Age Composition of Orange Roughy in the Eastern and Southern Management Zones

Final Report

D. C. Smith, S. G. Robertson and A. K. Morison

Project No. 95/032

FISHERIES
RESEARCH &
DEVELOPMENT
CORPORATION

MARINE & FRESHWATER
RESOURCES INSTITUTE

Age Composition of Orange Roughy in the Eastern and Southern Management Zones

Final report

D. C. Smith, S. G. Robertson and A. K. Morison

Fisheries Research & Development Corporation
Project No. 95/032

July 1998

ISBN: 0 7311 4219 5

Marine and Freshwater Resources Institute
PO Box 114
Queenscliff VIC 3225

Table of Contents

95/032 Age Composition of Orange Roughy in the Eastern and Southern Management Zones

Principal Investigator: **David C. Smith**

Address: **Marine and Freshwater Resources Institute**
PO Box 114
Queenscliff VIC 3225
Telephone: 03 5258 0111 Fax: 03 5258 0270

Objectives:

1. To compare the age composition in the Eastern and Southern Management Zones and estimate mortality rates.
2. To assess the degree of recruitment variability.
3. To examine stock structure using otolith morphometrics.

Non-Technical Summary

Orange roughy is an important species in the South East Fishery (SEF). The main areas in the SEF where orange roughy fishing has occurred are a major spawning aggregation off the east coast of Tasmania (the Eastern Management Zone) during winter and on non-spawning summer aggregations of the south coast of Tasmania (the Southern Management Zone). Some data support separate stocks off eastern and southern Tasmania with an undetermined amount of mixing. The current uncertainty in stock structure has important management implications, particularly on the size of the TAC that should be applied to the fishery. The results of a previous study of orange roughy age composition in 1992/93 indicated that there were some differences in age composition between zones and there were indications of episodic recruitment. Analyses of otolith morphometrics indicated that there were significant differences between samples from the two areas. However, because samples were taken during different seasons (i.e. winter and summer), interpretation of results was difficult.

This proposal was to repeat the earlier study and include samples from both areas during summer and winter.

Orange roughy were sampled from commercial landings from the Eastern and Southern Management Zones during winter 1995 and again in summer 1995/96. Fish were sampled in Tasmanian and Victorian ports. Saggital otoliths were extracted from each fish and length (cm SL) and sex recorded. Otoliths were processed at the Central Ageing Facility (CAF).

The age and size compositions were compared between areas and season, and with the results of the earlier study. Mortalities were estimated using catch curve analysis and Chapman and Robson’s method.

In the original application it was intended to use otolith morphometrics and Fourier shape analysis as the basis for examining stock structure. Preliminary, but extensive, analysis of otolith morphometrics cast doubt on the efficacy of this approach. A range of statistical techniques were used and significant differences between zone and

season were found. However, the results were ambiguous and extremely difficult to interpret.

Fourier analysis of otolith shape proved considerably more useful. Fourier shape analysis results in mathematical descriptions of an outline or silhouette that can be used to describe the shape and allow quantitative comparison. Approximately 400 otoliths were digitised from each area and each season and the Fourier series calculated using the CAF's image analysis system.

The amplitude of the first twenty harmonics from the Fourier series were used in the analyses. Low-order descriptors describe the gross features while high-order descriptors describe finer detail. Values were standardised for otolith size. Mean harmonic values were calculated for each area and season. Bootstrapping and randomisation tests were used to assess statistical significance.

Over 4000 orange roughy were sampled during this study. Length frequency distributions were typical of orange roughy from commercial landings. Overall, during winter, orange roughy sampled from eastern Tasmania were slightly larger than for those from the south. During summer the difference between areas was more pronounced but opposite to that in the winter. Fish ranged in age from 14 to 162 years but most fish were aged between 25 and 75 years. There were differences in age compositions between zones particularly during summer, when there was a greater proportion of old fish in samples from southern Tasmania, than for the east coast. The summer age composition from southern Tasmania was also quite different from other season/area combinations, with indications of a second mode/plateau at 50-70 years, particularly for females. For eastern Tasmania, the age composition in winter had relatively more older fish with a mode at 30-50 years compared to 25-35 years during summer. In summary, there were a greater proportion of larger and older fish in eastern samples during winter. The reverse was the case in the Southern Zone. These results were consistent with a movement of larger fish from south to east to the winter spawning aggregation.

Depending on the age groups used in the analyses, mortality rates calculated by both methods were similar and extremely low but were consistent with other studies. However, mortality rates for the Southern Zone in summer were consistently lower than all other area/season combinations. The significance of this is unclear but reflects the differences in age composition referred to above. For the east (winter), mortality rates ranged from 0.049 - 0.071 and for the south (summer), 0.026 - 0.033.

The results also suggest some recruitment variability, particularly in samples from the Southern Zone during summer, but there was no clear pattern across all area/season combinations.

For the winter spawning fishery, the results of this study show a marked shift to the left (i.e. smaller and younger fish) in the size/age distributions compared to 1992. For example the modal age in 1995 was 45 years compared to 50-60 in 1992. Similarly, there was a flattening of the size distribution and shift to the left in the age composition in southern summer samples (modal ages 50 and 33, for 1992/93 and 1995/96, respectively).

These results were surprising. Given the number of age classes in the exploited population it was not expected that the age/size distributions would change appreciably in the short term (e.g. a 20 year shift in modal age in 5 years). Possible explanations are that recruitment is variable (and there is evidence for this in the age compositions) and a larger number of recruits has entered the fishery than in previous years, or the decreasing population size has led to individuals maturing earlier, and therefore entering the fishery earlier. Some combination of both is also feasible.

The results of the Fourier shape analysis indicated significant differences in otolith shape within seasons between areas, and within areas between seasons, but not between areas and seasons. For example, there were no significant differences between the winter samples from the Eastern Zone and the summer samples from the Southern Zone. Conversely there were significant differences between summer and winter for the Eastern Zone. These analyses suggest the presence of two distinct stocks. The most likely distribution pattern for these stocks is one numerically dominant stock, which moves from eastern Tasmania in winter to more southerly latitudes in summer, and a second stock which occurs in lower numbers in both areas at all times of the year. The alternative distribution pattern is two distinct stocks which are migratory between the eastern and southern fishery with little or no mixing

Although orange roughy in the SEF may be one population genetically, the existence of some stock structure is suggested by parasite, otolith chemistry, other biological information and this study. However, the results of this study suggest that for management purposes orange roughy in the Eastern Zone during winter and the Southern Zone during summer should be considered as one stock.

Background

Orange roughy is a major species in the South East Fishery (SEF). The first substantial catches were taken in 1986 from non-spawning aggregations off the west coast of Tasmania. Catches increased dramatically to 26,000 t in 1989 and 41,000 t in 1990 following the discovery of a major spawning aggregation of the east coast of Tasmania and non-spawning aggregations of the south coast. Catches have subsequently declined following the introduction of TACs and ITQs. In 1996 the total TAC for orange roughy was 6,500 t (the allocated TAC was almost 8000 t) (Chesson 1997).

In the SEF there are three major management zones, the Eastern, Southern and Western (Figure 1). In 1996 TACs were 2000 t (1940 t allocated), 3000 t (4208 t allocated) and 1500 t (1804 t allocated) for the Eastern, Southern and Western Management Zones respectively. In recent years increased catches have also come from the Remote Zone.

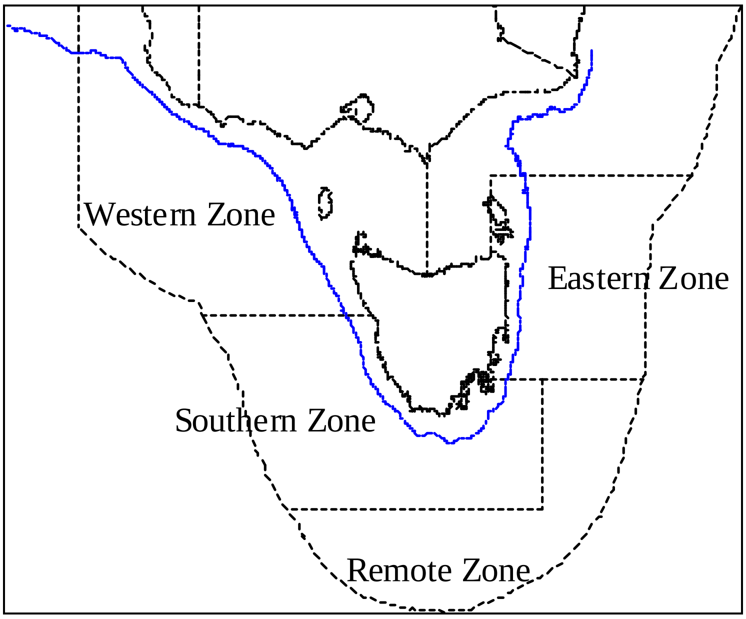


Figure 1. Orange roughy management zones of the South East Fishery. Fish were sampled from commercial landings from eastern and southern Tasmania, the Eastern and Southern Management Zones.

Spawning orange roughy have been taken throughout south-eastern Australia, but the only known major spawning aggregation is off St Helens in the Eastern Zone (Bell *et al.* 1992). A egg survey of the Southern Management Zone (Lyle 1991) did not indicate the presence of a large spawning aggregation off southern Tasmania. Similarly, industry surveys of the Western Zone failed to locate a large spawning aggregation (Smith and Smith 1993, Smith *et al.* 1994). A pilot egg survey in the Western Zone also led to the conclusion that a large spawning aggregation was unlikely in the survey area (Knuckey and Smith 1997).

Although orange roughy in the SEF may be one population genetically, the existence of some stock structure is suggested by parasite, otolith chemistry, and other biological information (Lester *et al*. 1988, Black and Dixon 1989, Ovenden *et al*. 1989, Edmunds *et al*. 1991, Elliott and Ward 1992, Smolenski *et al*. 1993, Elliott *et al.* 1994, Elliott *et al.* 1995). The data that are consistent suggest a difference between stocks off NSW and eastern Tasmania. Some data support separate stocks in the Eastern and Southern Management Zones with an undetermined amount of mixing at the St. Helens spawning hill (Anon 1995). The appropriateness of management zones in relation to stock structure is not known. There remains uncertainty about the relationships between orange roughy in each zone, particularly the Eastern and Southern zones where the main fishery occurs.

Orange roughy are extremely long-lived (Smith *et al*. 1995) with a maximum age in excess of 100 years and an age at maturity of about 30 years. The age composition of orange roughy catches was estimated for the Eastern and Southern zones from samples taken in July 1992 and January 1993, respectively (Anon 1995). The work was undertaken by the Central Ageing Facility from the examination of sectioned otoliths using the method of Smith *et al.* (1995). These data have been used extensively in Australian and New Zealand assessments, particularly in the estimation of natural mortality and implications of recruitment variability (Francis and Smith 1994; Chesson 1997, Bax 1997).

These data also indicated that there are some differences in age composition between zones and there are indications of episodic recruitment. The use of otolith morphometrics to discriminate between fish stock has proved successful for some species (eg Hopkins 1986; Messieh *et al* 1989). Similarly, Fourier analysis of otolith shape has also been used (Bird et 1986; Castonguay *et al* 1991; Friedland and Reddin 1994). Analyses of orange roughy otolith morphometrics indicated that there were significant differences between samples from the two areas (Anon 1995). However, because samples were taken during different seasons (i.e. winter and summer), interpretation of results was difficult.

This proposal was for the Central Ageing Facility to repeat the earlier study but for sampling to be undertaken in both areas during summer and winter.

Need

The current uncertainty in the orange roughy stock structure has important management implications, particularly in the size of the TAC that should be applied to the fishery. The results of the previous study indicate that there are significant differences between areas. However, because samples were taken during different seasons, interpretation of results is difficult. Sampling both areas during summer and winter will enable the within and between season differences in age composition and otolith morphology to be determined.

In their review of the 1994 Australian orange roughy assessment, Deriso and Hilborn recommend that further research on stock structure be performed. They recommend that age samples be collected during 1995 to provide a cross check on features of the 1992 age sample and to determine whether growth has changed in response to stock depletion. Deriso and Hilborn identified the following key areas that should be examined:

- the selectivity ogive; the 1992 data suggest full recruitment does not occur to about 50 years.
- natural mortality; recent analyses has shown that the estimate of natural mortality (0.046) derived from the age composition data may be to low.
- evidence for episodic recruitment
- estimates of annual variation in year class strength

The proposed project will address these areas.

The South East Fishery Assessment Group (SEFAG) identified further ageing of orange roughy in 1995/96 as a research need. (Staples and Tilzey 1994)

Objectives

1. To compare the age composition in the Eastern and Southern Management Zones and estimate mortality rates.
2. To assess the degree of recruitment variability.
3. To examine stock structure using otolith morphometrics

Methods

Collection of otoliths

Orange roughy were randomly sampled from commercial landings from the Eastern and Southern Management Zones during winter 1995 and again in summer 1995/96. Fish were sampled in Tasmania and Victoria. However, it proved difficult to obtain adequate samples from the east coast of Tasmania during summer. Consequently, arrangements were made with AFMA to charter a vessel on a charter for quota basis to obtain additional samples (A cruise report is given in Appendix 3).

