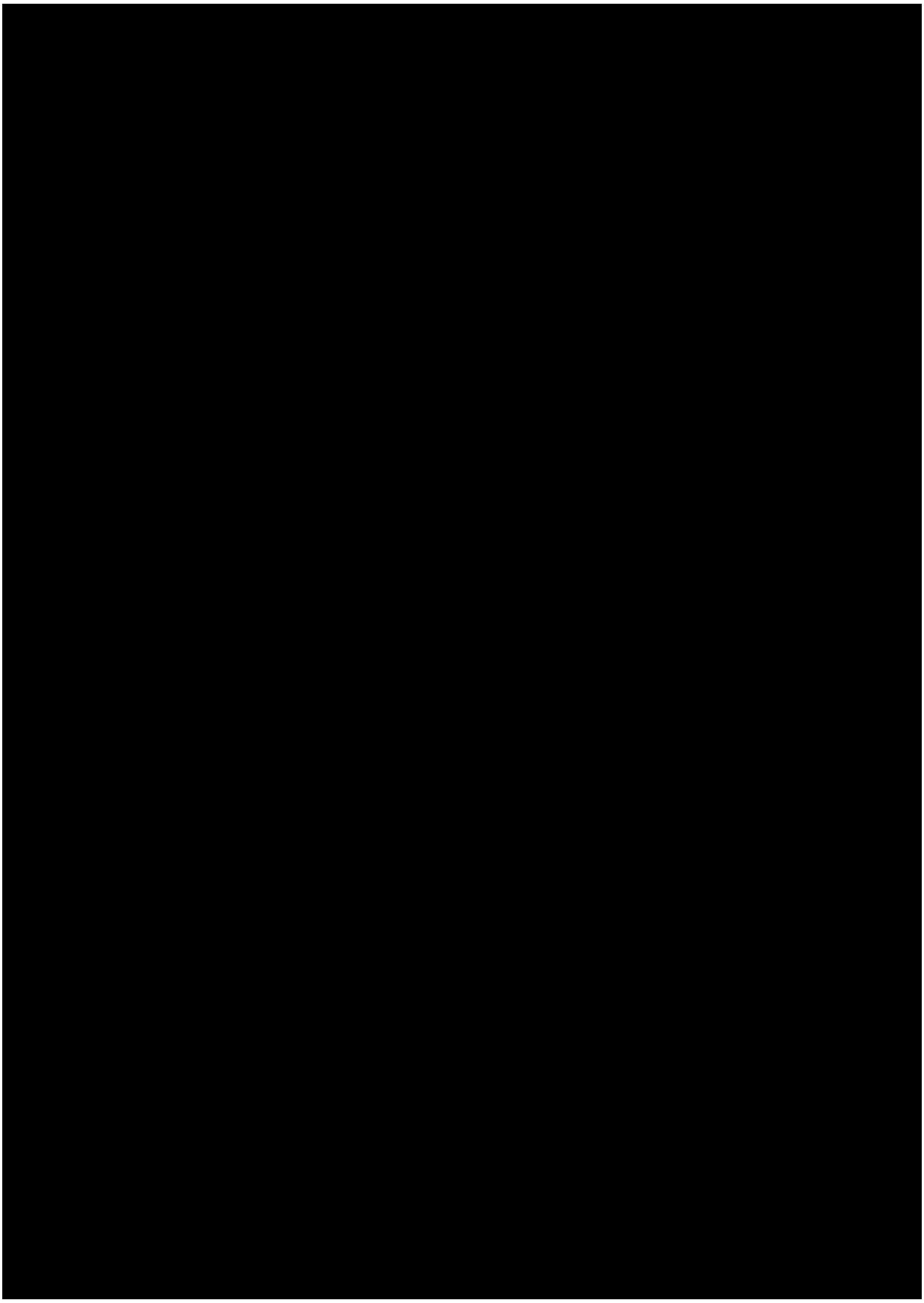

Figure 5: Catches of alfonsino and orange roughy by cluster and year from the haul-by-haul data. Because aggregated data could not be assigned at this scale, these plots do not give a true representation of catch by species and area over time.

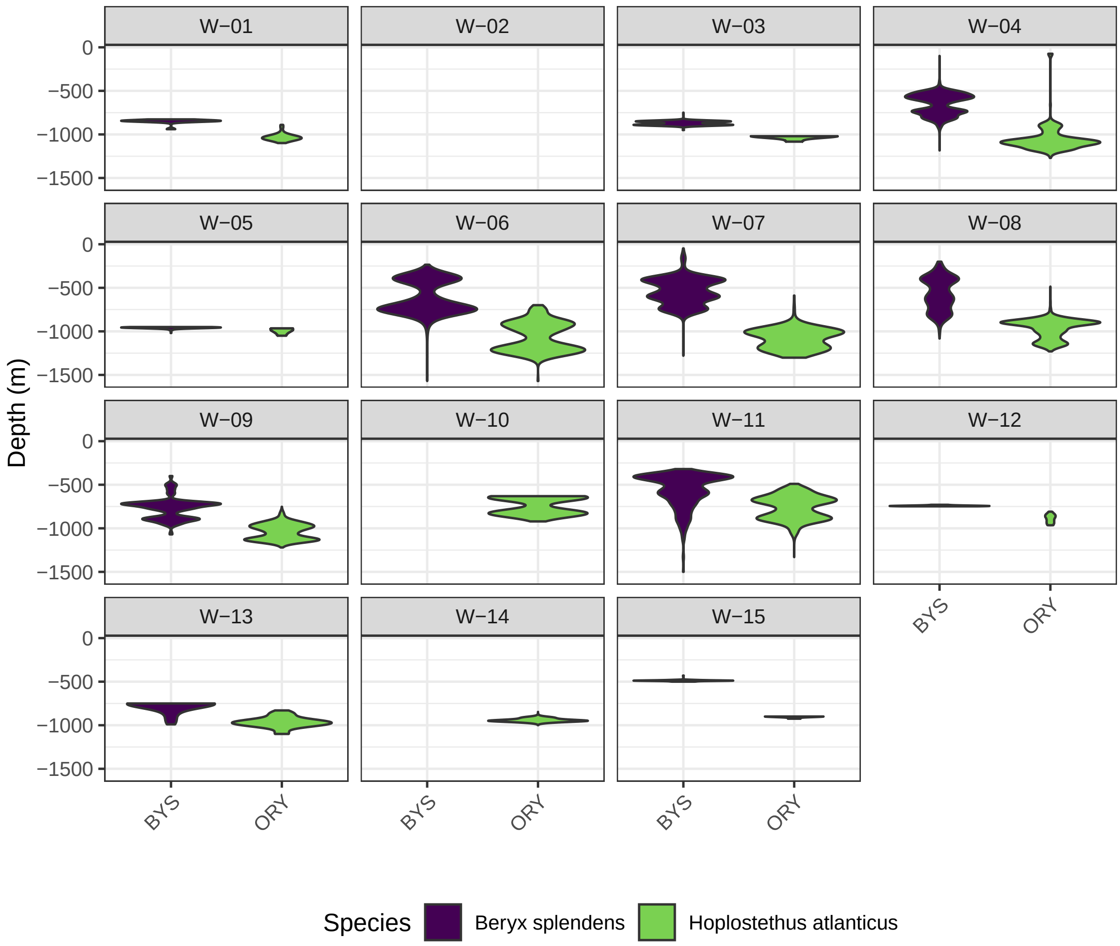

Figure 6: Catches of alfonsino and roughy by cluster and seabed depth at the start of the tow in the western region. The depth distributions of fishing effort that caught each species, displayed as violin plots, are weighted by catch quantity.

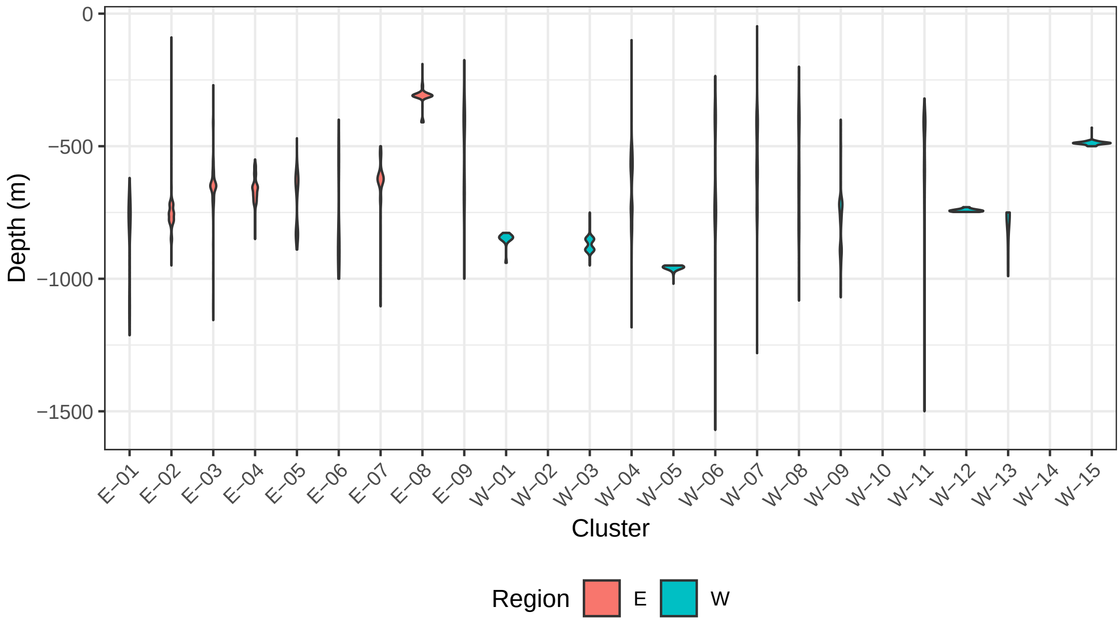

Figure 7: Catches of alfonsino by cluster and seabed depth at the start of the tow. The depth distributions of fishing effort that caught each species, displayed as violin plots, are weighted by catch quantity.

