ORY-2024-01 Report 1: Data characterisation and biological parameters for assessment of SIOFA orange roughy stocks

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Abstract

This report describes analyses carried out characterise logbook and observer data for the orange roughy fishery in the SIOFA region, and to prepare data and input parameters for the orange roughy stock assessment. Data for these analyses were provided by the SIOFA Secretariat. Analyses address length and age composition data, female maturity, length-weight relationships, growth curves, and CPUE. Estimates are provided for Long Walter's Shoal Ridge (LWSR), the South-West Indian Ocean Ridge (SWIOR), and the orange roughy assessment area (ORAA) Walter's Shoal Ridge (WSR).

Data preparation and cleaning identified issues that included duplication, inconsistent coding of variables, missing data, and data entry errors. The issues described in this report and the associated R scripts may be helpful for updating the database. Ageing data should be consolidated in the database, including otoliths that cannot be linked to individual fishing operations.

Lengths varied at the level of the tow, which was accounted for within all analyses. Further unexplained covariation may occur between groups of tows or linked to other factors not included in the analyses, such as fishing strategies. Similar correlations across groups of tows affected all analyses. This form of pseudoreplication can lead to incorrect findings of differences between groups.

Von Bertalanffy growth curves were developed for each assessment region, for males, females, and jointly for both sexes. Analyses showed higher asymptotic lengths for females than for males. Length weight relationships (LWRs) were updated and found to be less negatively allometric than previous results. They differed slightly between males and females, but not regionally. Catch and effort data from the Walter's Shoal ORAA were standardized to produce 2 short index series, constrained by vessel turnover and the small number of vessels fishing. CPUE varied between vessels and fishing locations. Indices were very uncertain and unlikely to reflect trends in abundance.

Recommendations

- R1: Consolidate ageing data into the SIOFA databases.
- R2: Address the identified data quality issues in the SIOFA databases.
- R3: Continue collection of age data to resolve uncertainties about spatial population structure and better inform natural mortality estimates.

1. Introduction

The SIOFA Scientific Committee (SC) provides scientific advice to the Meeting of Parties (MoP) on the status of stocks and sustainable yields of deep-sea fisheries resources. In 2018, the SIOFA Scientific Committee (SC3) conducted the first orange roughy stock assessments in the SIOFA region and provided advice to the Meeting of Parties on the stock status and sustainable yields for orange roughy. An updated orange roughy stock assessment was conducted and presented to SC7 in 2022.

As required under SIOFA CMM 15, orange roughy stock assessments are conducted every 3-5 years, and new orange roughy stock assessments were developed in 2025 for consideration by SIOFA. As required by the Terms of Reference (provided in Appendix A), these built on the previous two assessment, with improvements implemented where possible.

This report documents the preparation of biological parameters to address item 2 and part of item 3 of the Project Objectives in the TOR. The biological parameters are then used as inputs to the stock assessments. The stock assessments are described in 2 companion reports (Mormede & Hoyle, 2025a, 2025b), which address the remainder of Project Objective 3.

1.1 Orange roughy biology

Orange roughy (*Hoplostethus atlanticus*) are a commercially significant deep-sea species found in mesopelagic to bathypelagic zones, typically at depths of 700–1,500 meters. They inhabit both flat seabed and underwater topographical features (UTFs) such as seamounts, ridges, and knolls, which often serve as aggregation points for spawning and feeding. Their distribution spans the Southern Indian Ocean, among other regions globally, with distinct stocks often associated with specific ecological and oceanographic conditions (Tingley and Dunn, 2018).

This long-lived species is characterized by slow growth, late maturity, and low productivity, making them particularly vulnerable to overfishing. They grow slowly, reaching maturity between 23 and 31 years of age depending on the stock, and have an exceptional lifespan of up to 150 years, as validated through radiometric isotope studies of otoliths (e.g., Andrews et al., 2009). Maturity is marked by changes in otolith structure, referred to as the "transition zone," with size at maturity varying between regions but typically occurring at approximately 30-35 cm standard length (SL) (Francis and Horn, 1997).

Juveniles are generally found close to the seabed, and in shallower water than the adults, starting off at depths of around 850–900 m and spreading deeper, and over a wider depth range, as they grow (Dunn et al., 2009), such that seamounts and other features tend to be dominated by the largest orange roughy (Dunn and Forman, 2011).

Data from studies based on parasites (Lester et al., 1988) and otolith microchemistry (Edmonds et al., 1991; Thresher and Proctor, 2007) indicate that orange roughy are relatively sedentary for much of their lives. Genetic studies nevertheless suggest significant connectivity with some isolation by distance (Tingley and Dunn, 2018; Varela et al., 2013). The mechanism for genetic connectivity is not well understood. The low level of implied mixing indicates demographic separation between management areas for the purposes of stock assessment, and the potential for spatial population structure within management areas.

Spawning aggregations occur predictably during the winter months, typically between May and August in the southern hemisphere, at depths of 700-1,000 meters. They may be associated with UTFs or occur over flat seabed. These events are short-lived, resulting in dense schools that are highly susceptible to targeted fishing. Not all individuals spawn annually, and the mechanisms of skipped spawning remain poorly understood. Fecundity is relatively low, with females producing between 40,000 to 60,000 large eggs per spawning season.

Length-weight relationships are required to estimate biomass and fishery yield. They are used in assessment models to estimate total biomass from length frequency data, assess condition factors of fish populations, and monitor temporal or spatial variation in growth and body condition across different stocks. Orange roughy exhibit a negative allometric growth pattern, where fish become slimmer with increasing length. Variation in these parameters can occur due to regional differences, environmental conditions, or sex.

Growth is typically modelled using von Bertalanffy growth curves, which indicate slow growth and late maturity, with juveniles requiring decades to reach reproductive age. Maximum age can exceed 200 years. Orange roughy exhibit a high degree of variability in growth parameters among regions. Females generally grow larger than males (Branch, 2001), and populations in areas such as the Northeast Atlantic tend to reach greater maximum sizes compared to those in regions like New Zealand.

Historically subject to "boom and bust" fisheries, orange roughy populations have often faced overfishing, necessitating robust assessments and sustainable management practices. This report focuses on data from the Southern Indian Ocean Fisheries Agreement (SIOFA) region, integrating information on stock structure, biology, and fishery dynamics.

1.2 Summary of the fishery

Orange roughy fishing occurs primarily in the western part of the SIOFA area associated with the Madagascar Plateau and the Southwest Indian Ridge (Middleton et al., 2024). A review of orange roughy stock structure recommended ongoing assessment and management based on a two-area approach, as proposed by Roa-Ureta et al. (2022). These two areas (assessment regions) are outlined with red ovals in Figure 1. The western area is Long Walter's Shoal Ridge (LWSR), and the eastern is the South-West Indian Ocean Ridge (SWIOR).

Additional spatial units are defined by the SIOFA statistical areas, with ORY fishing occurring in statistical areas 1, 2, 3a and 3b. Their borders are outlined in black in Figure 1. The orange roughy assessment areas (ORAA's) defined by Cordue (2018a; 2018b) are marked in magenta in Figure 1. Most orange roughy catches have historically been taken from the Walter Shoal Ridge (WSR). The WSR is also the area with the most information available, including biomass estimates using acoustic surveys and some length and age information.

Catches from 2000 to 2020 were taken from the previous stock assessment Roa-Ureta (Roa-Ureta et al., 2022). Catches for 2021-2023 were updated with the new information provided by SIOFA. Catches by feature between 2021 and 2023 were computed by splitting the global catch in WSR according to the reported spatial distribution.

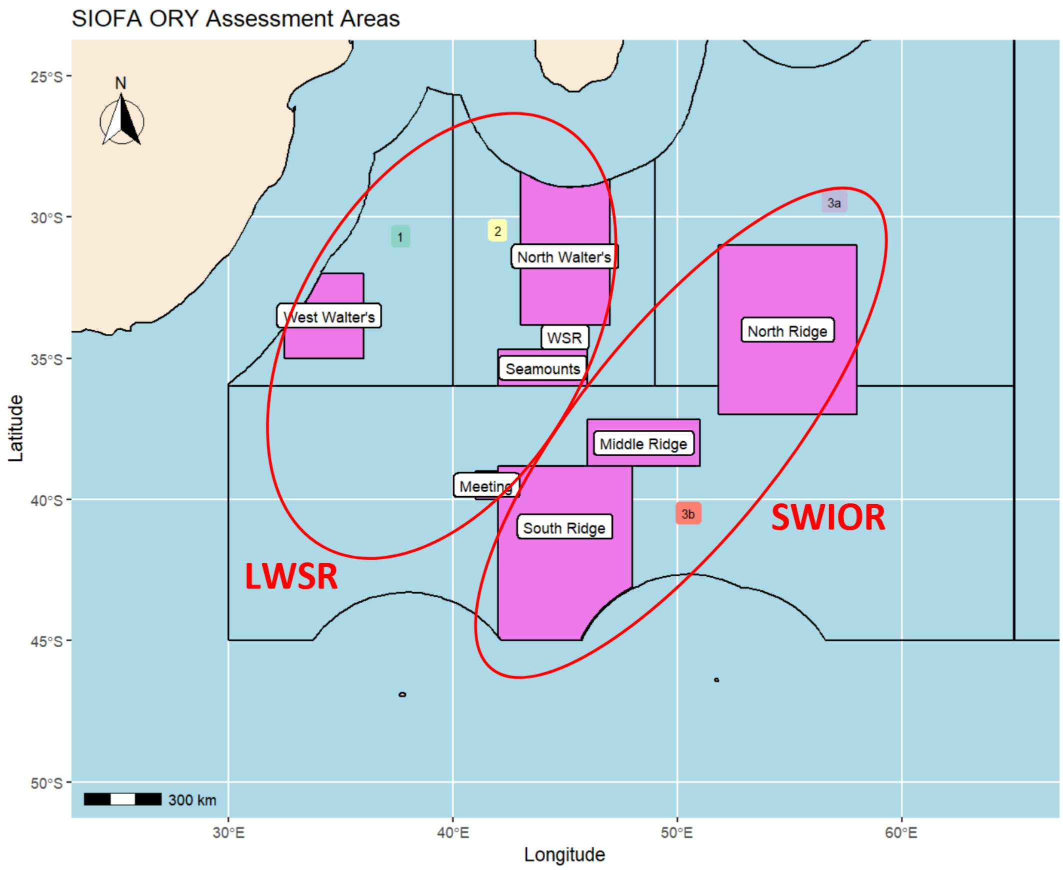

Figure *1: Map of SIOFA areas used for orange roughy assessments (in magenta). Labels indicate the names of single assessment areas with the Walter Shoal Ridge area noted as WSR. The red ovals denote the grouping into two larger areas for stock assessment purposes. the Long Walter's Shoal Ridge (LWSR) and South-West Indian Ocean Ridge (SWIOR). Reproduced from Figure 2 of the SIOFA fisheries summary for orange roughy (SIOFA Secretariat, 2023).*

2. Analyses

2.1 Data preparation and cleaning

Data for these analyses were provided by the SIOFA Secretariat. Data from the SIOFA databases were provided in two Excel spreadsheets. Logbook data (2021-2022) comprised one worksheet for fishing activities and another for catch by species, linked to activities by the activity code. Two thirds of data rows were event-by-event observations, and the other third were aggregated. Observer data (2003-2023) included three sheets: one with fishing operation information, the second with biological sample data, and the third with ageing data. Sampling data were linked to operations via an operation code. All observer data represented individual fishing events.

For the logbook data, fishing duration was calculated as the period between the start and end of a tow. Aggregated data report only the tow start datetime and location, so duration could not be calculated. Aggregated data were therefore excluded from CPUE analyses. Distance was calculated as the shortest distance between the tow start and end locations, according to the Vincenty ellipsoid method implemented in the R package *geosphere* (Hijmans, 2024). Of six tows with negative durations, in one case an error was corrected and the duration recalculated, while the other 5 tows were removed. Eleven tows with duration over 10 hours were removed, as were 12 tows with durations of zero. Duplicate tow records led to removal of 1165 records.

Tows were allocated to SIOFA subareas, ORAAs, and assessment regions based on their tow start longitude and latitude. Spatial analyses used the SIOFA_SC_Spatial_layers database. Within the WSR ORAA, five groups of tows with similar start locations were identified and labelled as representing seamounts 1 to 5.

Catch data were loaded, filtered to include only orange roughy catches, and linked to fishing activity records by the activity ID. Matching activity records were unavailable for 701 catch records. These were omitted, leaving 4723 catch observations. Most of these (3201) matched one catch record to each activity record, but a further 171 activity records and 1522 catch records joined with more than one ORY catch record per activity. Some of these catches were different and others appeared to be duplicates. All records with more than one catch record were omitted from CPUE analyses.

In the observer data operational details, one negative longitude was corrected to positive, which was consistent with the likely vessel location. Three fishing locations with data entry errors were corrected, and 6 more were removed. Fishing durations and distances were calculated as for logbook data, using the tow start and end date, time, and location. The 9 durations over 20 hours were set to NA, as were the 60 negative durations, many of which may have switched the set start and end time during data entry. As with logbook data, effort was allocated to SIOFA subareas, ORAAs, and assessment regions based on their tow start longitude and latitude.

Observer fish sample data were linked to operation details via the operation id code.

Sex data were cleaned by adjusting all F and M values to lower case, merging the values u, FM, ?, U, Un, UN, UNK, and NA (missing) as 'u', and merging i, I and J as 'i'.

Length types SL, Standard, Standard length, and STL were merged as 'SL'. Advice from the advisory panel and plots of log length versus log weight supported the pooling of UF as another code for standard length. Remaining length types were SL (standard length), LCF (length caudal fork), ULN (unknown length), and NA (missing).

Observer ageing data were linked to operation details via the operation identifier (OpID) code.

Ageing data were provided in 4 different formats: 1) extracted from the observer database as described above; and in 3 text files 2) 'final clean.walters.ages.csv' = clean.walters, 3) 'final clean.swior.ages.csv' = clean.swior, and 4) '2021-10-28 SIOFA Orange Roughy Age Data.csv' = age.csv. The datasets did not all provide the same fields, and there was some overlap with the same samples occurring in more than one data source.

The observer database included fine scale location (latitude and longitude) in most cases, but the age data text files indicated only a broad regional location, with different categorization depending on the source. The clean.swior records were all allocated to assessment region SWIOR, with no defined statistical area or ORAA. The clean.walters otoliths were all sampled from Walter's Shoal (Barnes and Ó Maolagáin, 2024) and were allocated to the WSR ORAA, statistical area 2, and the LWSR assessment region. The age.csv file reported 3 locations. Those labelled South Ridge were allocated to the South Ridge ORAA, statistical area 3b, and assessment region SWIOR. Those labelled West were allocated to statistical area 2 and assessment region LWSR, with no ORAA. Those labelled West (core) were allocated to ORAA WSR, statistical area 2, and assessment region LWSR. However, most of the otoliths in the age.csv file had no recorded set date and were therefore omitted at a later stage. The remaining 46 otoliths all came from the South Ridge ORAA.

An additional spatial definition field was developed for growth analyses (loc3) which combined the available ORAAs (North Walter's, WSR, and Seamounts) for region 2 with SWIOR for region 3.

The operation id provided in the observer database was unavailable for the other 3 age data sources. An operation identifier can be used to allow for covariation within sampling events, which otherwise tends to cause overdispersion. For clean.walters and clean.swior, a proxy operation id was developed by combining the date, tow number, and source fields. For age.csv, vessel, date, and location were combined.

Preliminary analysis indicated likely duplication between age data sources. For example, in data sampled in 2019, all ages older than 100 occurred in pairs at ages 102, 106, 112, 117, 120, and 180. We compared data from all datasets by age, length, sex, sampling date, fish weight, and the finest available common location. In the 'clean.swior' file, 183 of the 269 samples were determined to be duplicates, while in the clean.walters file, 80 of 291 samples were duplicates. No duplicates were removed from the database dataset or from the age.csv file. The age.csv file did not include fish weight information but analysis without this field also found no duplicates.

Wherever duplication was identified, the record with less location information was removed. We also removed observations without sampling date, without estimated age, and where sex was unknown. This left 851 observations: 508 from the observer database, 46 from the age.csv file, 86 from clean.swior, and 211 from clean.walters.

2.2 Length and age compositions

Length frequency data were available from the observer dataset (Figure 2). Sex was reported mostly as male of female, but included some fish recorded as either immature or unknown sex. There was considerably variability in mean size by year and among ORAAs (Figure 3).

Factors associated with length variation were explored by fitting generalized additive models. The square root of the length was used as the response variable to improve residual distributions. Operation ID was fitted as a random effect, and year, month, sex and ORAA were offered as explanatory variables. Locations outside defined ORAAs were included with ORAA 'unknown'.

All variables were statistically significant, with the largest variation associated with the sex and the operation ID (Table 1). Data sampled in months, years and ORAAs with a large number of observations had relatively consistent expected lengths (Figure 4). The outliers came from months, years, and ORAAs with sample sizes that were much smaller than the bulk of the sampling.

These results support the common observation that there is considerable covariation in lengths not only within sets, but also between sets on the same plume, particularly for consecutive sets by the same vessel.

Table 1: Anova table from a model of factors affecting length measurements.

	df	F	p-value
year	12	3.748	1.06E-05
month	11	3.954	9.06E-06
sex	3	1070.06	< 2e-16
ORAA	7	2.364	0.0206
s(OpID)	255.8	41.76	<2e-16

Age frequency data were prepared using the 'Catch-at-age' software package (Bull and Dunn, 2004). This package develops age-length keys from age sampling data and uses them to convert length composition data into age composition data, including information on effective sample size by year.