Saggital otoliths were extracted from each fish and length (cm SL) and sex recorded. A total of sample of 4039 otoliths were taken. Numbers by area and season are shown in Table 1.

Table 1 Number of orange roughy sampled from commercial landings July 1995 - March 1996 by area (Eastern and Southern Management Zones) and season.

Season	East	South	Total
Winter	1618	1030	2648
Summer	432	959	1391
Total	2050	1989	4039

Target numbers (approximately 1000 otoliths per area season) were met except for the east coast during summer, despite the vessel charter. Considerable time and resources were spent trying to improve sample sizes for the Eastern Management Zone during summer but due the apparent low numbers of orange roughy being caught a larger sample size was not possible.

Otolith preparation and age determination

Otoliths were processed at the Central Ageing Facility. To ensure age estimates were unbiased otoliths were sub-coded and ages obtained with no reference to zone, season, sex or length.

Otoliths were weighted to the nearest milligram. A comparison of the weight of left and right otoliths using a paired t test showed no significant difference at the 0.05 level.

One otolith was sectioned using the methods described by Smith *et al.* (1995). Briefly the method is as follows. Otoliths were embedded in a block of clear polyester resin and sectioned, longitudinally, along the anterior/posterior axis, using a "Gemmasta" circular saw with a diamond blade of 0.15 mm thickness. Sections were approximately 0.2-03 mm thick. No further preparation was required other than to mount them on slides with a clear mountant and cover slip. In most cases, three sections were taken through each otolith to ensure that a section was obtained through the primordium. Increments were counted using a compound microscope at magnifications of 40 and 100 times.

The number of increments before the last major zone (LMZ) seen in otolith sections prior to the finer increments at the tip was also recorded. This is equivalent to the transition zone, a term used by New Zealand workers, and is regarded as indicating age-at-maturity.

A random sub-sample was re-aged by a second reader to allow calculation of precision estimates

Age composition and mortality rates

The age composition was compared between areas and season, and with the results of the earlier study (Anon 1995). Mortalities were estimated using catch curve analysis and Chapman and Robson's (1960) method. The maximum likelihood estimator is:

$$\hat{M} = \ln\left(\frac{1+\bar{A}-T_c}{\bar{A}-T_c}\right)$$

where T_c is the age after which fish are fully recruited

and $\bar{A}$ is the mean of ages $\geq T_c$

The approximate variance of $\hat{M}$ is :

$$\text{var}(\hat{M}) \approx \frac{1}{n}(e^{\hat{M}} - 2 + e^{-\hat{M}})$$

where n is the total number of fish with ages $\geq T_c$

Curves were fitted, by least squares, to observed age composition for ages greater than Tc using the relationship:

$$N_a = N_{tc} \exp(-M(a-Tc))$$

Residuals were plotted for predicted - observed numbers at age

For species which are extremely long-lived, and have an old age at recruitment, the current age composition and right-limb of catch curves should continue to provide a valid estimate of natural mortalily even after several years of fishing mortality. Therefore it is assumed that *M* is equivalent to *Z.*

Stock Structure

In the original application it was intended to use otolith morphometrics and Fourier shape analysis as the basis for examining stock structure. The results of a previous study (Anon 1995) indicated that although otolith morphometrics were useful there were no apparent differences in otolith shape between areas. In the present study, nine individual measurements of the dimensions each otolith were taken. These were total otolith length, three measures of length from the otolith primordium, two widths, otolith depth, area, and circularity. Otolith weight was also considered.

Preliminary, but extensive, work cast doubt on the efficacy of this approach. GLM, multi-dimensional scaling (MDS), and MANOVA were used and significant differences between zone and season were found. However, the results were ambiguous and were extremely difficult to interpret. For example, from the MDS it was concluded that there were no universal significant differences between groupings for the morphometric variables, however, there were significant groupings for some ages. Similarly, although MANOVA showed large interactions with these variables, the interactions were not consistent across ages. Consequently, this approach was not continued.

Fourier analysis of otolith shape proved considerably more useful. Fourier shape analysis results in mathematical descriptions of an outline or silhouette that can be used to describe the shape and allow quantitative comparison (Bird *et al*. 1986). Fourier descriptors (harmonics) of otolith shape can be generated by taking either polar or cartesian coordinates. The former are generated by taking a Fourier expansion of radius vectors drawn from the centroid of a shape as a function of the angle about the centroid (Bird *et al*. 1986, Castononguay *et al* 1991). Points at the boundary are sampled at equal angles using the centroid as the origin. The second approach (Cartesian coordinates) involves taking equally spaced coordinates along the boundary or perimeter of the shape (Friedland and Reddin 1994). Low-order descriptors describe the gross features while high-order descriptors describe finer detail (Castononguay *et al* 1991).

Approximately 400 otoliths were digitised from each area and each season and the Fourier series calculated using Optimas. All analyses were undertaken using Cartesian coordinates. Because of the complex shape of orange roughy otoliths (Figure 2) radii from the computed centroid (with polar coordinates) can cross two boundaries. This causes errors in the reconstructed shape that is not detected by the software.

The amplitude of the first twenty harmonics (excluding the zero*th* harmonic) from the Fourier series were used in the analyses. Values were standardised for otolith size by dividing the n*th* harmonic by the zero*th* harmonic. Mean values were calculated for each harmonic. These values were compared between area and/or season by collapsing the two sets of means under test to one scalar value using the relationship:

$$\mathrm{Scalar\_value} = \sqrt{(\overline{\mathrm{H1}}_{area1} - \overline{\mathrm{H1}}_{area2})^2 + (\overline{\mathrm{H2}}_{area1} - \overline{\mathrm{H2}}_{area2})^2 + \ldots + (\overline{\mathrm{H20}}_{area1} - \overline{\mathrm{H20}}_{area2})^2}$$

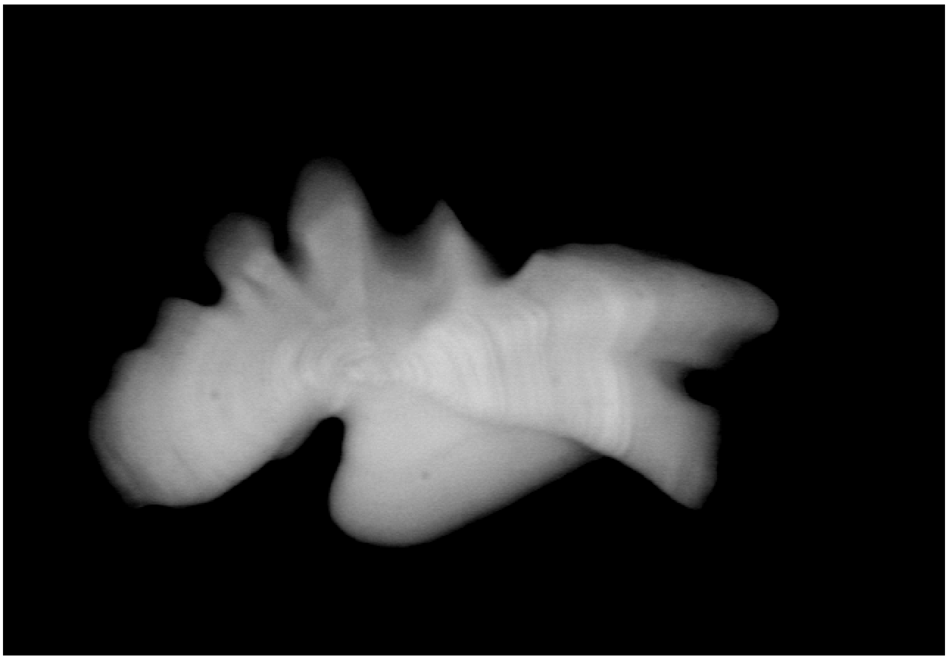


Figure 2 The complex morphology of an *Hoplostethus atlanticus* otolith

Bootstrapping (Efron and Tibshirani 1993) and randomization tests (Haddon 1996) were used to assess statistical significance.

Results

Length frequency distributions and age compositions

Length frequency distributions were typical of orange roughy from commercial landings (Figure 3 and 4). Distributions were uni-modal; fish ranged in length from 21 to 50 cm SL but most fish were in the 30 to 40 cm size classes. Modal sizes were higher for females than males.

Figures 3 and 4 show comparisons between areas within seasons and between seasons within areas, respectively. Overall, during winter, orange roughy sampled from eastern Tasmania were slightly larger than for those from the south. During summer the difference was more pronounced and opposite to that in the winter. Fish sampled from the south were relatively more abundant in the larger size classes.

For eastern Tasmania, orange roughy were, overall, slightly larger during winter than summer. For southern Tasmania, the reverse was true with fish relatively larger in summer.

The total number successfully aged was, 3266, 81% of orange roughy sampled. The number not aged was due to a combination of poor or failed preparation and/or difficulty in interpretation. The size distribution of fish not aged was almost identical to those aged indicating there was no apparent bias due to, for example, otoliths from larger (older) fish being harder to age (Figure 5).

Fish ranged in age from 14 to 162 years but most fish were aged between 25 and 75 years. The age frequency for combined areas and saesons was generally uni-modal with a mode at 30-40 years with a relatively consistent decline followed by a long tail. For clarity, fish were grouped into 5-year classes. Like the length frequency distributions there were clear differences between area and season (Figures 6 and 7). In summer, there was a greater porportion of old fish in samples from southern

Tasmania than in those from the east coast. The summer age composition from southern Tasmania was also quite different from other season/area combinations, with indications of a second mode/plateau at 50-70 years, particularly for females. summer sampes. For eastern Tasmania, the age composition in winter had relatively more older fish, with a mode at 30-50 years compared to 25-35 years during summer.

In summary, there were a greater proportion of larger and older fish in eastern samples during winter. The reverse was the case in the Southern Zone.

Winter **Summer**

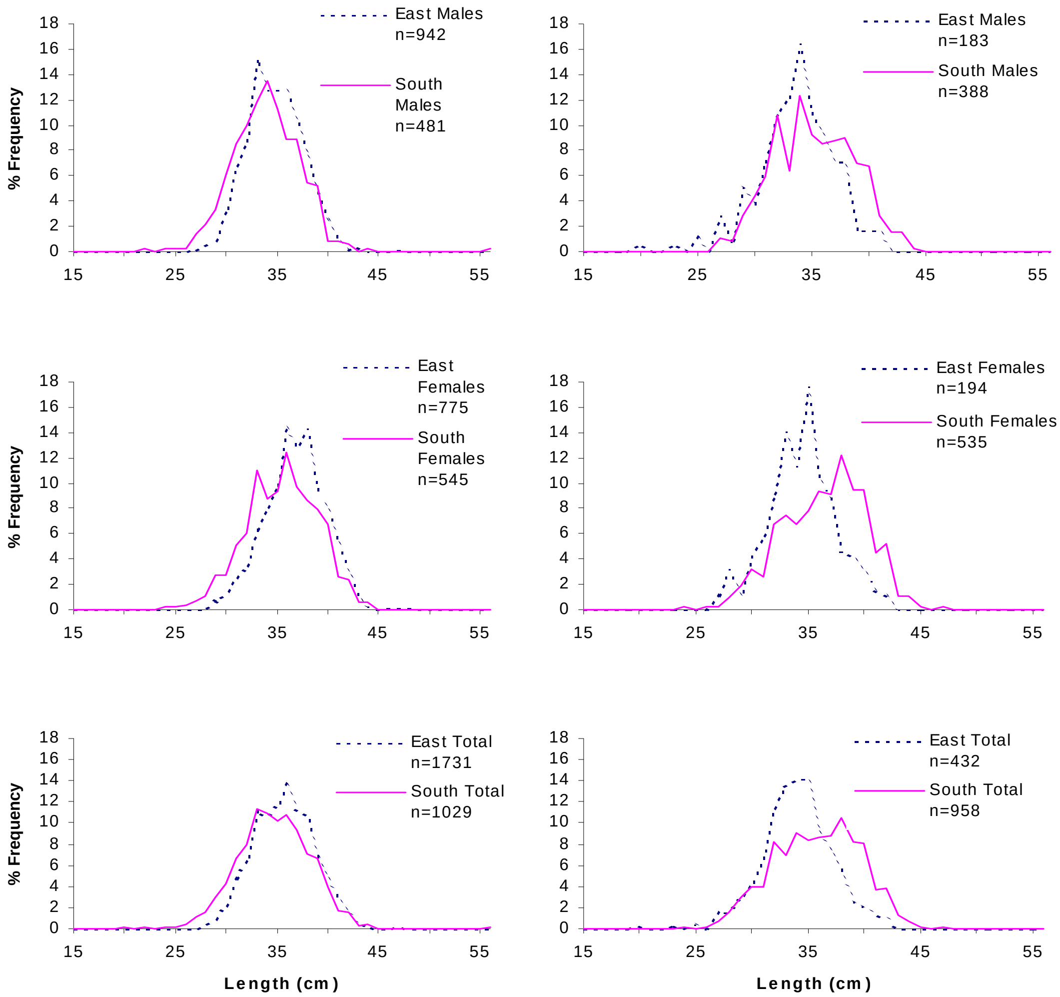


Figure 3 Percentage length frequency distributions for orange roughy sampled from commercial landings by season from the Eastern and Southern Management Zones.