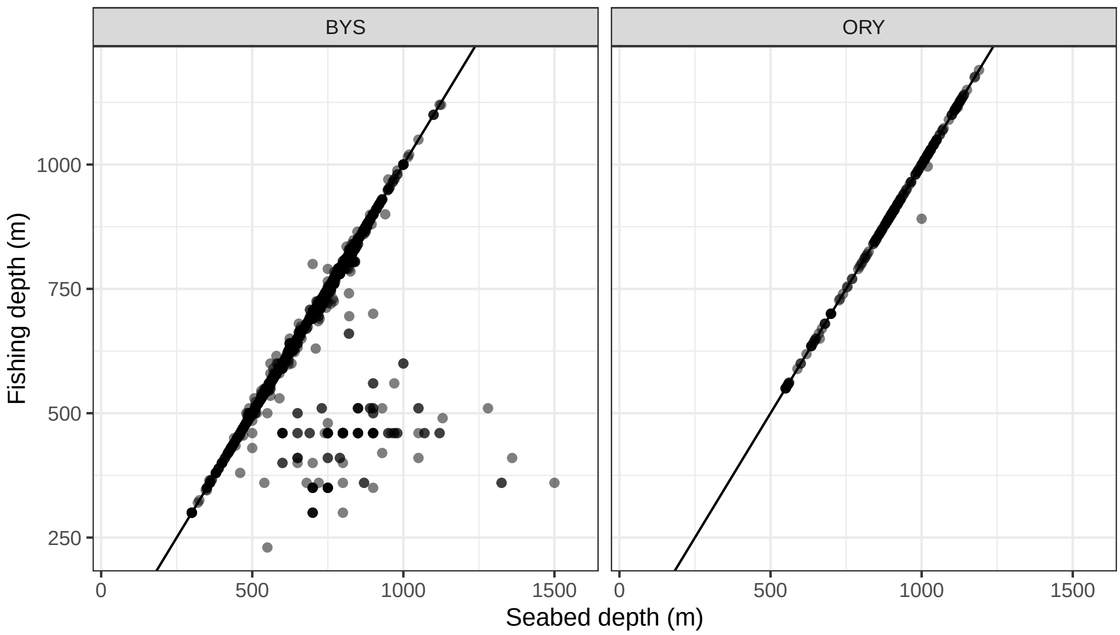

Figure 8: Depths of the net and the seabed at the start fishing, for tows catching alfonsino and orange roughy.

3.4 Size composition

Observer length frequency samples were typically of 100 fish (Figure 9).

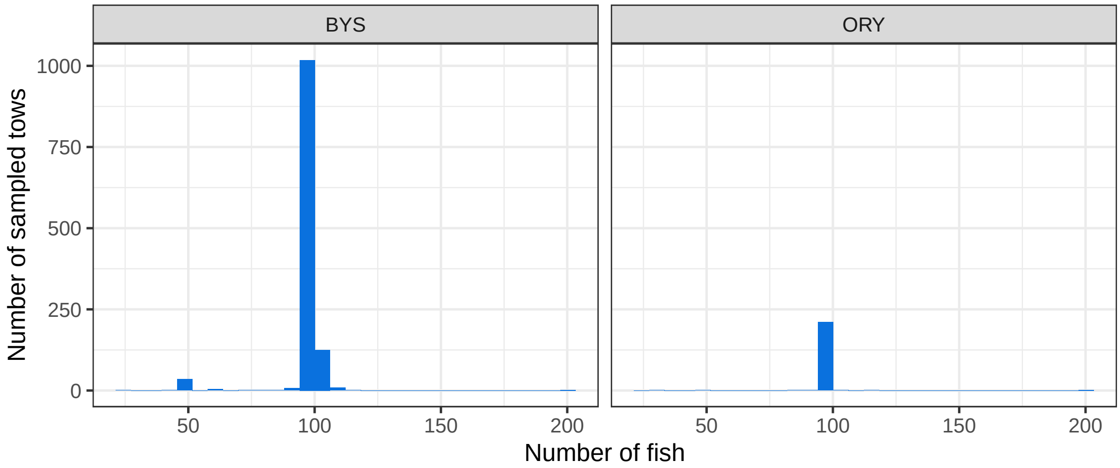

Figure 9: Length-frequency sample sizes (fish sampled per tow).

3.4.1 Orange roughy

Length data from orange roughy are available from the areas on the Madagascar Plateau, and in the central clusters on Southwest Indian Ridge; there are no samples from the smaller areas at the south-west of the Southwest Indian Ridge (Figure 10).

Figure 10: Trawl fishing effort clusters in the western region coloured according to whether they had (i) catches of more than 1 tonne of orange roughy in a year, and (ii) observer length-frequency samples for orange roughy.

Length-frequency distributions for orange roughy, by cluster and year, are usually unimodal or bimodal (Figure 11), although in some instances (e.g., W-08 in 2019) there is evidence of a third mode of larger fish. The larger mode was usually centred at a length of 45 cm or larger, and was a mix of male and female fish, with some indication that females grow larger. This difference is consistent with other fisheries where growth has been estimated separately by sex (Tingley & Dunn, 2018, table 11).

The smaller length mode was generally 30 cm or smaller, and had a high proportion of immature (or, at least, unsexed) fish. Given the known growth characteristics of orange roughy (Tingley & Dunn, 2018), it is unlikely that year-class progression will be apparent in length samples collected over time. As a result, it is likely that the bimodal distributions indicate periodic recruitment.

Regression trees for mean length in orange roughy tows (Figure 12) highlighted that the areas on the Madagascar Plateau (W-01 and W-04), together with area W-07, had the highest mean lengths and little evidence of a high proportion of smaller fish. The area with the smallest mean length, and the highest proportion of fish in the smaller size mode, was area W-06: the northernmost area on the Southwest Indian Ridge with catches of orange roughy. There is some indication that smaller fish were more prevalent in several areas in 2019, although small sample sizes, variation in the areas sampled by year, and the likelihood that fish are size stratified by depth, limit the conclusions that can be drawn.

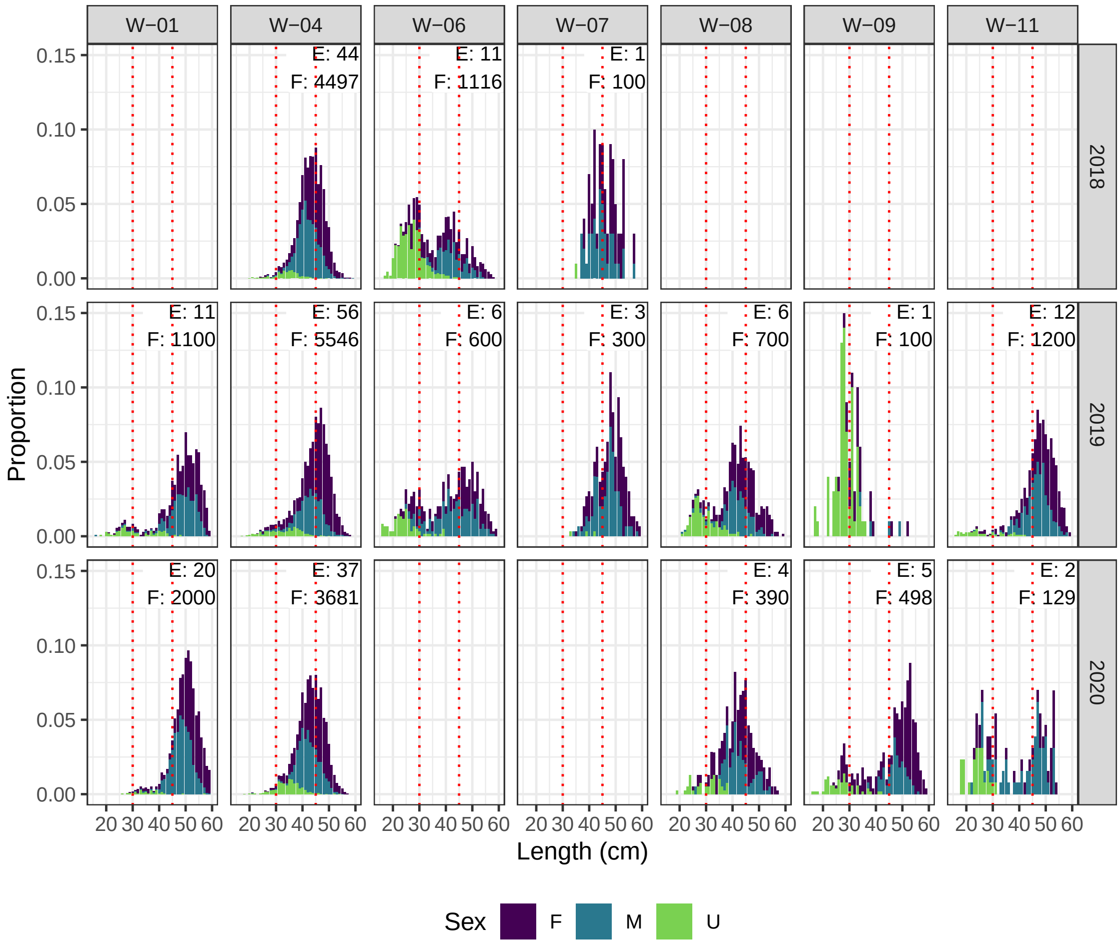

Figure 11: Length composition for orange roughy by cluster and year in the western region, expressed as proportions measured at length and sex with proportions calculated within each year and cluster. E = number of sampled tows; F = number of measured fish. Reference lines (red, dashed) are shown at 30 and 45cm.

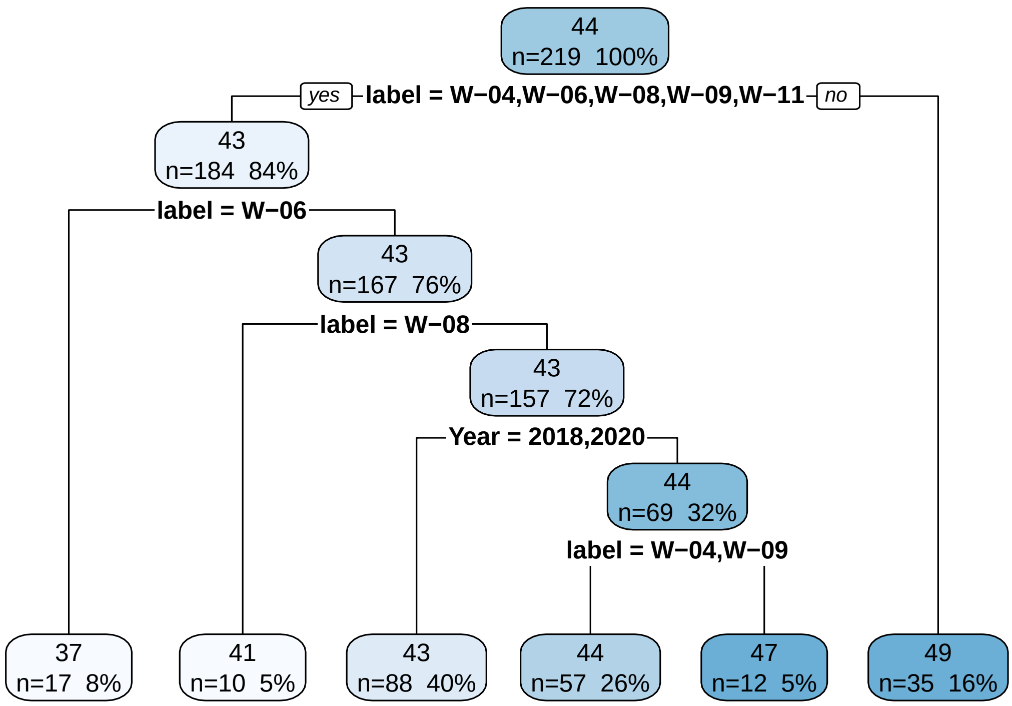

Figure 12: Regression tree examining variation in mean orange roughy length in a tow with location (cluster) and year.