Length composition data were available by sex and ORAA for 2003, 2004, 2009, 2010, 2012, 2013, 2014, 2019, 2020, 2022. Age structure data were available by sex and ORAA for 2019, 2020, and 2022 (Figures 3, 5, and 6).

Age compositions were developed by year, sex, and ORAA for the years 2019, 2020, and 2022 (Figure 7). These were subsequently pooled across sex and ORAA within assessment regions as required, to develop annual unsexed age composition estimates for each assessment region. Age structure data for 2022 were considered too sparse to use as assessment data inputs.

2.3 Maturity

2.3.1 Introduction

Maturity in the stock assessment is parameterised in terms of age, but maturity at age data is very limited. Additional and more comprehensive information is available in maturity at length data from observer sampling.

Fishing for orange roughy occurs largely in spawning aggregations, which means that most of the fish captured are mature spawners. This tends to positively bias the proportion mature in each age and length category, and negatively bias estimates of age and length at 50% maturity. Ogives from these analyses are therefore unlikely to be suitable for direct use in stock assessment. However, covariate relationships may be useful for understanding population structure.

The observer maturity at length data were analysed to investigate their potential to provide information for stock assessment, and to identify possible covariate effects on maturity, such as spatial and seasonal patterns.

2.3.2 Methods

There were 23934 records of ORY in the observer database. Sex was recorded as "f" (female, n=12347), "m" (male, n=9861), "u" (unknown, n=772), or "i" (immature, n=954) (Figure 2). Individuals reported as unknown sex or immature could not be used to estimate female maturity because they could be either male or female, so only females were retained for further analysis. Maturity stage was recorded as an integer from 1 to 6. Individuals recorded as stage 0 (n=20), 7 (n=1), 8 (n=3), or 22 (n=1) were omitted (Figure 8). Female maturity as considered to be stage 3 or above.

Analyses were carried out using generalized additive models (GAMs) implemented in the R package *mgcv* (Wood and Wood, 2020). Models used the parameter setting ‘gamma = 1.4’ in order to avoid overfitting the smoothers (Kim and Gu, 2004; Wood, 2006).

Models were fitted with the response variable being the proportion of females with maturity stage >=2. All models included length as a covariate, fitted as a smoother to allow for non-linearity, which improves model fit and reduces the risk of spurious significance when estimating covariate relationships. Fish caught in the same operation tend to be similar – they are not independent. The operation id (OpID) was fitted as a random effect intercept parameter to allow for covariation at the operation level. The error distribution was assumed to be binomial.

Preliminary analyses with used a model with the following configuration:

maturity ~ s(len, bs='ts', k=10) + ORAA + s(OpID, bs='re')

This model supported different maturity estimates spatially (p=0.0018), but data were unbalanced spatially and by month and year, so may have been affected by confounding. Subsequent models considered both month and the ORAA, with data removed outside the core months between April and August. Alternative models were run with the following spatial configurations: all combined, and separately for the assessment regions LWSR and SWIOR. Additional models for the ORAAs WSR and North Walter’s were unsuccessful due to insufficient length coverage.

Models were fitted by optimising the restricted maximum likelihood (REML), which tends to converge better and has fewer issues with local minima than the default GCV.Cp criterion. Models with different fixed effects were compared based on the AIC. AIC uses the penalized maximum likelihood estimates regardless of whether smoothness selection is done using ML or REML, so is valid for comparing fixed effects. Model selection was also carried out by using shrinkage smoothers (bs=”ts”), which effectively removed parameters with little support.

2.3.3 Results

The maturity dataset included 11580 observations. Of these, 9783 were in the LWSR assessment area, and 1797 were in SWIOR. Within LWSR, 1680 were within North Walter’s, 3888 were in WSR, and 3682 were outside the defined ORAA’s.

The base model that included data from all locations strongly supported the inclusion of the OpID covariate (chiSq =945.3, p < 2e-16), and it was included automatically in all subsequent models.

The model with data for all areas supported the inclusion of both the location and month (Tables 2 and 3). Within LWSR there was support for month. Within the SWIOR assessment area there was support for latitude but limited support for month.

Estimates of maturity at length were relatively consistent and well estimated for the larger spatial groups across LWSR and SWIOR assessment areas but broke down for small subsets at the ORAA level due to lack of sufficient data for small sizes. Covariate estimates by month were also limited for sparse data for some months and confounding between fishing location and month.

Estimates of maturity at length suggested larger L50 in the SWIOR region than in LWSR (Figure 9.A). There was considerable variation between operations (Figure 9.B). Within assessment regions, the ORAA did not explain significant variation (Table 2), even with the large differences between ORAA estimates in SWIOR (Figure 9.C). Seasonal results were inconsistent between regions, with the proportion mature at 40 cm increasing from April-May to June-July in LWSR, but with no apparent change in SWIOR (Figure 9.D).

Table 2: Effects associated with categorical spatial variables, by spatial grouping.

Spatial grouping	Parameter	df	Chi.sq	p-value
Combined	Location	8	21.36	0.00625
LWSR	Location	3	1.593	0.661
SWIOR	Location	4	2.676	0.613

Table 3: Effects associated with smoothing parameters, by spatial grouping.

Spatial grouping	Parameter	edf	Chi.sq	p-value
Combined	s(len)	3.947	4163.3	<2e-16
Combined	s(month)	3.999	4061.2	<2e-16
Combined	s(OpID)	135.761	693.4	<2e-16
LWSR	s(len)	4.368	2689	<2e-16
LWSR	s(month)	3.998	3190.8	<2e-16
LWSR	s(OpID)	97.973	544.9	<2e-16
SWIOR	s(len)	2.42E+00	2157.1	<2e-16
SWIOR	s(month)	7.51E-04	0	0.732
SWIOR	s(OpID)	3.96E+01	155.8	<2e-16

2.3.4 Discussion

Analyses of maturity at length were overall relatively inconclusive. The dominant source of variability was length. Although the analyses suggested significant differences in maturity at length between regions, the uncertain and conflicting results for other factors in the model suggest caution about accepting this result.

Fishing month explained substantial variability in LWSR analyses but, surprisingly, not in SWIOR, where the effect was small enough to be removed from the model via shrinkage. The relatively high contribution of fishing operation id to both analyses indicates that maturity states tended to be similar for all fish sampled from an operation. The way that the partial effects by operation were grouped (Figure 9.B), suggests that sets close together in space and time may also have similar maturity states. Important factors may be missing from the analysis. Further analyses of these data are needed to identify which factors, other than length, affect maturity state.

2.4 Length-weight relationships

2.4.1 Introduction

The length-weight relationship (LWR) is a key component of stock assessment models, and the required parameterization is usually linear on the log-log scale. However, these linear relationships can vary between analyses, depending on the data used and the analysis methods. In addition, LWRs and the factors that affect them can be informative about population structure.

Preliminary analyses were therefore carried out to understand the dataset and the factors that affect the LWR. Our analyses followed similar approaches to Chang et al. (2022) and Macdonald et al. (2023). Initial focus was on identifying covariates that affected the LWR, including sex, location, temporal factors (season and year). Although LWRs are usually close to linear, ontogenetic body shape changes can cause systematic patterns of non-linearity, such as sex-dependent changes associated with maturation (De Robertis and Williams, 2008; Finucci et al., 2019).

2.4.2 Methods

Only data measured as standard length were included for analysis of LWRs. Initial data exploration was carried out graphically and identified both some large outliers and very sparse data at small sizes. Lengths and weights outside the 0.1 and 99.9 percentiles were removed. Data from subarea 1 (West Walters) were also excluded. There was little apparent rounding in the length data, and a relatively minor rounding issue in the weight data, with peaks at multiples of 0.5 kg (Figure 10).

The dataset included samples from a range of years and months, but the majority came from 2020 and 2022, and the months June and July (Figure 11). Spatial sourcing varied through time, by both year and month.

Plots of weight versus length on the log scale (Figure 12) demonstrated small differences in the LWR by sex and possibly also by area.

Exploratory analyses were carried out using generalized additive models (GAMs) implemented in the R package *mgcv* (Wood and Wood, 2020).

Models were fitted with log(weight) as a function of log(length) and a range of covariates, including sex, location, month, and tow start depth. Models were also run separately by sex and for the assessment regions LWSR and SWIOR. The log(length) parameter was fitted as a smoother to allow for non-linearity, which improves model fit and reduces the risk of spurious significance when estimating covariate relationships. Models used the parameter setting 'gamma = 1.4' in order to avoid overfitting the smoothers (Kim and Gu, 2004; Wood, 2006).

Fish caught in the same operation tend to be similar – they are not independent. The operation id (OpID) was fitted as a random effect intercept parameter to allow for covariation at the operation level.

The error distribution was fat-tailed and symmetrical and was not well fitted by a Gaussian distribution. This pattern is common in modeling of length-weight relationships due to factors such as measurement errors, equipment variation between measurers, and rounding. Residuals were well fitted by the scaled-t distribution (Figure 13).

Models were fitted by optimising the restricted maximum likelihood (REML), which tends to converge better and has fewer issues with local minima than the default GCV.Cp criterion. Models with different fixed effects were compared based on the AIC. AIC uses the penalized maximum likelihood estimates regardless of whether smoothness selection is done using ML or REML, so is valid for comparing fixed effects. Model selection was also carried out by using shrinkage smoothers (bs="ts").

LWRs for use in the stock assessment were generated using a combined dataset that included both males and females, and data from both regions.

Bias correction was applied to allow for the fact that the regression operates on the log-log scale, but predictions are required on the natural scale. Weight predictions from the regression are unbiased predictions of the mean on the log scale since residuals are not skewed, but they are biased low on the natural scale where the exponentiated residual distribution is skewed. Predictions were corrected for bias by adapting a nonparametric approach, Duan's smear (Duan, 1983).

For each LWR fitted on the log-log scale, we modelled the relationship between predicted weights and observed weights using a linear regression with the intercept fixed at zero. The estimated trend line represented the increasing bias with increasing weight. The estimated trend coefficient was multiplied by the original 'a' parameter in the LWR model $wt \sim a_{raw}.\,length^b$, such that $a_{adj} = a_{raw} \times coeff$. For nonlinear fits, the weight predicted by the model on the log-log scale was multiplied by the smear coefficient to produce a bias-corrected prediction on the natural scale.

2.4.3 Results

Analysis results strongly supported the observation of different LW relationships by sex (dAIC=1106.3). They also strongly supported inclusion of the OpID parameter, with significant variation between tows (dAIC=6328). Regional differences were also supported (dAIC=146.6 for females, dAIC=39.7 for males). Length-weight relationships were nonlinear on the log-log scale for both sexes in SWIOR (dAIC=62.2 for females and 98.7 for males), and for females in LWSR (dAIC=50.8 for females, but linear model preferred for males with dAIC=11.6). Seasonal variation was weakly supported for males (dAIC=1.9) but not for females (dAIC=1.4). Covariates tested but not supported were tow start depth, tow start longitude, and tow start latitude.

Bias correction had a small but consistently positive effect on weights predicted from LWRs (Figure 14). Length weight relationships were very similar for LWSR and SWIOR, but there were moderate differences between males and females (Figures 15 and 16). For lengths above about 45 cm, predicted weights at length were significantly larger for the new LWRs than for those used in the previous stock assessment, and somewhat smaller below about 35 cm in length.

Table 4: Estimated length-weight parameters by sex and larger assessment region. Values of the a parameter in the a_adj column have been adjusted to correct for log transformation bias.

Sex	Region	a_raw	a_adj	b
Male	LWSR	1.396E-04	1.428E-04	2.602
Male	SWIOR	8.715E-05	8.862E-05	2.727
Female	LWSR	1.217E-04	1.257E-04	2.650
Female	SWIOR	4.622E-05	4.659E-05	2.902
Combined	LWSR	8.607E-05	8.879E-05	2.735
Combined	SWIOR	5.848E-05	5.927E-05	2.838

2.4.4 Discussion

The updated length weight relationships are significantly different from those applied in the last stock assessment, with estimates of the b parameter less negatively allometric than the previous value of 2.44. The reasons for this change were not investigated but may be due to the either the allowance for variability between operations, or to assuming a non-normal residual distribution. Adjusting for lognormal transformation bias had a quite small effect on the results. Together, these changes are unlikely to significantly affect the assessment outcomes, but nevertheless they should provide more accurate results.

2.5 Growth curves

2.5.1 Introduction

Growth modeling was carried out in two stages: initially with flexible generalized additive models (GAMs) implemented in mgcv (Wood and Wood, 2020), and then with von Bertalanffy growth curves implemented in brms (Bürkner, 2017). The aim of the GAM modeling was to identify factors that may affect growth. The flexibility of smoothers allows them to avoid restrictive assumptions about growth patterns and fit the data closely. This makes inferences about covariate effects more reliable than when assuming a particular growth pattern such as von Bertalanffy.

Although gam analyses are useful for quick and effective hypothesis testing, their flexibility makes it difficult to apply biological constraints to the derived estimates. For example, it is biologically reasonable to assume that mean length at age does not decline, but observed values can decline when data are sparse. A non-declining constraint is useful when fitting such data but is not available in the standard GAM smoothers. In addition, stock assessment models often require parameter estimates for a standard growth model such as von Bertalanffy or Richards curve. We therefore used nonlinear fitting methods to develop von Bertalanffy growth models for use in the stock assessment, with separate curves for the groups identified in the GAM analyses.

2.5.2 Methods

Initial data exploration and information from other stocks suggested that growth curves for males and females may be different, and that spatial growth variation may occur. Growth models were fitted both for combined sexes and separately for males and females. Growth modeling also tested for spatial variation. Two levels of spatial variation were explored: a) area 2 (Walters) versus area 3 (SWIOR); and b) with area 2 subdivided into ORAAs (North Walters, Seamounts, WSR), and area 3 (SWIOR).

Uncertainty was assumed to be normally distributed. Models used the parameter setting 'gamma = 1.4' in order to avoid overfitting the smoothers (Kim and Gu, 2004; Wood, 2006). To reduce overdispersion due to sampling effects, GAMs were fitted with the operation id included as a random effect. Models were built by adding terms sequentially from a base model with length as a function of a smoother on age, and a random effect on OpID. Stages included adding a fixed effect for sex, independent age smoothers by sex, and a fixed effect for location. Models were compared using the AIC, and by checking the significance of model terms. Goodness of fit was tested using the gam.check() function.

Analyses to develop the von Bertalanffy models were carried out using the R package *brms* (Bürkner, 2017), which is a wrapper for fitting linear and nonlinear models in the Stan language. Stan uses gradient-based Markov chain Monte Carlo (MCMC), with Hamiltonian Monte Carlo algorithm and its extension, the No-U-Turn Sampler (NUTS), for Bayesian inference. Eight thousand samples from the posterior distribution were obtained by combining samples across four chains, with each chain consisting of a warm-up period of 2000 discarded iterations followed by sampling the next 2000 iterations.

The models include population-level effects for period (t), and group-level effects for month (m), vessel (v), and a time period × statistical area interaction term (a)

Each model was structured as a standard von Bertalanffy: $L \sim L_\infty * \left(1 - e^{-k(age - t_0)}\right)$. Spatial and sex effects were accommodated by running separate models by sex and location. Errors were normally distributed and constrained to be proportional to predicted length via the estimated parameter *tau*. Variation in length at age by operation was modelled as a group effect (the Bayesian equivalent of a random effect) on L_∞, so that the degree of variation was proportion to age.

Analyses used normal priors and hyperpriors. Prior sd's for the k and t_0 parameters were initially trialled at 100 and 20 but due to lack of convergence were reduced to 10.

$$k \sim N(0, 10)$$

$$L_\infty \sim N(52{,}100)$$

$$t_0 \sim N(-2{,}10)$$

$$tau \sim N(0{,}100)$$

$$\epsilon_i \sim N(0, \sigma^2)$$

$$\sigma \sim N(0, \eta \times tau)$$

Each model was run with the following line of code.

brm(bf(length ~ eta, nl = TRUE) + nlf(eta ~ 1 + Linf * (1.0 - exp(-k * (age - t0)))) + nlf(sigma ~ eta * tau) + lf(Linf ~ 1|OpID, k ~ 1, t0 ~ 1, tau ~ 1), data = dataset, chains = 4, prior = priors, family = brmsfamily("gaussian", link_sigma = "identity"), iter = 4000, save_pars = save_pars(all = TRUE).

Models were checked for convergence by ensuring that k=1.00 for all parameters and examining traces.

2.5.3 Results

The best GAM model for the full dataset (Table 5) included independent smoothers on age for each sex, and a fixed effect for the more subdivided version of the location variable (Table 6 and 7). Growth curves by sex and location are provided in Figure 17. Additional independent analyses by sex (results not provided) found that the best model for females included independent growth curves by location, whereas for males a fixed effect on location was sufficient. Further analyses with the data subset that included fine-scale location found that latitude explained much of the growth rate variation.

Table 5: AIC estimates for alternative GAM growth models

Model parameters	**df**	**AIC**	**ΔAIC**
Age	94.3	4429.5	397.4
+ location	76.3	4090.2	58.1
+ sex	80.2	4059.1	26.9
+ age by sex	79.9	4032.1	0.0

Table 6: Significance of fixed effects in the final GAM growth model.