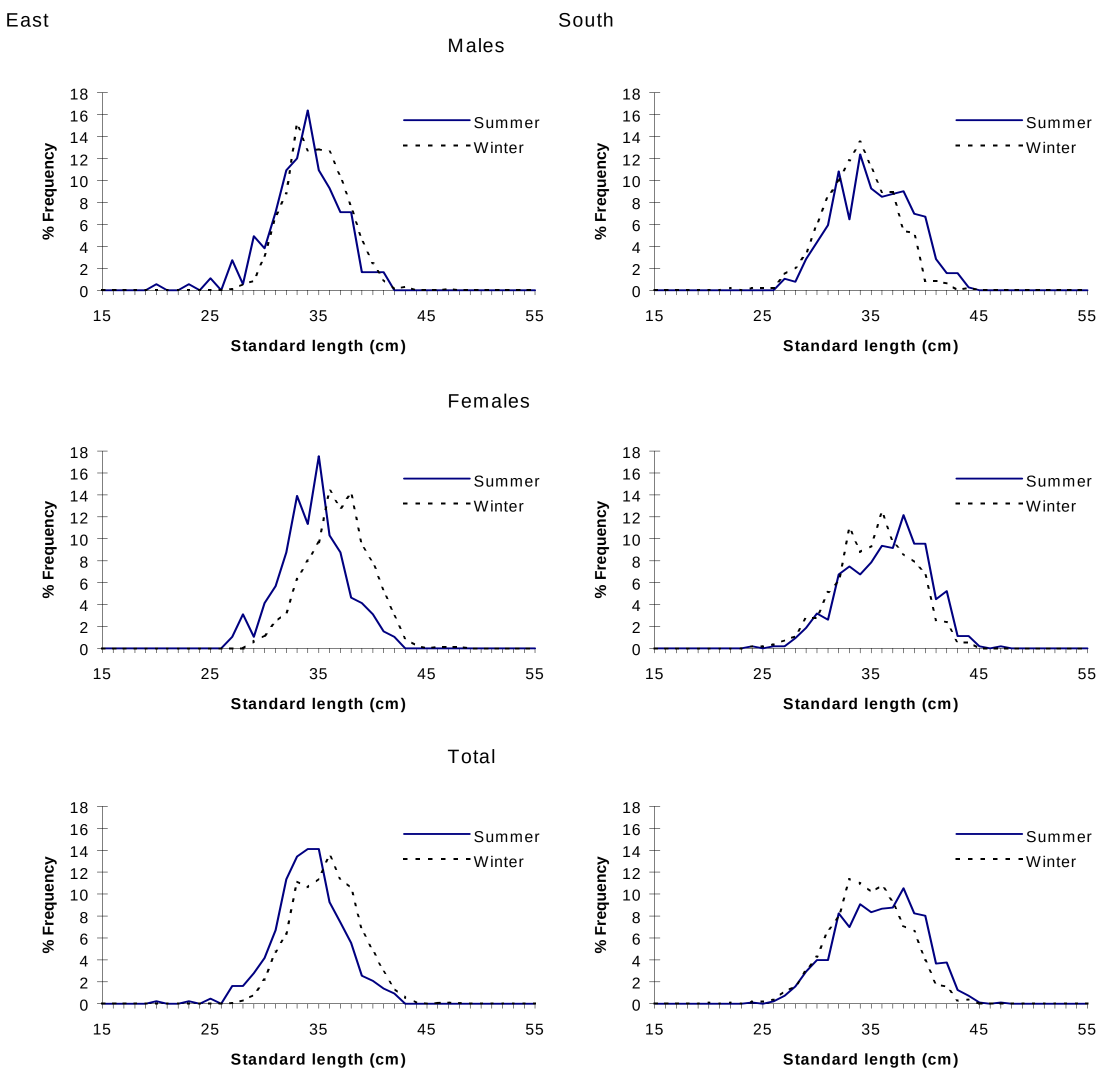


Figure 4 Percentage length frequency distributions for orange roughy sampled from commercial landings by zone during winter and summer.

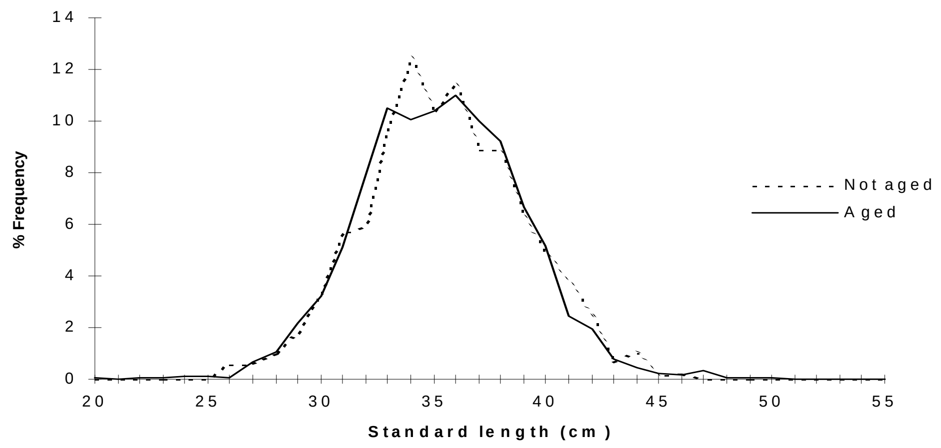


Figure 5 Comparison of percentage length frequency distributions for orange roughy aged with those for which ages were not assigned.

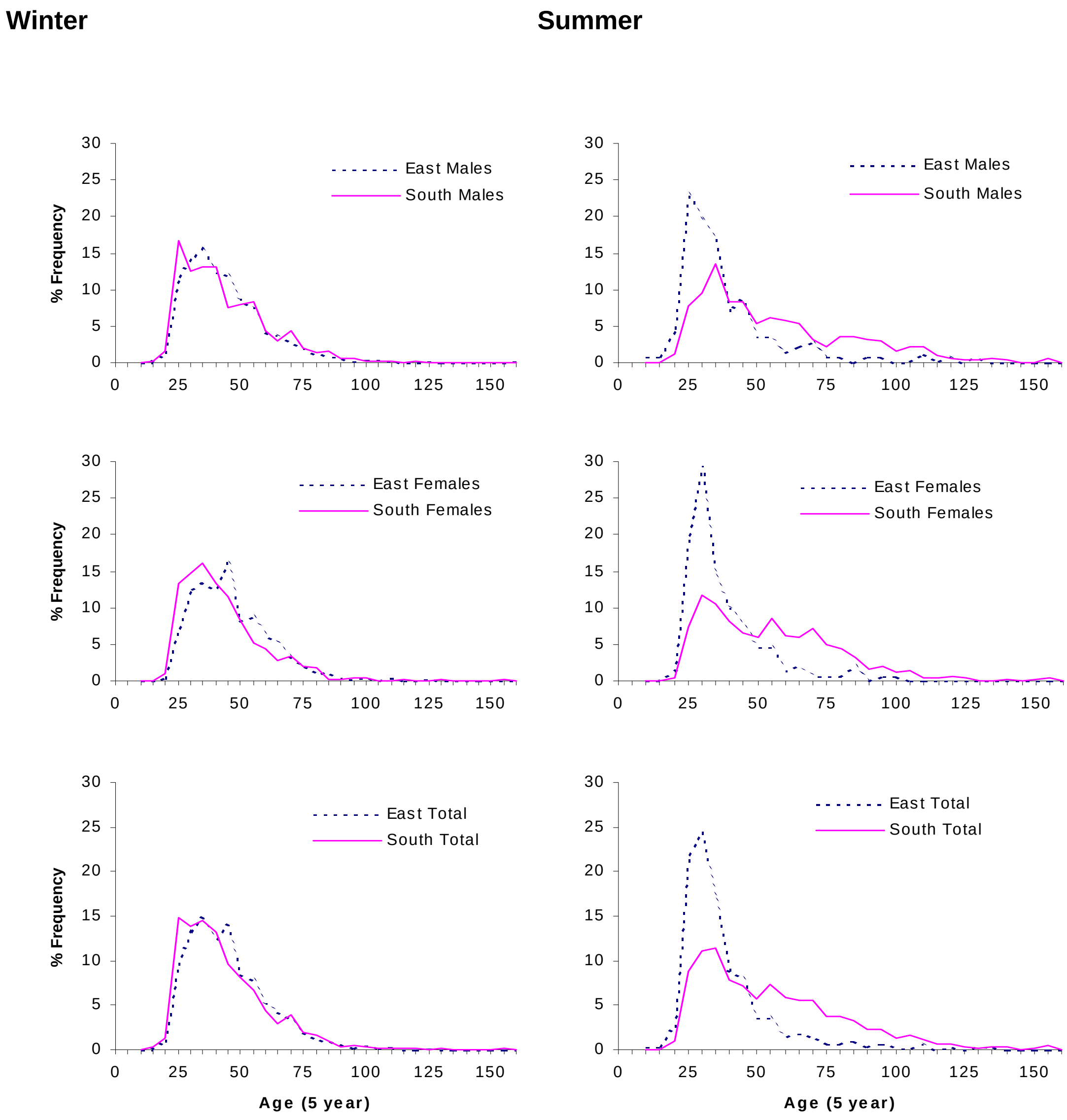


Figure 6 Percentage age compositions for orange roughy by season for orange roughy sampled from the Eastern and Southern Management Zones

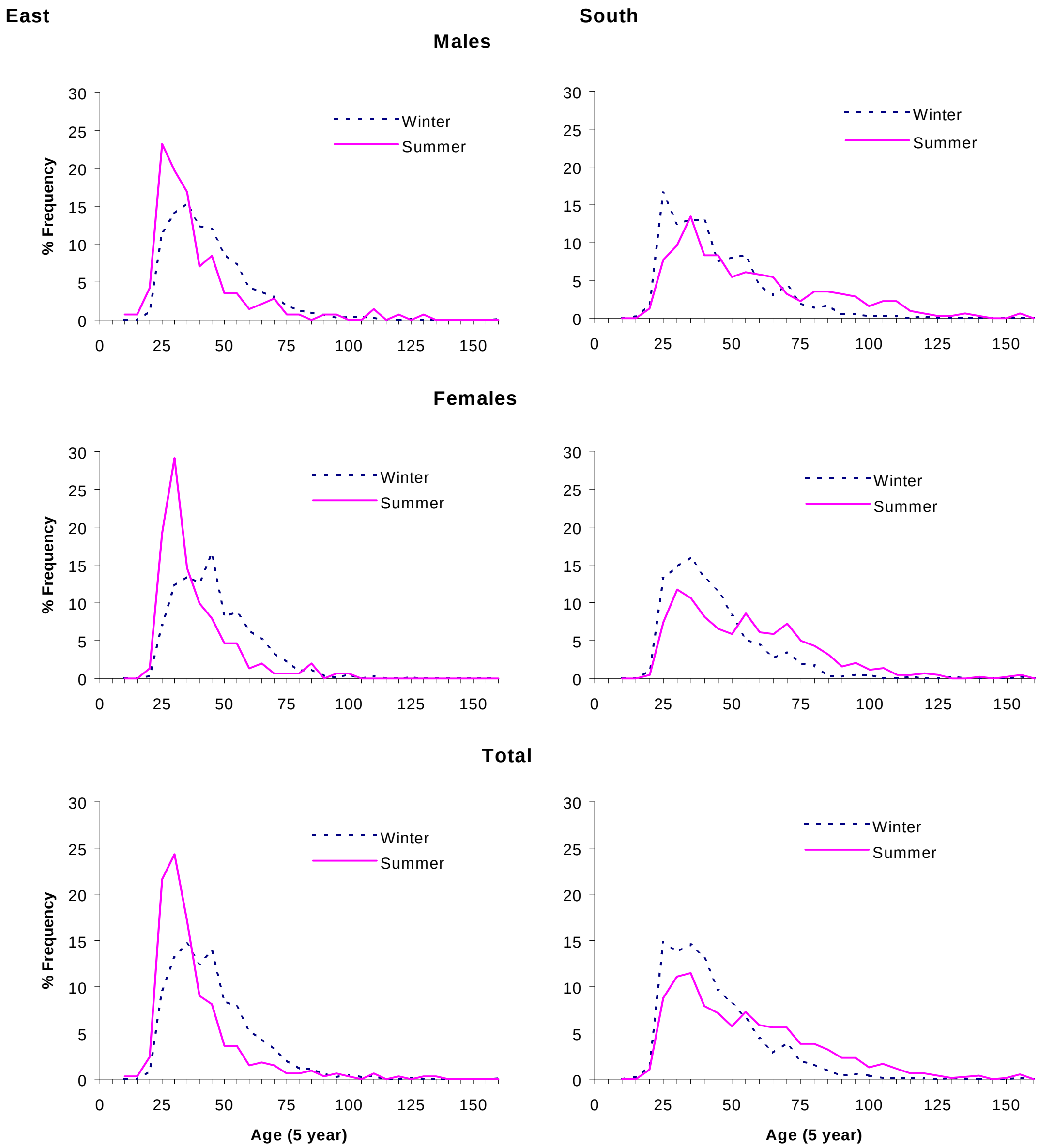


Figure 7 Percentage age compositions for orange roughy by zone for orange roughy sampled during winter and summer.