3.4.2 Alfonsino

Alfonsino have been caught in most of the areas with trawl effort and observer length samples are also available from most areas, often from multiple years (Figure 13, Figure 14).

As was the case with orange roughy, the length-frequency distributions by area and year were often either broadly unimodal or bimodal (Figure 13, Figure 14). The larger size mode will likely represent multiple year classes where fish have reached their asymptotic size but, unlike orange roughy, individual year classes of fish may still be apparent in the smaller length mode.

However, if this interpretation of the larger size mode is correct, the asymptotic sizes of alfonsino in the SIOFA area appear to be smaller than the (limited) estimates reported by Shotton (2016), which tend to be around 50 cm, and considerably smaller than the 69 cm assumed by Brandão et al. (2020).

In the western area (Figure 13), alfonsino sampled in 2016 and 2017 were almost exclusively in the smaller size mode, in all areas, but there are some indications that multiple year classes are present (e.g., W-06 and W-09 in 2016); however, modal progression of the fish in this smaller size class over subsequent years was not clearly occurring. In the eastern area (Figure 14), smaller fish have only been sampled from a couple of the locations defined by the clustering of effort.

At a broad scale, the areas can be categorised into areas where only the larger size mode (around 40 cm) has been observed, and areas where a smaller size mode is apparent, at least in some years. This is broadly consistent with the first partition in the regression tree for alfonsino mean size (Figure 15). Smaller fish have been observed in most of the western areas, except the northern areas W-01 and W-03, but only in eastern areas E-06 and E-09 which in the south-west and south-east of the area, respectively.

For the areas where small fish have been observed, there is some indication of variation in recruitment between areas. Areas W-04 and W-09 have smaller fish in 2016 than areas W-06, W-07, W-08 and W-11, and fewer small fish than these areas in 2018 and 2020.

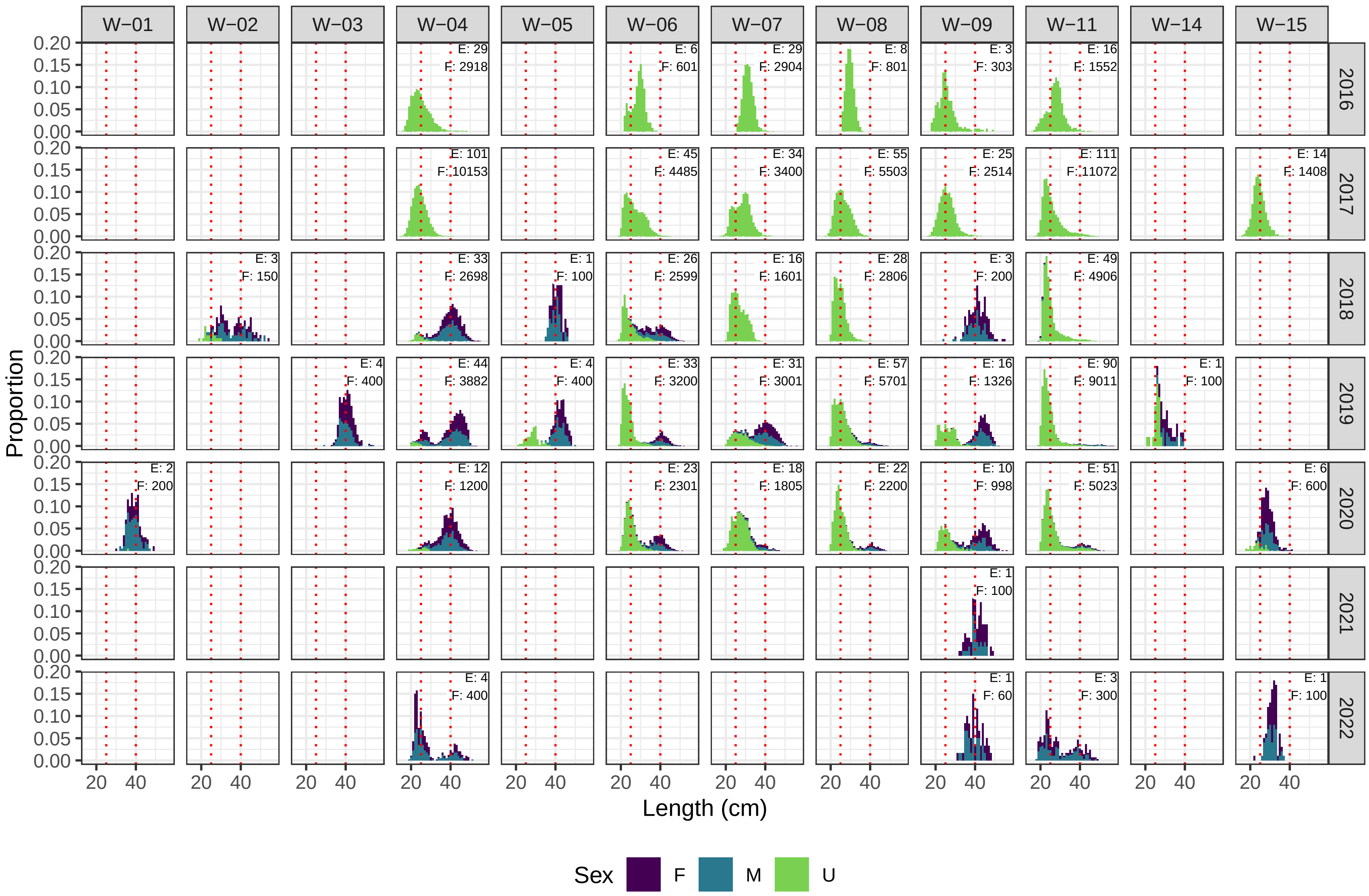

Figure 13: Length composition for alfonsino by cluster and year in the western region, expressed as proportions measured at length and sex with proportions calculated within each year and cluster. E = number of sampled tows; F = number of measured fish. Reference lines (red, dashed) are shown at 25 and 40cm.

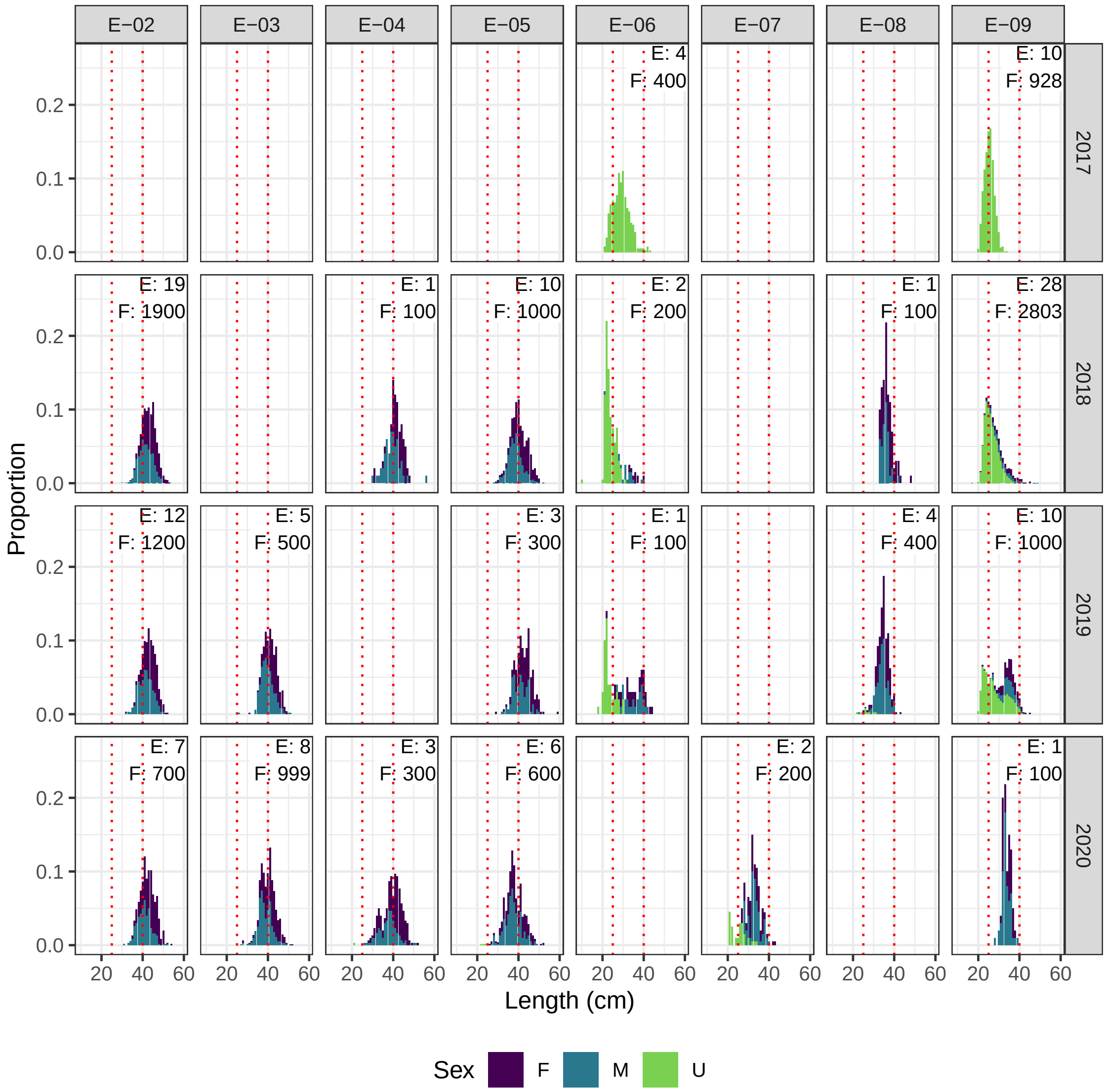

Figure 14: Length composition for alfonsino by cluster and year in the eastern region, expressed as proportions measured at length and sex with proportions calculated within each year and cluster. E = number of sampled tows; F = number of measured fish. Reference lines (red, dashed) are shown at 25 and 40cm.