Model parameters	**df**	**F**	**p-value**
sex	1	32.84	1.48E-08
loc3	3	12.58	5.14E-08

Table 7: Significance of smooth terms in the final GAM growth model.

Model parameters	**Effective df**	**F**	**p-value**
s(age)	3.46	48.72	0
s(age):sexf	2.98	10.21	6.35E-07
s(age):sexm	0.67	0.80	0.47
s(OpID)	66.79	1.76	0

Analyses using von Bertalanffy growth curves with brms provided growth curves with results that were consistent with those from the GAM, but they provided von Bertalanffy parameters and avoided declines in predicted length at age. Females were consistently found to grow larger than males. Estimates by spatial group were provided (Figure 18).

2.5.4 Discussion

Growth curves by sex consistently indicated that females grew to a larger size. Differences between sets (operation ID) were also observed. Location effects were moderately large, suggesting that mixing between locations may be low. However, given the unbalanced sampling design, further sampling and statistical analysis would be helpful to confirm this and to provide better information.

Table 8: von Bertalanffy parameter estimates for each model independently fitted with brms. Analyses for the sex 'FM' use combined data for both males and females. For each parameter, sd represents the uncertainty in the parameter estimate.

Location	Sex	L∞	K	t0	tau	L∞ sd	K sd	t0 sd	tau sd
All	F	55.44	0.0415	-0.91	0.0693	0.824	0.00346	1.866	0.00258
All	M	51.12	0.0451	-4.15	0.0621	0.659	0.00398	2.344	0.00291
All	FM	53.53	0.0426	-2.83	0.0676	0.569	0.00281	1.658	0.00184
LWSR region	F	56.33	0.0334	-10.78	0.0576	1.455	0.00463	4.219	0.00326
LWSR region	M	52.57	0.0401	-8.78	0.0537	1.260	0.00652	4.714	0.00441
LWSR region	FM	55.27	0.0334	-12.10	0.0568	1.089	0.00396	3.749	0.00219
SWIOR region	F	54.98	0.0436	1.46	0.0784	1.203	0.00479	2.122	0.00446
SWIOR region	M	50.65	0.0443	-3.29	0.0750	1.010	0.00504	2.710	0.00523
SWIOR region	FM	52.71	0.0442	-0.59	0.0796	0.866	0.00370	1.843	0.00334
WSR ORAA	F	56.14	0.0325	-12.07	0.0602	2.070	0.00577	5.012	0.00418
WSR ORAA	M	52.17	0.0395	-9.76	0.0552	1.609	0.00763	5.590	0.00549
WSR ORAA	FM	54.62	0.0334	-13.08	0.0584	1.417	0.00482	4.437	0.00277
N. Walters	F	56.40	0.0450	-2.65	0.0579	1.705	0.00930	6.490	0.00682
N. Walters	M	53.35	0.0460	-6.22	0.0485	1.661	0.01176	7.340	0.00611
N. Walters	FM	55.88	0.0424	-4.16	0.0567	1.410	0.00773	5.712	0.00452

2.6 CPUE

2.6.1 Introduction

CPUE was analysed to assess its potential as an index of abundance. CPUE is not necessarily proportional to abundance, and there were particular concerns in the case of this fishery. Most importantly, orange roughy is fished when aggregated, and CPUE is likely proportional to the density of the aggregation, rather than the density of the population on the whole fishing ground. Secondly, the ORY fishery is both technologically advanced and still developing, so CPUE is likely to be affected by improvements in technology, changing skill level of the fishers, and increasing knowledge of the fishing grounds. Third, vessels may be unlikely to set unless they identify a plume of fish with their sounders, in which case standardized CPUE would not index abundance.

2.6.2 Methods

ORY catch and tow duration were selected as the catch and effort variables. Duration was selected rather than distance because it was more consistently recorded, and because surface distance is not necessarily proportional to swept area when towing on a slope. Given the potential for gear to vary between vessels, it was important to include vessel identity as a factor in the analysis.

Catch and effort data were further filtered to select effort from the WSR region, and tows with duration of less than 1 hour (Figure 19).

A plot of the number of sets per vessel per year was used to identify a core fleet (Figure 20). Effort fell into two periods, with no overlap in vessel identity between effort before and after 2015. Data was only available for one vessel that operated in more than one year between 2001 and 2014, while there were data for 2 vessels operating 2019 - 2022.

The following model was fitted with mgcv to each period separately. Tow duration was fitted as a continuous variable using a smoother, and vessel and seamount were fitted as factors. Vessel was not included in analyses for the period before 2015 because there was only one vessel. Gaussian errors were assumed. Goodness of fit was assessed using the gam.check function.

$$log(catchwt) \sim year + s\big(log(duration)\big) + vessel + seamount + \epsilon$$

Simpler models were also run and compared using AIC, and effect significance was assessed from internal model estimates.

2.6.3 Results

For the early period, the best model included year and seamount, while tow duration was marginal. For the later period the best model included year, vessel, tow duration, and seamount. Models fitted the data well (Figure 21).

Data for the early period came from one vessel and catches were generally independent of tow duration. Catch rates varied annually, generally increasing until 2011 but then declining in 2012 and 2013. There was significant variation by seamount with highest CPUE on seamount 5 and lowest on seamount 3 (Figure 22). Indices are provided in Table 9

In the later period there was an increase in catch rates from 2019 to 2022. There was a significant positive relationship between tow duration and catch. The two vessels fishing during this period had significantly different CPUE, with higher catch rates for the vessel that did more fishing. As in the early period, catch rates were highest on seamount 5 and lowest on seamount 3. Indices are provided in Table 10.

Table 9: Predicted annual CPUE for the early period.

year	cpue	cv
2002	0.65	0.56
2003	0.46	0.66
2004	0.82	0.55
2005	0.21	0.80
2006	1.73	0.73
2009	0.91	0.67
2010	1.49	0.59
2011	2.99	0.65
2012	0.60	0.62
2014	0.13	0.78

Table 10: Predicted annual CPUE for the late period.

year	cpue	cv
2019	0.50	0.66
2020	0.68	0.67
2021	1.40	0.67
2022	1.42	0.66

2.6.4 Discussion

These patterns of increasing CPUE may reflect changes in technology and fisher knowledge of the stock rather than changes in population density. Indices also have very high CV, reflecting high variability in catch rates and the very small amount of data available to estimate parameters. Given the concerns noted in the Introduction, CPUE is unlikely to be a suitable index of abundance.

3. General Discussion

Analyses in this paper have provided parameters for the stock assessment of orange roughy in the SIOFA region, which is separated into 2 stocks in the LWSR and SWIOR regions, and also assessed in the WSR ORY assessment area.

Data preparation for these analyses was challenging. A large amount of data is held in the SIOFA database, which provides a degree of consistency. However, we found various issues in those data including duplication, inconsistent coding of variables, missing data, and data entry errors. We corrected the errors we identified for our analyses but are likely to have missed others. A particularly important dataset was the ageing data, which was both held in the SIOFA observer database and provided as three additional spreadsheets, each of which included less detailed information than the observer database. Careful checking demonstrated a large amount of overlap between the spreadsheets and the database, which was resolved by removing duplicate otolith records from the spreadsheet datasets.

We recommend that the Secretariat updates the database to resolve the issues identified in this report. For example, it would be useful to add the spreadsheet ageing data to the database (after removing duplicates), in a way that includes the otoliths that cannot be linked to an individual fishing operation.

Analyses in this paper have identified spatial structure in parameters for length-weight relationships, growth curves, and maturity ogives. These differences appear to be statistically significant, and in some cases are biologically significant. For example, growth curves that differ by area suggest lack of significant mixing between areas, which may have implications for understanding of stock structure. However, there remain some unresolved sampling issues in the dataset. Spatial variation can be caused by sampling effects, and sampling across the SIOFA area has been highly non-random.

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We thank the SIOFA orange roughy project advisory group (Dr Steve Brouwer, Mr Alistair Dunn, Dr Zhou Fang, Dr Marco Milardi and Dr Pavarot Noranartragoon) for guidance and feedback through this process. Thanks to Thierry Clot, Pierre Peries, and Steve Brouwer for assistance with the fisheries data. Thanks to the SIOFA Contracting Parties for allowing their data held by the Secretariat be used in this analysis. This project was funded by SIOFA under project code ORY2024-01.

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6. Figures

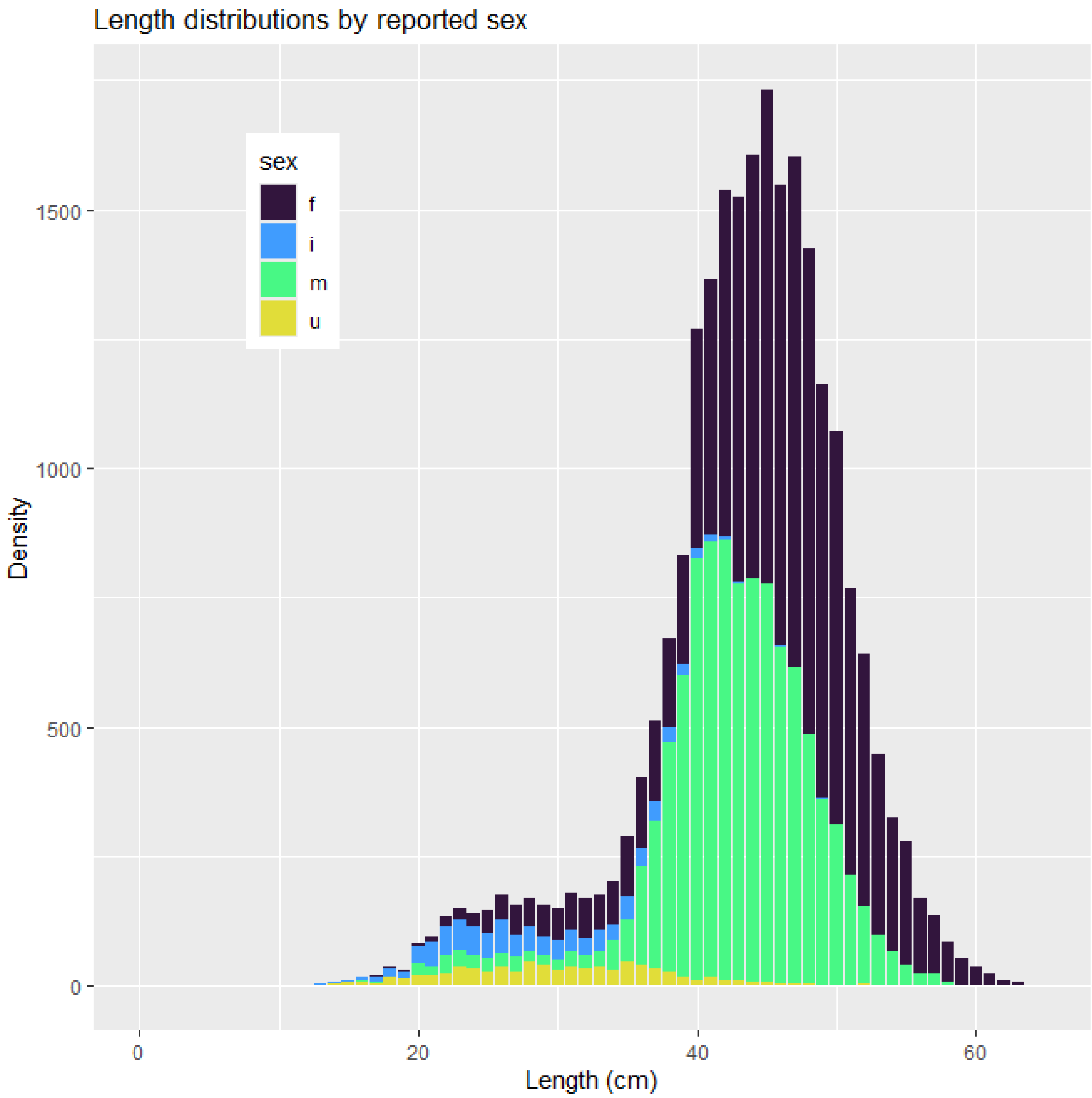

Figure *2: Length (cm) frequency distribution by reported sex, pooled across cleaned data from the observer database.*

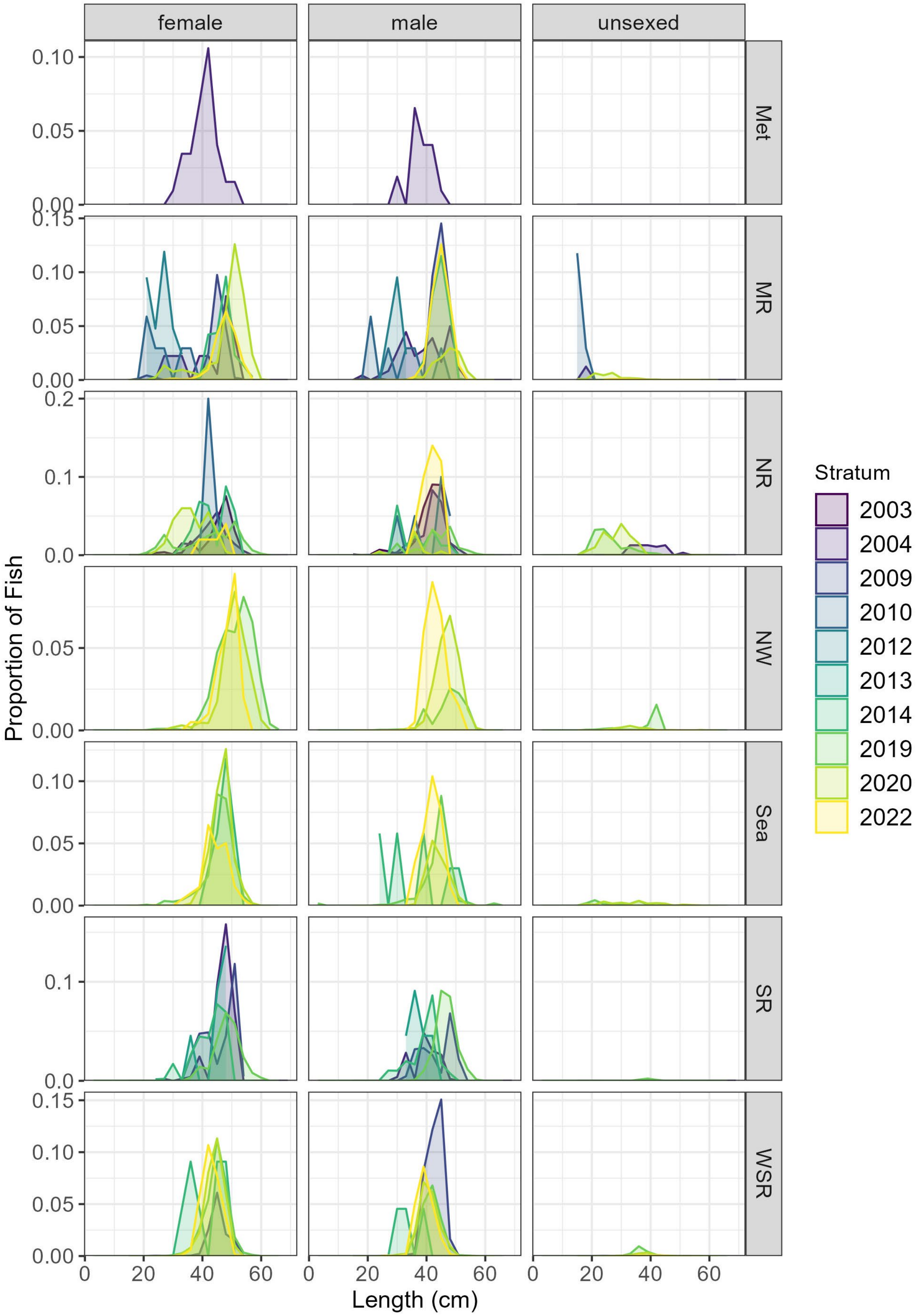

Figure 3: Scaled length frequencies by year, sex, and ORAA, aggregated into 3 cm bins for improved presentation. ORAA labels: MET = Meeting, MR = Middle Ridge, NR = North Ridge, NW = North Walter's, Sea = Seamount, SR = South Ridge, WSR = Walter's Shoal Ridge.

