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Determination of a cost effective methodology for ongoing age monitoring needed for the management of scalefish fisheries in Western Australia

Final FRDC Report – Project 2004/042

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Project 2004/042 Determination of a cost effective methodology for ongoing age monitoring needed for the management of scalefish fisheries in Western Australia

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Objectives

1. Determine for the 20 major WA scalefish species (4 - 5 in each bioregion) the relative accuracy of structures used to estimate age (e.g. Sectioned/whole otoliths, lengths, otolith weight, other otolith dimensions or some combination of these).
2. For each stock, examine the relative impact on the calculated age-compositions and their effect on model outputs and conclusions from varying (i) the method of ageing used (only where this is possible from available data) (ii) the number of individuals used in the samples (iii) the spatial distribution of the samples used (iv) if possible, the frequency of sampling.
3. Using agreed levels of precision for the model outputs, undertake cost benefit analyses to generate the most appropriate long-term age-structured monitoring program for each major scalefish species in WA by assessing the method(s) of ageing, sampling intensity within each year and the frequency of sampling among years.

Outcomes achieved

Cheaper methods of ageing fish have been developed for 20 of the 23 stocks of Western Australian scalefish examined in this study. These cost reductions were not always large, but the conclusive result that monitoring programs can utilize methods of ageing fish other than relying on counting rings on thin sections of otoliths (ear bones) is the norm and not the exception will have positive flow on effects for fisheries research and management in Western Australia. The most expensive part of any age monitoring program is the collection of samples. The minimum sample size required is ~300, with ~500 fish preferable. The clear depiction of the relative sampling and processing costs provided in this report can be used as a basis for developing better sampling programs that involve industry support.

This study was designed to develop a cost-effective system for obtaining estimates of the annual age structure (or age composition: the relative abundance of each 1-year age-class) of exploited fish stocks. The overall aim of the project was to reduce costs for individual stocks so that the sustainability status of more stocks could be assessed within the constraints of available funding. Biological databases for a variety of scalefish stocks, held at the Department of Fisheries, Western Australia, and Murdoch University, were interrogated to determine which held information that would allow examination of measures such as otolith weight or total length relative to ages estimated using the more traditional technique of counting “rings” on otoliths.

The ability to use alternative estimates of age (or “proxies”) rather than the more labour intensive method of counting rings on otoliths is dependent on establishing a reliable relationship, on a case by case basis, between age as initially estimated by counting rings and the alternative measure (e.g. fish length or weight, otolith weight). In this study we used two advanced statistical techniques to establish such relationships for 23 stocks of scalefish in Western Australia. Otolith weight was the most common alternative method found to be acceptable, followed by fish length.

The age structure generated using the alternative measure for each stock, had to be tested in assessments of stock status; this step was crucial for the project because of the longstanding belief that counting annuli on sectioned otoliths was the only method of aging scalefish. While this is true for the initial determination of age for the majority of scalefish species, there has remained an ongoing institutional bias against using anything but counts of otolith rings for ongoing age monitoring programs. One of the standard techniques for assessing stock status is to estimate the total mortality (Z), which is performed by applying “catch curve analysis” to the age structure information. The first test we used in this study was to compare the total mortality generated the age structure from counts of otolith rings versus those obtained using the alternative measures. The alternative measures for 20 of the 23 (87%) stocks examined provided acceptable alternatives to the annuli method, but in all cases larger sample sizes of the alternative measure were required to obtain reliable estimates of age structure.

Five of the stocks examined in this study also have simulation models with which the alternative ageing methods could be tested. These models confirmed that the alternative measures could be used with confidence to estimate the biomass of the stocks. These models also ascertained that regardless of which method is used to age fish, sample sizes should be above 300, and preferable 500, fish.

The costs of all aspects of the monitoring program for each stock were estimated and compared. The detailed tables of comparative costs will be provided to fishery biologist so that they have a basis for assessing were cost savings can be made. For all stocks the largest cost is to obtain the samples, particularly for those stock located in the northern half of the state (e.g. Goldband snapper, red emperor), and/or those which support a low-volume high-value fishery commercial fishery or a recreational fishery only (e.g. dhufish, inner Shark Bay pink snapper). The costs for processing samples for age determination and then the subsequent age determination are less than for the field sampling but nonetheless savings in these areas have also been identified.

Development of a full program of age monitoring for all scalefish stocks in western Australia awaits further liaison with fishery biologists and managers, who now need to consider the tradeoffs between cost and accuracy of the alternative methods.

Key words: otoliths, annuli, robust regression, mixture analysis

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1.0 Introduction

1.1 Background and Project Rationale

Ongoing monitoring and assessments of the status of the fish stocks of Western Australia is a necessary step to implement Ecologically Sustainable Development (ESD) for fisheries within Western Australia (Fletcher and Curnow 2002). Moreover, this was one of the main recommendations identified in the "Toohey Report" (Toohey et al. 2002) for the implementation of Integrated Fisheries Management of the coastal fisheries of Western Australia. Given the increasing constraints on the budgets available for monitoring programs, management agencies must ensure that this information is collected in the most cost effective manner. This project investigates the most appropriate monitoring methodology for each of 19 scalefish species (both commercial and recreational) in Western Australia (Table 1.1). This has been done by analysing the information already generated on the age and growth characteristics of these species in relation to the varying levels of precision of inputs required for specific stock assessment and management purposes.

Table 1.1 Scientific, Western Australian common names and standard common names of 19 commercially important species of finfish from Western Australia used in this study. Standard common names are those of Seafood Services Australia (2007).

Scientific Name	WA Common Name	Standard Common Name
Scomberomorus commerson	Spanish mackerel	Spanish mackerel
Plectropomus leopardus	Coral trout	Coral trout
Epinephelus rivulatus	Chinaman cod	Chinaman cod
Pristipomoides multidens	Goldband Snapper	Goldband Snapper
Lutjanus sebae	Red emperor	Red emperor
Epinephelus multinotatus	Rankin cod	Rankin cod
Lutjanus vitta	Flagfish	Brownstripe snapper
Nemipterus furcosus	Rosy threadfin bream	Rosy threadfin bream
Nemipterus peronii	Notched threadfin bream	Notched threadfin bream
Pagrus auratus	Pink Snapper	Snapper
Lethrinus laticaudis	Black snapper	Grass emperor
Pentapodus vitta	Western butterfish	Western butterfish
Arripis georgianus	Australian herring	Australian herring
Sillaginodes punctata	King George Whiting	King George Whiting
Mugil cephalus	Sea mullet	Sea mullet
Sillago schomburgkii	Yellow-finned whiting	Yellowfin whiting
Acanthopagrus butcheri	Black bream	Black bream
Glaucosoma hebraicum	Dhufish	Western Australian dhufish
Arripis truttaceus	Australian salmon	Australian salmon

The analysis of age structure provides vital information for use in the assessment of scalefish stocks. For example, the age structure of the catch can provide information on the age at first capture and the pattern of vulnerability to the gear used by the relevant fisheries. Furthermore, the age distribution provides an understanding of recruitment variability which, when combined with the maximum age, can be used to determine the relative vulnerability of a species to fishing. Because there can be more than one stock for a species, this report will emphasise stocks as the management units undergoing assessment.

Regular monitoring of the age structure of an exploited stock can provide information on how a stock is responding to fishing pressure. Thus, it can indicate whether recruitment levels are changing due to fishing (e.g. recruitment overfishing). Age structure information can also indicate if the overall level of mortality (fishing mortality plus natural mortality) is changing or if there have been changes in vulnerability to the fishing method. This latter application has now recently been adopted as the primary means of assessing important demersal scalefish stocks in the West Coast Bioregion of Western Australia (Wise et al. 2007).

Whilst useful on their own, age data are most effectively utilized within age-structured models (ASMs) that incorporate other information such as historical catches and in most cases fishing effort or catch rate. Such models can provide estimates of relative or absolute stock size. These outputs are commonly used to provide scientific advice for the development of management arrangements for fisheries and provide managers information on the impacts that may result from a given management scenario (e.g. various levels of catch and effort) under a variety of model assumptions. ASMs are used in Western Australia for a number of scalefish assessments, including pink snapper (*Pagrus auratus*) in Shark Bay and jobfish (*Pristipomoides spp.*) in the Kimberley and Pilbara regions. Models that include age structure information are generally more informative than models that rely on catch and effort data alone because they include consideration of the life history characteristics of the species being investigated.

The management for all major scalefish stocks within Western Australia is moving to an Integrated Fisheries Management (IFM) system that will require explicit allocation of access and maintaining the overall proportional catch by all sectors to agreed levels (Anon 2000; Fletcher & Curnow 2002). Consequently, an IFM system will require that stock assessments be completed for each of the major species within the four marine bioregions and be reassessed at appropriate intervals to ensure acceptable performance against specific sustainability objectives. Therefore, long term monitoring of each of these scalefish stocks will require the establishment of an ongoing time series of age data.

Most of the studies that have examined age and growth for Western Australian scalefish species have used counts of opaque bands of sectioned otoliths (e.g. Hyndes et al. 1998; Newman et al. 2001; Hesp et al. 2002) for estimating age. The preparation of each otolith for age determination usually involves a relatively high cost. This includes the labour costs associated with the acquisition of each sample, regardless of whether these are obtained on-board vessels, from factory/market sampling or the purchase of the sample. Additional costs are incurred in preparation of otoliths for microscopic examination and reading and interpreting the growth bands (i.e. annuli) on them.

This annuli method can also be applied to differing degrees of success to the age determination of fish using whole otoliths examined under a microscope with either transmitted or reflected light. For the purposes of this report, we will use the term annuli method to refer to age determination by counting internal bands of sectioned and whole otoliths.

For fishers that process their catch at sea (e.g. filleting), the carcasses are routinely discarded along with the otoliths. Therefore, those samples need to be purchased. A growing number of commercial fishers in Western Australia now sell their product whole, which does not allow the removal of otoliths prior to the fish being sold. Therefore, to obtain otoliths for some species will require the purchase of the entire fish or the collection of samples from fishery independent sources both of which can be expensive. Where such methods of collection are necessary, the number of samples obtained should be kept to the smallest sample size needed for accurate determination of age structure.

Generally, age determinations by transverse sectioning of otoliths from a large number of individuals are the most accurate and precise. This does not mean that other methods cannot provide data at a level of accuracy and precision suitable for monitoring the status of a stock. There is often a practical difference between the sampling regimes that can be logistically employed and those needed to provide a robust estimate of age and growth for a particular species. The initial research requires the establishment of the most accurate and precise ageing methods available and to validate those methods through the collection and analysis of as many individuals as possible. However, ongoing monitoring programs only need to use methods and sampling intensities needed to achieve the level of accuracy and precision required for stock assessment. The data collected needs to be matched with the intended stock assessment process.