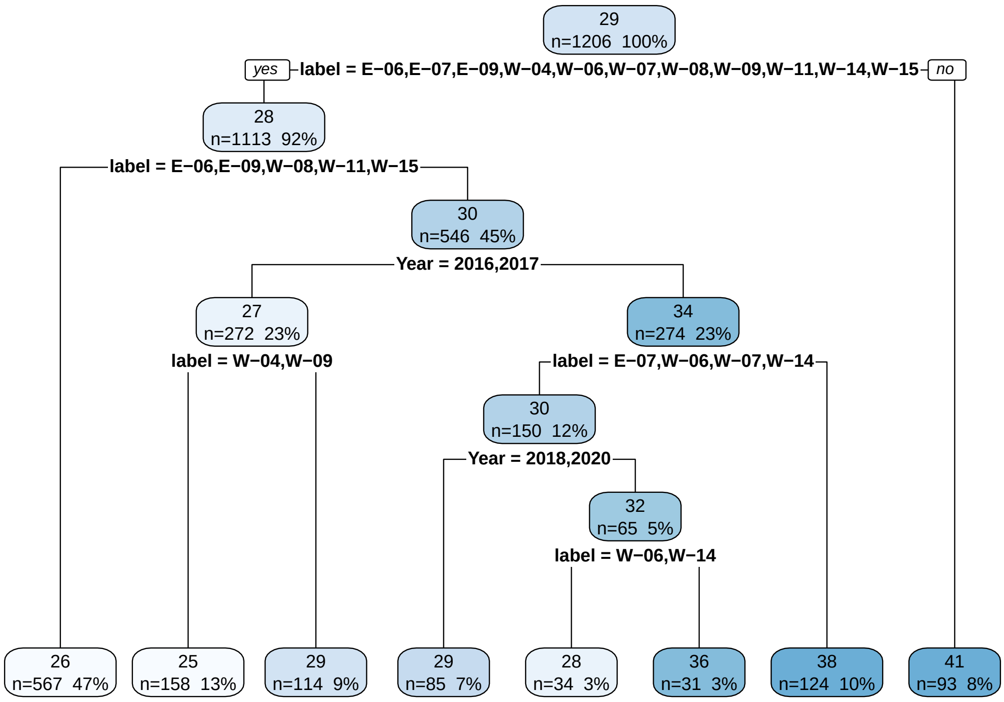

Figure 15: Regression tree examining variation in mean oragnge roughy length in a tow with location (cluster) and year. Region was also offered as an explanatory variable.

4. DISCUSSION

4.1 Literature review

The FAO has recently compiled global reviews of both alfonsino (Shotton, 2016) and orange roughy fisheries (Tingley & Dunn, 2018).

4.1.1 Orange roughy

Orange roughy are widespread globally, other than the northern Indian Ocean, and North Pacific (Tingley & Dunn, 2018), with fisheries off Australia, Chile, Namibia, New Zealand, in the northeast Atlantic and throughout the southern Pacific and southern Indian Oceans.

Orange roughy are now generally recognised to be long-lived, and slow growing. Mean size at maturity is typically estimated at around 30 cm and mean age at maturity at 25-30 years (Tingley & Dunn, 2018, tables 14 and 15).

Orange roughy eggs have been found in the mesopelagic habitat for a short time after spawning, but are associated with the benthos as early juveniles. Studies in the northeast Atlantic indicate juveniles initially have a shallower distribution than adults (< 800 m for years 1–3), but then go deeper (1200 m to 1700 m) until they approach maturity, with an adult depth range of 1000 m to 1500 m.

A range of techniques have been used to estimate stock boundaries in orange roughy. Results are often equivocal, and assessed populations are often defined at a relatively fine spatial scale. In the SIOFA area, the first assessments of orange roughy assumed that there were eight stocks all within the western SIOFA area (Figure 16; Cordue, 2018a), although the rationale for these boundaries was not generally documented. The primary assessment (Cordue, 2018b) was for the Walters Shoal Region which lies at the south of the Madagascar Plateau (within fishing effort cluster W-04). Spawning fish were reported to have been caught from eleven separate features within the area, but similar length-weight relationships were thought to provide some support for the hypothesis that the area could be considered to comprise a single stock.

The 2022 assessment of orange roughy applied a range of assessment approaches at different spatial scales, concluding that the assessments could reasonably be conducted for two areas, 'Long Walter's Shoal Ridge' which primarily comprises the areas at the southern end of the Madagascar Plateau, and 'Long Eastern Ridge' which comprises the areas on the Southwest Indian Ridge.

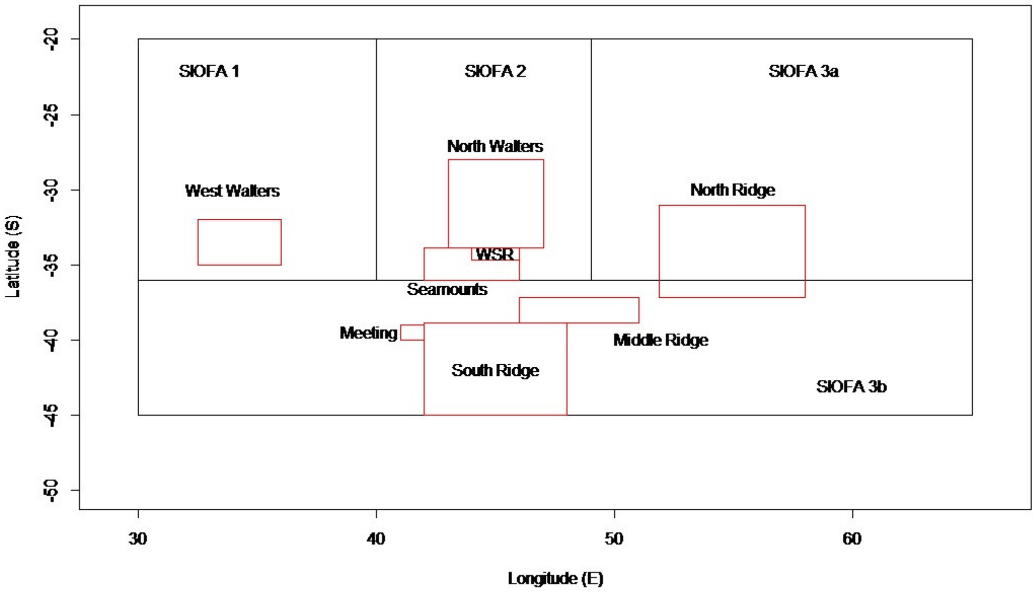

Figure 16: Orange roughy stock boundaries in the SIOFA region assumed by Cordue (2018a).

4.1.2 Alfonsino

Shotton (2016) noted that alfonsino have a widespread distribution; they are found along the European and African coasts, around oceanic islands of the Atlantic Ocean and in the Indian Ocean, in the northern Tasman Sea, along the Pacific coast of the Japanese Archipelago, the Southern Emperor and Northern Hawaiian ridges and westward towards Chile. Alfonsino fisheries are located around the Azores, in the Southeast Atlantic, the Southwest Indian Ocean, off Australia and New Zealand, on the Southern Emperor seamounts and in the southern area of the Northern Hawaiian Ridge. They were previously also fished around the Juan Fernández Archipelago in the Eastern Pacific.

Alfonsino reach a fork length of 15–20 cm in their first year, growing to 25 cm after 3 years and 40 cm after 10 years. They begin to mature in their second year, with most mature by age five or six, and 50 percent maturity at lengths from 23 to 44 cm.

Alfonsino larvae may have a pelagic phase of up to a year. Analyses of *Beryx splendens* mitochondrial DNA (Lévy-Hartmann et al., 2011) demonstrated a population subdivision between the Atlantic and Indo-Pacific Oceans and suggest that global oceanic currents are important in the distribution of larvae.

Within the Indian Ocean, morphometric studies suggested differences between fish in the western and eastern regions although recruitment to the eastern population from the west was considered possible (Ivanin, 1989, in Shotton, 2016).

The 2020 assessment of alfonsino in the SIOFA area (Brandão et al., 2020) assumed that the western and eastern areas represented separate stocks.

4.2 Oceanographic drivers

Oceanographic features can be key drivers in the structure of marine fish populations. Alfonsino are known to gather in large numbers over underwater features such as ridges and seamounts in the Indian Ocean (Shotton, 2016). Orange roughy can be caught on both flat seabeds (including the slope), and on the complex seabed topographies associated with underwater topographic features (UTFs) (Tingley & Dunn, 2018).

The bathymetry of the SIOFA region (Figure 17) is characterised by significant areas of abyssal plain, with a number of deeper basins, divided by several ocean ridge features. Significant areas are deeper than the practical limits for commercial trawl fishing.

Alfonsino are considered to disperse over long distances, particularly as larvae, and migratory patterns can be correlated with global oceanic currents (Lévy-Hartmann et al., 2011; Shotton, 2016). The SIOFA convention area is situated in the Indian Ocean Gyre that comprises the South Indian and Western Australia currents (Figure 18). These currents normally move counter-clockwise and could promote the dispersal and migration of individuals across and between the eastern and western fishing areas.