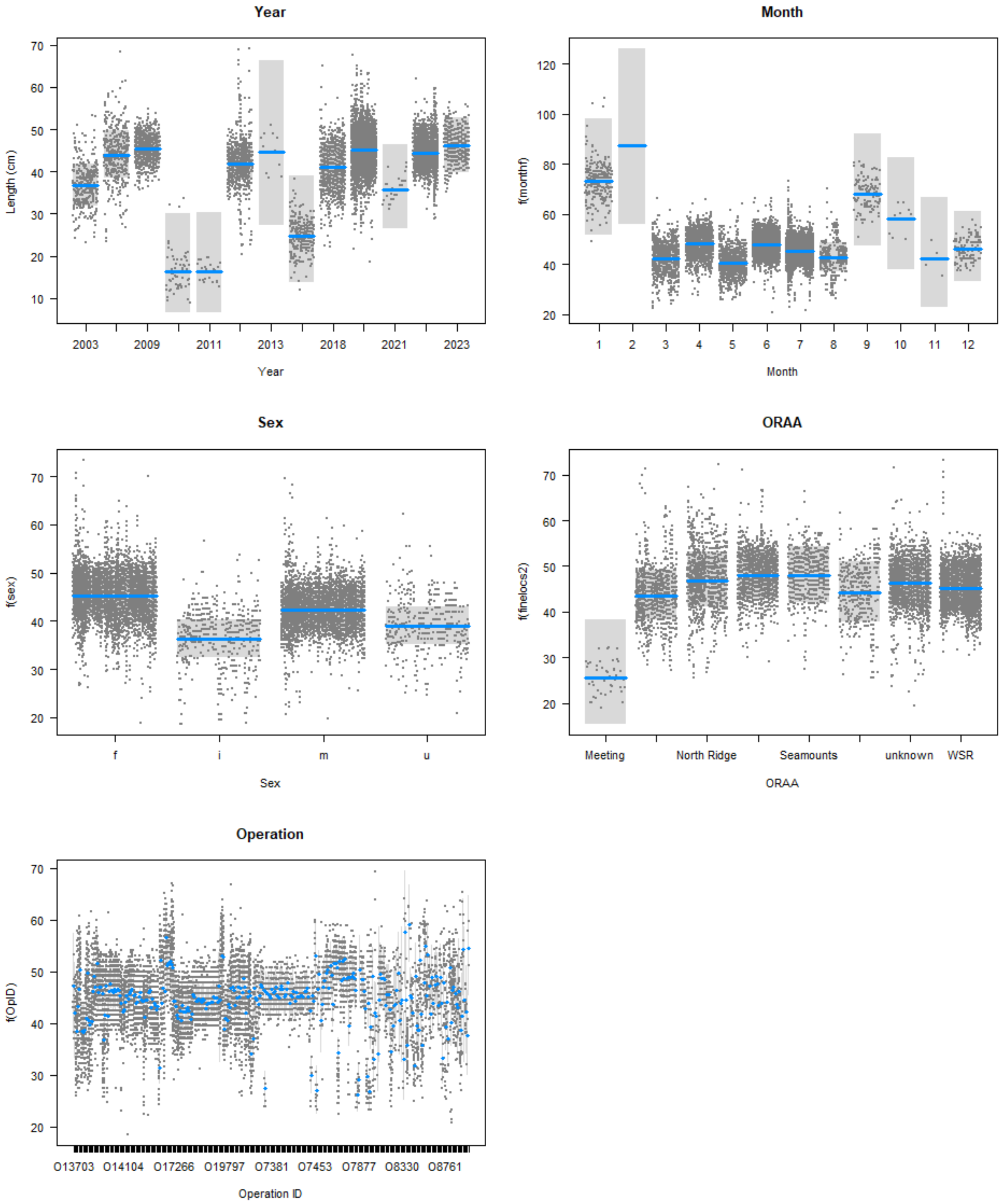

Figure 4: Results of size data standardization model after retransformation back to the length scale. The plot shows the contributions of covariate effects to length variation. The blue lines represent the values of the effect parameters. The points are partial residuals, which are the deviations of the observed data from the predicted values after accounting for all other terms in the model. The grey 95% confidence bands represent uncertainty around the fitted terms.

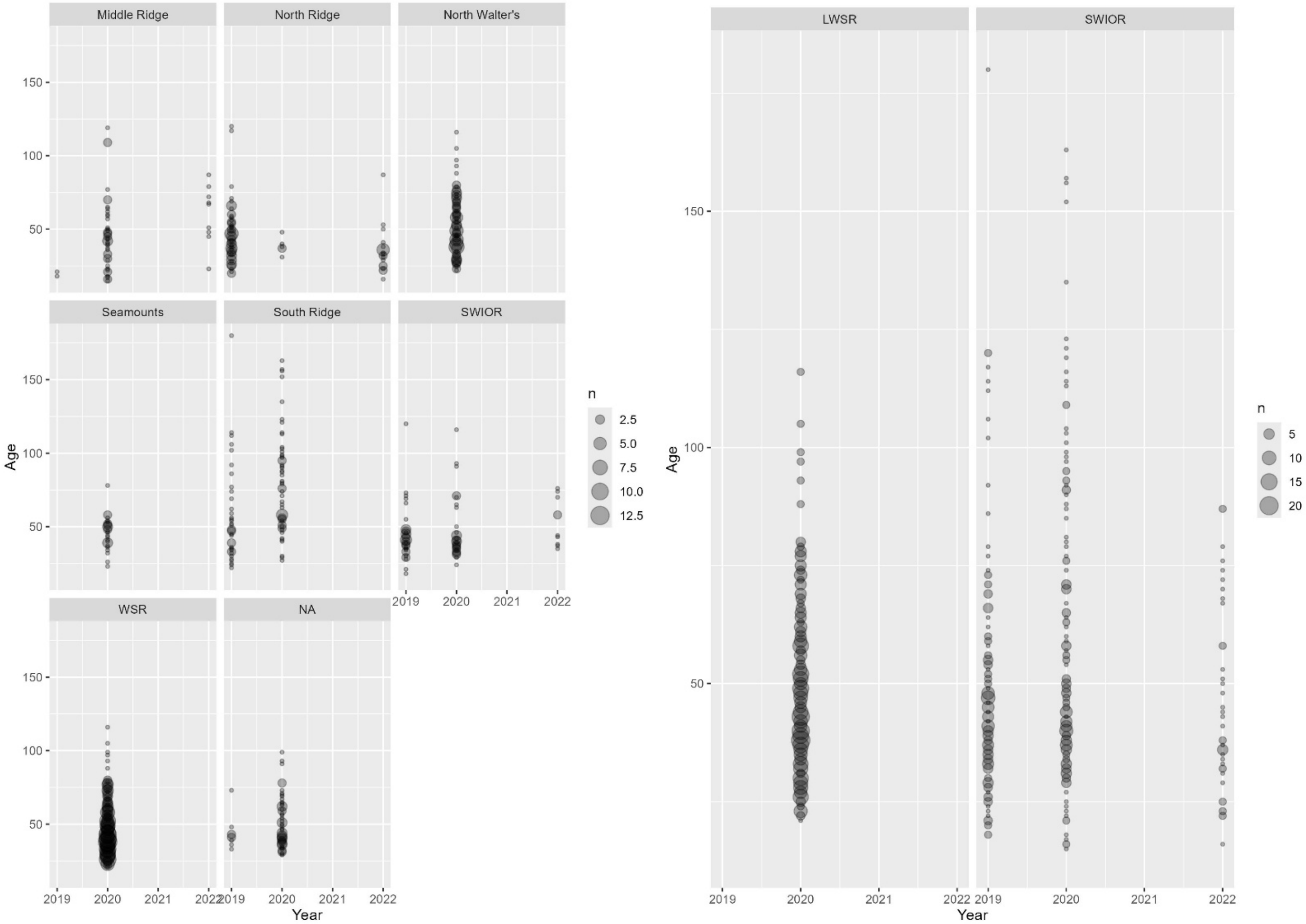

Figure 5: Numbers of fish sampled at age (in years) by location and year. The left-hand plot shows locations at the ORAA level where available, while the right-hand plot shows observations by assessment region.

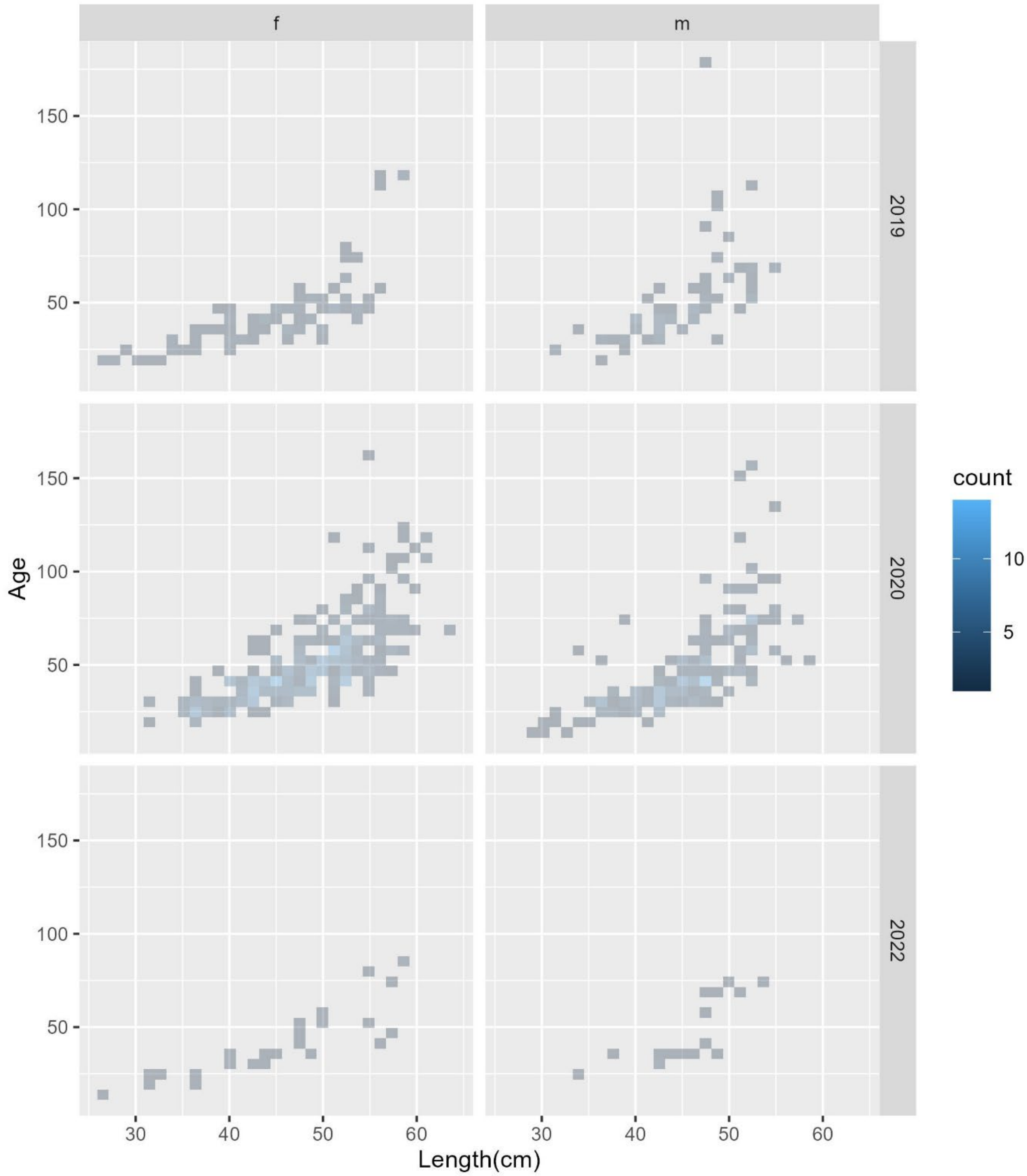

Figure 6: Raw age (years) at length (cm) data by year and sex, pooled across all locations.

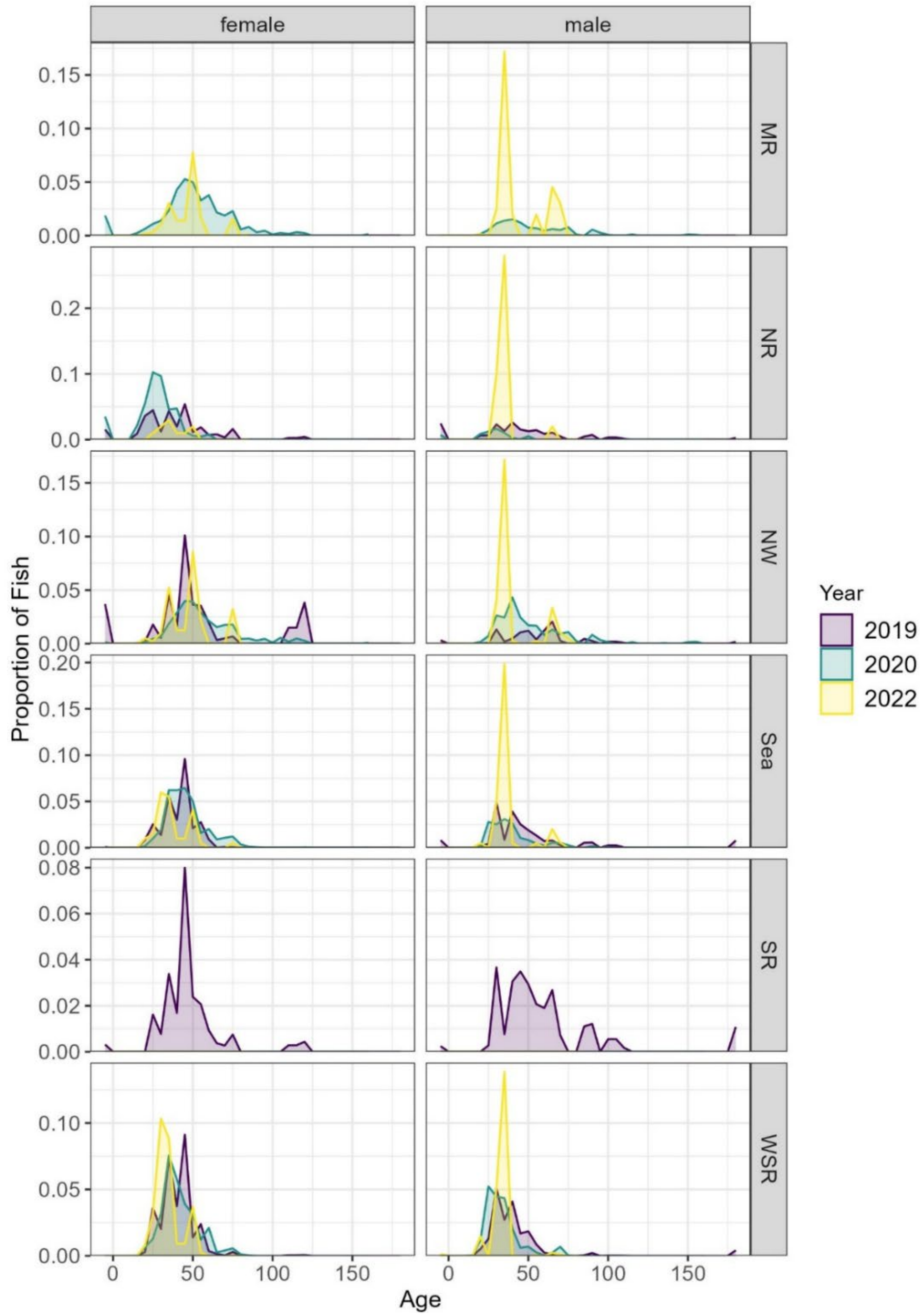

Figure 7: Scaled age (in years) frequency data by year, sex, and ORAA, aggregated into 3-year bins for improved presentation. ORAA labels: MET = Meeting, MR = Middle Ridge, NR = North Ridge, NW = North Walter's, Sea = Seamount, SR = South Ridge, WSR = Walter's Shoal Ridge.

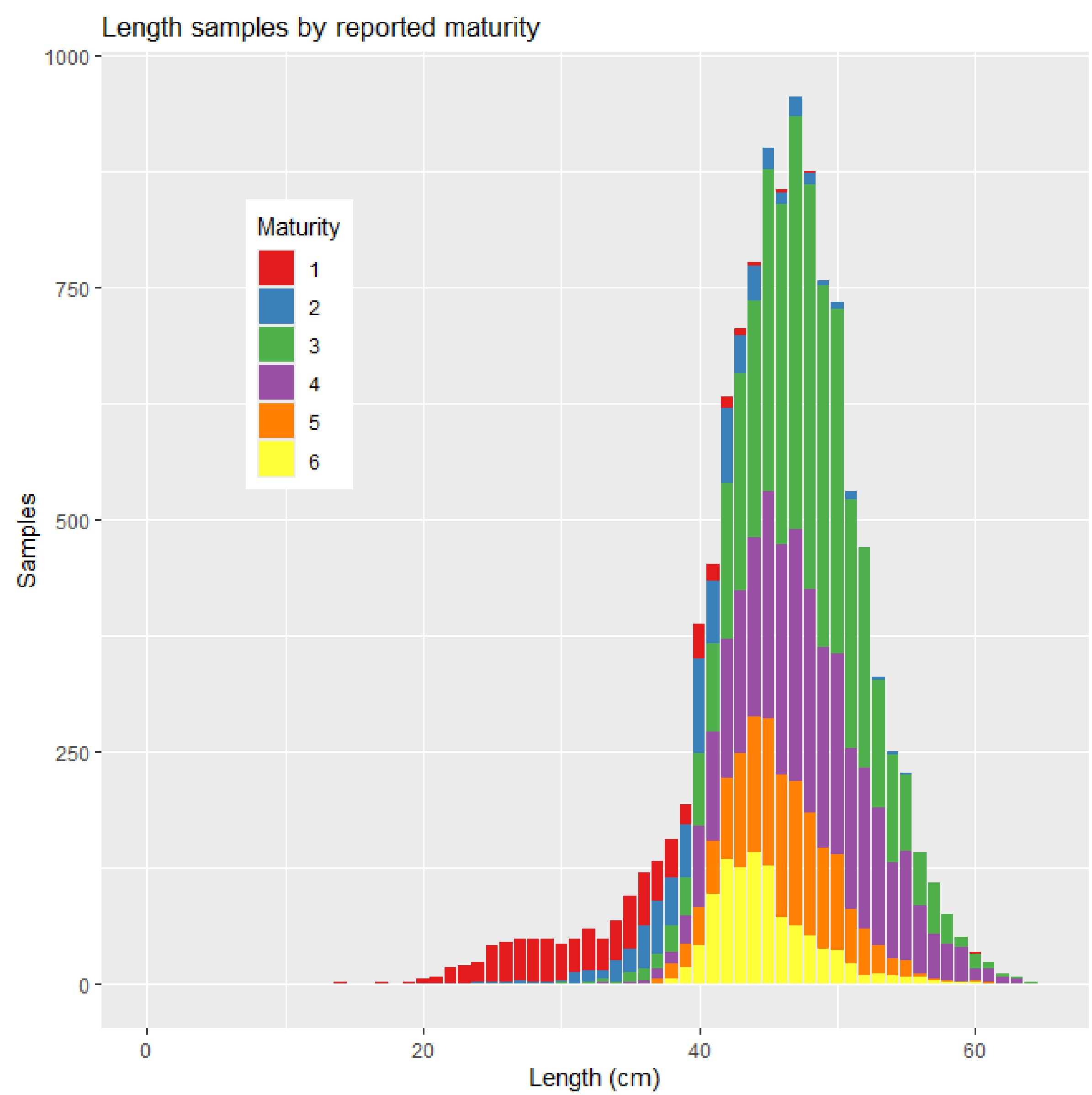

Figure 8: Frequency distribution of female size samples by reported maturity state.