The ability to accurately age individuals using methods other than sectioned otoliths varies greatly among species. This is affected by factors such the morphology of the otolith, the maximum age of the species, the growth trajectory (i.e. does growth continue throughout life, or largely stop at sexual maturity), the variability in recruitment between years etc. Whilst it is likely that most species can only be aged using sectioned otoliths, some species have been aged to acceptable levels of accuracy using length (Rowling 1997), otolith weight (Fletcher 1991, 1995) or by a combination of measures (Boehlert, 1985). There is significant merit in investigating whether these alternatives to the annuli method (i.e. proxies to the annuli method) can be used to provide suitable estimates of age for monitoring of scalefish stocks and whether the use of these proxies is more cost effective.

Similarly, the frequency with which data on the age distribution of a stock needs to be collected may also vary between species due to their biology and life history parameters. These variables include migration, spawning behaviour, longevity and the relationship between their recruitment dynamics with the behavioural characteristics of the fishing fleet that is exploiting that species. The frequency of sampling can be tailored for each stock once these variables are known.

The appropriate monitoring regime for managing the exploitation of a stock requires that the basic research into age and growth of that species have been completed. For many of the scalefish species in Western Australia, researchers both at the Western Australian Department of Fisheries and Murdoch University have already completed a significant amount of this basic age and growth work (e.g. size at age). Much of this work was completed in previous Fisheries Research and Development Corporation (FRDC) funded projects. What is now required is the translation of this work into an ongoing cost effective monitoring program which underpins the management of all major scalefish species in Western Australia.

Therefore, this project is not designed to generate new methods of age determination or to reinvent previously developed systems, especially where these have proven to have a high degree of effectiveness. Instead, this project seeks to utilise existing information generated by a large number of previous studies for use within an ongoing management framework.

1.2 Need

The implementation of Ecologically Sustainable Development and IFM within the management framework of scalefish fisheries of Western Australia will require periodic assessment of the status of the stocks of major species within each fishery. In some cases, age-structured models are being developed to provide stock assessments. However, even in those cases where full simulation models are not possible, assessing the status of these stocks would benefit greatly by periodical assessment of their age structure. Thus, collecting a suitably accurate and representative time series of age structures for each of the major scalefish species is a high priority for the effective management of all commercial and recreational fisheries across Western Australia.

To achieve these objectives, regular monitoring of the age structures of more than 20 species will be required for inputs into stock assessment models. Given the costs constraints and scrutiny now being imposed, it is important that the most cost efficient monitoring scheme is implemented. Such a monitoring scheme will provide estimates of the age distribution for stocks at a level required for suitably robust stock assessments to be completed. Whilst in most cases the ages have been estimated initially using sectioned otoliths, research will be conducted to determine if other ageing methods may be suitable (e.g. comparing sectioned otoliths with other morphometric parameters). Irrespective of what ageing method is used, determining the minimum number of individuals that are needed to provide accurate age estimates and determining how frequently these need to be sampled and at what spatial distribution are needed to provide data of sufficient quality for use in modelling their stock characteristics.

To determine the appropriate monitoring regime for scalefish stocks in Western Australia will require the completion of a series of rigorous analyses: these analyses will determine the relative level of accuracy of ageing techniques, and the costs of obtaining and processing the samples in relation to the precision and accuracy needed for stock assessment.

1.3 Objectives

1. Determine for the 23 WA scalefish stocks (4 - 5 in each bioregion) the relative accuracy of structures used to estimate age (e.g. Sectioned/whole otoliths, lengths, otolith weight, other otolith dimensions or some combination of these).
2. For each stock, examine the relative impact on the calculated age-compositions and their effect on model outputs and conclusions from varying (i) the method of ageing used (only where this is possible from available data) (ii) the number of individuals used in the samples (iii) the spatial distribution of the samples used (iv) if possible, the frequency of sampling.
3. Using agreed levels of precision for the model outputs, undertake cost benefit analyses to generate the most appropriate long-term age-structured monitoring program for each major scalefish species in WA by assessing the method(s) of ageing, sampling intensity within each year and the frequency of sampling among years.

2.0 Methods Overview

2.1 Objective 1

2.1.1 Species Selection

This project aimed to examine alternative ageing methods for 20 species/stocks; 23 stocks were eventually examined, with the focus on those requiring ongoing monitoring of age structure explicitly for providing fisheries management advice. In addition to the priority stocks for management, the stocks examined included a diverse range of species to determine if the results from the project would have broader applicability. The two criteria for selecting species/stocks for this study are described below.

2.1.1.1 Criterion 1

The Research Division of the Department of Fisheries prioritized the research needs of Western Australia's finfish species using a ranking system that considered inherent vulnerability to exploitation, current exploitation rates, and social, economic and indigenous importance. This list was developed with input from a variety of the Department's staff, and was subsequently presented to a wider audience within and outside of Western Australia (Lenanton et al. 2007). There was agreement that the prioritization process, which involved developing a matrix to assist with objectively assessing each species against the criteria, was suitably objective and that it provided a very useful guide for determining the most "at-risk" species. This "species matrix" was used to select four to five scalefish stocks from each bioregion to be assessed in this project.

2.1.1.2 Criterion 2

Other species that do not necessarily require ongoing age monitoring were selected according to their life-history characters and preferred habitat, with the aim to select a variety of short and moderate-lived species from inshore and offshore and temperate to tropical habitats.

2.1.2 Data Collation

The WA Department of Fisheries and Murdoch University, Western Australia have existing datasets with age information over a range of years for a large number of the important species relevant to the major scalefish fisheries in WA. All of this information was collated into a common database to facilitate analyses. Most of these datasets also contain relevant ancillary data for sex, length, otolith weight, and otolith dimensions (height or breadth).

All the data available for each of the identified species was collated and examined to determine if there were sufficient data to enable analysis. For those species where the data were not sufficiently complete, additional samples were obtained. This required an extended period of sampling for two stocks where minimal sampling had been done previously.

2.1.3 Assessment of Proxies for Age Determination

Statistical analyses were conducted on each of those species where information was sufficient to assess the level of accuracy and precision of age prediction. This was done using either a single proxy measure (e.g. length, otolith weight) or from combinations of the measures available. In this report, "proxies" for age determination refer to alternatives to using only otolith annuli.

Regression models were constructed to assess the level at which the "true" age (as determined by examining otolith annuli) can be predicted from the various proxies, both singly and in combination. Tests for homoscedasticity, autocorrelation, and specification error were conducted. Along with the performance of the best model fit that satisfied all assumptions, those tests were used to validate the models. The initial comparison between methods was based on the standard error of predicted age at a point close to the centroid of the predictor variable. For predictors (e.g. fork length, otolith height, otolith weight) the residual plots often show a specification error in the model. For these variables, by using non-linear regression procedures, an appropriate power of the predictor was usually found, thus producing a correctly specified model. The model of best fit determined which proxy provided the best alternative to using otolith annuli to estimate age.

The age structures generated by the proxies were then compared with the age structure (determined from the annuli method) using the Kolmogorov-Smirnov statistic. The precision of the predicted age obtained by models of the various proxies was important considerations for the cost benefit analysis and the determination of an optimal age estimation strategy.

2.2 Objective 2

The effectiveness of the alternative ageing methods was tested in two ways, depending on what assessment methods are used to generate advice for management. Firstly, for stocks with an age-structured models (ASMs) the model outputs relevant to making management decisions (or formulating management advice) were generated using age distribution estimates from alternative methods (the proxies) and compared with those generated using from the annuli method. Secondly, for stocks without ASMs, the estimates of total mortality (Z) obtained using the annulus method and proxies were compared. The effectiveness of the proxies was determined by evaluating if the management advice changed when the alternative age data was used. A critical consideration of the comparisons between alternative age structure information is the precision and accuracy needed for management purposes. Therefore, the comparisons included an analysis of the impact to the assessments from any decrease in precision, which necessitated consideration of number of sample collected.

2.3 Objective 3

2.3.1 Cost Benefit Analysis

A cost benefit analysis was conducted for each stock to determine the optimal sampling regime to generate acceptable, ongoing age-composition information.

To facilitate a concise understanding of the total costs associated with obtaining age information, the costs of obtaining age information for each stock was disaggregated into the following components

(i) Obtaining fish samples (e.g. fishery-dependent or fishery independent sampling)
(ii) Processing fish, excising otoliths and collecting morphometric data (e.g. total or fork length, head length, jaw length etc.)
(iii) Otolith preparation (weighing, whole mounting, sectioning and mounting)
(iv) Reading of otoliths

Once the actual costs of obtaining age information for a unit age estimate (e.g. for a single sectioned otolith, or a single measure of otolith weight) were determined these were applied to alternative sampling and age-estimation methods (i.e. of those found to be acceptable) to assess costs relative to obtaining particular precision levels.

3.0 Background on age determination

3.1 Data collection and ageing processes/techniques

This section provides a summary of the data examined in this study. Almost all data were already collated prior to the project. Those species for which data were collected and examined during the project include notched threadfin bream (included in the analyses) and asymmetric goatfish (not included in the analyses). Table 3.1 shows the species and stocks that were examined for this study along with number of samples and key biological parameters available for assessment, followed by brief descriptions of the ageing work undertaken for each species/ stock and the type of annual assessment, if any, undertaken. This section may be skipped if the reader wants to move directly to the analyses (Chapters 4-6).

Table 3.1 Summary of data collected for each stock of the species being assessed in this project. (FL – fork length; TL – total length; SL – standard length).

Bioregion	Species Name	Key parameters available	No. Fish
North Coast	Spanish mackerel *(Scomberomorus commerson)*	FL, TL, head length, upper jaw length, total weight, otolith weight, length, breadth and thickness, sex	1855
	Coral trout *(Plectropomus leopardus)*	TL, otolith weight, length and width, sex	352
	Chinaman cod (Epinephelus rivulatus)	FL, otolith weight, length, width, sex	202
Kimberley	Goldband Snapper (*Pristipomoides multidens*)	TL, FL, SL, total weight, frame weight, otolith weight, thickness, breadth and length, sex	3186
	Red emperor *(Lutjanus sebae)*	TL, FL, SL, total weight, otolith weight, length, breadth and thickness, sex	2058
Pilbara	Red emperor *(Lutjanus sebae)*	TL, FL, SL, total weight, otolith weight, length, breadth and thickness, sex	2478
	Rankin cod (*Epinephelus multinotatus*)	FL, total weight, otolith weight, sex	898
	Flagfish *(Lutjanus vitta*)	FL, total weight, otolith weight, breadth and length, sex	1802
	Rosy threadfin bream *(Nemipterus furcosus)*	FL, total weight, otolith weight, sex	1759
	Notched Threadfin Bream (*Nemipterus peronii)*	TL, FL, total weight, otolith weight, sex	340

Gascoyne	Pink Snapper *(Pagrus auratus*)-Oceanic	TL, FL, SL, total weight, otolith weight, length, breadth and thickness, sex	809
	Pink snapper *(Pagrus auratus*) - Freycinet	FL, total weight, otolith weight, sex	1059
	Black snapper (*Lethrinus laticaudis)*	TL, FL, SL, total weight, otolith weight, sex	4172
	Western butterfish *(Pentapodus vitta)*	FL, TL, total weight, otolith weight, sex	595
West Coast	Australian herring (*Arripis georgianus*)	TL, FL, total weight, otolith weight, sex	954
	King George Whiting (*Sillaginodes punctata*)	TL, total weight, otolith weight, sex	1382
	Sea mullet *(Mugil cephalus)*	TL, FL, total weight, otolith weight, sex	1215
	Yellow-finned whiting *(Sillago schomburgkii)*	TL, FL, total weight, otolith weight, sex	728
	Black bream *(Acanthopagrus butcheri)*	TL, SL, total weight, otolith weight, sex	1405
	Dhufish *(Glaucosoma hebraicum*)	TL, FL, total weight or frame weight, otolith weight, sex	>1000
South Coast	Australia salmon *(Arripis truttaceus)*	TL, FL, total weight, sex	451

3.2.1 Spanish mackerel (*Scomberomorus commerson*)

3.2.1.1 Summary of age information

The geographical range of the samples of *S. commerson* collected ranged from the Gascoyne region to the Kimberley, with the majority of samples coming from the more northern and eastern areas Mackie et al (2003). Data for fork length (FL), total length (TL), head length (HL), upper jaw length, total weight, sex, gonad weight and gonad macroscopic stage were collected. The length range of samples was between 58 mm and 1650 mm fork length. The otolith dimensions measured were weight, length, breadth and thickness (height). The condition of each otolith was also recorded i.e. whether the otolith was broken or unbroken.