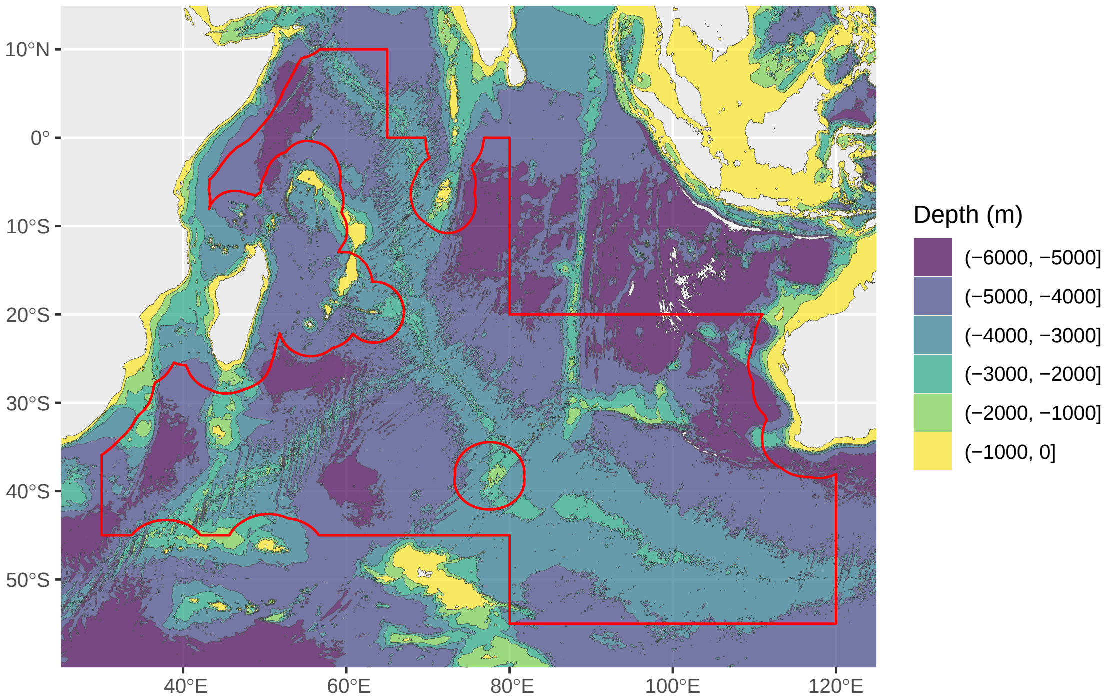

Figure 17: Bathymetry of the SIOFA region, using the GEBCO 2023 grid.

At a finer spatial resolution, there are local eddy features apparent near most of the fishing areas identified in the SIOFA trawl data, but also stronger currents flowing eastward (Figure 19). This includes the South Indian Current which passes over the Southwest Indian Ridge to the south of the major fishery areas and, while generally flowing eastward, also promotes generally northward flowing currents in the southern Indian Ocean. A more minor eastward current is also evident from the south of Madagascar to the Ninetyeast Ridge. The westward flow of the South Equatorial Current generally lies further north than the areas fished for alfonsino and orange roughy.

The mesoscale eddy features suggest that local retention of larvae is possible, at least within the western and eastern areas, and especially in the case of orange roughy with its short pelagic phase. However, the longer pelagic phase of alfonsino, together with the generally eastward flowing currents at the latitudes of the main fishing areas, indicates that the hypothesis of recruitment between areas, especially from the western area to the eastern area as suggested by Shotton (Ivanin, 1989, in 2016) is plausible.

Predictions of larval dispersal patterns using detailed hydrodynamic models are possible; however, differences between models (Ross et al., 2020), and the difficulty of accounting for the swimming behaviour of larvae once these are no longer able to be modelled as passive particles (Faillettaz et al., 2018; Gary et al., 2020), suggests that such predictions would be subject to substantial uncertainty.

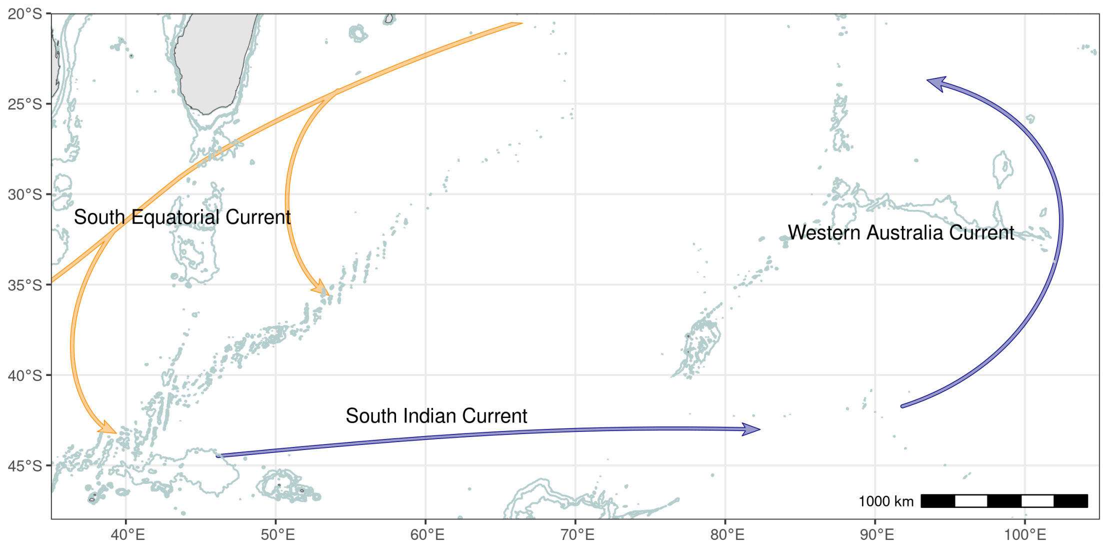

Figure 18: Fishing effort clusters, bathmetry, and major oceanic currents (South Equatorial, Western Australia and South Indian currents) in the SIOFA area, with warm (orange) and cold (blue) currents indicated by colored arrows.

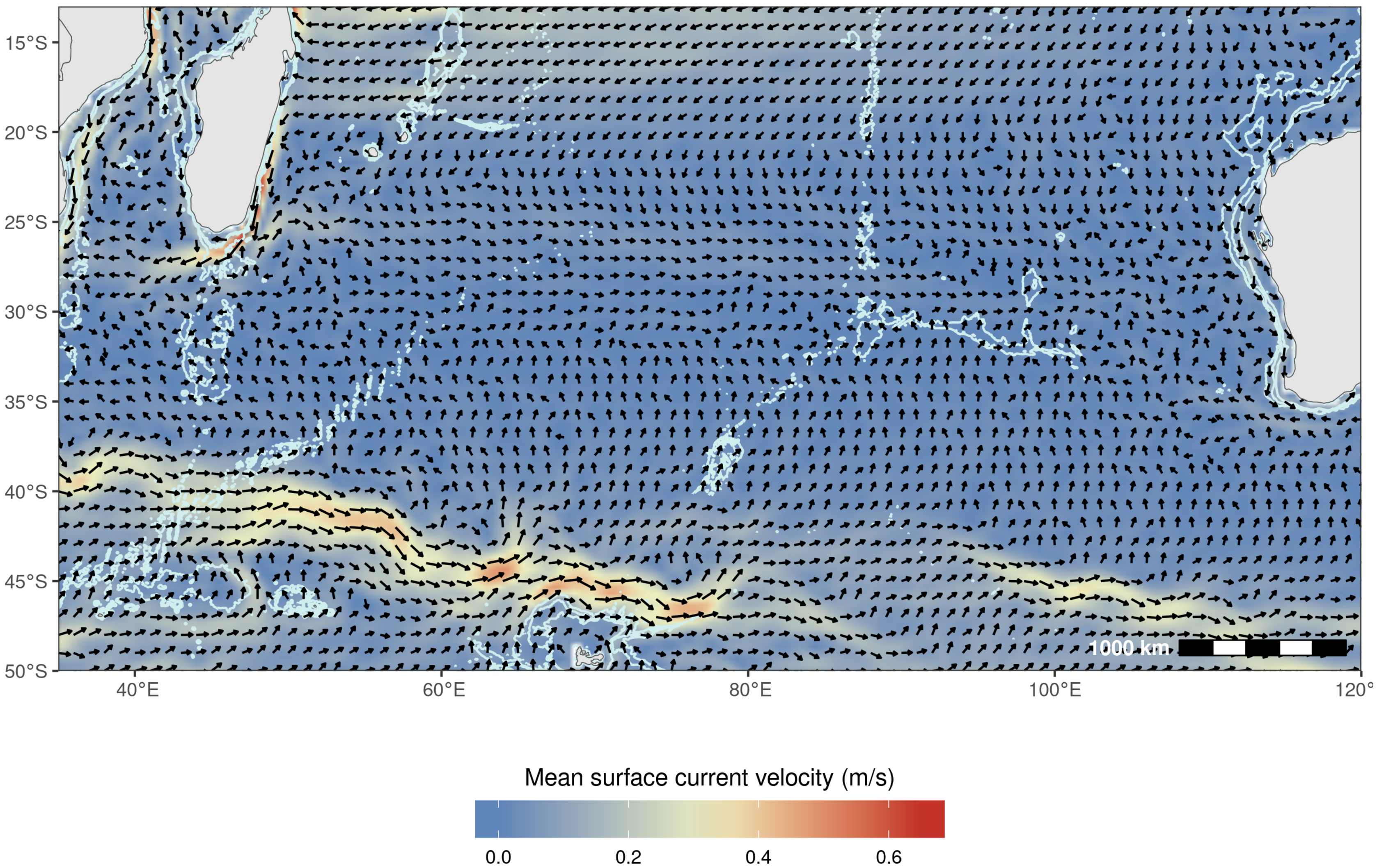

Figure 19: Fishing effort clusters, bathymetry and OSCAR surface current data in the SIOFA area. Average current speed in metres per second is shown via the colour scale while average current direction, and relative velocity, is indicated by the arrows.

4.3 Population genomic study for assessing stock structure

Marine ecosystems are considered highly connected, and genetic homogeneity is expected across large areas because few barriers to gene flow exist (e.g., Shanks, 2009). However, marine populations are typically large, with high genetic diversity that can facilitate adaptation to new and differing environments. Such adaptations can result in differentiation over small spatial scales, and differences in genetic composition have been described among individuals across relatively small geographical distances (see, for example, Grummer et al., 2019, for a recent review).

Alfonsino is a benthopelagic marine fish species with an extensive distribution, found broadly across regions of the Indian Ocean. The species occurs in large concentrations over ridges and seamounts in the middle of the Indian Ocean, including the Southwest Indian Ridge (SWIR), the Mid-Indian Ridge and Ninetyeast Ridge (Shotton, 2016). Dispersal patterns may be correlated with global oceanic currents (Lévy-Hartmann et al., 2011; Shotton, 2016). In order to understand stock structure in the SIOFA management area, a genomics approach based on hierarchical sampling could be considered.

4.3.1 Current genetic methods

Genetic methods have been employed to investigate fish stock structure since the 1970s. Early studies used small datasets of neutral loci, but the small numbers of markers often lacked the statistical power required to detect low rates of genetic differentiation. More recent methods, using thousands of markers spread across the genome, are being developed; examples include New Zealand hoki (*Macruronus novaezelandiae*; Koot et al., 2021) and snapper (*Chrysophrys auratus*) in New Zealand (Oosting, 2021) and Australia (Bertram et al., 2022).

These approaches are still under development; for both snapper and hoki in New Zealand, stock divisions relevant to fisheries management are considered to occur within the groupings identified by the genetic studies. However, while an absence of detectable genetic structure would not confirm a lack of stock structure, the presence of genetic differences would provide a clear indication of stock separation.