Mortality rates and recruitment variability

Mortality rates calculated from catch curve analysis for a range of age groups (30-80, 40-80, 50-80 and 30-100, 40-100, 50-100) are shown in Table 2. These ranges were based on inspection and to allow comparison with previous studies. Mortality rates and cvs estimated using Chapman and Robson's method are given in Table 3. Figures 8 and 9 show plots of fitted survival curves and residuals for the main fisheries. Catch curves and mortality/residuals for east summer and south winter are given in Appendix 4.

Depending on the age groups used in the analyses, mortality rates calculated by both methods were similar and extremely low but were consistent with other studies. However, mortality rates for the Southern Zone in summer were consistently lower than all other area/season combinations. The significance of this is unclear but reflects the differences in age composition referred to above. For the east (winter), mortality rates ranged from 0.049 - 0.071 and for the south (summer), 0.016 - 0.033.

The plots of residuals also suggest some recruitment variability, particularly in samples from the Southern Zone during summer, but there was no clear pattern across all area/season combinations.

Table 2 Results of catch curve analysis for orange roughy sampled 1995/96 by zone and season. The slope of linear regressions through selected age groups represent mortality. Catch curves are shown in Appendix 4.

Age Groups		**East Summer**	**South Summer**	**East Winter**	**South Winter**
30-80	Slope	-0.075	-0.020	-0.049	-0.047
	R^2	0.966	0.855	0.909	0.948
30-100	Slope	-0.061	-0.023	-0.060	-0.057
	R^2	0.931	0.934	0.934	0.948
40-80	Slope	-0.070	-0.016	-0.060	-0.052
	R^2	0.941	0.754	0.953	0.954
40-100	Slope	-0.055	-0.022	-0.067	-0.062
	R^2	0.903	0.904	0.953	0.954
50-80	Slope	-0.064	-0.018	-0.066	-0.054
	R^2	0.884	0.628	0.955	0.914
50-100	Slope	-0.049	-0.024	-0.071	-0.065
	R^2	0.849	0.892	0.947	0.914

Table 3 Results of mortality estimation using the Chapman and Robson (1960) method for a range of age at full recruitment (Tc).

	East		South	
	Summer	Winter	Summer	Winter
Tc 40	40	40	40	40
M	0.056	0.060	0.033	0.058
cvs	0.094	0.035	0.042	0.049
Tc 30	30	30	30	30
M	0.066	0.050	0.029	0.040
cvs	0.063	0.029	0.036	0.039
Tc Mode	31	45	33	29
M	0.069	0.067	0.033	0.052
cvs	0.064	0.039	0.038	0.038

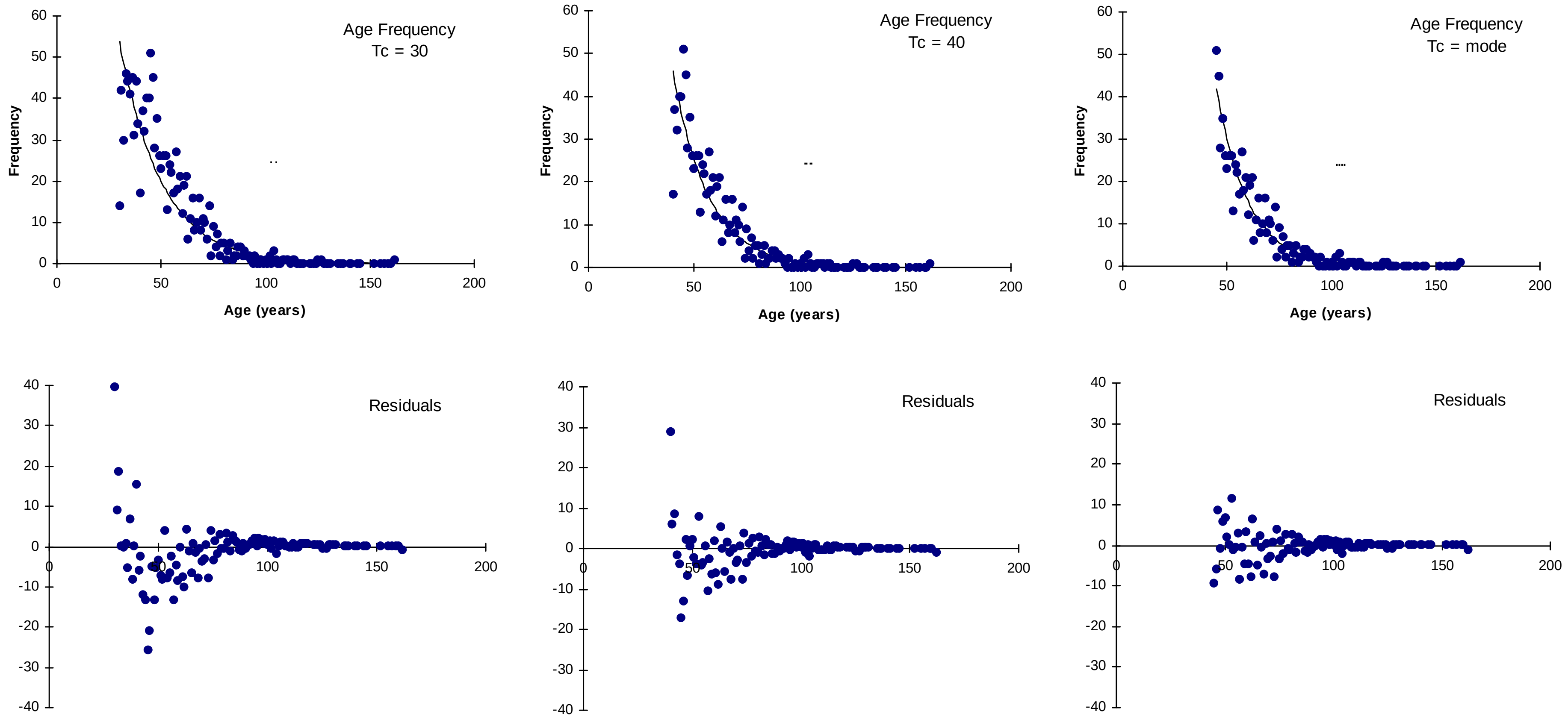


Figure 8 Estimated survival curves, observed age composition and residuals for orange roughy samples from the Eastern Management Zone, winter 1995.

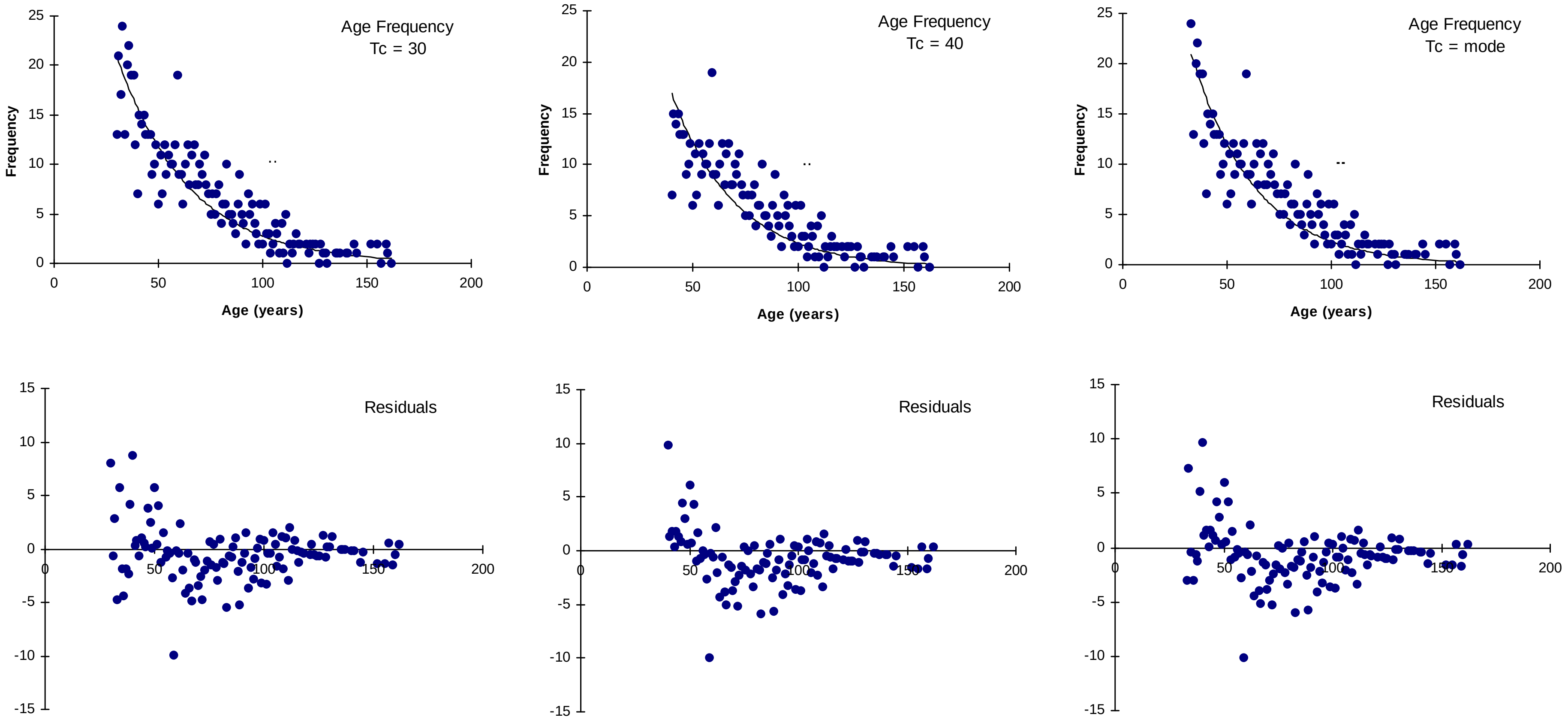


Figure 9 Estimated survival curves, observed age composition and residuals for orange roughy samples from the Southern Management Zone, summer 1995/96

Comparison of 1995/96 length and age composition with 1992/93

For the winter spawning fishery, the results of this study show a marked shift to the left (i.e. smaller and younger fish) in the size/age distributions compared to 1992. For example the modal age in 1995 was 45 years compared to 50-60 in 1992. Similarly, there was a flattening of the size distribution and shift to the left in the age composition in southern summer samples: modal ages 50 and 33, for 1992/93 and 1995/96, respectively (Figure 10).

The change in age composition was seen in both females and males (Figure 11).

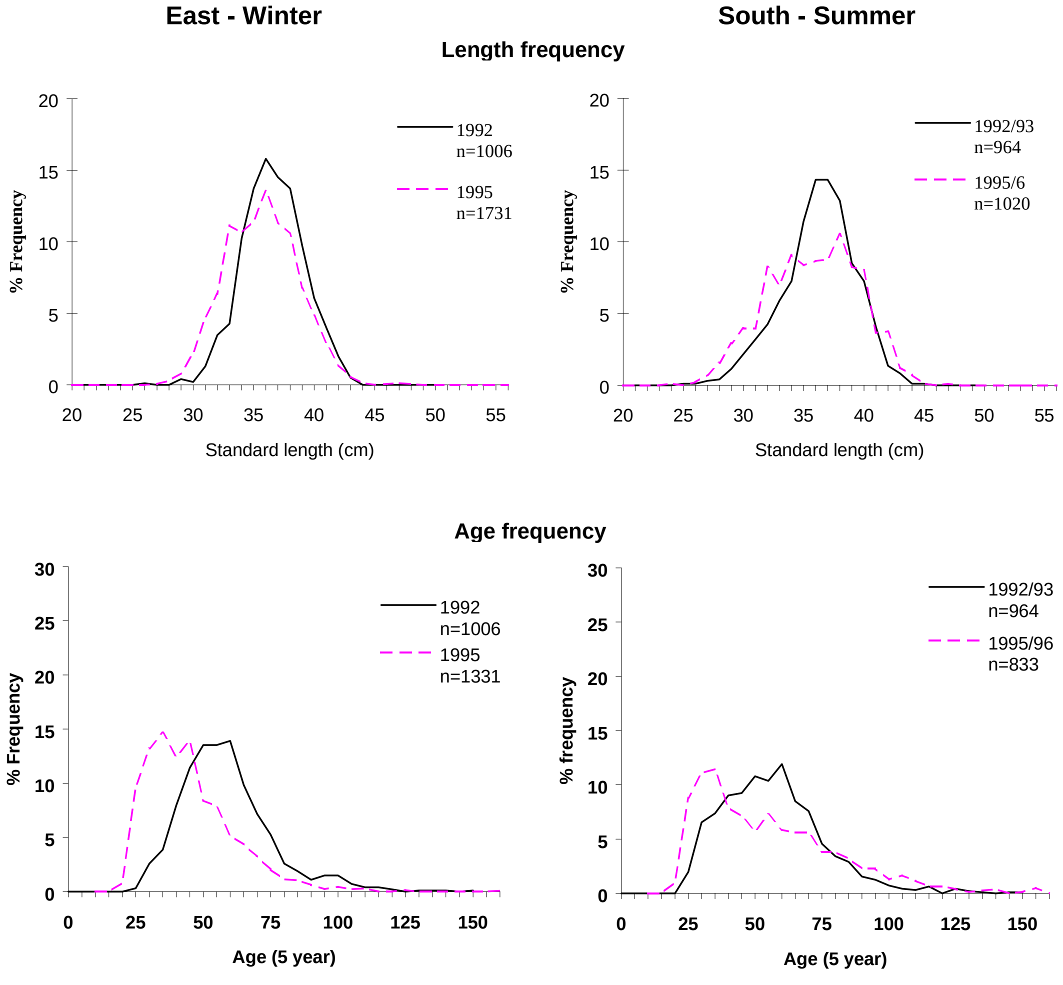


Figure 10 Comparison of orange roughy size and age compositions between 1992/93 and 1995/96.