The majority of the otoliths collected were sectioned and read using a transmitted light microscope. Some otoliths were read whole by immersing them in 70% glycerol solution and examining them under a dissecting microscope with reflected light and a black background (Lewis and Mackie 2002). A comparison was made between whole and sectioned otoliths using a *t*-test to determine if there was a significant difference in the level of agreement between the two ageing techniques. Whole otoliths were shown to be accurate for *S. commerson* with up to eight annuli (constituting the majority of the population). The sectioning of whole otoliths with more than eight annuli was needed to accurately determine the age of these individuals.

3.2.1.2 Current assessment method

Review of annual catches. Periodic assessment of F.

3.2.2 Coral Trout (*Plectropomus leopardus*)

3.2.2.1 Summary of age information

Mackie and Black (1999) generated age estimates for coral trout from the Pilbara region of Western Australia. Otolith weights, lengths and breadths were measured during that study.

Ferreira and Russ (1994) validated the age of coral trout from Lizard Island, North Great Barrier Reef in Queensland. They found that sectioned otoliths were more accurate at measuring age for fish over 6 years of age, while whole otoliths could be read accurately for fish up to 6 years of age.

3.2.2.2 Current assessment method

None. No stock assessment has been done for this species.

3.2.3 Chinaman cod (*Epinephelus rivulatus*)

3.2.3.1 Summary of age information

A total of 203 samples of *Epinephelus rivulatus* were collected at Ningaloo Reef between August 1994 and September 1996 as part of FRDC Project 95/025 (Mackie and Black 1999). Methods of capture included spear gun and hook and line. Sex, FL, and the weight, length and width of otolith were recorded.

Preliminary analysis indicated that otoliths could not be read whole. Age was estimated for 202 sectioned otoliths. Validation techniques included marginal increment analysis and oxytetracycline otolith staining.

3.2.3.2 Current assessment method

None. No stock assessment has been done for this species.

3.2.4 Goldband Snapper (*Pristipomoides multidens*)

3.2.4.1 Summary of age information

Samples of *P. multidens* were collected between 1995 and 1999 in the Kimberley region (Newman & Dunk 2002). Sampled fish ranged from 245 mm to 701 mm FL (Newman & Dunk 2002). The biological parameters collected were total, fork and standard lengths, total weight, clean weight, frame weight, sex, and gonad weight and gonad macroscopic stage. The otolith dimensions measured were weight, length, breadth and thickness. Information on chipped or broken otoliths was also recorded.

Preliminary analysis indicated that otoliths could not be read whole. Each otolith was sectioned and mounted on slides. The presumptive annuli were then counted under a dissecting microscope with reflected light on a black background. Each section was read four times, counts were compared and the precision of age estimates was calculated (Newman & Dunk 2002). Any otoliths that had structural irregularities were considered indecipherable and were discarded.

The precision of otolith readings was found to be very high (Average percentage error = 10.4%). There was a relatively high level of accuracy between the otolith readings and indicates that the ageing protocol is replicable (Newman & Dunk 2002). From those data collected, otolith length and breadth were also found to be good predictors of fish length, while otolith weight was found to be a reliable predictor for age. Otolith height was also found to be an accurate measure for predicting age (88%) accuracy.

Marginal increment analysis was used to validate age in *P. multidens*. A classification system based on the width of the observed band at the outer edge of the otolith was adopted for the marginal increment analysis. Each otolith edge type was classified into three different categories translucent, narrow opaque (opaque area less than half of the previous zone) and wide opaque (opaque zone greater than half of the previous opaque zone) (Pearson 1996). Otoliths displayed a consistent trend of alternating opaque and translucent zones. During the months of January to May, there was a period of quick growth; and thus, a translucent zone was formed (Newman & Dunk 2002). In the colder months June to December an opaque zone was laid down. A consistent annual trend was evident and the laying down of these zones represented valid annual growth increments.

3.2.4.2 Current Assessment Method

An age-structured model has been completed for goldband snapper in the Kimberley region. This model is updated every three years. The catch and catch rate for this species is reviewed every year in the Pilbara Demersal Finfish Fishery.

3.2.5 Red emperor (*Lutjanus sebae*)

3.2.5.1 *Summary of age information*

Otoliths of red emperor were collected during studies of key targeted scalefish stocks the Kimberley and Pilbara regions (Newman et al 2001; Stephenson and Mant 1999). The information collected included: total length, fork length, standard length and total weight. Where possible, gonad weight and sex were obtained from each fish. Otolith weight, length, breadth and height (thickness) were also recorded.

Reading of whole otoliths was found to consistently underestimate age (Newman et al. 2000). Fish were aged using transverse sections of sagittal otoliths. Otoliths with structural irregularities such as unusual calcification, deterioration of the ventral lobe or poorly defined annuli were considered unreadable and were not included in the age determination of Kimberley *L. sebae*. Annuli were counted without reference to length and weight and each section was read on three separate occasions. Each section was read under a microscope with reflective light on a black background. Marginal increment analysis was the main age validation technique (Stephenson and Hall 2003).

Otolith annuli were quite distinct and easy to read in sectioned otoliths of *L. sebae*, displaying clear opaque and translucent zones. The marginal increment analysis confirmed that one annulus was formed every year. The results showed that the mean monthly marginal increment was lowest in September-October and highest in July-August (Newman & Dunk 2002). Injection of tagged fish with calcein produced marked otoliths that provided direct evidence, from recaptures, that one annulus is formed each year (Newman & Dunk 2002).

3.2.5.2 Current Assessment Method

An age structure model was developed for red emperor in both the Kimberley and Pilbara region.

3.2.6 Rankin Cod (*Epinephelus multinotatus*)

3.2.6.1 Summary of age information

Rankin cod were sampled in the Pilbara region for a number of years as part of an ongoing monitoring program for the scalefish fisheries in this region. The biological measurements recorded were fork length, total weight, and sex and gonad weight. Sagittal otoliths were extracted from each fish and weighed.

Preliminary analysis indicated that otoliths could not be read whole. Otoliths were sectioned and read under a dissecting microscope with transmitted light. Growth rings on otoliths appeared as a series of wide, dark opaque zones and narrow light translucent bands. The number of dark opaque zones (growth annuli) was counted by two readers. No marginal increment analysis was conducted due to the poor definition of the outermost rings

3.2.6.2 Current Assessment Method

Annual review of catches and catch rate in the Pilbara Demersal scalefish fishery. A review of the status of this species has shown that there has been a recovery of older fish in the population from 1998 to 2006 suggesting the species is not over-exploited.

3.2.7 Flagfish (*Lutjanus vitta*)

3.2.7.1 Summary of age information

Ages have been estimated for 1802 flagfish *(Lutjanus vitta)* collected from routine fishery monitoring in the Pilbara region. The parameters measured for this species were: fork length, sex, total weight and gonad weight (Stephenson and Mant 1999). Weight of sagittal otoliths was also measured. For each fish the mean otolith weight was determined for otolith pairs that had no chips or broken pieces from each otolith.

Davis and West (1992) found that both urohyals and whole otoliths were readable for young fish of *L. vitta* off Western Australian waters, but obscure for older fish. Otoliths were sectioned and then read under a dissecting microscope with transmitted light. The growth rings on the sectioned otoliths appeared as distinct dark opaque zones. Two independent readers read these annuli. Most of the discrepancies that arose between readers were reconciled. The use of marginal increment analysis validated the annual periodicity of growth annuli (Stephenson and Hall 2003).

Data were pooled for marginal increment analysis because of the smaller number of fish between 9 and 12 years of age. The results showed that the opaque zone formed between mid-July and mid-September. The timing of opaque zone formation was found to be slightly different to that reported by Davis and West (1992), who found that the opaque zone formed mainly in the month of October (Stephenson and Hall 2003).

3.2.7.2 Current Assessment Method

There is an annual review of catch and catch rates for this species in the Pilbara Demersal Finfish Fishery.

3.2.8 Rosy Threadfin Bream (*Nemipterus furcosus*)

3.2.8.1 Summary of age information

Nemipterus furcosus were collected and processed as part of a survey of the Pilbara trawl fishery in Western Australia (Stephenson and Mant 1999).

Measurements taken from each fish included fork length, total weight, and sex and gonad weight. Both sagittal otoliths were removed from each fish and were weighed. A mean otolith weight was recorded when both otoliths were not damaged. Where one of the otoliths was chipped or broken, a single otolith weight was recorded.

Preliminary analysis indicated that otoliths could not be read whole. Sectioned otoliths were examined under a dissecting microscope with transmitted light. The zones on the otoliths appeared as a series of wide, dark opaque zones separated by narrow translucent zones. Age validation was achieved for this species by using marginal increment analysis. Chemical tagging with oxytetracycline was attempted as part of a tag release program. A total of 119 fish were tagged and injected with tetracycline but no marked fish were recaptured.

The clarity of translucent and opaque zones was often very poor. The discontinuities in growth annuli made age determination very difficult. Despite the fact that annuli were harder to distinguish in *N. furcosus*, the marginal increment analysis confirmed that growth ring formation occurs annually (Stephenson and Hall 2003). The timing of the new growth formation for *N. furcosus* was found to be from mid July to late September (Stephenson and Mant 1999).

3.2.8.2 Current Assessment Method

The catch and catch rate for this species is reviewed every year in the Pilbara Demersal Finfish Fishery.

3.2.9 Notched Threadfin Bream (*Nemipterus peronii*)

3.2.9.1 Summary of age information

Nemipterus peronii were collected and processed as part of a survey of the Pilbara trawl fishery in Western Australia (Stephenson and Mant 1999). The parameters measured include total length, fork length, total weight, and sex.