4.3.2 Sampling design considerations

For alfonsino, a stratified sampling approach can be developed using the two distinct fishery regions, the western area (Figure 3) and eastern area (Figure 4), as the key strata. Sites within strata would be spread across the fishing clusters identified within each area, aiming to span the major axis of each area. The western area could be further stratified into two strata, one which includes the Madagascar Plateau (i.e, W–01 and W–04 in Figure 3) and another covering the ridge southeast of the plateau (a section of the SWIR, W–12 to W–02 in Figure 3). Sampling multiple sites across clusters within each area will help to determine if there is genetic heterogeneity among clusters within strata, and also provide information for developing hypotheses for genetic variation across strata, and factors that could influence such patterns.

A minimum of three sampling sites should be selected in the major strata. For the western area, at least one site should be sampled on the Madagascar Plateau (or at least two sampling sites if the western area is stratified into plateau and ridge strata). The clusters of spatial effort (Figure 2) can be utilised as sampling sites within strata in the specification of a sampling design.

To understand alfonsino stock structure may require a large sample size of individuals per sampling site (n > 50), however this could potentially be reduced to 30 individuals (Foster et al., 2021). Recent fisheries genomic studies generally collect around 30 individuals for each sampling site (Bertram et al., 2023; Koot et al., 2021; Papa et al., 2022). A sample size of 30 individuals per sampling site is therefore recommended, which should be sufficient to detect rare alleles among groups. In the initial stages, processing and analysing 10–15 individuals per sampling site could provide a genomic dataset for a preliminary study to understand genomic structure and the likely final sampling intensity required to achieve useful statistical power. The remaining samples would then be processed if required.

We recommend a whole-genome (WG) approach for DNA sequencing which provides a comprehensive coverage of the entire genome, and better resolution of genetic information. However, a reduced representation (RR) approach could be a cost-effective option for sequencing a large number of samples. This approach is generally cheaper than whole-genome sequencing, but also carries significant risks (Andrews et al., 2016; Maroso et al., 2018), requiring careful experimental and analytical design (Christiansen et al., 2021). The reduced approach may not identify signatures of local adaptation (Lowry et al., 2017), thereby missing potentially important sources of population structure.

Approximate (as of June 2023) estimates of cost for sampling designs based on RR and WG sequencing have been compiled. Sequencing costs (Table 5) are given in NZD. Additional costs beyond those tabulated in Table 6, including logistics and data analysis costs, should be anticipated and will depend on the sequencing methods selected.

Table 5: Indicative cost of sequencing for genomics sampling of alfonsino populations.

Process	Indicative cost* (NZD)
DNA Extraction	$5 – $10
Whole genome approach (e.g. Novaseq)	$120 per fish
Reduced-Representation Sequencing	$40 per fish

*There is additional cost to consider for logistics and data analysis

Table 6: Indicative sequencing cost of sampling designs to consider for alfonsino populations. Additional costs arise for logistics (postage etc), analysis and reporting by the research provider.

Samples per site	Sites per stratum	Sequencing option	Estimated cost (incl extraction; NZD)
10	3	Whole Genome	7800
30	3	Whole Genome	23400
10	3	Reduced-Rep Seq	3000
30	3	Reduced-Rep Seq	9000

5. CONCLUSIONS

Density-based clustering was successfully applied to elucidate patterns in the trawl fishing effort for alfonsino and orange roughy in the SIOFA area. The trawl fisheries were clearly associated with bathymetric features; it is likely that this association is due in part to the distribution and behaviour of the target species, but is also related to the constraints of the trawl fishing method.

Two broad areas of trawl fishery activity were identified: one in the western part of the SIOFA area associated with the Madagascar Plateau, and the Southwest Indian Ridge (SIOFA subareas 2, 3a, 3b), and an eastern area, associated with the Ninetyeast Ridge, the Diamantina Escarpment, and adjacent seamount areas (SIOFA subareas 4, 5; Figure 20). Haul by haul catch data indicated that the eastern area was almost exclusively an alfonsino fishery, whereas the western area supported both alfonsino and orange roughy fisheries, with the latter typically fishing deeper.

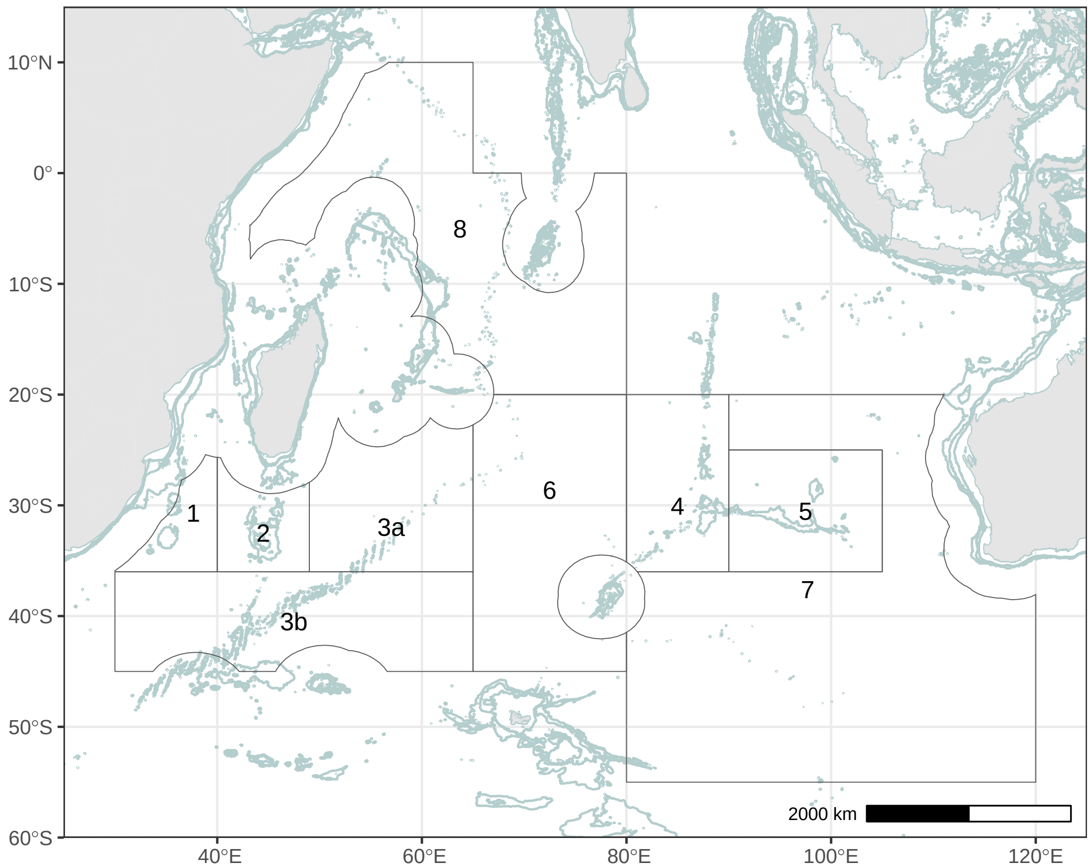

Figure 20: Clusters of trawl fishing effort and baythmetry in the SIOFA area, in relation to the SIOFA subareas. Depth contours at 500, 1000 and 2000 m are illustrated, based on the GEBCO 2023 grid.

5.1 Orange roughy

Orange roughy length distributions by area and year were either unimodal or bimodal. In general, smaller fish were more apparent in areas on the Southwest Indian Ridge than on the Madagascar Plateau, although any conclusions based on these observations are necessarily cautions due to the limited years with data, and the possible confounding of depth. However, these patterns are generally in line with the two area approach for orange roughy assessment proposed by Roa-Ureta et al. (2022).

Finer scale divisions, such as those used in the 2018 assessments (Cordue, 2018a, 2018b) are potentially justified if fish movement is limited and there is genuine affinity to fine-scale features. Managing at finer scales generally represents a more cautious approach, but risks patterns being confounded by fish movement and data series being too patchy for effective assessment modelling. Abundance trends for the different fishery areas, and ideally age composition data, would assist in further resolving finer scale patterns in the orange roughy stocks.

5.2 Alfonsino

For alfonsino, there is evidence that smaller fish are generally more prevalent in the western fishery area, with adult fish present in both areas. The apparently long pelagic larval phase in alfonsino, and oceanographic patterns in the south Indian Ocean, imply that connectivity between the eastern and western areas is possible. It is less clear that adult alfonsino, once settled, move substantial distances. One hypothesis for the variation in size of younger fish between areas in the western region is that pelagic juveniles are circulating in mesoscale eddies and that different sub-areas receive differential recruitment from year to year as circulation patterns vary. At present, the two region assessment approach adopted by Brandão et al. (2020) would appear to be a pragmatic choice, but a closer examination of abundance trends between areas within regions would be sensible in future assessments.

Modern genetic methods, particularly those that use genetic information from organisms' entire genomes, are able to detect spatial structuring in some populations at a scale that is relevant to fisheries management. In other cases, however, there is other evidence of stock structuring at finer scale than genetic analyses suggest. A design for a genetic stock differentiation study for alfonsino in the Indian Ocean is outlined, but should probably be considered as one of a number of approaches used to elucidate stock structure, rather than a sufficient approach in isolation. Age composition data from different areas would also assist in determining stock structure, while contributing to estimation of year class strengths when used in stock assessment modelling.

Resolving stock structure in fisheries is seldom straightforward; as a result it is advisable that stock assessments routinely assess the sensitivity of results to alternative stock hypothesis, in order to provide information that allows robust management in the face of these uncertainties.

6. RECOMMENDATIONS

- Our examination of the spatial patterns in the SIOFA trawl fisheries indicated that the two-area approaches in the recent SIOFA assessments for orange roughy and alfonsino are appropriate. However, the data for defining stock structure are not strong, and the sensitivity of results to alternative stock hypothesis should be considered in future assessments.

- For orange roughy, the two area approach proposed by Roa-Ureta et al. (2022) is recommended for ongoing assessment and management; these areas are (i) SIOFA subarea 2, and (ii) SIOFA subareas 3a and 3b (Figure 20).

- In the case of alfonsino, the two area approach of Brandão et al. (2020) is also recommended; these areas are (i) SIOFA subareas 2, 3a and 3b, and (ii) SIOFA subareas 4 and 5 (Figure 20).

- For alfonsino, connectivity between the western and eastern fishery areas is possible. A genetic study, ideally based on whole genome sequencing, could be undertaken. However, a lack of genetic differentiation would not necessarily indicate a lack of stock structure relevant to fishery management.

- Examination of abundance trends and, ideally, age compositions at a range of spatial scales would assist in further resolving stock structure while contributing to future assessment modelling.