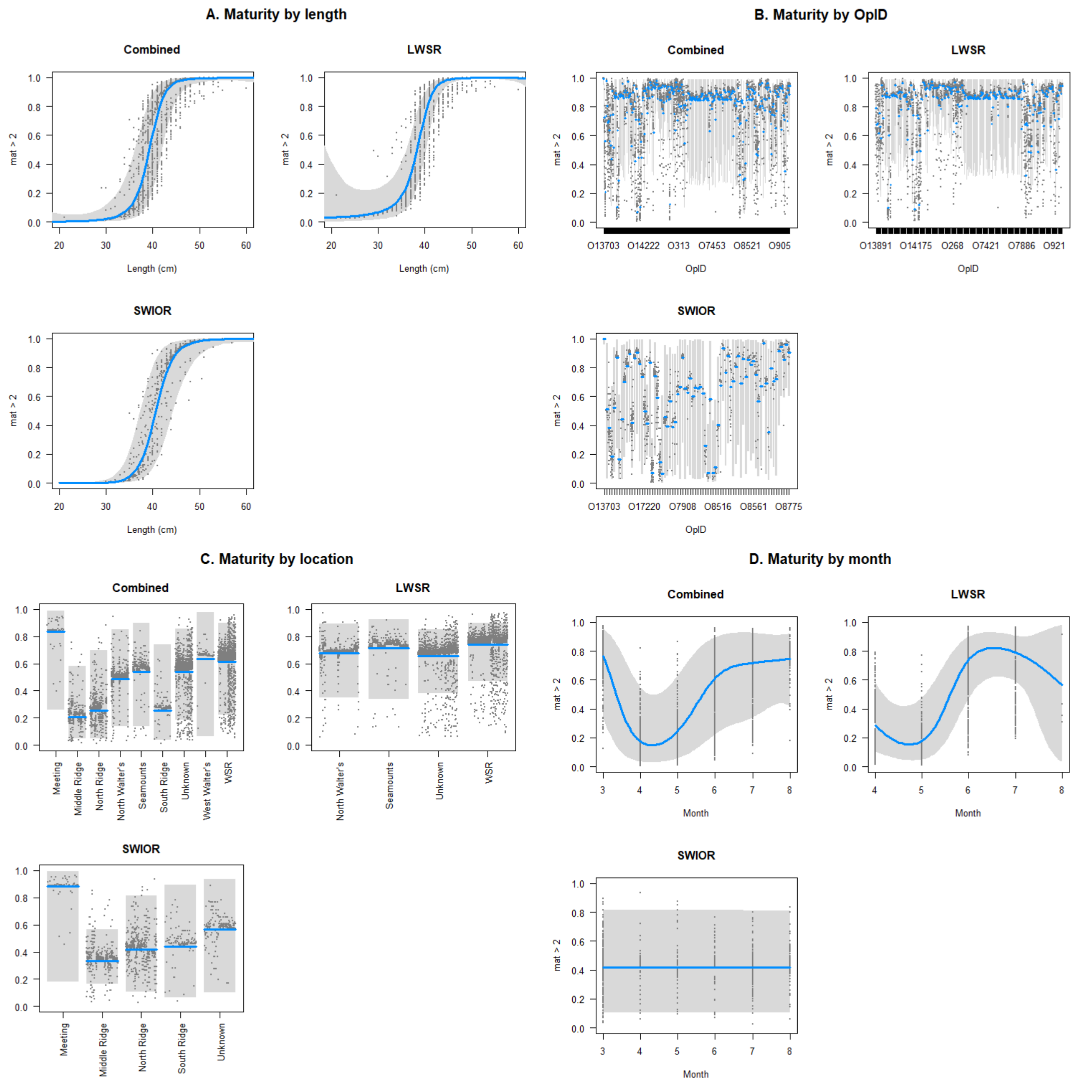

Figure 9: Plots of maturity by spatial grouping versus the covariates length (A. top left), OpID (B. top right), month (C. bottom left), and latitude (E. bottom right). Predicted probabilities of maturity are for the value on the x axis, and for other parameters at length 40cm, month 6, and the median or modal values of other parameters.

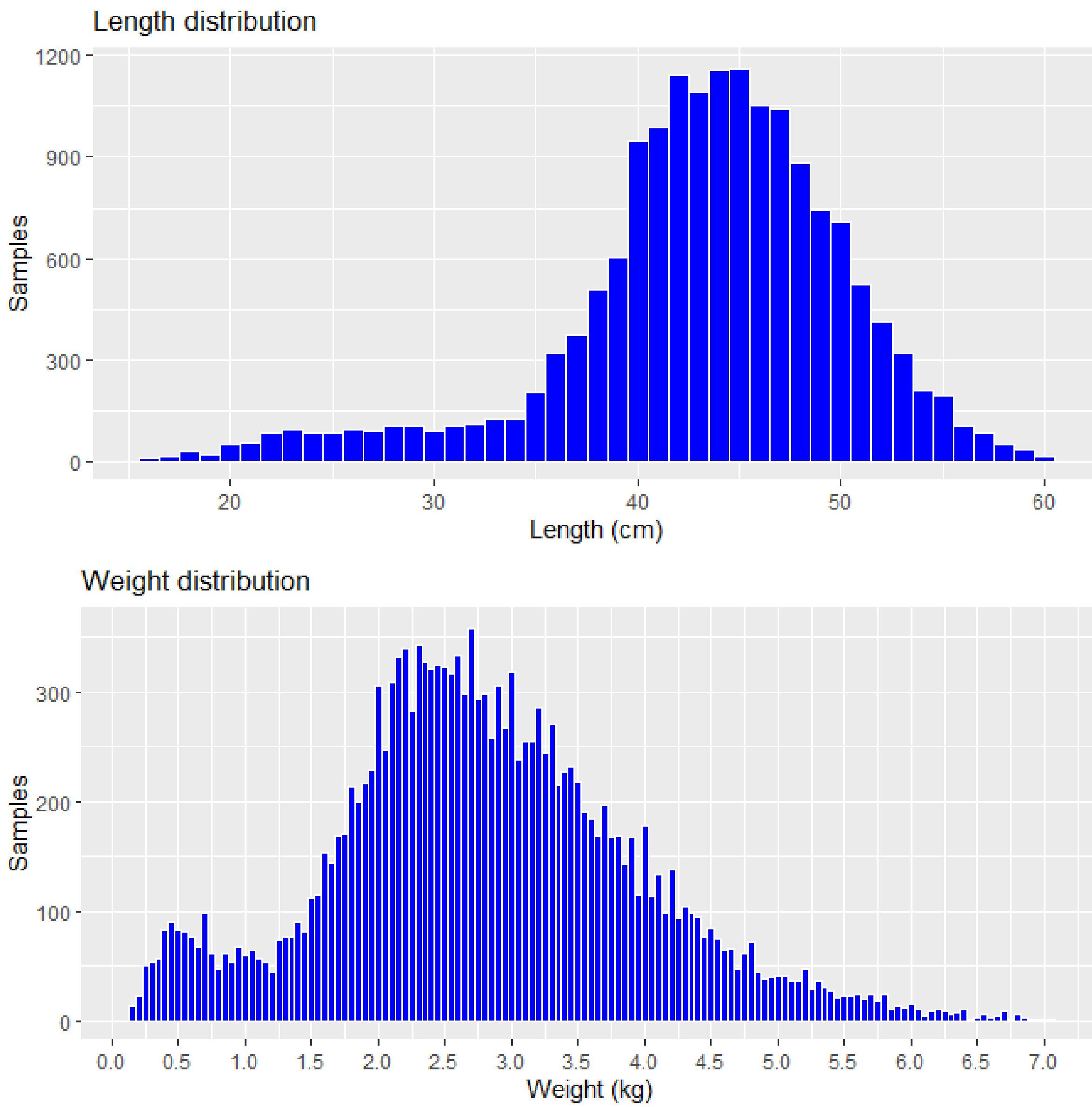

Figure 10: Frequency histograms of the cleaned data used to estimate length-weight relationships, with lengths (above) and weights (below).

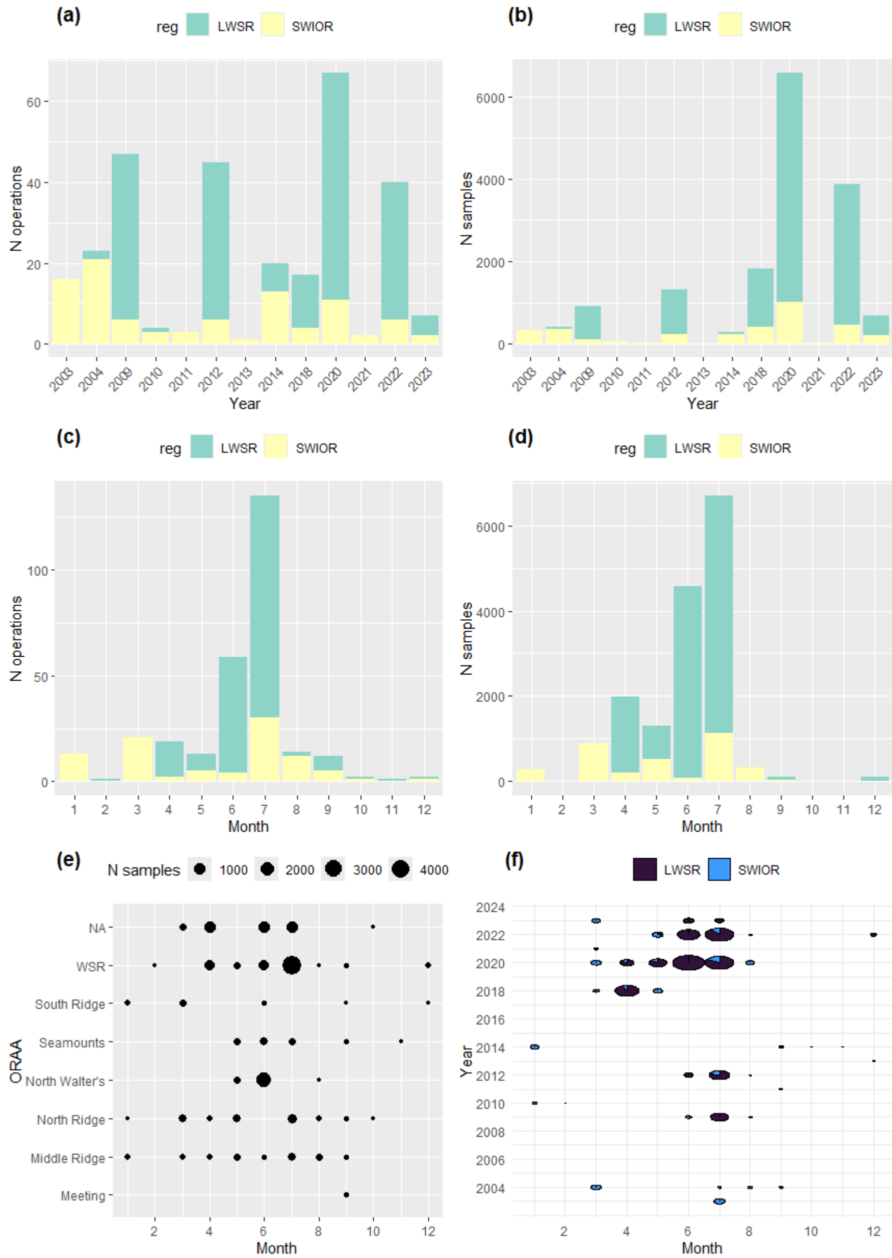

Figure 11: Characteristics of data used to estimate length-weight relationships: a) bar plot of operations per year by assessment region; b) bar plot of samples per year by assessment region; c) bar plot of operations per month by assessment region; d) bar plot of samples per month by assessment region; e) circle plot showing numbers of samples by month and ORAA; f) pie plot of samples per year, month and assessment region. The circle area represents the number of samples, and the pies show the proportions by region.

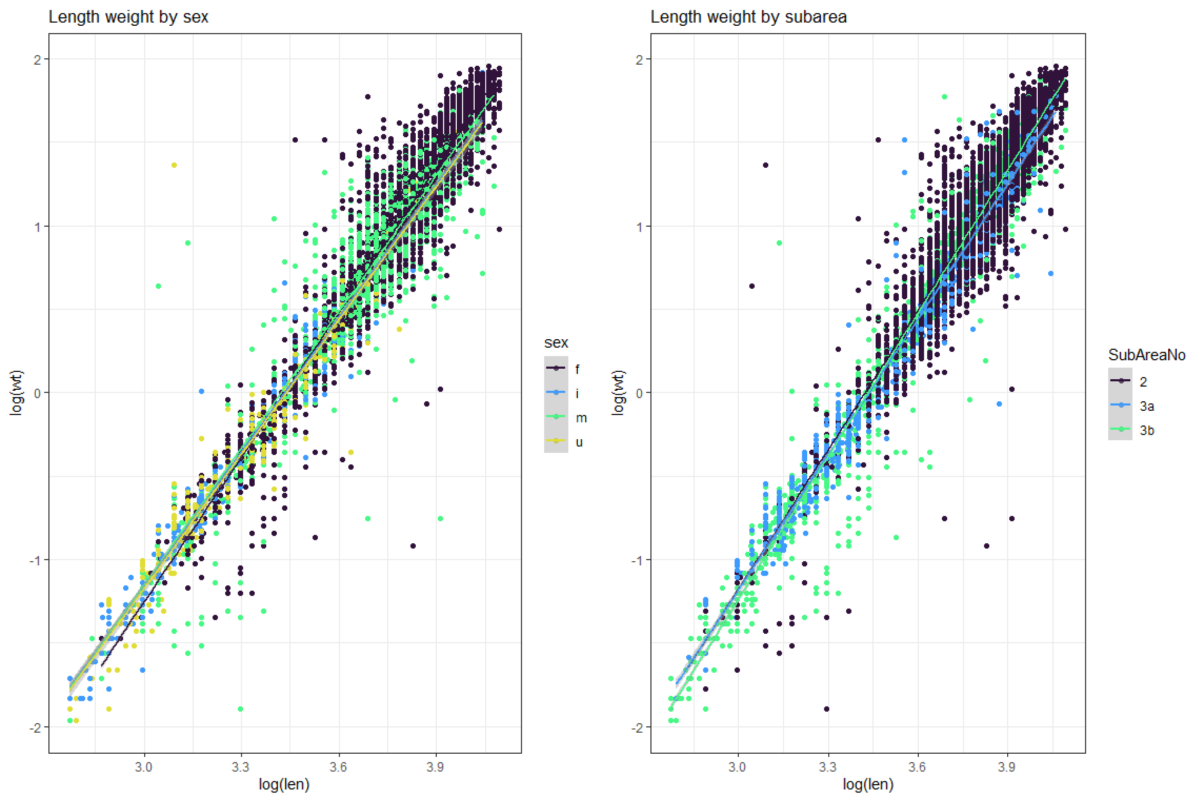

Figure 12: Plots of log length (cm) versus log weight (kg) by sex (left) and subarea (right), with a line fitted to data from each group. The sexes in the left-hand plot are f=female, m=male., i=immature, and u=unknown. The subarea numbers in the right-hand plot are 2, 3a and 3b, as identified in Figure 1.