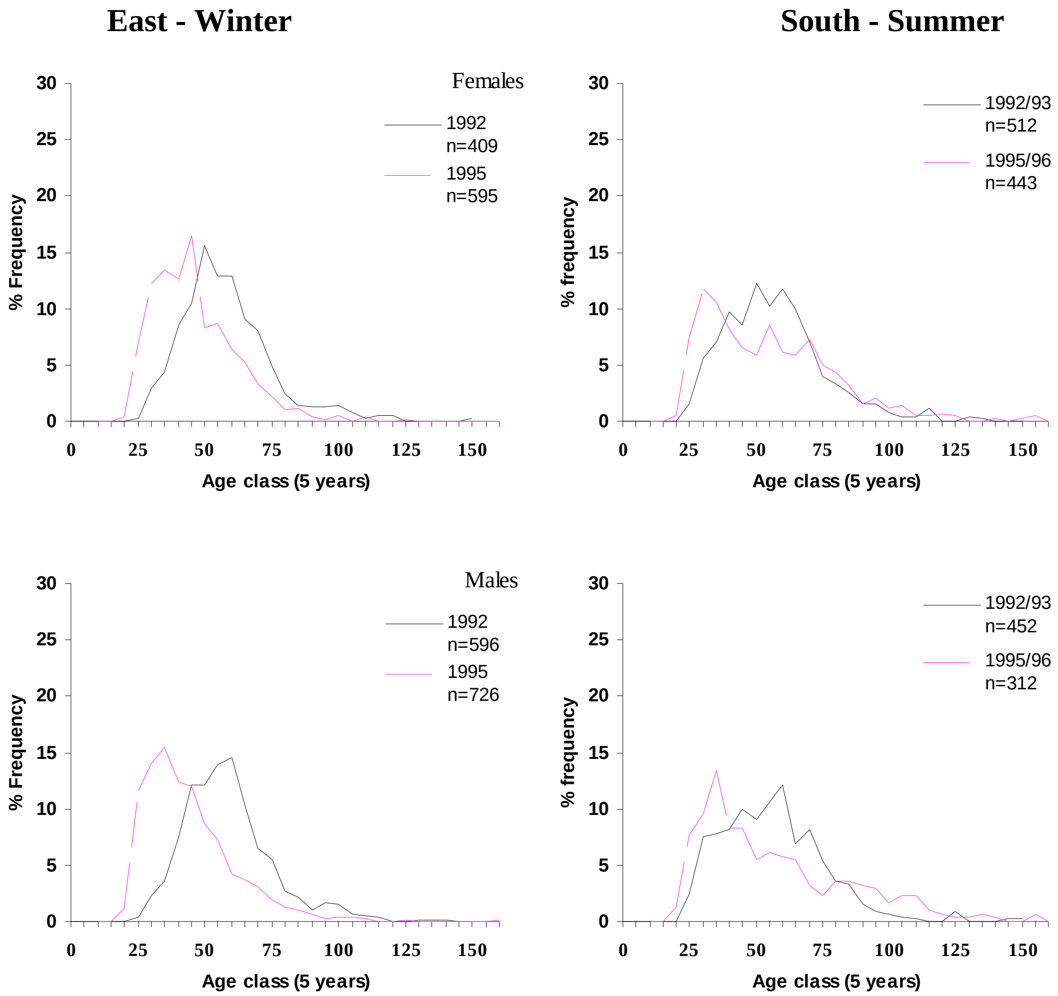


Figure 11 Comparison of female and male orange roughy age compositions between 1992/93 and 1995/96.

Stock structure

Scalar values, calculated from the Fourier analyses, were compared between areas and between seasons. The "distance" between these areas/ seasons is shown in Table 4. If no difference occured the resultant scalar value would be close to zero.

	East - Summer	East - Winter	South - Summer	South Winter
East - Summer		0.0127	0.0152	0.005
East - Winter			0.0071	0.0099
South - Summer				0.011
South - Winter				

Table 4. Scalar values of observed differences in means

Bootstrapping was used to give 95% confidence intervals on the scalar values. This process is random sampling with replacement of the Fourier harmonics to generate new arrays of harmonics from within each area and season and between each area and season. New scalar values were generated for each comparison. This was repeated 4000 times and the frequency distribution of expected scalar values was calculated. The bootstrapped means were bias corrected by:

Bias Corrected Mean = 2 x Observed mean -bootstrapped mean

Confidence values around the bias corrected means were calculated using 95% quantiles on the distribution of bootstrapped scalar values (Figure 12).

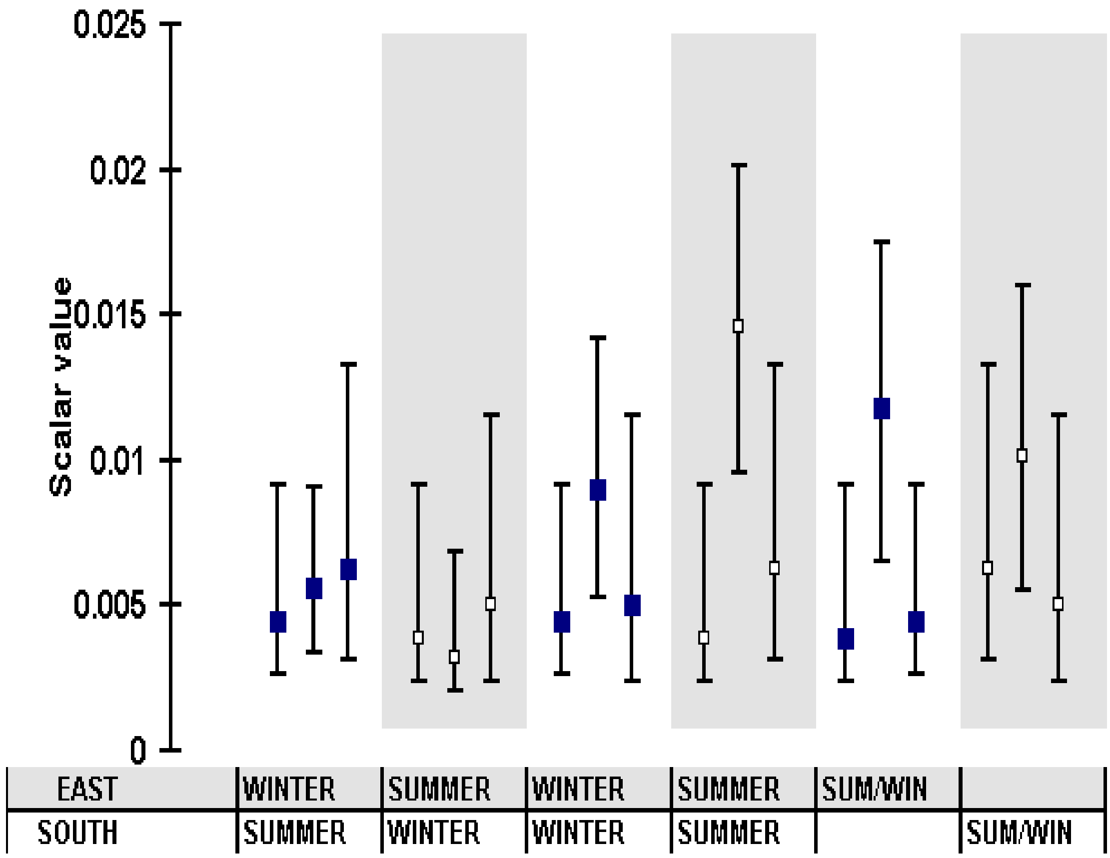


Figure 12. Bootstrapped means and confidence intervals for within and between area/season comparisons. Means and confidence intervals are grouped by threes. The outer represent within comparisons and the inner between.

To assist interpretation means and confidence intervals were also calculated for within each area/season combination. An example of the frequency distributions of bootstrapped scalar values is shown in Appendix 5.

Figure 12 indicates that there were greater differences within seasons between areas and within areas between seasons than for those between areas and seasons. The probability of the observed difference occurring was calculated using a randomization technique. The two groups of harmonic arrays under test were randomly mixed together, new means calculated, then a new scalar value calculated

The randomization procedure was repeated 4000 times. The observed scalar values between comparisons were compared on the frequency distributions produced through randomization to determine the probability of the observed distances occurring.

		East	South	
		Winter	*Summer*	*Winter*
East	*Summer*	0.003	<0.0001	0.510
	Winter		0.206	0.030
South	*Summer*			0.017

Table 5. Results of randomization comparisons. The shaded squares indicate no significant differences.

The results of the randomization tests are shown in Table 5. Appendix 5 shows examples of distributions of randomized scalar values for significant and non-significant comparisons.

The results of this analysis indicated significant differences in otolith shape within seasons between areas and within areas between seasons but not between areas and seasons. For example, there were no significant differences between the winter samples from the Eastern Zone and the summer samples from the Southern Zone. Conversely there were significant differences between the Eastern Zone in summer and winter.

These analyses suggest the presence of two distinct stocks. The most likely distribution pattern for these stocks is one numerically dominant stock, which moves from eastern Tasmania in winter to more southerly latitudes in summer, and a second stock which occurs in lower numbers in both areas at all times of the year as shown in Figure 13. The alternative distribution pattern is two distinct stocks which are migratory between the eastern and southern fishery with little or no mixing (Figure 14).

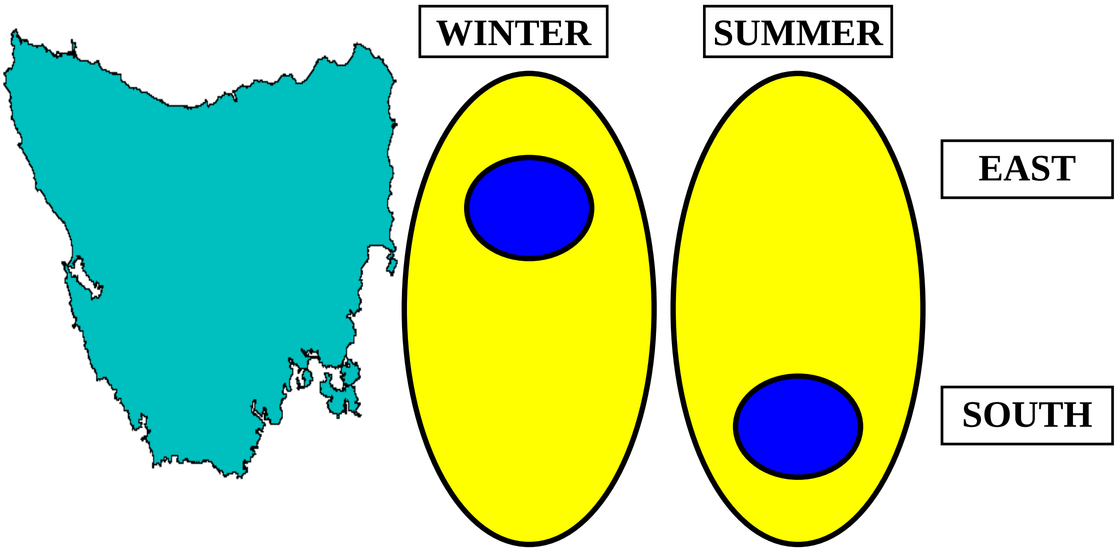


Figure 13. First hypothesis of *Hoplostethus atlanticus* stock structure

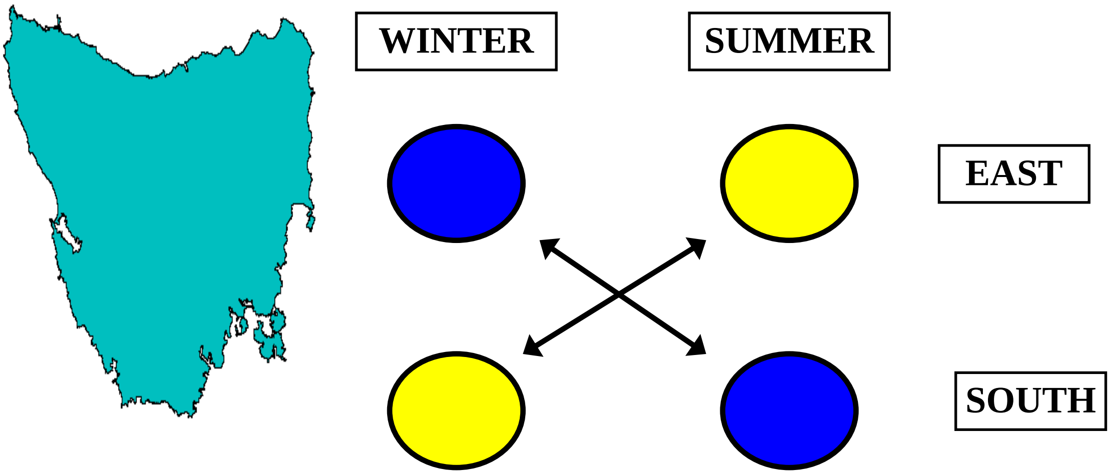


Figure 14. Alternative hypothesis of *H. atlanticus* stock structure.