7. ACKNOWLEDGEMENTS

This work was funded by the SIOFA Secretariat under projects SER2022-BYS1 and SER2022-ORY1. Ultimate funding for these projects was provided by the European Union (Grant Agreement: SI2.837681). The projects were managed by SIOFA's Science Officer, Marco Milardi and supported by an advisory group of Scientific Committee members: Science Committee Chair, Alistair Dunn; Steve Brouwer; Takehiro Okuda; and Sebastián Rodríguez Alfaro. We are particularly grateful to Maren Wellenreuther (Plant & Food Research and the University of Auckland) for advising on recent genomic approaches to population differentiation, appropriate sampling approaches, and indicative costs.

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APPENDIX A Data notes

Extracts of catch, effort and observer data from the SIOFA Secretariat databases were adequate for undertaking the key analyses contracted in this project. However, there were a number of issues apparent in these data, which we note here to assist in future analyses.

A.1 Database documentation

The SIOFA website (https://siofa.org/management/CMM/02) allows data users to discover how data provided to SIOFA should be provided by Members. However, there is little information on how data are validated and stored by the Secretariat; database documentation would be a valuable resource for those contracted to analyse SIOFA's data holdings.

Project-specific extracts from the SIOFA databases would ideally be accompanied by the SQL code used to make the extract, to assist in interpretation. In particular, understanding the joins that have been made between data tables assists in interpreting whether apparent duplicate records exist in the source data or have arisen in the extract process.

In this project we found that a tow could have multiple catch records of the same species. This is not necessarily contrary to the data format specified in the trawl catch-effort spreadsheet[2] but cases where the catch weight is also the same are clearly suspicious. Double counting of catches is undesirable in any data analysis.

A.2 Database resolution

The haul-by-haul format data was the key data source for the spatial analyses undertaken in this project. This has been the only data format accepted by SIOFA since 2020; however, some haul-by-haul data were available as far back as 1999. In our analyses it was not generally possible to associate the aggregated catch data to a spatial cluster, due to the limited spatial resolution of the aggregated data. However, a potential concern is that, in years when both haul-by-haul and aggregated data are available, some haul-by-haul effort may also be included in the aggregated dataset. For analyses that need to use both datasets to establish total catch and effort, it will be necessary to confirm that any such duplication is eliminated, to avoid double-counting.

A.3 Observer data fields

Our extract of observed data had limited information on the sampled tows (position and date). In the ideal world, it would be possible to link observer samples to the haul-by-haul catch and effort data. If this is not possible, it is desirable that the observer data contains fuller information about the sampled tows. This would include information about the tows (e.g., depth) and about the catch (totals, and quantity sampled).

[2]https://siofa.org/sites/default/files/documents/cmm/SIOFA_vessel_catch_and_effort_TRAWL_2022.xlsx

Fish length data in our extract were recorded in both centimetres and millimetres, and needed to be standardised. Although such corrections can be straightforward, they should be avoided by ensuring that data are stored in standard units. It is apparent that some fish and gonad weight data are also in varying units (i.e., grams and kilograms).

We considered examining fish maturity data to assist in interpretations of stock structure. However, it appears that these are not recorded using a consistent approach: not all values are integers, and it is probably that different sources will have used different maturity scales (e.g., 5 versus 8 stages).

Where fish measured by observers are not sexed, greater clarity around whether the fish were immature, or whether sexing was not possible or not attempted, would be desirable.

Consideration should be given to observer sampling approaches that do not specify an exact sample size (i.e., 100 fish) as fixed-sample size approaches have the potential to introduce sampling bias.

APPENDIX B Project terms of reference

Terms of Reference (ToR) for the provision of scientific services to SIOFA Scientific Committee

Project title: Stock structure of alfonsino (*Beryx splendens*)

Project Code: SER2022-BYS1

INTRODUCTION

SIOFA CMM2020/01 (paragraph 6a) requires the SIOFA Scientific Committee to provide advice to the Meeting of the Parties on the status of stocks of deep-sea fishery resources, including alfonsino (*Beryx splendens*). In 2020, the SIOFA Scientific Committee (SC3) conducted the first alfonsino stock assessments in the SIOFA region and provided to the Meeting of Parties on the stock status and sustainable yields. In 2023, the assessment for alfonsino will be updated.

This document describes the project Terms of Reference (ToR), milestones, and administrative matters for a consultancy to undertake alfonsino stock assessments. Once appointed, the Consultant should direct any questions and clarifications to the SIOFA Science Officer (Marco Milardi, marco.milardi@siofa.org) who will coordinate the project and its interactions with the project advisory panel, the relevant SC HoDs and the SIOFA Scientific Committee Chair, as appropriate.

1. TERMS OF REFERENCE

The project objective and tasks are described as below. The Consultant shall undertake these tasks and consult with the project coordinator, to ensure that the project objectives are met.

A project advisory panel consisting of the SIOFA Scientific Committee Chair, selected members of the SIOFA Scientific Committee, and the SIOFA Secretariat will meet periodically with the consultant to assist the consultant access and interpret reports, data, and to provide advice on relevant analyses or data interpretation for the project.

1.1 Overall objectives

Objective 1: Provide advice to the SIOFA Scientific Committee on the stock structure of alfonsino (*Beryx splendens*) in the SIOFA Area, including consideration of hypotheses on the alfonsino life cycle in the SIOFA Area.

Objective 2: Provide advice on appropriate management units for SIOFA to use in future monitoring and stock assessments of alfonsino (*Beryx splendens*).

Objective 3: Evaluate the feasibility of genetic stock discrimination for alfonsino (*Beryx splendens*), including the development and design of a genetic stock discrimination project to improve understanding of the stock structure of alfonsino in the SIOFA Area.

1.1.1 Task 1: Literature review

Review the previous stock assessments, SIOFA reports and publications, the general scientific literature, and other relevant information sources, including alfonsino stocks in other areas, to summarise information that may assist in the determination of alfonsino stock structure, including the definition of biological stocks, and hence appropriate management units for alfonsino in the SIOFA Area.

1.1.2 Task 2: Review of catch-effort and scientific observer data

Review the relevant catch-effort, acoustic, and scientific observer data (e.g., age, length, and other biological data) held by SIOFA that would assist in the determination of alfonsino stock structure and hence appropriate management units for alfonsino in the SIOFA Area.

The review should also evaluate the available data and how the hypotheses of stock structure may be improved and evaluated by additional fisheries dependent and independent information, including the use of genetic stock discrimination methods.

1.1.3 Task 3: Review of bathymetric, oceanographic, and other relevant environmental data

Review available bathymetric, oceanographic, and other relevant environmental drivers to assist in the determination of alfonsino stock structure and hence appropriate management units for alfonsino in the SIOFA Area.

1.1.4 Task 4: Proposal for Management units based on the stock structure

Provide advice to the SIOFA Scientific Committee on the stock structure of alfonsino and hence appropriate Management Units for SIOFA to use in future monitoring and stock assessments of alfonsino, including describing any uncertainties and alternative plausible definitions, as well as the relationship to previously defined Management Units for alfonsino and SIOFA Area and sub-Area boundaries.

1.2 Task 5: Genetic stock discrimination

Evaluate the feasibility of genetic stock discrimination for alfonsino (*Beryx splendens*), including the development and design of a genetic stock discrimination project to improve the understanding of stock structure in the SIOFA Area, by:

(i) evaluating the feasibility of a genetic stock discrimination project, and

(ii) develop and design a genetic sampling project including specifications of the number of samples, locations and timing for the collection of samples using commercial fishing operations, the contents of a genetic sampling kit for observers and/or vessels, timelines, and costs for the project.

1.3 Reporting requirements

1. Provide updates and engage with the project advisory panel that will assist the consultant access and interpret reports, data, and to provide advice on relevant analyses or data interpretation for the project

2. Provide a draft report detailing the methods, outcomes of reviews, conclusions, and recommendations to the SIOFA project advisory panel for review by 31 January 2022.

3. Update the draft report in (2) by considering any comments and advice from the project advisory panel and submit this report to SIOFA Secretariat for submission to the SIOFA Scientific Committee meeting in 2023 by 15 February 2023

4. Present the draft report in (3) to the SIOFA Scientific Committee to its meeting in March 2023 by videoconference.

5. Provide an amended final report to the SIOFA Secretariat, considering any comments made at the SIOFA Scientific Committee meeting in March 2023, by 15 April 2023

6. Provide all the information collected to the SIOFA Secretariat (including that sourced from the Secretariat) before the final payment of the contract is made to the consultant. Such information includes electronic data files, analysis codes, biological samples, and other relevant data if applicable.

1.4 Confidentiality and distribution of project outcomes

The Consultant shall not release confidential data provided for conducting this study to any persons nor any organisations, other than SIOFA Secretariat. The consultant shall delete all the confidential data after the completion of the contract. Any arrangements for ownership, storage, or disposal of physical samples shall be agreed by SIOFA as a part of the contract.

All Intellectual Property generated as a part of this contract shall become the property of SIOFA unless otherwise excluded in the proposal and agreed by SIOFA in the contract.

All reports and presentations will be reviewed by the SIOFA Secretariat prior to any form of further distribution. The Consultant will revise the report according to comments received from the review process before the report or presentation is accepted as a submission against the requirements in the Terms of Reference.

1.5 Relevant SIOFA information

1. SIOFA data (provided by the SIOFA Secretariat upon request)
2. SIOFA reports:
   a. SIOFA SC reports and National Reports. Scientific Committee Meeting | SIOFA (apsoi.org)
   b. MoP reports. Meeting of the Parties | SIOFA (apsoi.org)
   c. SIOFA technical and scientific reports (public reports available from apsoi.org, and restricted reports available from the SIOFA Secretariat to the project consultant)

2. WORK PLAN AND PAYMENT SCHEDULE

The funds for this project are budgeted under General Objective 1 of the SIOFA/EU Grant Agreement SI2837681 - Scientific Work Support, for a total allocated budget of 10 000 euro (including all costs and including any travel related expenses).

The consultant shall follow the timeline described in Table 1 below.

Table 1: Timeline for payments, milestones, and report submission

Milestone	Date	Activities
Initiation of contract	1 December 2022	First instalment payment (30% of the total contract sum)
Delivery of draft report	15 February 2023	Submission of draft report to SC8
Delivery of final report	15 April 2023	Submission of final report and project information to SIOFA.