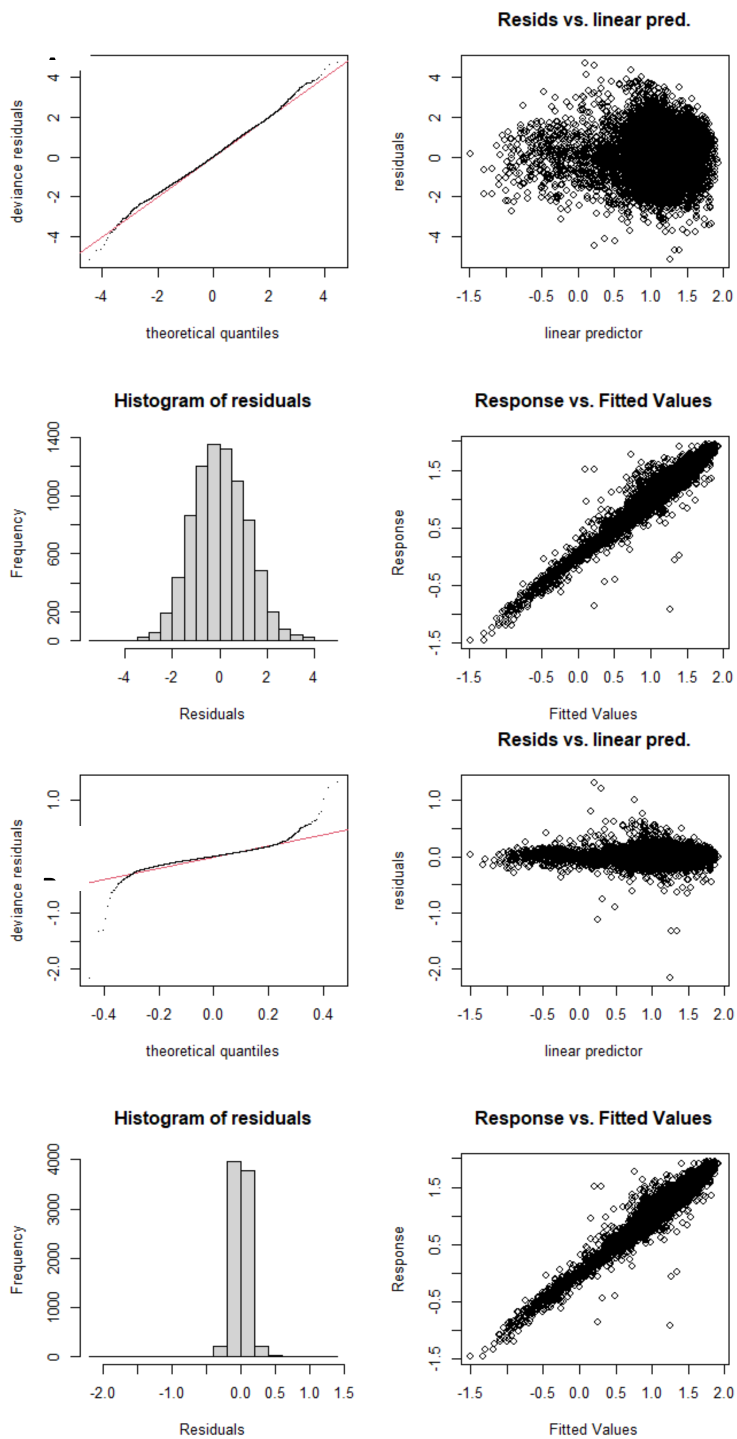

Figure 13: Diagnostic plots to compare model goodness of fit of 2 models with different residual distributions. Both models are fitted to the same data with the same covariates. The four plots above (group A) use the scaled t-distribution, while the four below (group B) use the Gaussian distribution.

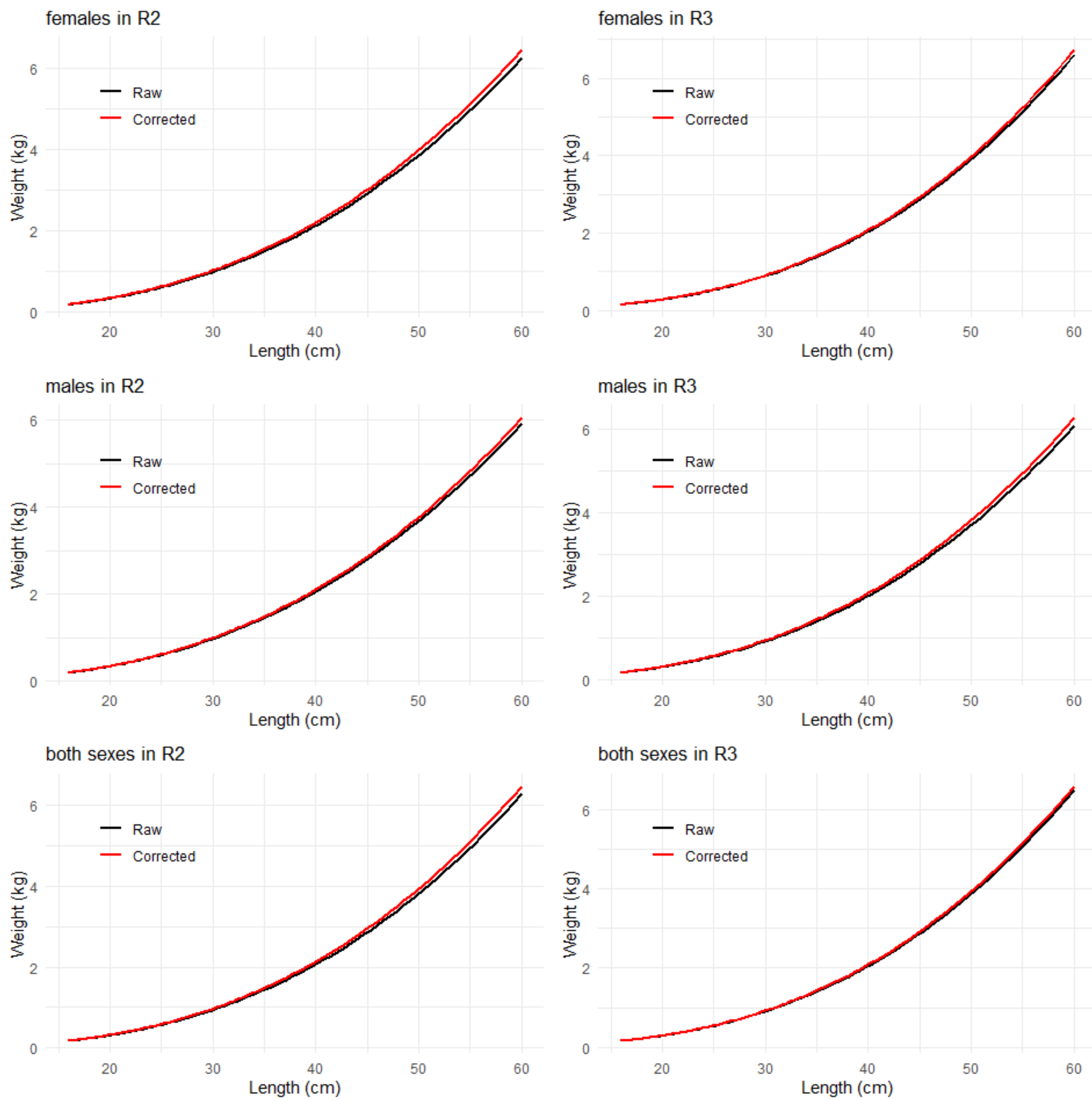

Figure 14: Comparison of the uncorrected and bias corrected predicted weights (kg) at length (cm) on the natural scale.

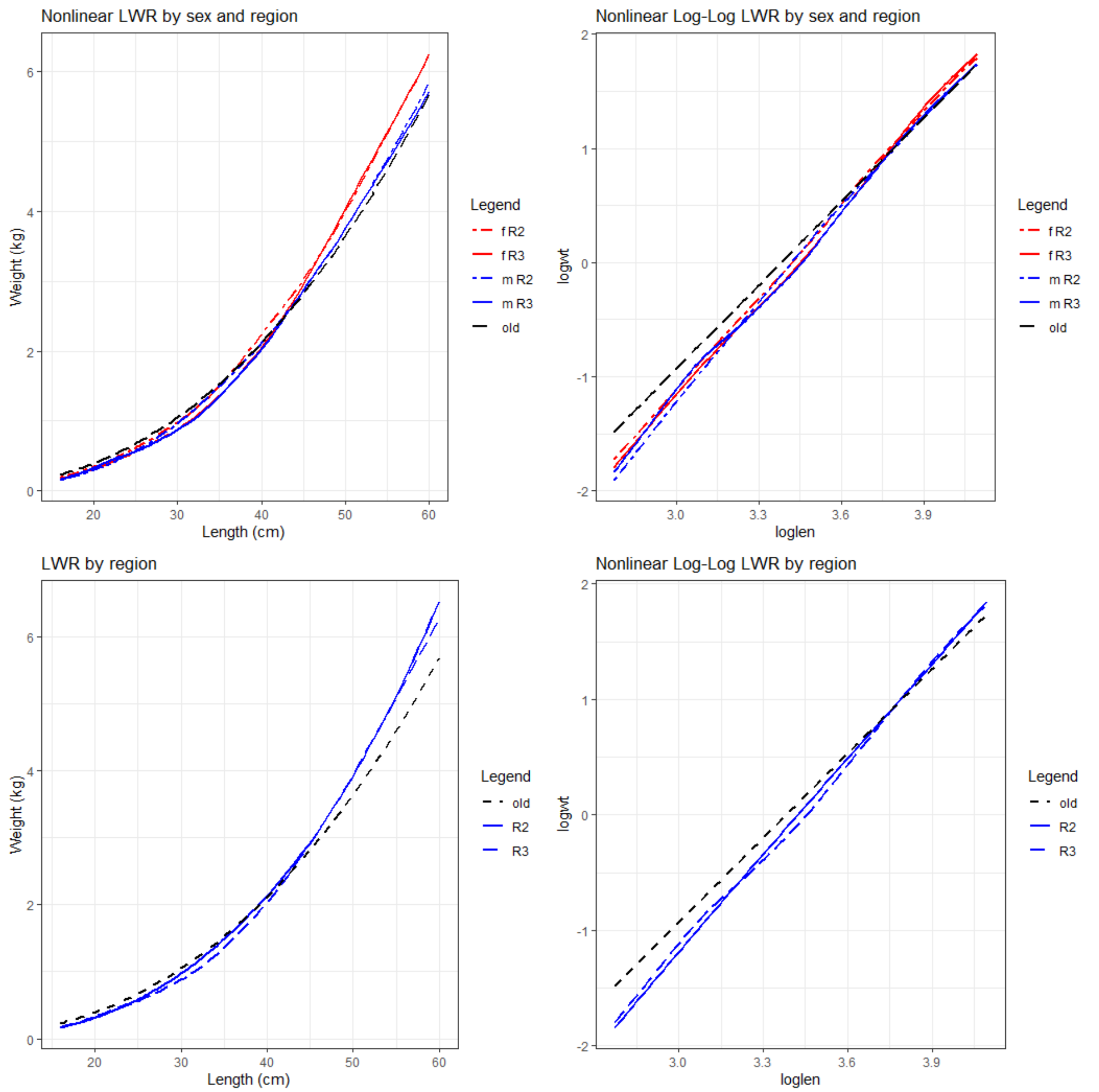

Figure 15: Results from models that allow for nonlinear length effects. Predicted weights (kg) at length (cm) by sex and region (above) and for combined sexes by region (below). Plots on the left are on the natural scale and have been bias-adjusted. Plots on the right are on the log-log scale. Each plot also includes the LWR used in the last stock assessment, identified as 'old'.

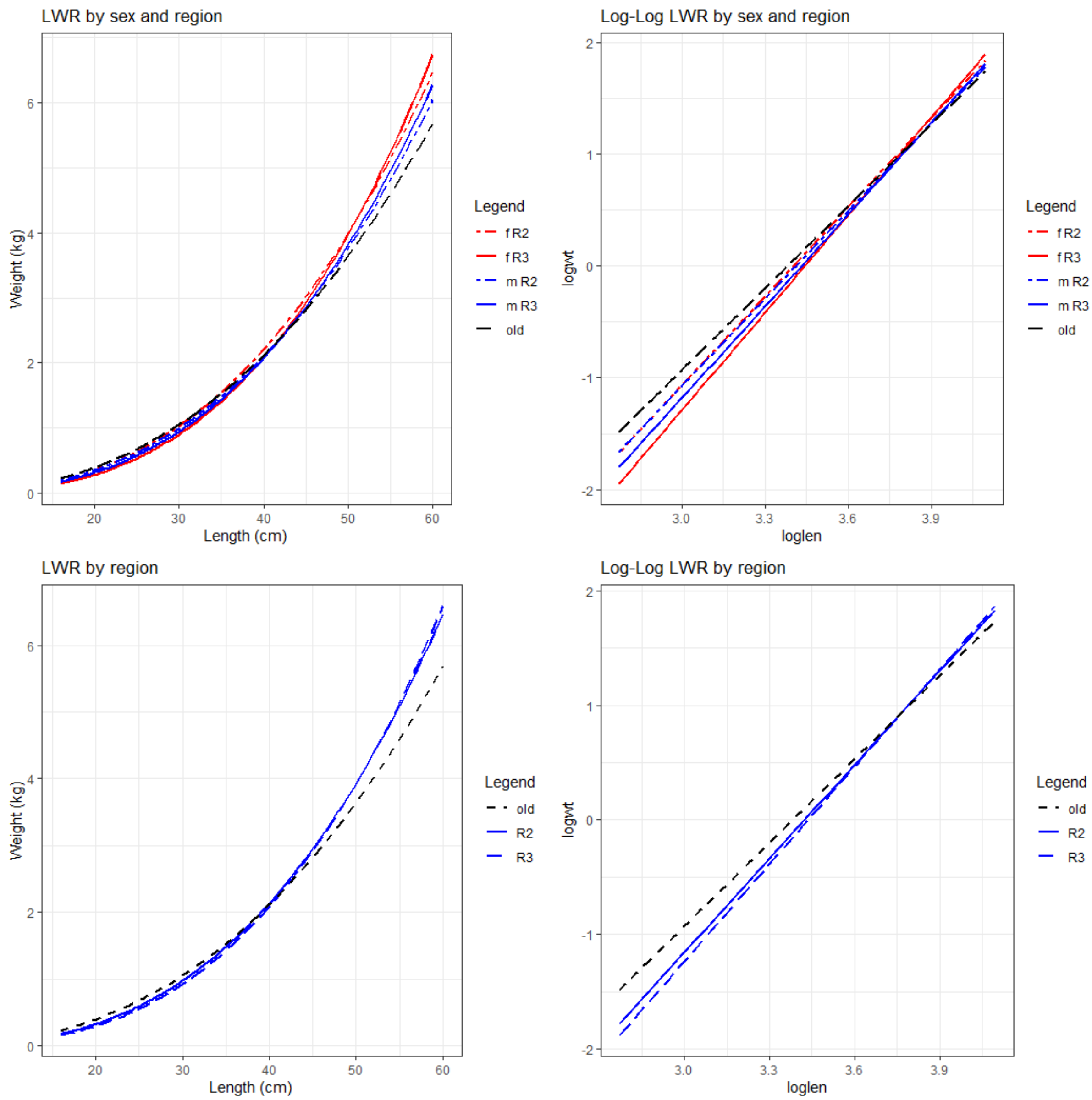

Figure 16: Results from models that assume linear length effects. Predicted weights (kg) at length (cm) by sex and region (above) and for combined sexes by region (below). Plots on the left are on the natural scale and have been bias-adjusted. Plots on the right are on the log-log scale. Each plot also includes the LWR used in the last stock assessment, identified as 'old'.

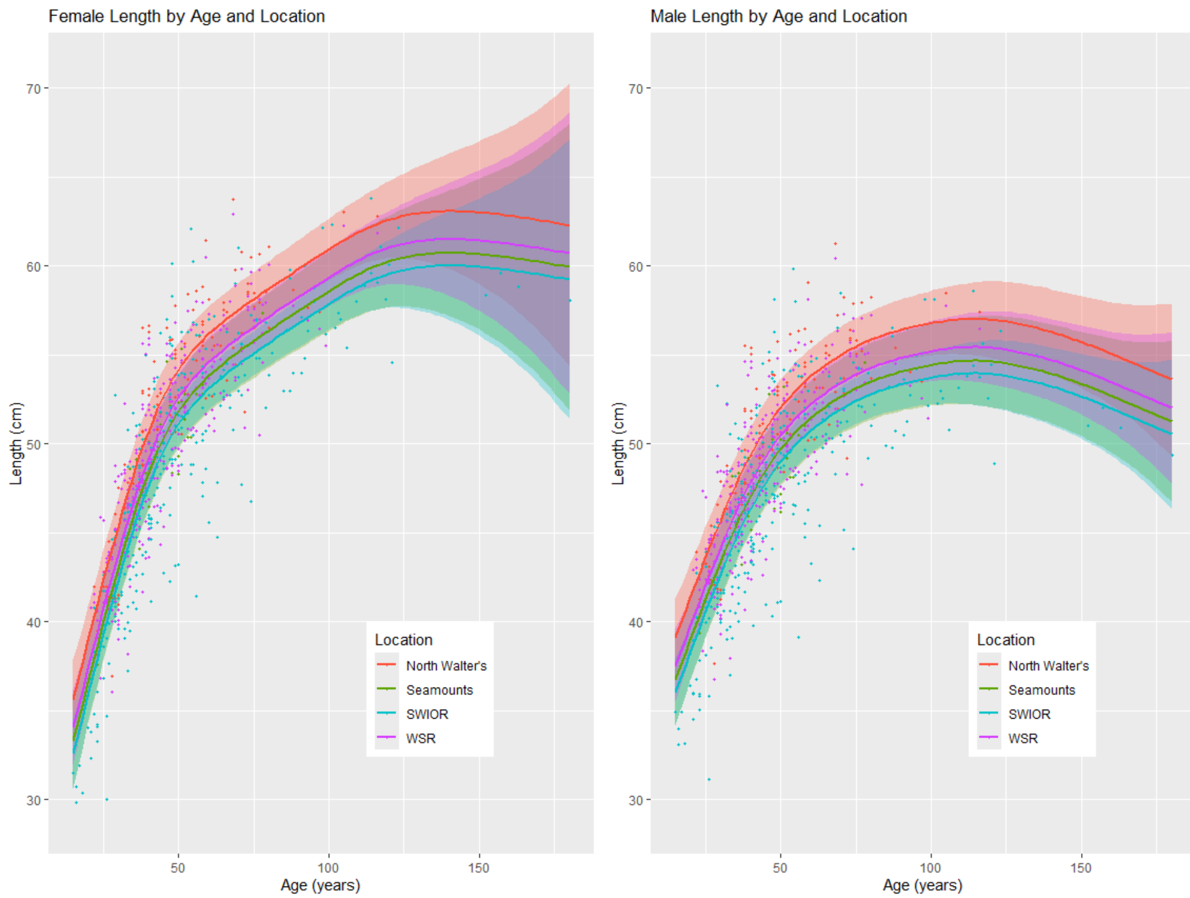

Figure 17: Predicted length (cm) at age (years) by location and sex based on the best fitting GAM to the full dataset. The lines represent expected length at age, sex, and location at the median value of the OpID random effect. The filled areas cover the 95% confidence band. The points are partial residuals.