Preliminary analysis indicated that otoliths could not be read whole. 206 otoliths out of 580 were selected for ageing by otolith section, of which 121 were successfully read. Based on the 58.7% readability rate, we estimate that approximately 340 otoliths are readable from the 580 fish available.

3.2.9.2 Current Assessment Method

The catch of this species is small and it is not used as an indicator species in the Pilbara Demersal Finfish Fishery.

3.2.10 Pink snapper (*Pagrus auratus*)

3.2.10.1 Summary of age information

There is an extensive data set available for pink snapper. More than 10000 fish have been sampled in the last decade. There is an ongoing monitoring program for pink snapper all Western Australian bioregions.

Biological parameters recorded, include total length, fork length, standard length, sex and total weight. Otolith weight, length, breadth and thickness were also been measured.

In the early 1980s, scales were used to age fish sampled from the commercial fishery. Since then there has been a shift toward using transverse sectioning of the sagittal otoliths for age determination. Preliminary analysis indicated that otoliths could not be read whole. Therefore, all of the pink snapper sectioned otoliths were examined under a dissecting microscope with transmitted light. Opaque zones appeared as dark and translucent zones as light. However, more recently, sectioned otoliths of *P. auratus* have been examined under reflected light against a black background whereby the opaque zones appear light and translucent zones appear dark. This approach has improved the ability of the reader to determine the outer edge of the opaque zones and therefore increase the accuracy of marginal increment analysis (Jackson et al. 2006). Marginal increment analysis was used to validate the periodicity of growth rings on the otoliths. Chemical staining with oxytetracycline was successfully used to validate the annual periodicity of growth increments.

3.2.10.2 Current Assessment Method

Age-structured models have been completed for pink snapper in the inner Shark Bay recreational fishery and also the Shark Bay oceanic commercial fishery. In the West Coast Bioregion an F-based weight-of-evidence approach is used.

3.2.11 Blue-lined emperor (*Lethrinus laticaudis*)

3.2.11.1 Summary of age information

Between 1999 and 2001, Ayvazian et al (2004) collected *L. laticaudis* from Shark Bay as part of a research program into the age, growth, reproductive biology and stock assessment of this species.

Biological information recorded for each fish included total length (TL), fork length (FL) and standard length (SL) to the nearest mm, whole and cleaned weight, gonad weight and sex. The sagittal otoliths were removed from each fish and the otolith weight was recorded.

Otoliths of *L. laticaudis* were examined by reading the otoliths whole and also by examining transverse sections of the otolith. Whole otoliths were immersed in 70% glycerol solution and examined through a dissecting microscope with transmitted light. Sectioned otoliths were also examined under the same microscope and light source. Avayzian et al. (2004) showed that there was consistency between readings of whole otoliths and sectioned otoliths of *L. laticaudis* up to and including the age of 8 years. Marginal increment analysis was used to validate the annual periodicity of translucent annuli.

Annulus formation of opaque bands on a yearly basis was confirmed by marginal increment analysis (Ayvazian et al. 2004). The opaque zones formed during the late spring and summer between the months of November and January. The deposition of the opaque zones coincided with gonad maturation and spawning activity that occurred when the water temperature was highest. Between the months of February and October, wide translucent zones were evident, suggesting a period of fast growth through the autumn, winter and early spring months (Ayvazian et al. 2004).

3.2.11.2 Current Assessment Method

A yield-per-recruit model was developed for *L. laticaudis* in the Shark Bay region.

3.2.12 Western Butterfish (*Pentapodus vitta*)

3.2.12.1 Summary of age information

Samples of *P. vitta* were collected from trawl programs in November and December of 1997 from Shark Bay, Western Australia (Mant et al 2006).

The biological measurements that were recorded were fork length, total length, total weight and sex of each individual fish. Both the sagittal otoliths were extracted and weighed and a mean otolith weight was recorded where both otoliths were not damaged. In otolith pairs where one of the otoliths were chipped or broken, a single otolith weight was recorded.

After a preliminary investigation of the sagittal otoliths of *P. vitta*, it was found that sectioned otoliths provided more accurate zone counts than whole otoliths. Therefore, all of the otoliths that were used in the age analysis were sectioned and viewed with transmitted light under a dissecting microscope. Otoliths of *P. vitta* have distinct and clearly defined opaque and translucent zones (Mant 2000). Growth rings were quite easy to identify in the sectioned otoliths. Two independent readers counted annuli for each sectioned otolith. Marginal increment analysis was used to validate the periodicity of growth ring formation. To establish the level of confidence that can be placed in the interpretation of ring count in otolith sections, the precision of ring counts from 175 sectioned otoliths was examined (Mant 2000).

3.2.12.2 Current Assessment Method

A stock assessment of this species was completed by Mant (2000) as part of an honours thesis project.

3.2.13 Australian Herring (*Arripis georgianus*)

3.2.13.1 Summary of age information

Samples of *A. georgianus* were collected and processed as part of a study to develop an index of recruitment for this species (Gaughan et al 2004). Samples of *A. georgianus* have also been collected as part of ongoing monitoring of this species.

The recorded biological measurements include total length, fork length, total weight and sex, gonad weight and otolith weight. The condition of the otolith (i.e. broken or chipped) was also recorded.

All of the fish were aged by reading whole otoliths. None of the otoliths that were extracted from the fish samples was sectioned. Previous research on Australian herring has showed that reading whole otoliths was just as effective as sectioned otoliths (Fairclough et al 2000). Therefore, reading of whole otoliths appears to be a suitable method for ageing. Marginal increment analysis showed that growth annuli were formed annually.

Whole otoliths examined by Gaughan et al (2004) revealed a high level of agreement between the readers in the number of rings counted. Most of the otoliths were found to be quite easy to read and translucent and opaque zones were easily distinguishable.

3.2.13.2 Current Assessment Method

An age structure spatial model was developed for Australian herring in 2000 as part of the stock assessment project for this species (Ayvazian et al 2000). Annual reviews of catches and catch rates from the commercial and recreational fishery are used to provide a relative index of breeding stock abundance.

3.2.14 King George Whiting (*Sillaginoides punctata*)

3.2.14.1 Summary of age information

Gaughan et al (2004) collected *S. punctata* from both the south and west coast regions of Western Australia

The biological parameters collected included total length (TL), total weight, and sex and gonad weight. Where otoliths were collected, otolith weight and condition (i.e. broken or chipped) were recorded.

All otoliths were examined whole, by immersion in 70% glycerol and read under a dissecting microscope using reflected light. Examination of the otoliths of *S. punctata* revealed that the outer rings were very difficult to distinguish in fish over the age of about 4 years (i.e. > 400 mm TL) (Gaughan et al 2004). Therefore, in order to obtain an accurate reading of age, the otoliths were sectioned for any fish that was greater than 400 mm TL or those that contained more than four growth rings. Fowler & Short (1998) found similar results for otolith reading of *S. punctata* off South Australian waters.

Marginal increment analysis was conducted only on those fish collected from the south coast as Hyndes et al. (1998) showed that growth rings were formed annually for *S. punctata* from south-western Australia. The results of the marginal increment analysis showed that there were different times of the year when the marginal increment decreased. Even though the marginal increment decline occurred over a wide temporal scale, it was shown that ring deposition occurred annually for each fish.

There have been a number of studies on the age determination of King George Whiting. Fowler and Short (1998) used an alternative method for otolith preparation by breaking and burning. This was found to be no less precise or accurate than reading sectioned otoliths. This technique is much quicker and less labour intensive and could be used as a possible alternative to current otolith preparation techniques for *S. punctata*.

3.2.14.2 Current Assessment Method

Annual reviews of catch and catch rates in Wilson Inlet are used to develop an index of juvenile recruitment into the fishery in the South Coast Bioregion. Catch and catch rates are reviewed annually for this species in the West Coast Bioregion

3.2.15 Sea mullet (*Mugil cephalus*)

3.2.15.1 Summary of age information

Gaughan et al (2004) collected *M. cephalus* between August 1999 and June 2002 from locations on the lower west coast and south coast of Western Australia.

The parameters that were measured were total length (TL), fork length (FL), total weight, gonad weight, otolith weight and sex. The sagittal otoliths from each fish were removed and then weighed.

At first, otoliths were read whole by immersing them in glycerol solution and looking at them under a dissecting microscope using reflected light. Reading of whole otoliths was found to be ineffective due to the poor clarity of translucent and opaque zones. Therefore, all *M. cephalus* otoliths that were collected were sectioned. Marginal increment analysis was used to validate the age estimates.

Estimates of age of *M. cephalus* by two independent readers produced a percentage agreement of 86% (Gaughan et al 2004). The readability of otoliths of *M. cephalus* was relatively high.

Marginal increment analysis of *M. cephalus* otoliths was done independently between the south and west coasts which revealed that there was a difference in the timing of the decline in the marginal increment between regions. However, on further examination it was confirmed that the formation of the opaque zone occurred annually (Gaughan et al 2004).

3.2.15.2 Current Assessment Method

The catch and catch rates for this species are monitored each year.

3.2.16 Yellow-finned Whiting (*Sillago schomburgkii*)

3.2.16.1 Summary of age information

S. schomburgkii was collected by Gaughan et al (2004).

The biological measurements that were recorded for this species were total length (TL), fork length (FL), total weight, otolith weight, and sex and gonad weight.

Like those for Australian herring, the growth rings (annuli) were quite clear and distinct in each otolith. Therefore, all fish were aged by reading whole otoliths (Gaughan et al. 2000). Each otolith was placed in glycerol solution and examined microscopically under reflected light. For those otoliths that were examined, there was a 90% agreement in the number of rings counted by two independent readers

Marginal increment analysis for fish from the south coast was found to be ineffective due to a lack of samples. However, previous work on this species by Hyndes and Potter (1997) had shown that ring formation occurred annually.

3.2.16.2 Current Assessment Method

The catch and effort data from statutory fishery returns are used to calculate a catch per unit effort (CPUE) for this species. A trigger level CPUE has been developed for this yellow finned whiting in the Inner Shark Bay Scalefish Fishery.

3.2.17 Black Bream (*Acanthopagrus butcheri*)

3.2.17.1 Summary of age information

A. butcheri was collected as part an assessment of fish-kills in 2003 and 2004 in the Swan River.

For each fish the total length, standard length in mm, total weight, sex and macro gonad stage were measured. The weights of both sagittal otoliths were measured. If any of the otoliths were chipped or broken, this information was also recorded.

Otoliths form each individual fish were examined by reading the otoliths whole and by sectioning each otolith. Whole otoliths were immersed in 70% glycerol solution and read with a dissecting microscope under transmitted light. Marginal increment analysis was used to validate the periodicity of growth annuli. Information from this project confirmed that the deposition of growth annuli does occur annually in *A. butcheri* and that the number of opaque zones in sectioned otoliths can be used to determine the age of this species.

A comparison of ring counts between whole vs. sectioned otoliths showed that whole otoliths underestimated the age of fish over the age of 6 years. In fish that were not older than 6 years, there was no significant difference between age estimates from whole or sectioned otoliths (Fowler & Short, 1998).