		Final instalment payment (70% of the total contract sum) on acceptance of the final report and the submission of project information

3. SUBMISSION OF APPLICATIONS

The applicants should have appropriate experience and knowledge of developing stock structure hypotheses and preferably on the stock dynamics and life cycle of alfonsino. The applicants should submit a proposal to the project coordinator (SIOFA Science Officer - Marco Milardi, marco.milardi@siofa.org) containing the following items:

1. A current CV that summarises the applicant(s) relevant educational background and professional experience
2. A brief proposal (indicatively 1-2 pages) outlining the proposed methods and analyses, including a description of how the objectives of the ToRs will be achieved
3. Any proposed exclusions to the intellectual property clause
4. The proposed consultancy price (including all consultant expenses and project related costs), noting that the available budget for this work is a maximum of €10 000
5. Identification of any project risks and associated mitigation and management required to successfully complete the project
6. A statement that identifies any perceived, potential, or actual conflicts of interest of the applicant(s), including those described in paragraph 4 of the SIOFA recruitment procedure (see Box 1), and
7. Any additional relevant information the applicant(s) wish to submit.
8. We note that similar projects for Patagonian toothfish and orange roughy in the SIOFA Area are also available, and we encourage consultants to submit combined proposals for these projects if appropriate.

Only applications received before 12 AM (9 AM UTC) on Monday the 19th of December, Reunion Island time, will be considered in the following selection process.

4. EVALUATION CRITERIA FOR THE SELECTION OF CANDIDATES

The selection criteria will be developed by the evaluation panel along with the project manager, the Secretariat, and the Chairpersons of the relevant subsidiary bodies. The criteria may include following items:

1. Adequate submission of information to allow the panel to evaluate the candidate
2. Evaluation of the proposal from the candidate, including the proposed contract price
3. Ability to undertake and complete the analyses or work required in the ToR
4. The candidate's agreement with confidentiality provisions required for the project
5. Acceptable conflict of interest statement
6. Agreement with the data submission and intellectual property terms required in this ToR, and
7. Financial and resourcing considerations.

5. CONFLICTS OF INTEREST. PARAGRAPH 4 OF SIOFA'S RECRUITMENT PROCEDURE

To ensure that situations relating to potential and actual conflict of interests are avoided, persons falling into the following categories may not normally be considered for SIOFA consultancy: (i). any person designated as a designated representative or alternate representative of a CCP to the Meeting of Parties

(MOP) as per Rule 3.1 of the Rules of Procedure, and to the SC and any other subsidiary bodies of the MOP, as per Rule 21.3 of the Rules of Procedure; (ii). Any person fulfilling the function of Chair or Vice-Chair of the MOP or Chair or Vice-Chair of a SIOFA subsidiary body or working group; (iii). Any person acting as a member of a delegation involved in the SIOFA decision-making process resulting in recommendations and/or approval for the SIOFA work requiring the engagement of a consultant; and (iv). Individuals who were SIOFA Secretariat staff members at the time when the recommendations and/or approval for the SIOFA works were adopted or who are members of immediate family (e.g., spouse or partner, father, mother, son, daughter, brother, or sister) of any Secretariat staff member or of the persons identified in 4 (i), (ii), and (iii).

6. CONTACTS

Project Coordinator – SIOFA Science Officer (Marco Milardi, marco.milardi@siofa.org)

Administration – SIOFA Executive Secretary (Thierry Clot, thierry.clot@siofa.org)

Terms of Reference (ToR) for the provision of scientific services to SIOFA Scientific Committee

Project title: Stock structure of orange roughy (*Hoplostethus atlanticus*)

Project Code: SER2022-ORY1

INTRODUCTION

SIOFA CMM2020/01 (paragraph 6a) requires the SIOFA Scientific Committee to provide advice to the Meeting of the Parties on the status of stocks of deep-sea fishery resources, including orange roughy (*Hoplostethus atlanticus*). In 2018, the SIOFA Scientific Committee (SC3) conducted the first orange roughy stock assessments in the SIOFA region and provided to the Meeting of Parties on the stock status and sustainable yields. In 2022, the assessment for orange roughy was updated and the management units revised.

This document describes the project Terms of Reference (ToR), milestones, and administrative matters for a consultancy to assess the orange roughy stock structure. Once appointed, the Consultant should direct any questions and clarifications to the SIOFA Science Officer (Marco Milardi, marco.milardi@siofa.org) who will coordinate the project and its interactions with the project advisory panel, the relevant SC HoDs and the SIOFA Scientific Committee Chair, as appropriate.

1. TERMS OF REFERENCE

The project objective and tasks are described as below. The Consultant shall undertake these tasks and consult with the project coordinator, to ensure that the project objectives are met.

A project advisory panel consisting of the SIOFA Scientific Committee Chair, selected members of the SIOFA Scientific Committee, and the SIOFA Secretariat will meet periodically with the consultant to assist the consultant access and interpret reports, data, and to provide advice on relevant analyses or data interpretation for the project.

1.1 Overall objectives

Objective 1: Provide advice to the SIOFA Scientific Committee on the stock structure of orange roughy in the SIOFA Area, including consideration of hypotheses on the orange roughy life cycle in the SIOFA Area.

Objective 2: Provide advice on appropriate management units for SIOFA to use in future monitoring and stock assessments of orange roughy.

1.1.1 Task 1: Literature review

Review the previous stock assessments, SIOFA reports and publications, the general scientific literature, and other relevant information sources, including orange roughy stocks in other areas, to summarise information that may assist in the determination of orange roughy stock structure, including the definition of biological stocks, and hence appropriate management units for orange roughy in the SIOFA Area.

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1.1.2 Task 2: Review of catch-effort and scientific observer data

Review the relevant catch-effort, acoustic, and scientific observer data (e.g., age, length, and other biological data) held by SIOFA that would assist in the determination of orange roughy stock structure and hence appropriate management units for orange roughy in the SIOFA Area.

The review should also evaluate the available data and how the hypotheses of stock structure may be improved and evaluated by additional fisheries dependent and independent information.

1.1.3 Task 3: Review of bathymetric, oceanographic, and other relevant environmental data

Review available bathymetric, oceanographic, and other relevant environmental drivers to assist in the determination of orange roughy stock structure and hence appropriate management units for orange roughy in the SIOFA Area.

1.1.4 Task 4: Proposal for Management units based on the stock structure

Provide advice to the SIOFA Scientific Committee on the stock structure of orange roughy and hence propose appropriate Management Units for SIOFA to use in future monitoring and stock assessments of orange roughy, including describing any uncertainties and alternative plausible definitions, as well as the relationship to previously defined Management Units for orange roughy and SIOFA Area and sub-Area boundaries.

1.2 Reporting requirements

1. Provide updates and engage with the project advisory panel that will assist the consultant access and interpret reports, data, and to provide advice on relevant analyses or data interpretation for the project

2. Provide a draft report detailing the methods, outcomes of reviews, conclusions, and recommendations to the SIOFA project advisory panel for review by 31 January 2022.

3. Update the draft report in (2) by considering any comments and advice from the project advisory panel and submit this report to SIOFA Secretariat for submission to the SIOFA Scientific Committee meeting in 2023 by 15 February 2023

4. Present the draft report in (3) to the SIOFA Scientific Committee to its meeting in March 2023 by videoconference.

5. Provide an amended final report to the SIOFA Secretariat taking into account any comments made at the SIOFA Scientific Committee meeting in March 2023, by 15 April 2023

6. Provide all the information collected to the SIOFA Secretariat (including that sourced from the Secretariat) before the final payment of the contract is made to the consultant. Such information includes electronic data files, analysis codes, biological samples, and other relevant data if applicable.

1.3 Confidentiality and distribution of project outcomes

The Consultant shall not release confidential data provided for conducting this study to any persons nor any organisations, other than SIOFA Secretariat. The consultant shall delete all the confidential data after the completion of the contract. Any arrangements for ownership, storage, or disposal of physical samples shall be agreed by SIOFA as a part of the contract.

All Intellectual Property generated as a part of this contract shall become the property of SIOFA unless otherwise excluded in the proposal and agreed by SIOFA in the contract.

All reports and presentations will be reviewed by the SIOFA Secretariat prior to any form of further distribution. The Consultant will revise the report according to comments received from the review process before the report or presentation is accepted as a submission against the requirements in the Terms of Reference.

1.4 Relevant SIOFA information

1. SIOFA data (provided by the SIOFA Secretariat upon request)
2. SIOFA reports:
    a. SIOFA SC reports and National Reports. Scientific Committee Meeting | SIOFA (apsoi.org)
    b. MoP reports. Meeting of the Parties | SIOFA (apsoi.org)
    c. SIOFA technical and scientific reports (public reports available from apsoi.org, and restricted reports available from the SIOFA Secretariat to the project consultant)

2. WORK PLAN AND PAYMENT SCHEDULE

The funds for this project are budgeted under General Objective 1 of the SIOFA/EU Grant Agreement SI2837681 - Scientific Work Support, for a total allocated budget of 8 333 euro (including all costs and including any travel related expenses).

The consultant shall follow the timeline described in Table 1 below.

Table 1: Timeline for payments, milestones, and report submission

Milestone	Date	Activities
Initiation of contract	1 December 2022	First instalment payment (30% of the total contract sum)
Delivery of draft report	15 February 2023	Submission of draft report to SC8
Delivery of final report	15 April 2023	Submission of final report and project information to SIOFA. Final instalment payment (70% of the total contract sum) on acceptance of the final report and the submission of project information

3. SUBMISSION OF APPLICATIONS

The applicants should have appropriate experience and knowledge of developing stock structure hypotheses and preferably on the stock dynamics and life cycle of orange roughy. The applicants should submit a proposal to the project coordinator (SIOFA Science Officer - Marco Milardi, marco.milardi@siofa.org) containing the following items:

1. A current CV that summarises the applicant(s) relevant educational background and professional experience
2. A brief proposal (indicatively 1-2 pages) outlining the proposed methods and analyses, including a description of how the objectives of the ToRs will be achieved
3. Any proposed exclusions to the intellectual property clause
4. The proposed consultancy price (including all consultant expenses and project related costs), noting that the available budget for this work is a maximum of €8,333
5. Identification of any project risks and associated mitigation and management required to successfully complete the project
6. A statement that identifies any perceived, potential, or actual conflicts of interest of the applicant(s), including those described in paragraph 4 of the SIOFA recruitment procedure (see Box 1), and
7. Any additional relevant information the applicant(s) wish to submit.
8. We note that similar projects for toothfish and alfonsino in the SIOFA Area are also available, and we encourage consultants to submit combined proposals for these projects if appropriate.

Only applications received before 12 AM (9 AM UTC) on Monday the 12th of December, Reunion Island time, will be considered in the following selection process.

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1. Adequate submission of information to allow the panel to evaluate the candidate
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