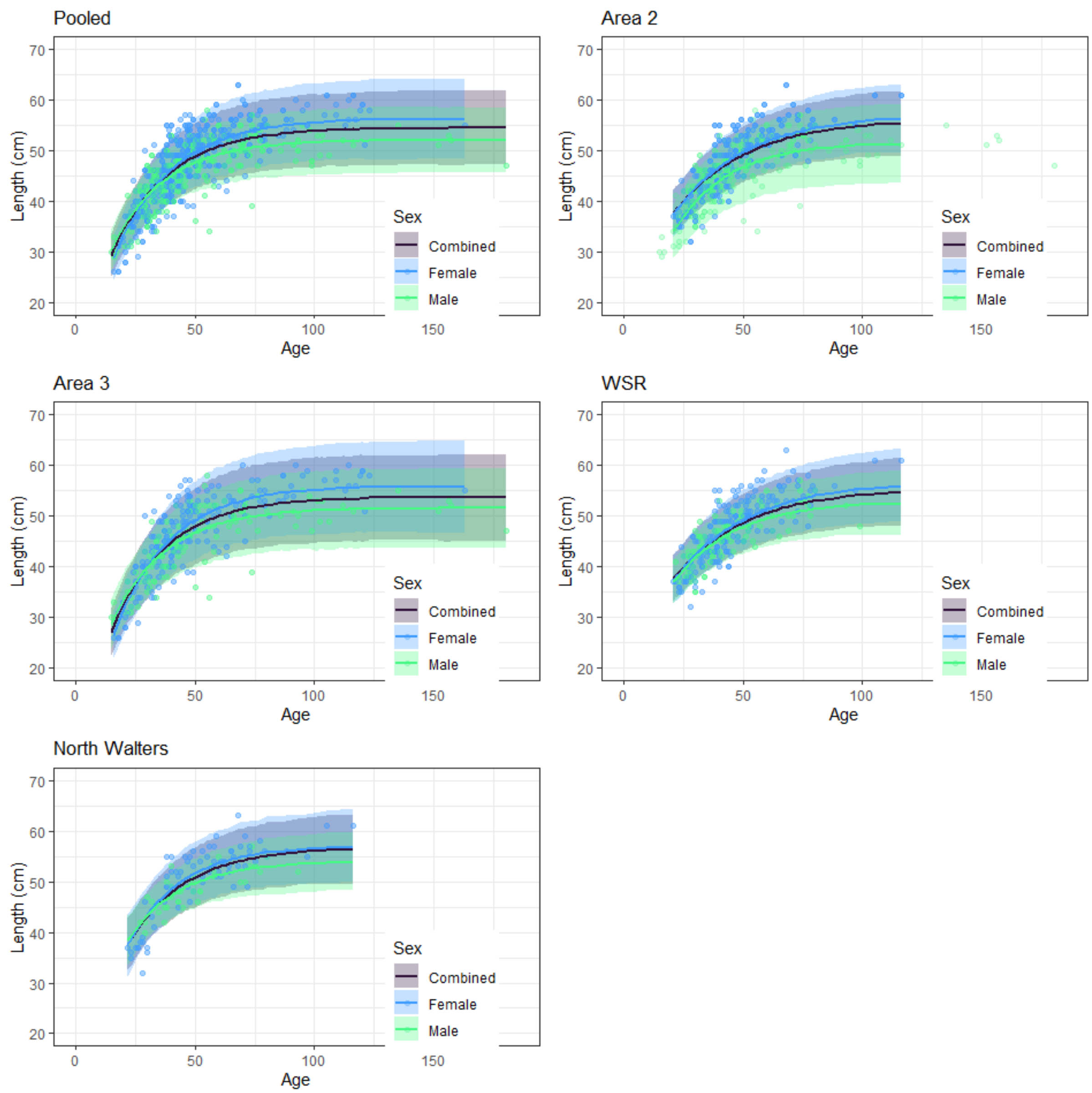

Figure 18: von Bertalanffy growth curves showing length (cm) against age (years) by grouped location and sex, estimated using brms. Area 2 is LWSR and Area 3 is SWIOR.

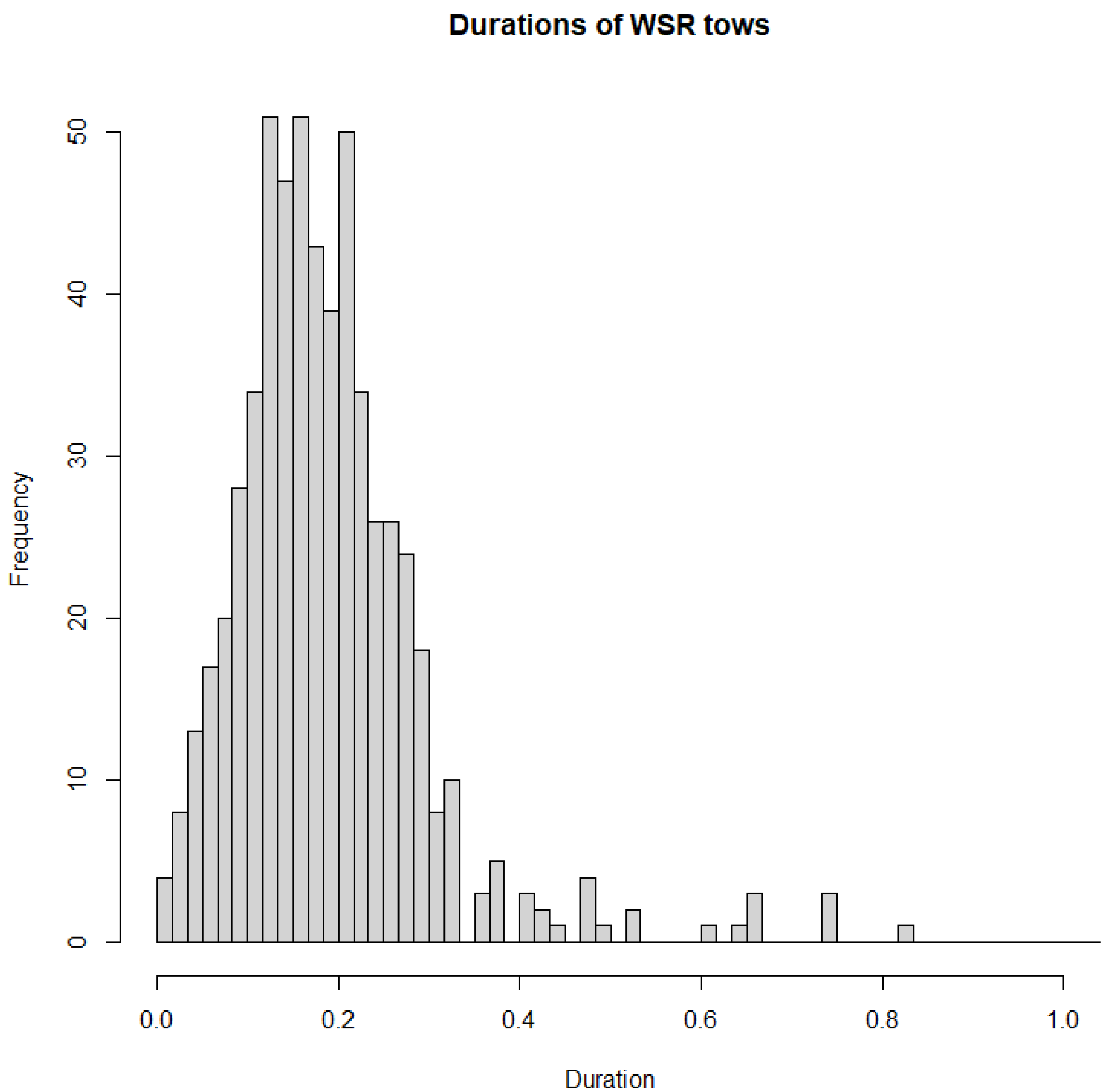

Figure 19: Frequency distribution of tow durations (in hours) included in the WSR region CPUE dataset.

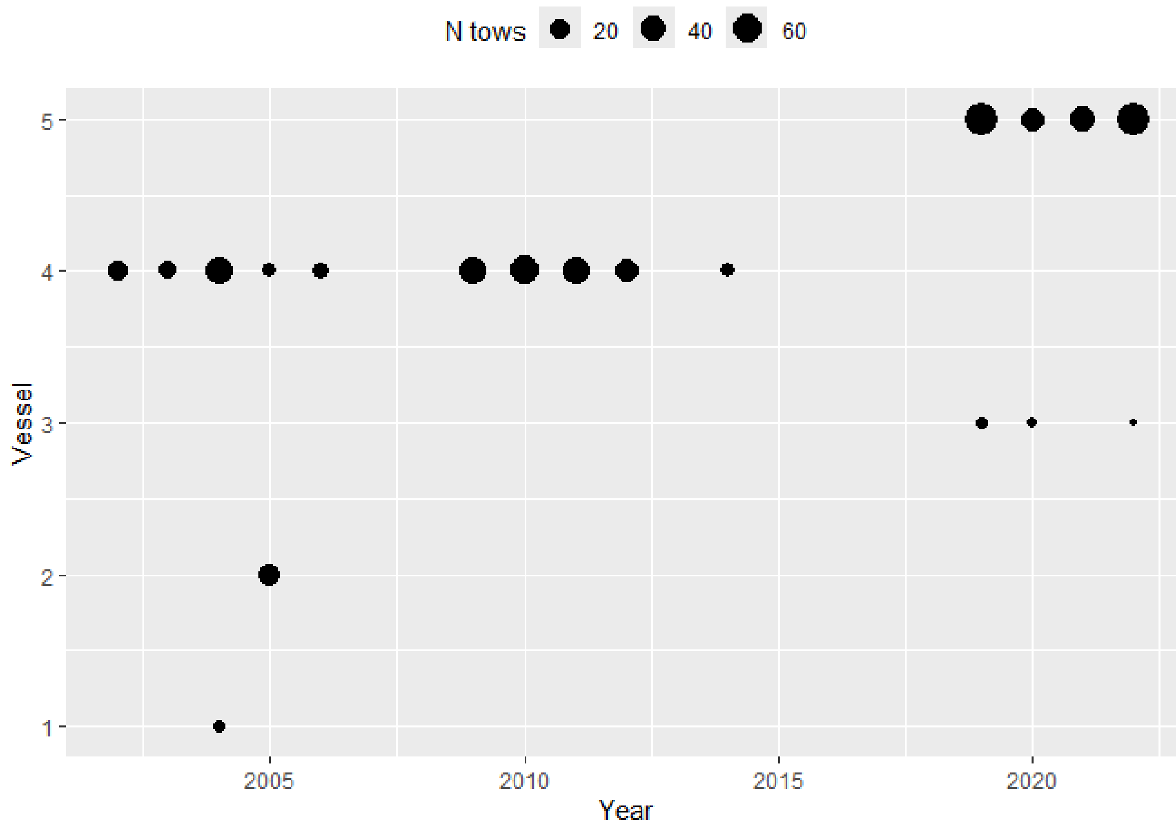

Figure 20: Distribution of tows per vessel through time in the WSR region, as reported in logbooks.

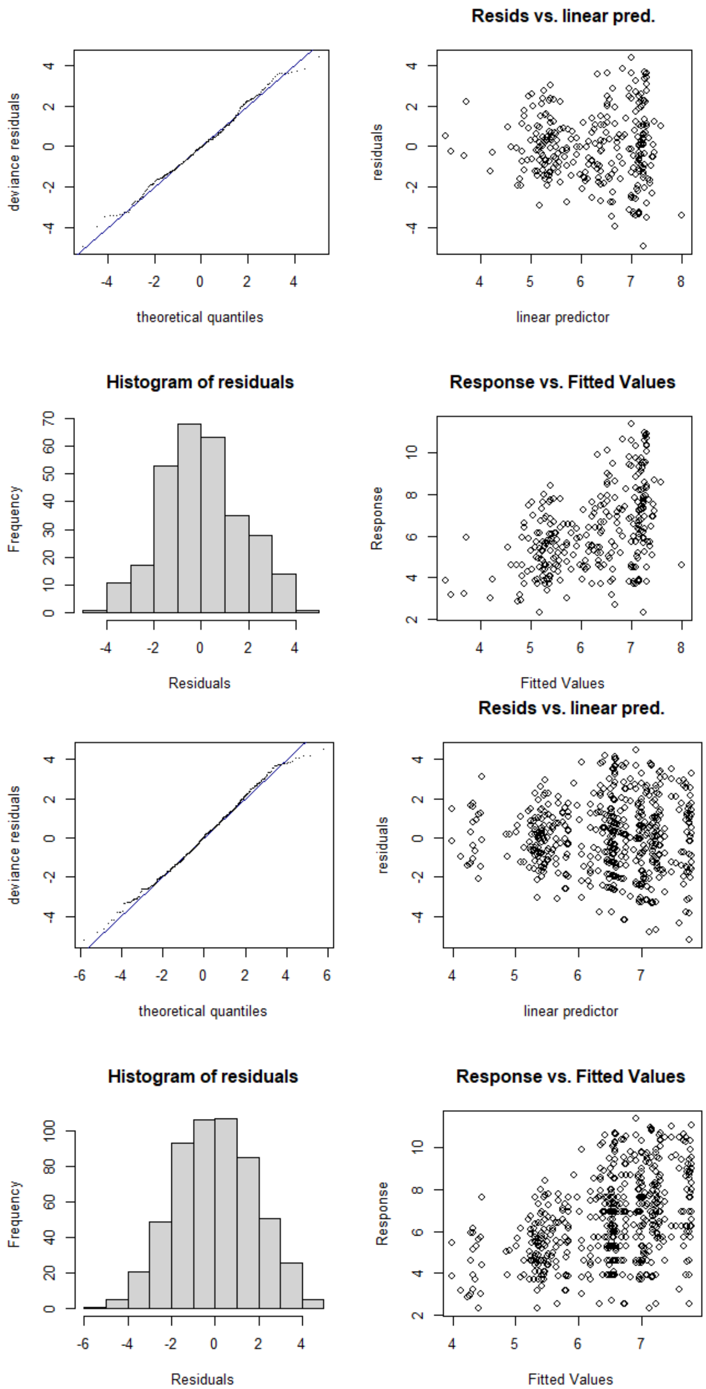

Figure 21: Model diagnostic plots for CPUE analyses. The early period is above, and the later period is below.

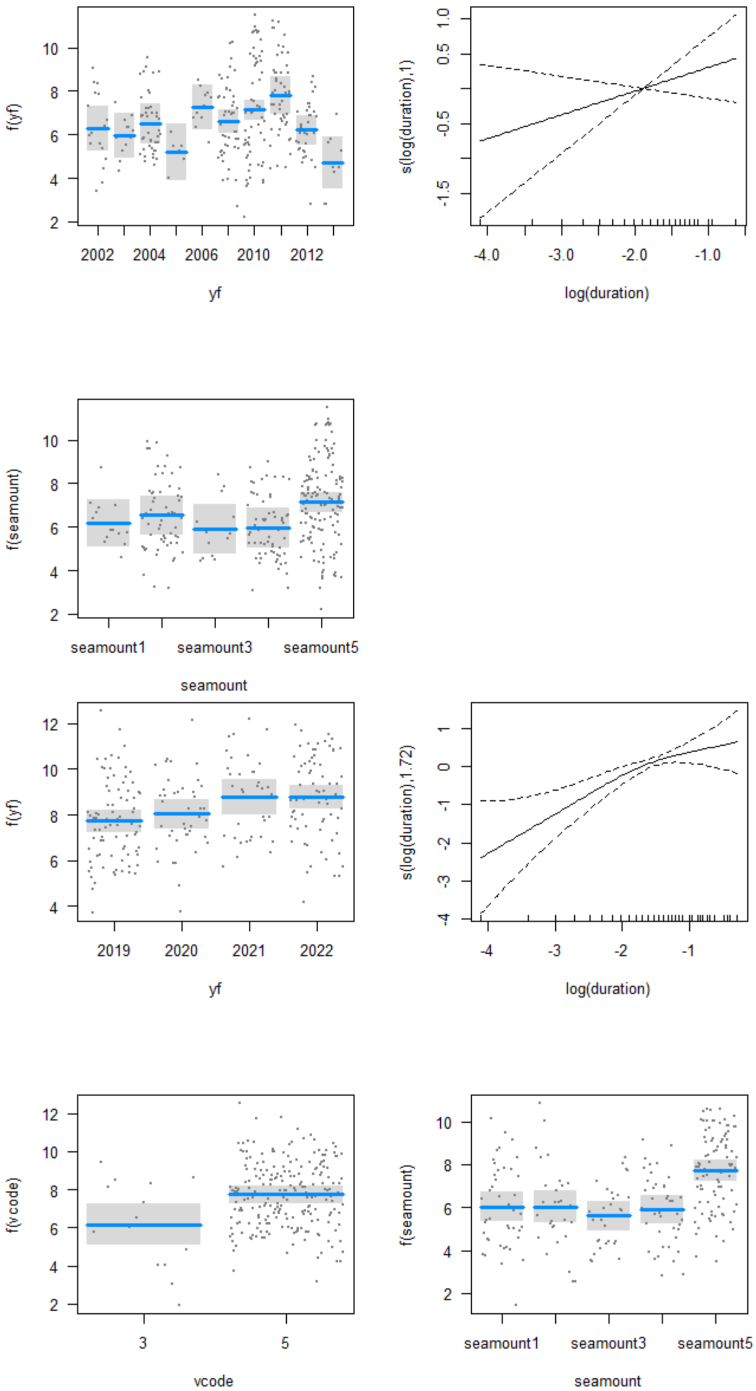

Figure 22: CPUE GAM model effect plots for the early period (above) and the recent period (below). Bars associated with factors represent the predicted means after adjusting for other factors. Points are partial residuals.