3.2.17.2 Current Assessment Method

Regular reviews of catch and catch rates are made for this species in each estuary.

3.2.18 Australian Salmon (*Arripis truttaceus*)

3.2.18.1 Summary of age information

Samples of *A. truttaceus* were collected between Aug 1999 and Oct 2001 (Gaughan et al 2004). The majority of animals collected were from the south coast region of Western Australia. The biological parameters recorded included total length (TL), fork length (FL), and total weight, sex and gonad weight.

Preliminary analysis indicated that otoliths could not be read whole. All otoliths were sectioned and read under a microscope with transmitted light. Marginal increment analysis was then used to validate the annual periodicity of growth rings (opaque zones). Marginal increment analysis of pooled samples from both regions revealed that the main months when opaque zones are laid down are between August and November and thus verified an annual periodicity of opaque zone formation.

Identification of opaque and translucent zones was found to be quite difficult in some of the otoliths that were examined. In juvenile fish, a large degree of sub-annual banding occurred in the first year, making the identification of the first opaque zone difficult (Gaughan et al 2004). The opaque zone could be more easily defined for individuals of two or more years in age.

3.2.18.2 Current Assessment Method

A biomass dynamics model has been developed for this species in which catches and catch rates provide an index of stock abundance.

3.2.19 Dhufish (*Glaucosoma hebraicum*)

3.2.19.1 Summary of age information

Samples of *G. hebraicum* were collected from various locations throughout the West Coast Bioregion. Both commercial and recreational fishers provided samples.

The biological measurements recorded include total length, standard length and otolith weight.

Hesp et al (2002) found that reading whole otoliths underestimated the age of the fish. They determined that sectioned otoliths gave a much more accurate measure for ageing. Dhufish otoliths were subsequently sectioned for this study. All of the otoliths were sectioned and examined under reflected light against a black background. Marginal increment analysis was used to validate the periodicity of growth annuli in this species (Hesp et al. 2002).

3.2.19.2 Current Assessment Method

Catch and catch rates are monitored annually for this species. The management of this species is currently being further developed. F-based assessments now form the key part of the annual assessment.

4.1 Determination of sample size and proxy measures for estimating age structure

4.2 Statistical methods

The concept of Kolmogorov-Smirnov precision is defined together with its application to estimation of minimum sample size requirements to be confident of the underlying age distribution for each species/stock. Target precision levels are set in order that at least a minimum amount of information is available for a given distribution. For many stocks in this project, we showed that these targets could be achieved using ageing by otolith sections or whole otoliths, assuming the sampling distribution is representative and unbiased. Precision estimates are included for models over a range of proxies, including length (fork, standard or total), total weight, otolith weight, and otolith height and head length. Two methods of estimation used were (i) regression analysis with required variance-stabilizing transformations, and (ii) mixture analysis. The mixture method is presented as an asymptotically unbiased alternative procedure for cases where the regression method becomes significantly biased (e.g. vertical asymptotes, low correlations). A table of minimum sample size results are provided for competitive models/proxies that fall within the required Kolmogorov-Smirnov precision range.

4.2.1 Determination of precision levels

4.2.1.1 Age determination by otolith sections or whole otoliths

The precision value for each species/stock is defined as the limit on differences in cumulative relative frequency in the age distribution that one would expect given random sampling variation. The Kolmogorov-Smirnov (KS) result allows us to calculate the precision level with a $(1-\alpha)$% confidence interval for a given unbiased empirical distribution compared with the underlying generating distribution. Likewise, the KS statistic provides a $(1 - \alpha)$% confidence bound for the natural variation in cumulative relative frequency between successive unbiased, independent realizations of a distribution. No knowledge of the characteristics (or moments) of the age distribution is required.

Given that we have a sample size n of either otolith sections or whole otoliths (or a combination of reading methods) used to age a particular species/stock of fish, the precision level is defined as

$$D/\sqrt{n},$$

Where D is the KS statistic that is assigned to a given confidence level $(1 - \alpha)$%.

Table 4.1 Typical values of D for a given α.

α	0.10	0.05	0.025
D	1.224	1.358	1.480

Management of fisheries is ultimately concerned with the number of samples required to achieve specified levels precision with confidence $(1 - \alpha)\%$. For this project, we will restrict ourselves to the $\alpha = 0.05$ level. The key precision range we are targeting is 0.04 to 0.08. If the precision level is coarser than 0.08, we cannot be confident that there is much useful information in the result of the age determination analysis. To obtain a precision finer than 0.04 is generally too costly and unproductive, given that there are always sampling biases.

4.2.1.2 Age determination by use of proxies

When using an unbiased proxy for ageing a fish, the precision level has two components. These include confidence degrees of error resulting from

i) Random variation

ii) Proxy bias

iii) Sample bias inherent in the proxy selection.

Even when the proxy sample contains a bias, the former two precision components are sufficient for monitoring purposes. If, on the other hand, we want an absolute specification of the age distribution for a given species/stock, the third precision component accounting for the proxy sample bias is required.

Added to the Kolmogorov-Smirnov component for the proportion of aged fish with proxy information (m; $m \leq n$) is the variation caused by the fitting of the proxy. Whilst the KS component is straightforward to calculate, it is not so for those data and methods used to predict the age distribution by proxy information and it is difficult to estimate the associated component of precision level. There is a variety of data available for the 20 species under consideration, including total weight, fork length, standard length, total length, head length, otolith weight, otolith height, and otolith breadth. Only one or two proxies may turn out to be significant for each species/stock. We explored two quite different techniques of statistical fitting and were able to compare the methods for a given proxy and fish species/stock.

We follow the philosophy of Francis and Campana (2004) as an alternative to traditional regression techniques. They argue that a mixture approach to modelling fish age distributions based on otolith or other proxy information is asymptotically unbiased, whereas regression techniques using the same information are inherently biased. In this project, we provide two key improvements to the approach of Francis and Campana (2004). The first is that precision estimation processes of the regression and mixture biases enable us to compare results between mixture and regression techniques, and subsequently choose the superior method in each case. Secondly, a parsimonious approach to selection of the age structure when using the mixture method makes the problem of estimation and inference far more tractable, especially when there is a need to iterate such processes hundreds of times for simulation purposes. The suggestion by Francis and Campana (2004) to use multiple proxies will not be implemented in this project, since:

i) It is rarely necessary if the relationships with single proxies are sufficiently strong.

ii) High correlations among predictor variables can lead to problems in model fitting.

iii) The additional dimension of complexity for the mixture approach doesn't necessarily warrant the time invested. A single proxy mixture technique will suffice.

4.2.2 Mixture analysis vs. regression

Asymptotes in fisheries studies lead to serious biases for the prediction of distributions using regression analysis. By contrast, the mixture approach is asymptotically unbiased. However, the regression method specifies a stronger relationship between two variables. There is a trade-off between regression and mixture methods in the prediction performance of age distributions because of finite sample sizes. It is not always clear whether the regression method or mixture method is superior. Sometimes, there are several equally ranking (i.e. competitive) models and/or proxies for each species/stock. Only competitive models are tested and included in the results for each species/stock.

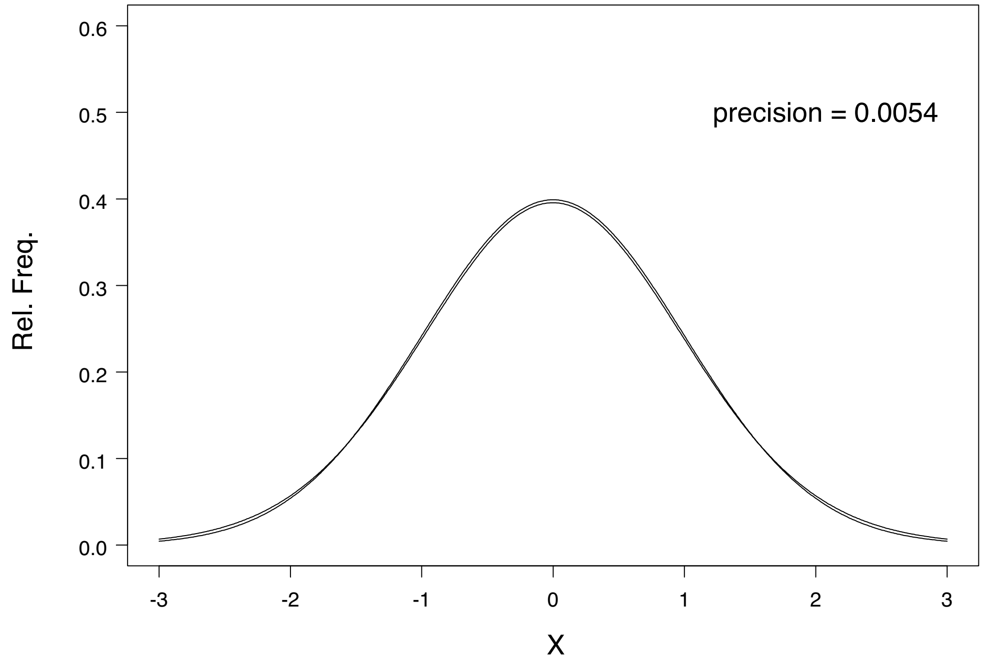
4.2.2.1 Determination of the distribution model

In statistics, we need to differentiate the standard normal distribution from the *t*-distribution for a sample size of $n \leq 30$. The maximum difference in cumulative relative frequency (i.e. precision) between the two distributions for $n = 30$ is 0.0054 (Fig. 4.1). In fisheries, we would not require such high levels of differentiation in precision, because the "tails" of the distributions are very similar. Although the level of precision is coarser, we would not necessarily be too concerned to differentiate between the normal distribution and the closest fitting Laplacian distribution (precision = 0.0282) (Fig. 4.1). Although the rate of decay in the "tails" is mathematically different, the practical inference we would make is that the distributions are reasonably similar. In fact, what we are doing is approximating the tails of the normal density by an exponential decay function (Laplacian density), so this example approximates the coarser bound of precision that we are interested in.