Discussion

The results presented here are based on the largest sample size taken for age composition in any study of orange roughy. Due to the species' extreme longevity, large sample sizes were required and ages from over 3200 fish were used in this study. Generally the objectives of the project were met although the question of recruitment variability remains uncertain.

The study showed that there were a greater proportion of larger and older fish in eastern samples during winter. The reverse was the case in the Southern Zone with a greater proportion of large and older fish during summer. Population structuring in size between areas has previously been reported (Lyle *et al.* 1991) and in size and age (Anon 1995). These results were consistent with the hypothesis of a movement of larger fish from south to east to the winter spawning aggregation.

For the winter spawning fishery, the results of this study show a marked shift to the left (i.e. smaller and younger fish) in the size/age distributions compared to 1992. Similarly, there was a flattening of the size distribution and shift to the left in the age composition in southern summer samples compared to 1992/93. These results were surprising. Given the number of age classes in the exploited population it was not expected that the age/size distributions would change appreciably in the short term (e.g. an approximately 20 year shift in modal age in 5 years).

There are a number of possible explanations. First, the changes seen could reflect sampling variability. For example, during the 1992/93 study orange roughy from the winter fishery were sampled from late June to early July, whereas in the current study samples were only obtained during early July. However, re-examination of data from the early study did not indicate any significant monthly differences. Additionally, Lyle *et al* (1991) reported little within season difference in size composition. Individual catches are often dominated by one sex or the other, and given the differences in size distributions between sexes potential biases may exist. However, in this study the changes were seen in data for both sexes, Finally, the changes reported here were seen in data for both the Eastern and Southern Zones. It would appear extremely unlikely, therefore, that sampling bias could be a prime contributor to the observed differences between sampling periods.

Alternate explanations are that recruitment is variable and a larger number of recruits has entered the fishery than in previous years, or the decreasing population size (about 30% of virgin biomass in 1995; Nic Bax personal communication) has led to individuals maturing earlier, and therefore entering the fishery earlier. There is evidence for the former in the age composition data, particularly in samples from the Southern Zone during summer, but there was no clear pattern across all area/season combinations. Targeted orange roughy aggregations are composed almost exclusively of adult fish. Juveniles are commonly found on smooth bottom trawl grounds across the SEF. Size compositions of fish on these grounds are typically bimodal (Lyle *et al*. 1991, Smith *et al.* 1995) which has been attributed to slow growth, variable mortality rates or possibly episodic recruitment. There have been no recent surveys from which the latter could be investigated.

Changes in age and size at first maturity in response to fishing pressure and stock depletion have been reported in a number of fisheries (Jorgenson 1988, Rochet 1996, Trippel *et al.* 1997). Given the estimated depletion of the orange roughy stock such a response may be occurring here. However, at this stage, whether the changes seen in the age composition represents episodic recruitment, changing age at maturity or some combination of both cannot be determined.

The results of the Fourier shape analysis indicated significant differences in otolith shape within seasons between areas and within areas between seasons but not between areas and seasons. The previous study (Anon 1992) also found no difference in otolith shape between samples from the south in summer and the east in winter. However, significant differences in otolith morphometrics were reported. This was attributed to growth variability between areas. It appears more likely that this reflected the different age/size compositions in the samples between areas.

Calcified structures, including otoliths, have been used widely as aids to stock discrimination (Casselman *et al.* 1981, Ihssen *et al.* 1981, Bird et 1986; Castonguay *et al* 1991; Friedland and Reddin 1994, Colura and King 1995). However, the mechanisms by which stock-specific otolith shape occurs is less clear. Otolith shape and size varies considerably between species. Indeed, Smale *et al*. (1995) suggests the greater use of otolith morphology in the systematics of teleosts. For within species variation, most studies report that it occurs but discussion of mechanisms is limited to statements about the environment effecting fish calcified structures (eg. Secor *et al.* 1991, Colura and King 1995). Clearly, this is an area which requires further study.

It is suggested that the analyses indicate the presence of two distinct stocks. The preferred hypotheses is a numerically dominant stock, which moves from eastern Tasmania in winter to more southerly latitudes in summer. This is consistent with the changes seen in the size and age composition seasonally. It is also consistent with the reproductive studies of Bell *et al.* (1992) who reported that not all mature female orange roughy spawn each year and that this proportion varies temporally and spatially. The proportion of non-spawners at the St Helens spawning aggregation off the east coast of Tasmania declined toward the spawning period. Conversely the proportion of non-spawners off southern Tasmania increased as the spawning season approached. These results are consistent with a migration of fish from the south to the east during winter.

Although orange roughy in the SEF may be one population genetically, the existence of some stock structure is suggested by parasite, otolith chemistry and other biological information. The results of this study suggest that for management purposes, orange roughy from the Eastern (winter fishery) and Southern Management Zones (summer fishery) should be considered one stock.

Benefits

This project has provided real benefits to the management of the SEF orange roughy fishery. Prior stock assessments have presented results for separate east and southern stocks and for one combined stock. The 1997 orange roughy assessment presented only the combined stock hypothesis as a result of this project thus giving greater certainty to management of the fishery. Additionally the use of Fourier analysis is now being used to assess other orange roughy “stocks”. Current assessment models do not use explicit age composition data. The Orange Roughy Assessment Group recommends that the stock reduction and risk assessment models be extended to include changes in age composition and stock structure to improve the reliability of the assessment in light of the results of this study.

Further Development

Further work on the age composition of orange roughy form Tasmania is proposed. CSIRO has located otolith samples collected from eastern Tasmania during 1987. These data would provide a picture of the age composition prior to intensive fishing. An ARF project has been developed to undertake this work (Nic Bax personal communication). Orange roughy will be sampled during 1998/99 as part of the CAF's SEF workplan. This work will provide additional confirmation of the shift in modal age and enable further examination of the alternate recruitment hypotheses.

Fourier shape analysis is currently being used to assess the stock structure of orange roughy on the South Tasman Rise, particularly inside and outside the EEZ.

Why otolith morphology varies between stocks is poorly understood and further research is needed to determine the factors and mechanisms by which this occurs.

Conclusion

The results presented here are based on the largest sample size taken for age composition in any study of orange roughy. Generally, the objectives of the project were met although the question of recruitment variability remains uncertain.

The study showed that there were a greater proportion of larger and older fish in eastern samples during winter. The reverse was the case in the Southern Zone with a greater proportion of large and older fish during summer. These results were consistent with the hypothesis of a movement of larger fish from south to east to the winter spawning aggregation.

For the winter spawning fishery, the results of this study show a marked shift to the left (i.e. smaller and younger fish) in the size/age distributions compared to 1992. Similarly, there was a flattening of the size distribution and shift to the left in the age composition in southern summer samples compared to 1992/93. These results were surprising. Given the number of age classes in the exploited population it was not expected that the age/size distributions would change appreciably in the short term (e.g. an approximately 20 year shift in modal age in 5 years).

There are a number of possible explanations. First, the changes seen could reflect sampling variability. However, it is argued that it is extremely unlikely that sampling bias could be a prime contributor to the observed differences between sampling periods. Two alternate explanations are presented to explain the differences in age composition. First, a larger number of recruits has entered the fishery than in previous years, or second the decreasing population size has led to individuals maturing earlier, and therefore entering the fishery earlier. Further studies are needed to distinguish between these alternate hypotheses.

The results of the Fourier analyses suggest the presence of two distinct stocks. The most likely distribution pattern for these stocks is one numerically dominant stock, which moves from eastern Tasmania in winter to more southerly latitudes in summer, and a second stock which occurs in lower numbers in both areas at all times of the year. The alternative distribution pattern is two distinct stocks which are migratory between the eastern and southern fishery with little or no mixing

The results of this study suggest that for management purposes orange roughy from Eastern and Southern Management Zones should be considered as one stock.

Acknowledgments

We wish to thank the skipper and crew of the Saxon Progress for their assistance with sampling orange roughy off eastern Tasmania during March 1996. Miriana Sporcic provided statistical advice. Ken Smith and David McKeown collected samples. Staff of the Central Ageing Facility registered and prepared samples. Drs Nic Bax and Tony Smith provided valuable discussion of the results and insights into their implications.

References

Anon. (1995). Trial studies of alternate techniques for stock delineation of orange roughy. FRRF Project 1992/93#18. Final Report to AFMA.

Bax, N. (1997). Orange Roughy 1997 South East Fishery Assessment Group. Australian Fisheries Management Authority, Canberra.

Bell, J.D., J.M. Lyle, C.M. Bulman, K.J. Graham, G.M., Newton and D.C. Smith (1992). Spatial variation in reproduction, and occurrence of non-reproductive adults, in orange roughy, *Hoplostethus atlanticus* Collett (*Trachichthyidae*), from south-eastern Australia. *Journal of Fish Biology* **40**, 107-122.

Bird, J.L., D.T. Eppler, and D.M. Checkley (1986). Comparison of herring otoliths using Fourier series shape analysis. *Canadian Journal of Fisheries and Aquatic Sciences* **43**: 1228-1234.

Black, M. and Dixon, P.I. (1989). Population structure of orange roughy (*Hoplostethus atlanticus*) in Australian waters. Centre for Marine Science, University of New South Wales, Internal Report. (University of NSW Kensington, Australia).

Casselman, J.M., Collins, J.J., Crossman, E.J., Ihssen, P.E. and Spangler,G.R. (1981). Lake whitefish (*Coregonus clupeaformis*) stocks of the Ontario waters of Lake Huron. *Candian Journal of Fisheries and Aquatic Sciences* **38**,1772-1789.

Castonguay, M., P. Simard, and P. Gagnon. (1991). Usefulness of Fourier analysis of otolith shape for Atlantic mackerel (Scomber scombrus) stock discrimination. . *Canadian Journal of Fisheries and Aquatic Sciences* **48**: 296-302.

Chapman, D.G. and Robson, D.S. (1960) The analysis of a catch curve. *Biometrics* 16:354-368

Chesson, J. (ed.) (1997). The South East Fishery 1996, Fishery Assessment Report compiled by the South East Fishery Assessment Group: Australian Fisheries Management Authority. Canberra.

Colura, R.L. and King, R.L. (1995). Using scale and otolith morphologies to separate spotted seatrout (*Cynoscion nebulosus*) collected from two areas within Galveston Bay. In: 'Recent Developments in Fish Otolith Research' (Eds. D. H. Secor, J. M. Dean and Campana, S. E.) The Belle W Baruch Library in Marine Science Number 19: 617-630.

Edmunds, J S, Caputi, N amd Morita, M (1991). Stock discrimination by trace element analysis of otoliths of orange roughy (*Hoplostethus atlanticus*), a deep-water marine telost. *Australian Journal of Marine and Freshwater Research* **42**, 383-9.

Efron, B., and Tibshirani, R. J. (1993). 'An introduction to the Bootstrap. (Chapman and Hall: New York.) 436 pp.

Elliott, N G, and Ward, R D (1992). Enzyme variation in orange roughy, *Hoplostethus atlanticus* (Teleostei: Trachichthyidae), from southern Australian and New Zealand waters. *Australian Journal of Marine and Freshwater Research* **43**, 1561-71.

Elliott, N G, Smolenski, A J , and Ward, R D (1994). Allozyme and mitochondrial DNA variation in orange roughy, Hoplostethus atlanticus (Teleostei: Trachichthyidae): little differentiation between Australian and North Atlantic populations. Marine Biology **119**, 621-7.

Elliott, N G, Haskard, K and Koslow, J A (1995). Morphometric analysis or orange roughy (*Hoplostethus atlanticus*) off the continental slope of southern Australia. *Journal of Fish Biology* **46**, 202-20.

Friedland, K.D., and D.G. Reddin. (1994). Use of otolith morphology in stock discriminations of Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences* **51**, 91-98.

Francis R.I.C.C. and Smith, D.C (1995). Mean length, age, and otolith weight as potential indicators of biomass depletion of orange roughy, *Hoplostethus atlanticus New Zealand Journal of Marine and Freshwater Research* **29**, 581-587

Haddon , M. (1996). Fisheries Modelling. FRDC Quantitative Fisheries Training Unit Course, Queenscliff Victoria.

Hopkins, P.J. (1986). Mackerel stock discrimination using otolith morphometrics. ICES Council Meeting 1986, Collected Papers. 17pp

Ihssen, P.E., Booke, H.E., Casselman, J.M., McGlade, J.M., Payne, N.R. andUtter, F.M., (1991). Stock identification: materials and methods. *Canadian Journal of Fisheries and Aquatic Sciences* **38**, 1838-1855.