7. Appendix A: Terms of Reference

SIOFA | APSOI
Southern Indian Ocean Fisheries Agreement
Accord relatif aux Pêches dans le Sud de l'Océan Indien

Project title: Orange roughy stock assessment (2024-2025)

Project Code: ORY-2024-01

Terms of Reference

1. Introduction

The SIOFA Scientific Committee (SC) provides scientific advice to the Meeting of Parties (MoP) on the status of stocks and sustainable yields of deep-sea fisheries resources. In 2018, the SIOFA Scientific Committee (SC3) conducted the first orange roughy stock assessments in the SIOFA region and provided advice to the Meeting of Parties on the stock status and sustainable yields for orange roughy. An updated orange roughy stock assessment was conducted and presented to SC7 in 2022.

As required under SIOFA CMM 15, orange roughy stock assessments are conducted every 3-5 years, and the next Scientific Committee (SC10) (March 2025) will consider the new orange roughy stock assessments to provide its advice to the MoP.

Summaries of the Scientific Committees advice from previous assessments are available in the reports from SC3 and SC7.

2. Methods

Undertake assessments of the orange roughy stocks in the SIOFA area. This should build on and improve the work of the two previous assessments (Cordue 2018a and b, Roa-Ureta et al. 2022). While there could be multiple sub-stocks of orange roughy in the SIOFA area, until work is completed on the stock structure, two stocks should be assumed: one on Long Walter's Shoal Ridge (LWSR, Walter's shoal, Walter's Shoal Ridge, and associated seamounts) and another on the South-west Indian Ocean Ridge (SWIOR, Meeting, South Ridge, Middle Ridge, and North Ridge) (Figure 1).

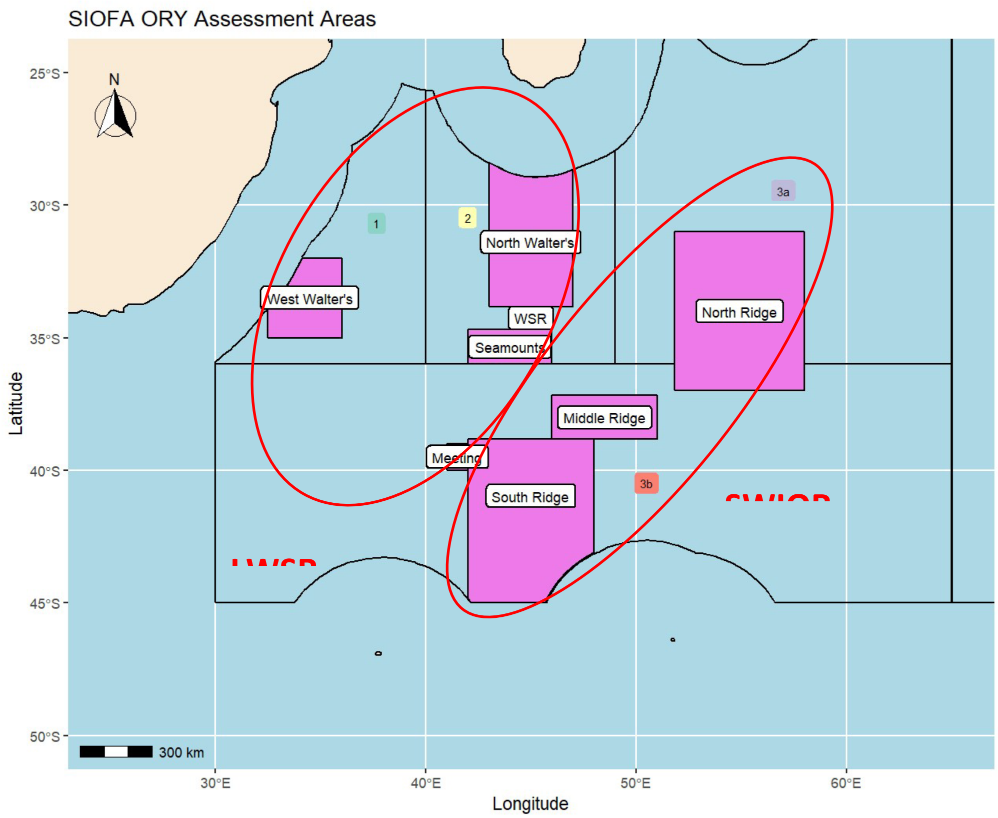

Figure 1 – Map of SIOFA Areas used for assessments (in magenta) for orange roughy as defined by Cordue (2018a, 2018b) and used by Roa-Ureta et al. (2022) (source: SIOFA Spatial layers). Labels indicate names of single assessment areas. Red ovals denote the grouping of single assessment areas into two larger management units for purposes of stock assessment by Roa-Ureta et al (2022). These management units are labelled Long Walter's Shoal Ridge (LWSR) and South-west Indian Ocean Ridge (SWIOR).

New information since the previous assessments include updated age and growth analyses, maturity analyses, acoustic biomass indices, and catch/effort data.

The outcomes of the assessments should be collated in a report and presented to SC10 in 2025. As a part of this project, the consultants will be required to present preliminary methods, draft reports, and results as they are developed to the project Advisory Panel for review.

3. Project objectives

1. During the project, present the work to the SIOFA orange roughy assessment Advisory Panel to discuss data inputs, the assessment approach, and preliminary results.

2. Develop standardised CPUE indices for each stock. Note this should standardise, to the extent possible, using factors such as location (e.g., area and seamount), season, gear parameters, alfonsino

bycatch, prevailing weather, etc. As the fishery has been undertaken by 1-3 vessels only, standardisation by vessel may not be possible.

3. Review the previous stock assessments, and use all new information (including updated growth, maturity, and local area acoustic abundance data), and other relevant information to undertake a statistical catch-at-age stock assessment to determine the stock status of orange roughy for Walters Shoal and the Southwest Indian Rise. The outcomes of the assessment should include the following:

    a. Evaluation of the stock against the SIOFA interim reference points (Target = 40%B0 and Limit = 20%B_0). A range of other reference points should also be considered and estimates of stock status, fishing mortality, and biomass should be provided in the terminal year of the assessment and over time including, at least but not limited to status in relationship to B40% and B20%, MSY, SB_{MSY}, SB_0, $SB_{F=0}$, SB/SB_{MSY}, $SB/SB_{F=0}$, SB/SB_0, F, F_{MSY}, F/F_{MSY}, F40%B_0.

    b. Appropriate sensitivities to model structural assumptions, choices of biological parameters, acoustic and CPUE abundance indices, and age composition data.

    c. Estimates of 20-year projected status (at 5-year intervals) under a range of future catch scenarios and appropriate estimates of future productivity (i.e., year class strengths). Analysis should include projections using constant catch and constant fishing mortality strategies with both annual and 5-year changes in catch limits.

    d. Kobe I (stock status trajectories) and appropriate Kobe II (strategy risk matrix) summaries of the stock assessment results. Refer to Table 1 below as an example of the Kobe II risk strategy matrix from Indian Ocean Tuna Commission (IOTC), showing risk probabilities violating target and limit reference levels for F and B (biomass) next 3 and 10 years in 9 different catch levels (0%, ±10%, ±20%, ±30% and ±40% of the current level).

4. Provide relevant text to update Section 6 of the SIOFA Fisheries Summary: orange roughy.

Table 1: Example of a Kobe II Risk Strategy Matrix.

Table 2. Albacore: SS3 aggregated Indian Ocean assessment Kobe II Strategy Matrix based on the model options (i) Model 1 (ii) Model 2 (iii) Model 3 (Model 4 was not used for management advice). Probability (percentage) of violating the MSY-based target (top) and limit (bottom) reference points for constant catch projections (2017 catch level, ± 10%, ± 20%, ± 30% ± 40%) projected for 3 and 10 years.

Reference point and projection timeframe	Alternative catch projections (relative to the catch level for 2017) and probability (%) of violating MSY-based target reference points ($SB_{targ} = SB_{MSY}$; $F_{targ} = F_{MSY}$)								
	60% (22,901)	70% (26,718)	80% (30,534)	90% (34,351)	100% (38,168)	110% (41,985)	120% (45,802)	130% (49,618)	140% (53,435)
$SB_{2020} < SB_{MSY}$	0.614	0.678	0.715	0.769	0.818	0.828	0.87	0.883	0.898
$F_{2020} > F_{MSY}$	0.074	0.224	0.4	0.556	0.654	0.731	0.766	0.788	0.782
$SB_{2027} < SB_{MSY}$	0.176	0.307	0.456	0.572	0.713	0.823	0.898	1	1
$F_{2027} > F_{MSY}$	0.002	0.085	0.287	0.473	0.718	0.878	1	1	1

4. Relevant SIOFA information

1. SIOFA data (provided by the SIOFA Secretariat upon request) 2.
SIOFA spatial data layers. Available at:
https://github.com/SIOFASecretariat/SIOFA_SC_Spatial_layers

3. SIOFA reporting templates. Available at:

https://github.com/SIOFASecretariat/SIOFA_Reporting_templates

4. SIOFA reports:

   a. SIOFA SC, SC Working Group, and National Reports. Scientific Committee Meeting | SIOFA

   (https://siofa.org/)

   b. SIOFA MoP reports. Meeting of the Parties | SIOFA (https://siofa.org/)

   c. SIOFA technical and scientific reports (public reports and abstracts of restricted reports are available from https://siofa.org/, and full restricted reports will be made available by the SIOFA Secretariat to the project consultant upon request and after the approval of relevant CCPs.

5. Key project indicators

1. Follow the project timeline as detailed in this agreement, including the submission of deliverables, to meet the project objectives.

2. Collect any necessary data as early as possible, e.g., by submitting a data request to the SIOFA Secretariat.

3. Attend the project pre-assessment electronic meeting with the Advisory Panel (composed of members of the SIOFA Scientific Committee and the SIOFA Secretariat) to discuss the project setup and development. Further engage, as requested, with the Advisory Panel during the project to assist the consultant access and interpret reports, data, and obtain the Advisory Panels advice on relevant analyses, methods, and data interpretation for the project.

4. Present preliminary results during the project, as required, to the project Advisory Panel, and respond and revise any project outputs based on their review.

5. Provide regular (i.e. every 2-3 months), proactive updates to the Project Coordinator and the Advisory Panel throughout the project, in particular informing promptly of any unforeseen delay or variations to the project.

6. Submit deliverables on time and appropriately formatted, as required. Each deliverable will go through a SIOFA review to ensure that it meets the quality targets and the project objectives as set out in the Terms of Reference.

7. Appropriately acknowledge the project funding source (SIOFA) within each deliverable.

8. Take into reasonable account the outcomes of the SIOFA review or any comments made by meeting attendees, when revising the deliverables.

6. Deliverables

1. Attend (virtually) the project Advisory Panel meetings.

2. Presentation of methods and results to the SIOFA SC annual meetings (March 2025) 3. A Draft Report that addresses the project objectives and tasks as laid out in this contract. Revise and update the Draft Report based on review by the project Advisory Panel, and the SIOFA Scientific Committee. The report should follow the guidelines and format available at https://github.com/SIOFASecretariat/SIOFA_Reporting_templates. In particular, the report should include a concise (max 300 words) summary, and should detail the methods, the outcomes, conclusions, and concise recommendations. The Draft Report will also be submitted to the SIOFA Scientific Committee.

4. Provide relevant revisions to Section 6 of the SIOFA Fisheries Summary: orange roughy.

5. A Final Report that follows the guidelines and format available at https://github.com/SIOFASecretariat/SIOFA_Reporting_templates and includes any review comments from the SIOFA Scientific Committee on the Draft Report. The Final Report will also be submitted to the next SIOFA Scientific Committee.

6. Provide all the information collected as a part of this project to the SIOFA Secretariat (including that sourced from the Secretariat) before the final payment of the contract. Such information includes electronic data files, analysis code, biological samples, and other relevant data where applicable.

7. Presentations of reports to the Scientific Committee may be given virtually and travel to the meetings is not obligatory. All project meetings will take place virtually. No additional travel costs will be paid.

7. Acceptance of Draft and Final Reports

1. Draft and Final Reports must be submitted in English to the Project Coordinator at the SIOFA Secretariat.

2. Draft and Final Reports will be reviewed using the procedures outlined in paper MOP-09-12 (Annex B), see also:

   https://github.com/SIOFASecretariat/SIOFA_Reporting_templates/tree/main/SC%20reports/Review%20template%20for%20consultant%20reports.

3. Payment of contracts milestones will be subject to acceptance of the submitted reports by SIOFA.

8. Intellectual property clause and confidentiality

The Consultant shall submit 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. 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.

The Consultant shall not release confidential data provided for conducting this study to any persons nor any organizations, other than SIOFA Secretariat.

The Consultant shall delete all the confidential data upon the completion of the contract.

9. Work timeline and payment schedule

The funds for this project, budgeted under the SIOFA budget, allow for a maximum total budget of 50,000 Euro (including all costs and 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	September 2024	First instalment payment (30% of the total contract sum)
Delivery of draft report	30 January 2025	Second instalment payment (30% of the total contract sum) upon satisfactorily submission of draft report, in a format suitable for submission to SC, to the Project Coordinator. The draft report will be submitted to SC10 (on 15 February).
Presentation of preliminary results	17-26 March 2025	Presentation of preliminary methods and results to the SC10 meeting (virtual)

Delivery of final report	15 April 2025	Submission of final report in a format suitable for submission to SC and submission of all project information to the project coordinator. Final instalment payment (40% of the total contract sum) on acceptance of the final report by the advisory panel and the final submission of project information

10. Submission of applications

1. A current CV that summarises the applicant(s) relevant educational background and professional experience.

2. A brief proposal (indicatively 3-4 pages) outlining the proposed methods and analyses, including a description of how the objectives of the ToR will be achieved.

3. Any proposed exclusions to the intellectual property clause or variations to the work timeline and payment schedule.

4. The proposed consultancy price (including all consultant expenses and project related costs), noting that the available budget for this work indicated in Section 9.

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 Section 12), and

7. Any additional relevant information the applicant(s) wish to submit.

The applicants must have appropriate experience and knowledge of similar work in their portfolio.

Applications must be submitted to the SIOFA Science Officer Marco Milardi (marco.milardi@siofa.org, CC secretariat@siofa.org). Only those applications received before 12:00 PM (9:00 AM UTC) on Sunday the 1st of September 2024, Reunion Island time, will be considered.

11. Evaluation criteria for the selection of candidates

An evaluation panel, the SIOFA Secretariat, and the Chair and Vice-Chair of the SIOFA Scientific Committee will select one successful applicant for this contract. The selection criteria will include the following:

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 this 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.

12. 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).

13. Contacts

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

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

14. References

Cordue, P. 2018a. Stock assessment of orange roughy in the Walter's Shoal Region. SAWG(2018)-0105 Rev1, SIOFA. Available at:

https://siofa.org/sites/default/files/documents/meetings/SC-03-

07.1.1%2804%29%20Rev1%20Stock%20assessment%20of%20orange%20roughy%20Walter%27s%20Shoal.%20Cordue%2C%202018_0.pdf

Cordue, P. 2018b. Assessments of orange roughy stocks in SIOFA statistical areas 1, 2, 3a, and 3b. SAWG(2018)-01-06 Rev 1, SIOFA. Available at:

https://siofa.org/sites/default/files/documents/meetings/SC-03-

07.1.1%2805%29Rev1%20Assessment%20of%20orange%20roughy%20stocks%20SIOFA%20Areas%201%2C%202%2C%203a%20and%203b.%20Cordue%2C%202018_0.pdf

Roa-Ureta R. et al. 2022. Stock Assessment of the orange roughy (*Hoplostethus atlanticus*) under management by the Southern Indian Ocean Fisheries Agreement (SIOFA): 2000 to 2020. SC-07-35, SIOFA. Abstract available at:

https://siofa.org/sites/default/files/documents/meetings/SC-07-35-%5BABSTRACT%5D-ORY-stockassessment-2021-v4-reduced.pdf The full version will be made available on request to the successful consultant.