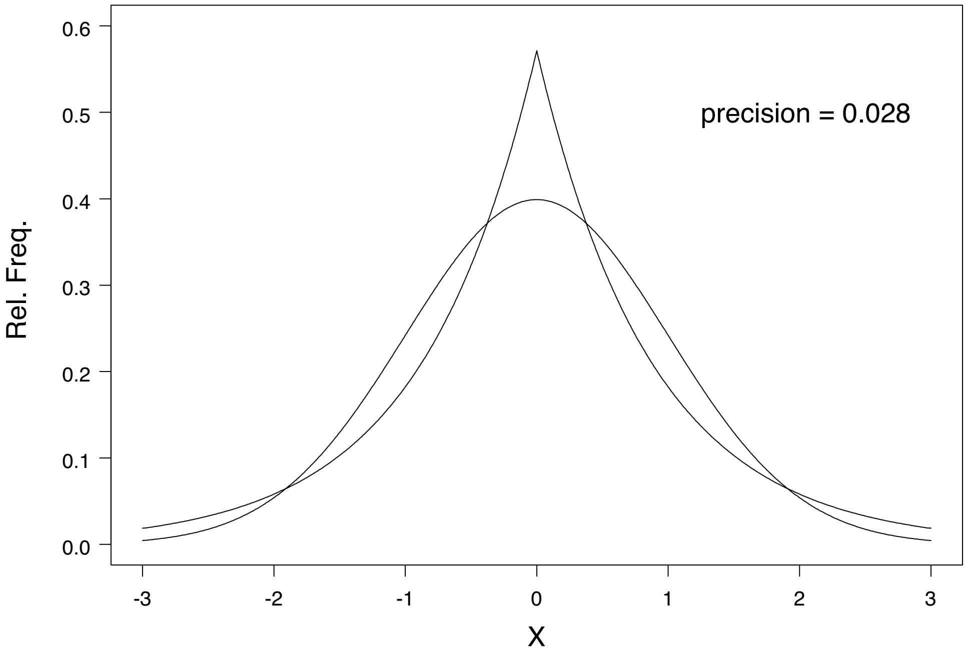
However, we would be concerned if one age distribution looked normal and another was uniform, since the uniform distribution has no "tails". The precision exceeds 0.0484 for any given uniform distribution when compared to the normal distribution. Likewise, a comparison of the gamma distribution that best fits the goldband snapper age distribution in the Kimberley (shape = 6.28, scale = 1.69) and the normal distribution with the same variance that minimizes the precision value reveals some significant divergent characteristics (precision = 0.390) (Fig. 4.1). The right skewness of the gamma distribution is apparent, and the tails are not the same. Still coarser in precision is the optimal uniform approximation of the aforementioned gamma distribution (precision = 0.0675). This is a similar extinction scenario as the one described above.

The final example is a comparison between the exponential distribution and the triangular distribution with the same average slope as the corresponding exponential distribution (Fig. 4.1). Again, we see an extinction scenario where the right-hand "tail" of the exponential distribution is truncated. We would want to be able to detect such a scenario. An example of an approximately exponentially distributed age distribution is black bream.

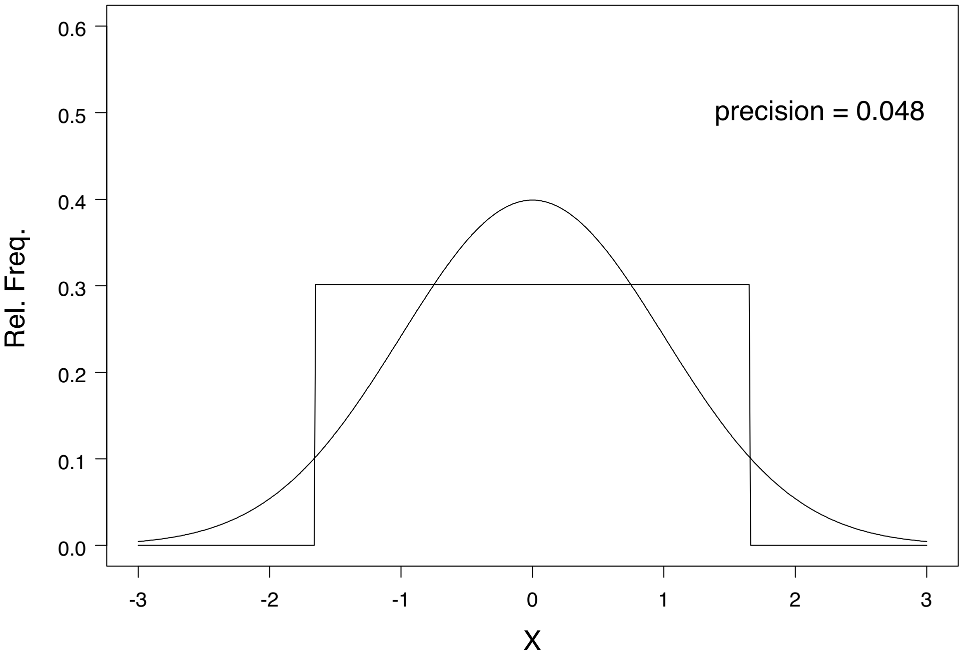
Therefore, we set the range of interest for the critical precision level to be (0.04, 0.08), where the right-hand point (0.08) of the range is deliberately chosen to be double the precision level where we would begin to conclude that the distributions are different (0.04).



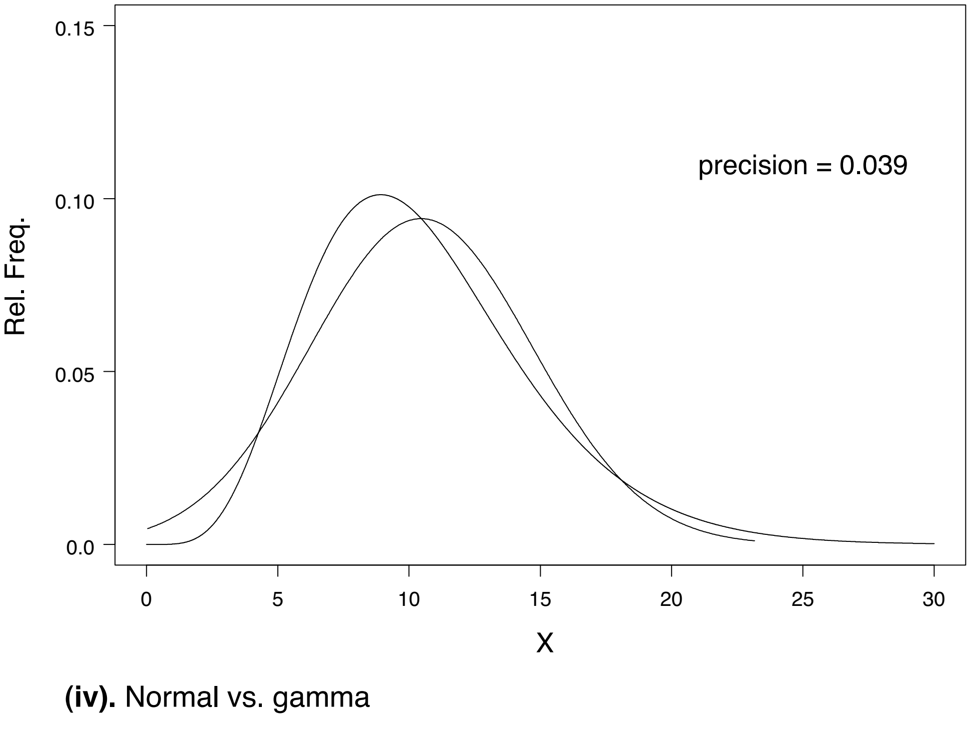
(i) Normal v. *t*-distribution



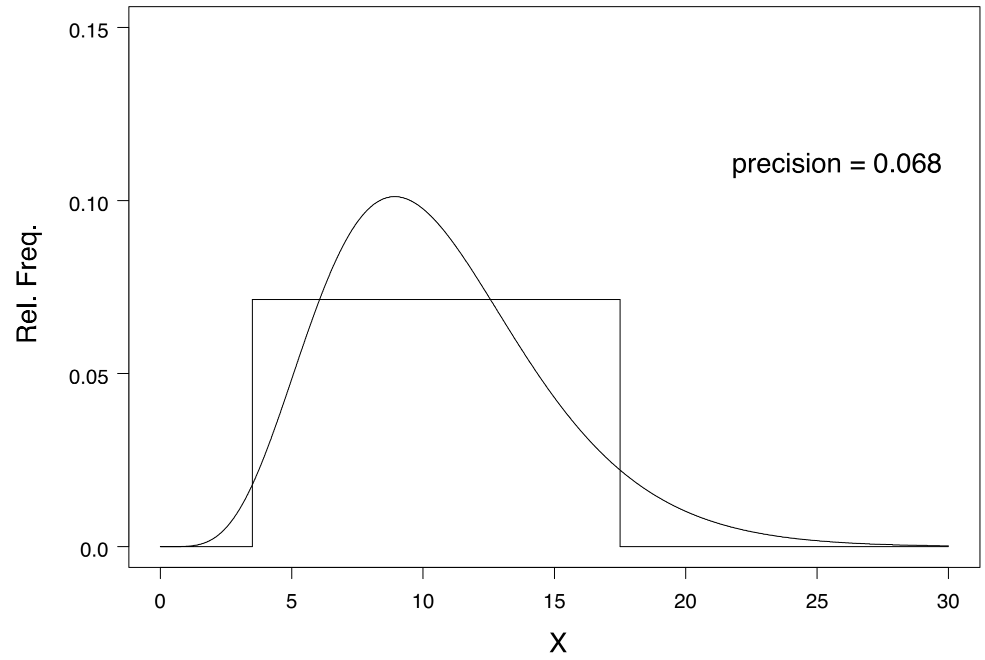
(ii). Normal vs. Laplacian



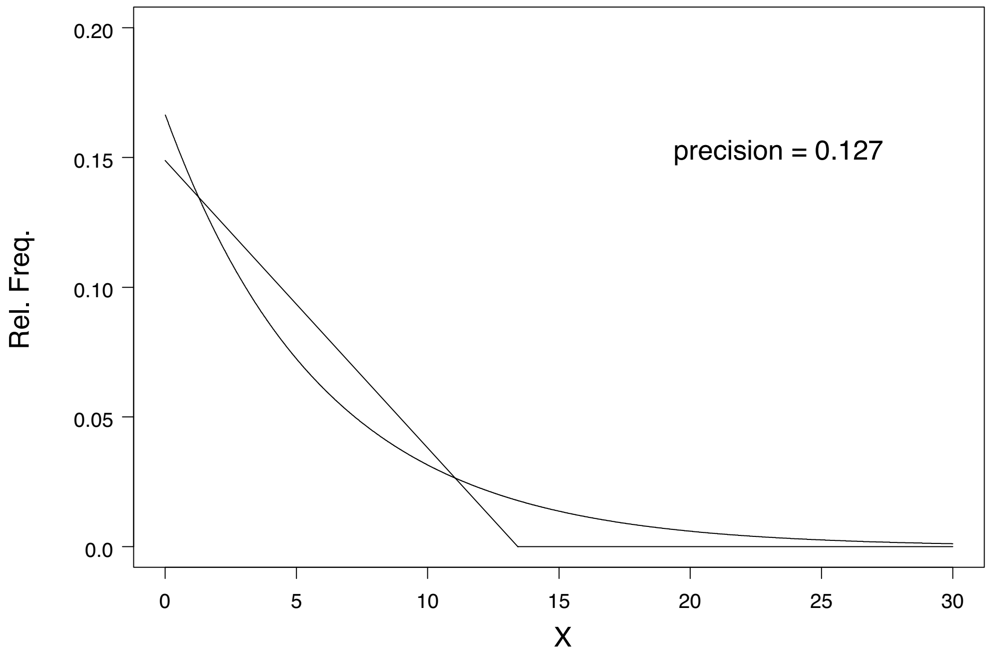
(iii). Normal vs. uniform



(iv). Normal vs. gamma



(v). Gamma vs. uniform



(vi) Exponential vs. triangular.