Jorgensen, T. (1988).Long-term chages in age at sexual maturity of the northeast Arctic cod (*Gadus morhua* L.). ICES, C.M. 1988/G:42.

Knuckey, I.A., and Smith, D.C. (1997). Pilot egg survey of orange roughy in the SOuth East Fishery's Western zone. Final Report to FRDC Project 96/110

Lester, R J G, Sewell, K B, Barnes, A and Evans, K (1988). Stock discrimination of orange roughy, *Hoplostethus atlanticus*, by parasite analysis. *Marine Biology* **99**, 137-43. Lyle, J.M. Kitchener, J.A. and Riley, S.P. (1991) An assessment of the orange roughy resource off the coast of Tasmania. Final Report to FIFDC, Project 87/65.

Lyle, J.M., (1991). Orange roughy plankton survey off southern Tasmania. Tasmanian Department of Primary Industry and Fisheries Unpublished report to AFMA, 9 pp

Lyle, J.M. Kitchener, J.A. and Riley, S.P. (1991) An assessment of the orange roughy resource off the coast of Tasmania. Final Report to FIFDC, Project 87/65.

Messieh, S.N., C. MacDougall and R. Clayton (1989). Separation of Atlantic herring (*Clupea barengus*) stocks in the southern Gulf of St Lawrence using digitised otolith morphometrics and discriminant function analysis. *Canadian Technical Report of Fisheries and Aquatic Sciences*. 1647, 26pp.

Ovenden, J.R. Somolenski, A.J. and White, R.W.G. (1989). Mitochondrial DNA restriction site variation in Tasmanian populations of orange roughy (*Hoplostethus atlanticus*), a deep-water marine teleost. *Australian Journal of Marine and Freshwater Research* **40**, 1-9.

Rochet, M.-J. (1996). The effects of fishing on demographic traits of fishes.ICES C.M. 1996/Mini:1. 6pp

Secor, D. H., Dean, J.M. and Lagan, E.H. (1991). Manual for otolith removal and preparation for microstructural examination. (The Electric Power Research Institute and the Belle W. Baruch Institute for Marine Biology and Coastal Research).

Smale, M, J., Watson, G, and Hech, T. (1995). Otolith atlas of southern African marine fishes. Ichthyological Monographs of the J.L.B. Smith Institute of Ichthyology, No. 1 xiv, 253 Pages, 149 plates.

Smith, D.C., Smith, K and Roob, R. (1994). 1994 Western zone orange roughy survey. Final Report to AFMA. 8 pp.

Smith, D.C., G.E., Fenton, S.G. Robertson and S.A. Short (1995). Age determination and growth of orange roughy (*Hoplostethus atlanticus*): A comparison of annuli counts with radiometric ageing. *Canadian Journal of Fisheries and Aquatic Sciences* **52**, 391-401

Smith, K and Smith, D.C. (1993). 1993 Western zone orange roughy survey. Report to AFMA. 8 pp.

Smolenski, A J, Ovenden, J R and White, R W G (1993). Evidence of stock separation in southern hemisphere orange roughy (*Hoplostethus atlanticus*, Trachichthyidae) from restriction enzyme analysis of mitochondrial DNA. *Marine Biology* **116**, 219-30.

Staples, D. and R. Tilzey (1994). The South East Fishery 1994. Fishery Assessment Report compiled by the South East Fishery Assessment Group. Australian Fisheries Management Authority, Canberra.

Trippel, E.A., O.S. Kjesbu and P. Solemial.(1997). Efects of adult age and size structure on reproductive output in marine fishes. In ‘Early life history and recruitment in fish populations’. (Eds R. C. Chambera and E.A Trippel). Chapman and Hall, London. Pages 31-62

Appendix 1 Intellectual Property

The intellectual property developed in this project are shared between FRDC and MAFRI. FRDC will be acknowledged in all publications resulting from the project.

Appendix 2 Staff

D.C. Smith	Principal Investigator
S G Robertson	Otolith preparation and reading, and Fourier analysis
AK Morison	Project scientist
M Sporcic	Statistical advice
K Smith -	Field sampling
D McKeown	Field sampling

Appendix 3
Cruise Report: Orange Roughy Sampling St Helen's Area

Vessel: Saxon Progress

Observer: Ken Smith

The cruise departed Hobart Sunday 17 March 1996 at ~ 2000 Hrs. The rounding of Tasman Island greeted us with Gale conditions (10 metre seas and 50 knot winds). Arrived in the St Helen's area with moderating weather and the search for fish marks began. No marks where seen so a number of shots where done on and around the hill and an area 25 mile north. Results were poor. After 36 hours of unsuccessful searching and fishing and with another bad weather forecast the cruise was called off. The vessel proceeded to Portland through Bass Strait (10 metre seas and 50 knot winds), no fishing was done after leaving the area, the vessel arrived in Portland ~ 2000 Hrs Thursday 21 March 1996.

Shot and catch details

SHOT NO	DATE	LOCATION	CATCH
1	18/3/96	St Helen's Hill 41.13 / 148 45	76 orange roughy 32kg spikey oreo
2	18/3/96	St Helen's Hill 41.13 / 148 45	pin-up no fish
3	18/3/96	St Helen's Hill 41.13 / 148 45	2 forange roughy
4	18/3/96	St Helen's Hill 41.13 / 148 45	4 orange roughy
5	18/3/96	St Helen's Hill 41.13 / 148 45	33 orange roughy
6	18/3/96	St Helen's Hill 41.13 / 148 45	3 blue-eye 1 blue grenadier 6 spikey oreo 5 deep sea cod
7	19/3/96	St Helen's Hill 41.13 / 148 45	37 orange roughy
8	19/3/96	St Helen's Hill 41.13 / 148 45	23 orange roughy
9	19/3/96	25 mile North 40.50 / 148.52	14 orange roughy

Macroscopic Staging of Orange Roughy Gonads

Stage 1. Immature, gonads very small cannot distinguish sex

Stage 2. Maturing stage, gonads are small in size, no eggs distinguishable to the naked eye, gonad translucent.

Stage 3. Maturing eggs are distinguishable to the naked eye (orange colour). Gonad has increased in size.

Stage 4. Maturity, ripe, eggs are distinguishable to the naked eye and translucent with orange dots. Gonad is maximum size.

Stage 5. Spawning, sexual products are discharged with very light pressure on the body wall.

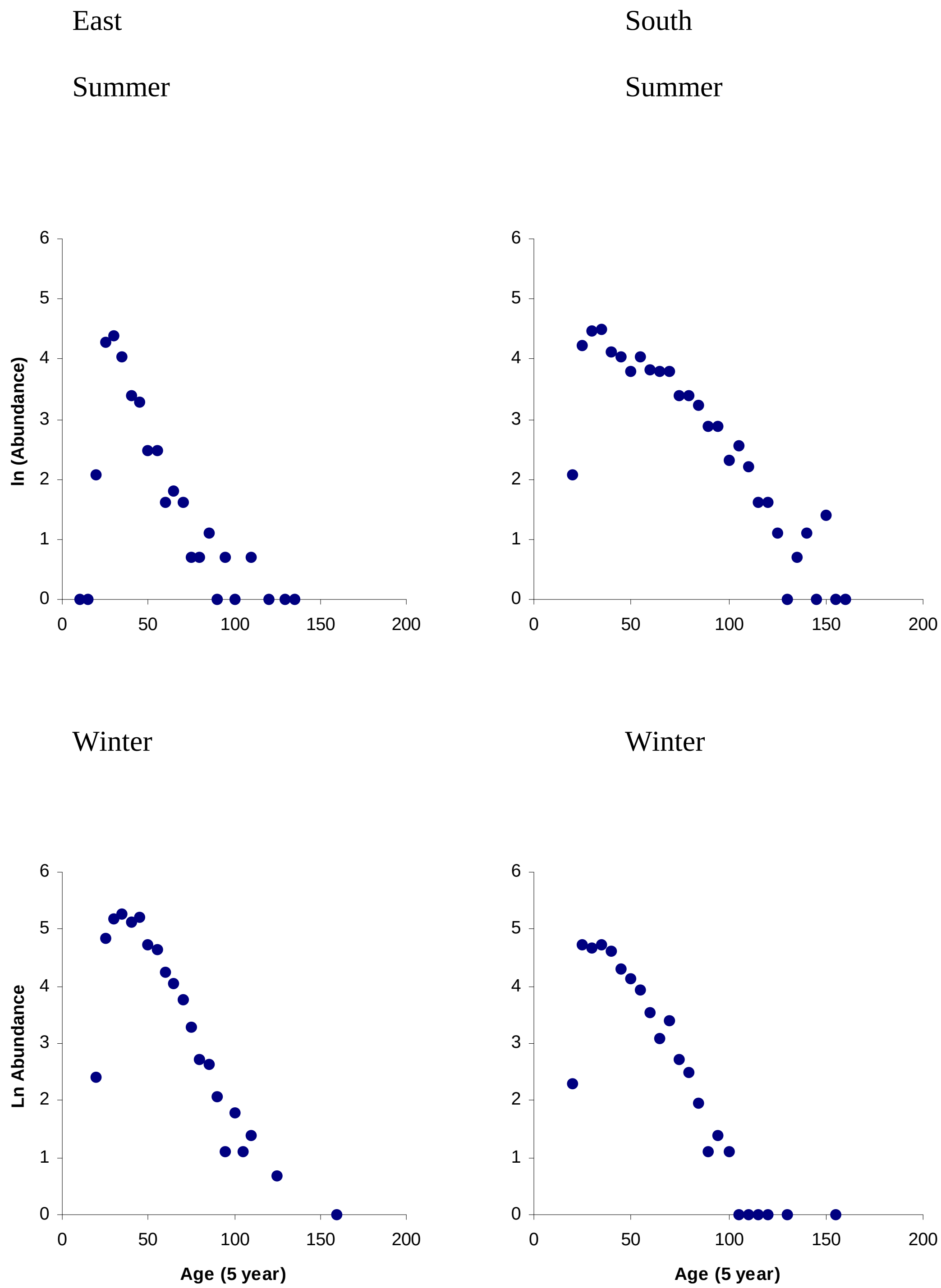
Stage 6. Spent, eggs have been discharged a small quantity may remain, gonad is flacid and reddish purple.

Unviable. Gonad can be reddish/purple but not have the flacid appearance of the Stage 6, internal matter is granular/ mash in texture unviable eggs.

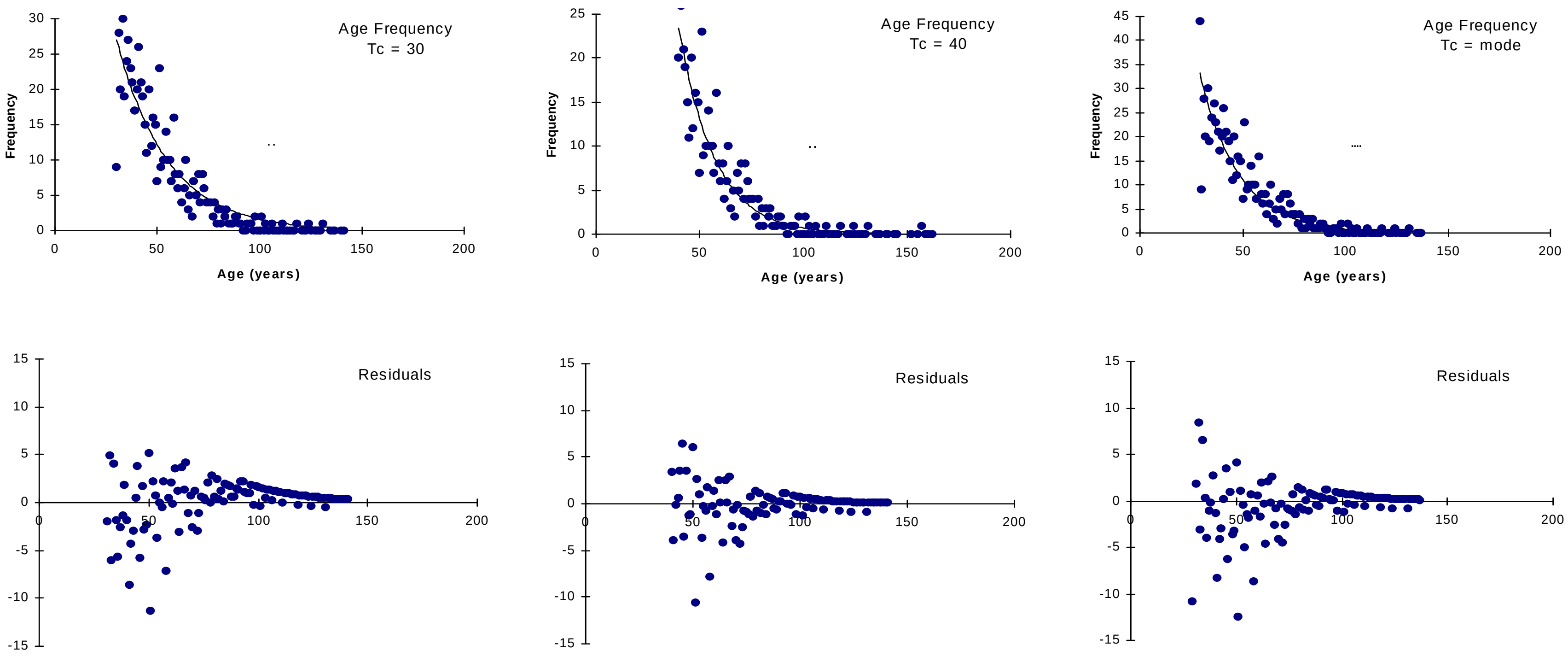
Orange roughy size and reproductive stage.