Figure 4.1 Comparison (including relative precision) of error distribution models described in the text. The standard normal distribution versus (i) t-distribution, (ii) Laplacian distribution, (iii) uniform distribution, and (iv) gamma distribution. (v) Gamma vs. uniform distributions. (vi) Exponential vs. triangular distribution.

4.2.2.2 Regression approach

Transformations are used to guarantee correct model specification. Identity, square root or logarithmic transformations are performed on the age (response) variable to stabilize the variance. If there are 0+ fish in the sample, a unit shift is used in the logarithmic transformation. The proxy (predictor) variable is transformed to achieve linearity. Such transformations are chosen from the $\frac{X^k}{k}$ family, for any $k > 0$ and, in the limiting case ($k \to 0$), $\log X$. $k = 1$ represents the identity.

The proxy age distribution is computed from the regression estimates (intercept, slope, variance) in the transformed space by calculating the quantiles that fall into each age class.

The precision level component due to regression bias is independent of the sample size m. The bias can be estimated directly from the R^2 regression estimate by computing the maximum absolute difference between cumulative distributions of the biased and (predicted) unbiased regression fits.

At $\alpha = 0.05$ significance level, the precision is defined as

$$p = \frac{1.358}{\sqrt{m}} + \beta ,$$

Where β is the regression bias (independent of sample size).

Alternatively, the sample size N required to obtain a precision level p with 95% confidence is given by

$$N = \left(\frac{1.358}{p - \beta} \right)^2$$

4.2.2.3 Mixture approach

Fit a mixture of g bivariate normal distributions to the proxy/age data with centres

$\mu_{i,}$ $i = 1,...,g$ and (constant) parameters σ_1 σ_2, ρ estimated by maximum likelihood using the ms function in SPLUS. The number of groups g is selected by the Bayesian Information Criterion (BIC). Other alternative information criteria (e.g. Akaike) would suffice as penalization functions.

The proxy age distribution is computed from the regression estimates (centres, group weights, bivariate variances/covariance) by calculating the quantiles that fall into each age class.

The precision level component due to the mixture model is calculated with confidence $(1 - \alpha)$% determined by a sample-limited bootstrapping process. We find that the distribution of precision values for realizations is very symmetric, centralized and slightly heavy-tailed. An estimate for the precision level bound calculated at significance level α can therefore be found by examining the quantile-quantile plot (Figure 4.1) of the Kolmogorov-Smirnov statistic against the t-distribution, and selecting df to be the closest distributional match. We conclude that distribution of precision values is approximately t_{19}.

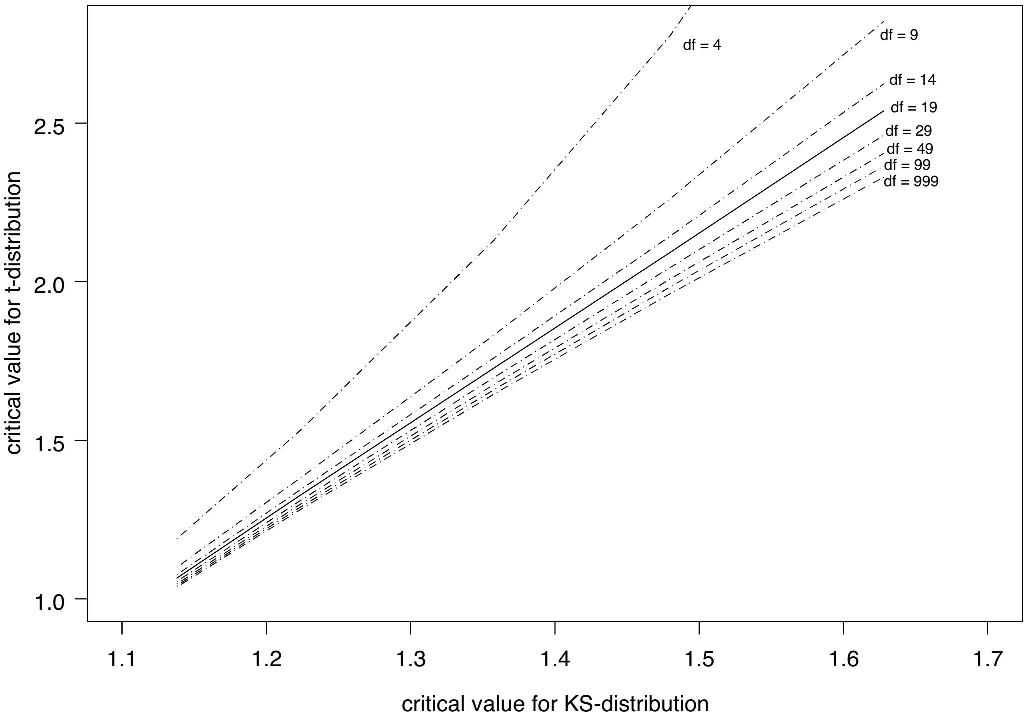


Figure 4.2 Q-Q plot of Kolmogorov-Smirnov distribution against t-distribution with varying degrees of freedom: df = 19 maximizes the quantile distributional correspondence.

If we want a 95% confidence in the two precision components, then 97.5% confidence is required for each component. At an $\alpha = 0.05$ significance level, the precision is thus defined as

$$p = \frac{1.480}{\sqrt{m}} + \bar{\beta} + t_{19,0.025}\ s_{\beta,m},$$

Where $\bar{\beta}$ is the expected finite sample mixture bias, and $S_{\beta,m}$ is the standard deviation of the distribution of the mixture bias (dependent on *m*). The asymptotic rate $\bar{\beta} \rightarrow 0$ as $m \rightarrow \infty$ is a function of the likelihood function and the Bayesian Information Criterion (BIC) penalisation function. As *m* increases, the number of groups chosen in the mixture analysis also increases, thus reducing the bias. However, we emphasize this is a slow process, so that $\bar{\beta}$ is more or less constant for the practical kind of sample sizes we are considering. In fact, $\bar{\beta}$ would be asymptotically reduced at a logarithmic rate in terms of the sample size. Hence, the sample size *N* required to obtain a precision level *p* with 95% confidence is given by

$$N = \left(\frac{1.480 + t_{19,0.025}\ s_{\beta,m}\ \sqrt{m}}{p - \bar{\beta}} \right)^2 .$$

4.2.3 A note on Type I and Type II errors and implications for management

A Type I error is defined as rejecting the null distribution when it actually holds. This is measured by the probability parameter α. In this context, α measures the risk of concluding an age distribution has changed in structure, based on observables, when in reality it has not. Such a decision is problematic from a management point of view, since it appears that a decision has been made in a non-conservative way.

On the other hand, a Type II error is defined as accepting the status quo distribution when it has changed constitution. This risk probability is measured by the parameter β, and is interpreted as a failure to identify key changes in distribution of a population. While this situation is conservative from a management point of view, the risk is that the ecological population may be overfished until such time that there are sufficient data to correct the Type II error.

One key advantage of the Kolmogorov-Smirnov statistic in its non-parametric (i.e. distribution-free) nature is that the hypothesis testing is invertible. This means that we are able to test Type I or Type II errors using the same statistic, and the number of samples required to maintain a given level of precision remains the same. This contrasts significantly with parametric tests such as the *t*-test, which require non-centrality distributions to calculate the Type II error. Thus, we can be equally confident with the K-S statistic when concluding that the distribution of a population has remained the same when in reality it has, or deciding that the distribution has changed when it actually has.

4.3 Results

4.3.1 Proxy estimators of age

Competitive results for the 23 stocks are shown in Table 4.2. For some stocks more than one proxy was found; across all stocks examined 29 proxy measures provided significant fits. Otolith weight was the chosen proxy measure for 18 of the 29 significant models, with length (standard, fork or total) accounting for a further 5 models. Head length provided the most promising proxy age measure for Spanish mackerel (the only species for which this parameter was measured). Total weight was a potential proxy estimator of age for black bream and Australian salmon.

The model fit and age structure generated using the annuli method and the proxy measures for each stock are shown in the upper 4 panels of Figures 5.1 – 5.29.

Table 4.2 Proxy alternatives for estimating age, and applied transformations, for 23 stocks of scalefish in Western Australia. Note that for some stocks > 1 proxy is provided, for those cases were one could not be selected over the other. Dhufish have three stocks (management units) in the West Coast Bioregion (WCB).

Bioregion	Species/ Stock	Method	Proxy	Transformation for regression	Sample Size
North Coast (general)	Spanish Mackerel	Regression	Oto weight	$\sqrt[3]{} / \log$	1814
		Regression	Head length	I / log	1767
	Coral Trout	Regression	Total length	$\log / \sqrt{}$	352
	Chinaman Cod	Regression	Oto weight	$\cdots^{3/4} / \sqrt{}$	202

Kimberley	Goldband Snapper	Regression	Oto weight	$\sqrt{\ } / \log$	2417
		Mixture	Fork length		3182
	Red Emperor	Regression	Oto height	$\sqrt[4]{\ } / \log$	1977
Pilbara	Red Emperor	Regression	Oto weight	$\sqrt{\ } / \sqrt{\ }$	1827
	Rankin Cod	Mixture	Oto weight		872
	Flagfish	Regression	Oto weight	$\sqrt{\ } / \sqrt{\ }$	1794
	Rosy Threadfin Bream	Mixture	Oto weight		1713
	Notched Threadfin Bream	Regression	Oto weight	I / I	340
Gascoyne	Pink Snapper (oceanic)	Mixture	Fork length		808
		Regression	Oto weight	log / log	733
	Pink Snapper (Shark Bay)	Regression	Oto weight	$\ldots^{7/4} / \mathrm{I}$	699
	Blue lined emperor	Regression	Oto weight	$\sqrt{\ } / \log(\ldots+1)$	4172
	Western butterfish	Regression	Oto weight	I / I	595
West Coast	Australian Herring	Regression	Oto weight	$\sqrt{\ } / \log$	854
	King George Whiting	Regression	Total length	$\sqrt{\ } / \log(\ldots+1)$	1378
	Sea Mullet	Regression	Oto weight	$\sqrt{\ } / \log(\ldots+1)$	1066
		Regression	Total length	$\sqrt{\ } / \log(\ldots+1)$	1212
	Yellow-finned Whiting	Regression	Total length	$\ldots^{5/4}$/log(…+1)	728
	Black Bream	Regression	Standard length	$\mathrm{I} / \sqrt{\ }$	1401
		Regression	Total weight	$\sqrt{\ } / \log(\ldots+1)$	1273
	Dhufish (North WCB)	Regression	Oto weight	$\log / \log$	939
	Dhufish (Metro WCB)	Regression	Oto weight	$\log / \log$	515
	Dhufish (South WCB)	Regression	Oto weight	$\log / \log$	802
South Coast	Salmon	Regression	Total length	I / I	451
		Regression	Total weight	$\sqrt{\ } / \mathrm{I}$	450

4.3.2 Case studies of Identification of proxies using regression analysis and mixture analysis.

In this section, two case examples are provided to compare the regression and mixture methods. Mixture analysis is theoretically superior because, unlike regression analysis, it does not assume that one variable is dependent on the other and hence error distributions are more adequately considered. However, this statistical advantage also means that in some case the mixture analysis had greater difficulty in fitting the data. The examples below show that either technique can provide a better (more useable) result than the other but that this depends on the characteristics of the data and hence vary among species.