Total							
Length cm	**Female**				**Total Female**	**Male**	**Total**
	Stage 1	**Stage 2**	**Stage 3**	**Univable**			
20							
21	1						1
22	1						1
23							
24						1	1
25						1	1
26		1			1	2	3
27		2			2	3	5
28		2	1		3	3	6
29	3	1	2		3	7	13
30		1	3		4	6	10
31		1	7		8	11	19
32		3	5		8	13	21
33		3	12		15	13	28
34		2	7		9	8	17
35			6		6	8	14
36		1	7		8	5	13
37			4		4	5	9
38		1	4		5	5	10
39			4		4	4	8
40	1		2	1	3	2	6
41			3		3		3
42							
43							
44							
45							

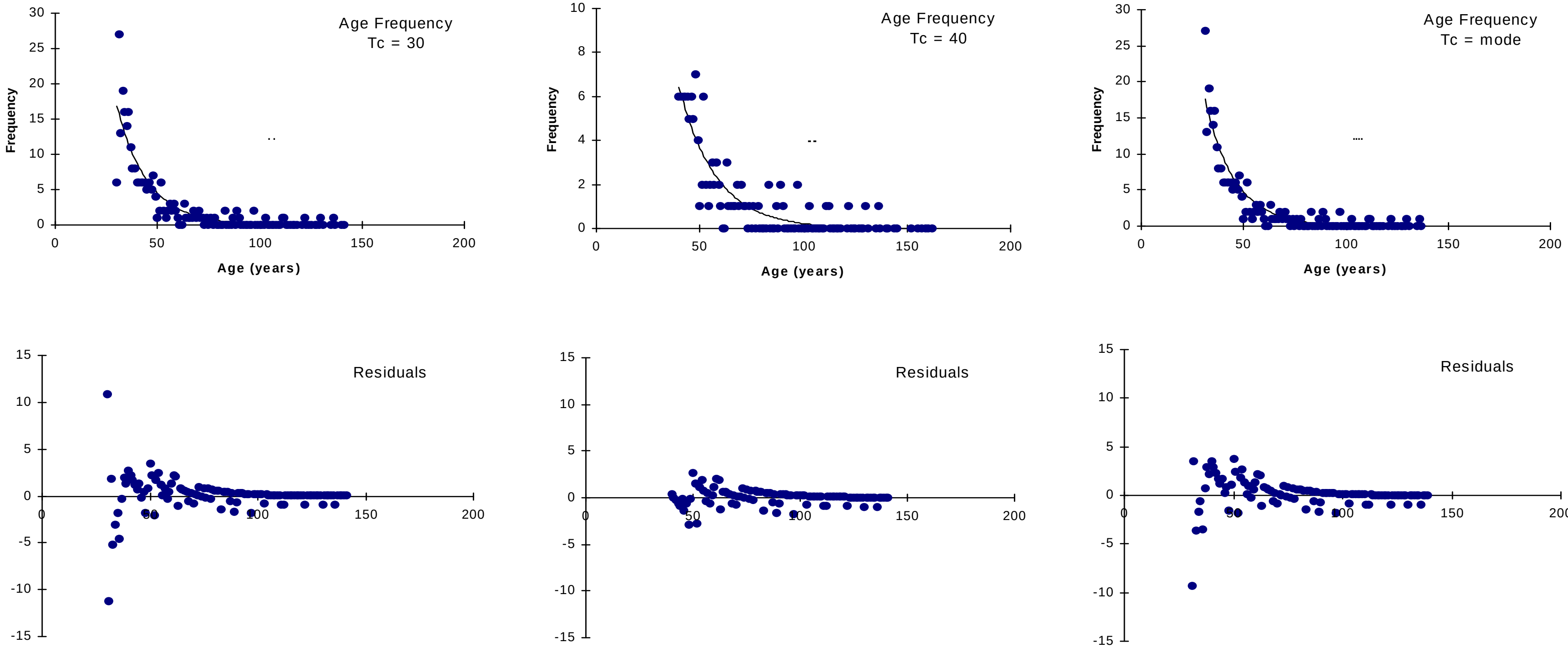
Appendix 4



Appendix 4.1 Catch curves for orange roughy by area and season.

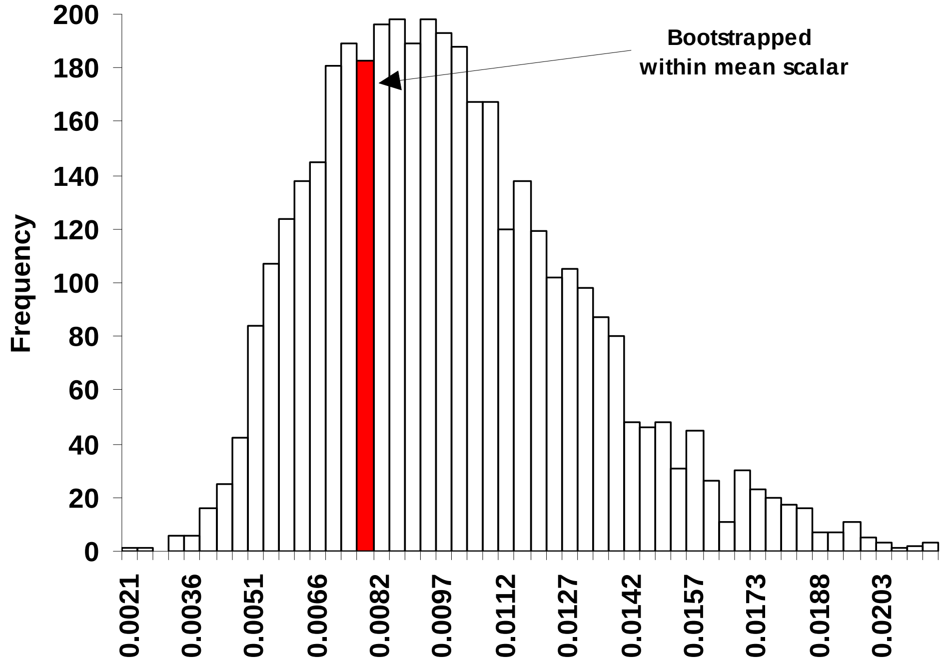


Appendix 4.2 Estimated survival curves, observed age composition and residuals, Southern Management Zone - winter.

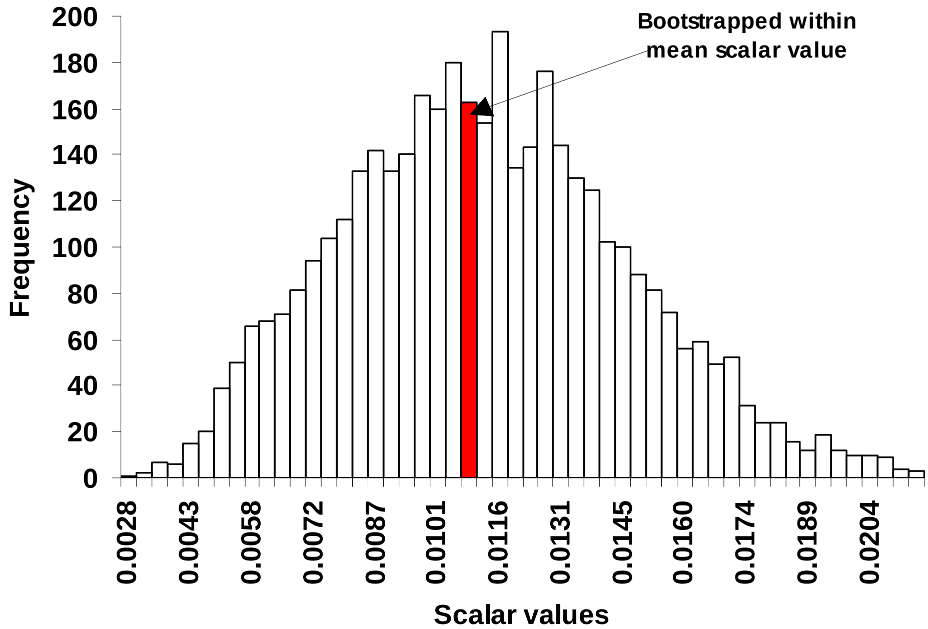


Appendix 4.3 Estimated survival curves, observed age composition and residuals, Eastern Management Zone - summer.

Appendix 5

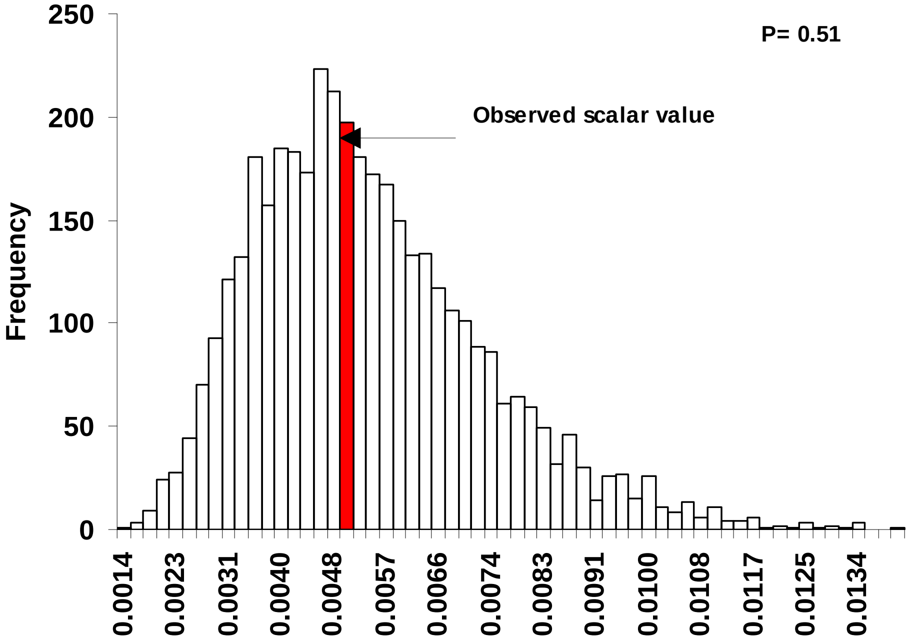


South winter within bootstrap
.

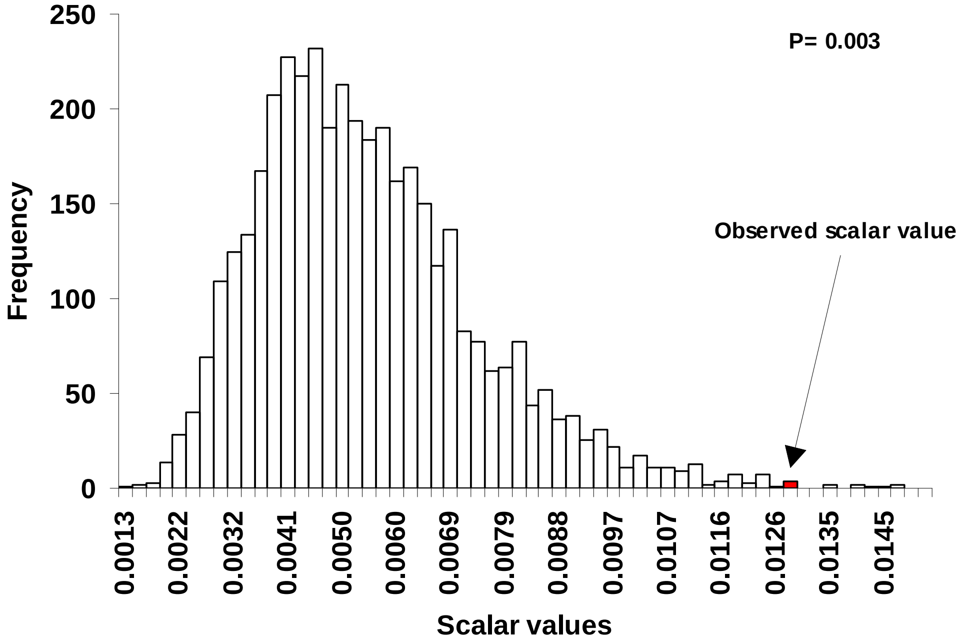


South summer within bootstrap
Bootstrapped 4000 times

Appendix 5.1 Examples of the distribution of bootstrapped scalar values



East summer / south winter randomisation (not significant)



East summer / south summer randomisation (significant)
Randomised 4000 times

Appendix 5.2 Examples of the results of randomisation tests for significant and non-significant comparisons.