4.3.2.1 Example 1. Goldband snapper, Kimberley region

Using otolith weight as the proxy to be tested, both the regression analysis (Fig. 4.3, and mixture analysis (Fig. 4.4) appeared to provide good fits. This was confirmed in Figure 4.5 where the predicted age distributions derived from each model show good concordance with the actual distribution derived from sectioned otoliths.

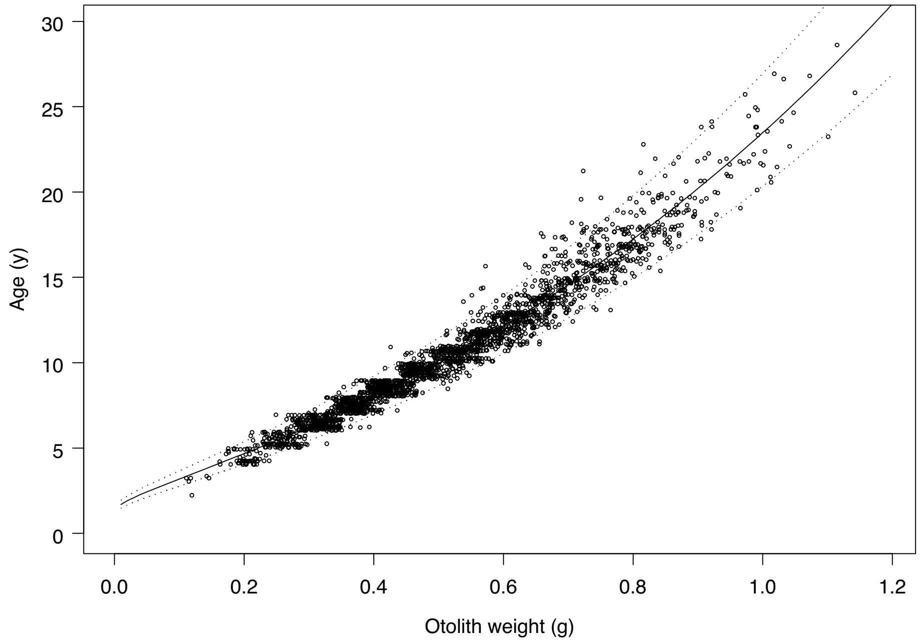


Figure 4.3 Regression analysis of age vs. otolith weight for Kimberley Goldband snapper.

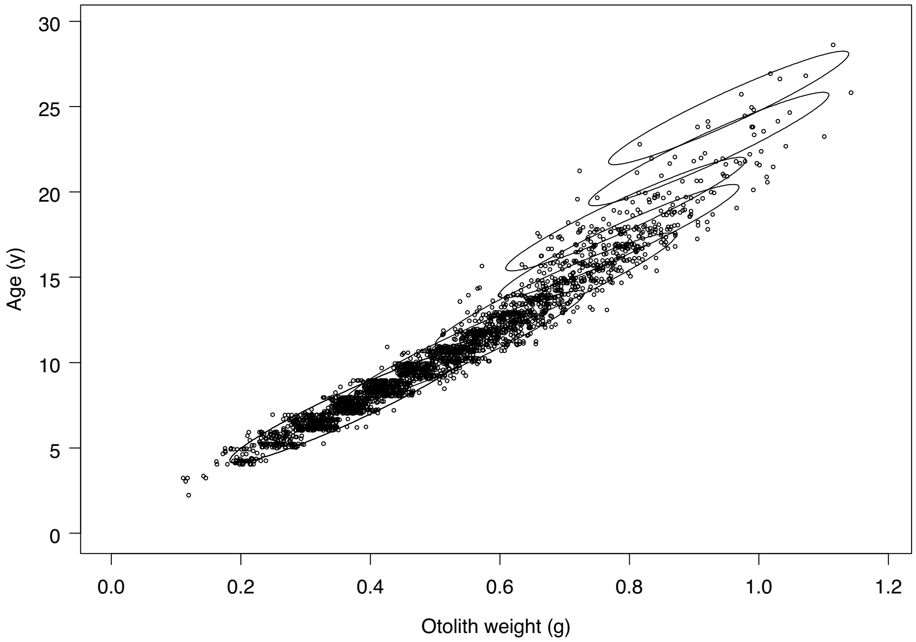


Figure 4.4 Mixture analysis of age vs. otolith weight for Kimberley Goldband snapper.

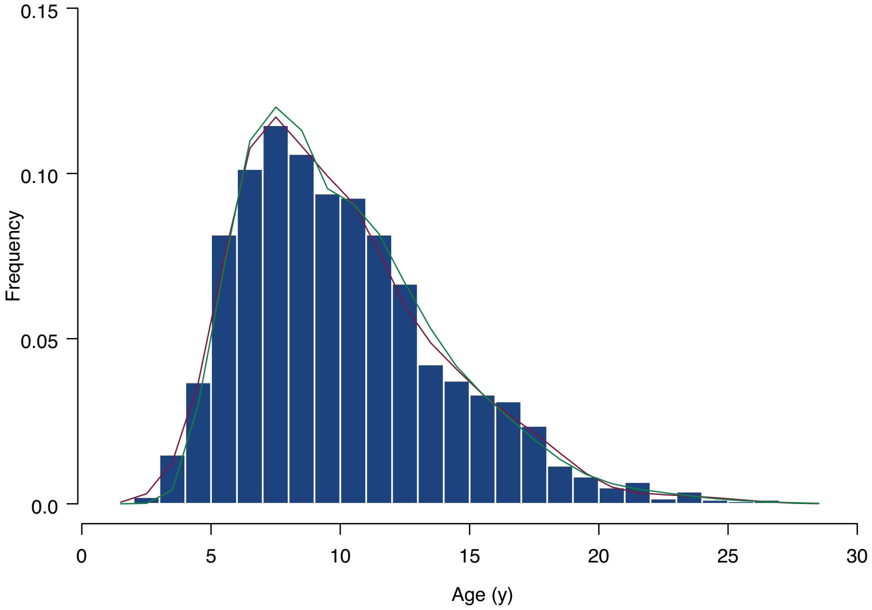


Figure 4.5 Histogram of actual age distribution obtained using sectioned otoliths for goldband snapper, overlaid with expected age distributions determined from regression (maroon line) and mixture (green) analyses.

4.3.2.2 Example 2. Pink snapper - oceanic stock in the Gascoyne Bioregion

Using otolith weight as the proxy to be tested, both the mixture analysis (Fig. 4.6, and regression analysis (Fig. 4.7) appeared to provide relatively poor fits compared to those for goldband snapper in the preceding section. However, an examination of the predicted age distributions from each model against the actual distribution confirms that the mixture method is superior for the oceanic pink snapper stock (Fig. 4.8).

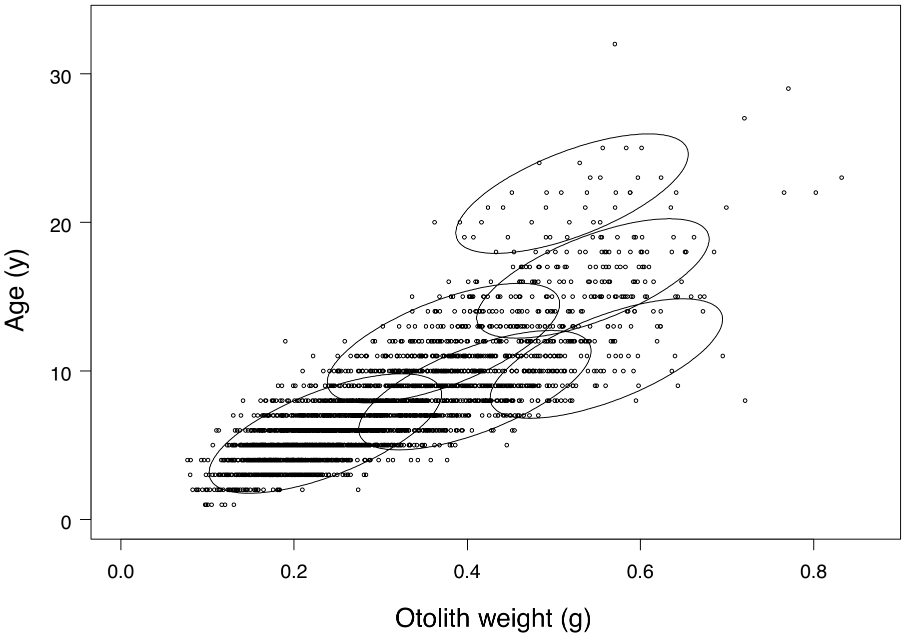


Figure 4.6 Mixture analysis of age vs. otolith weight oceanic pink snapper.

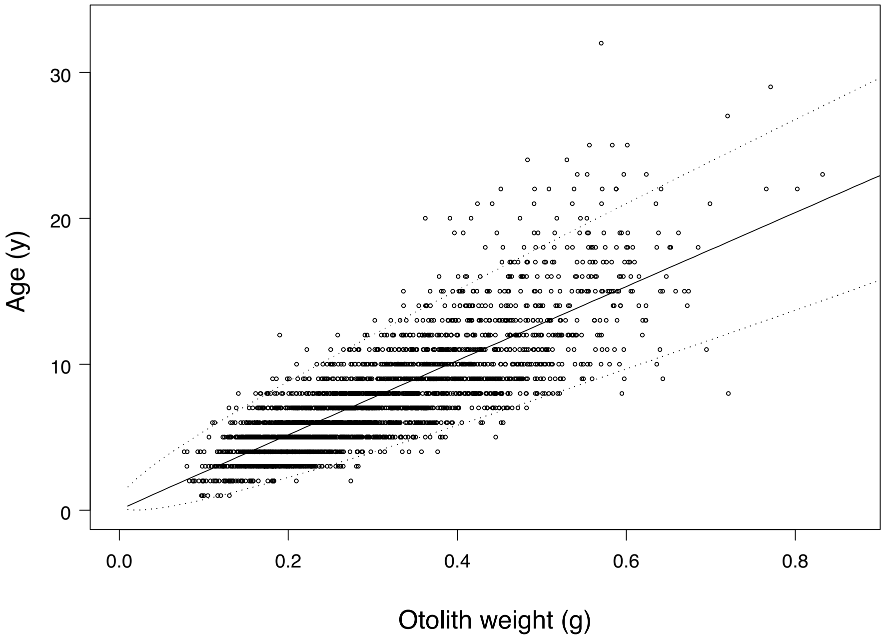


Figure 4.7 Regression analysis of age vs. otolith weight for oceanic pink snapper.

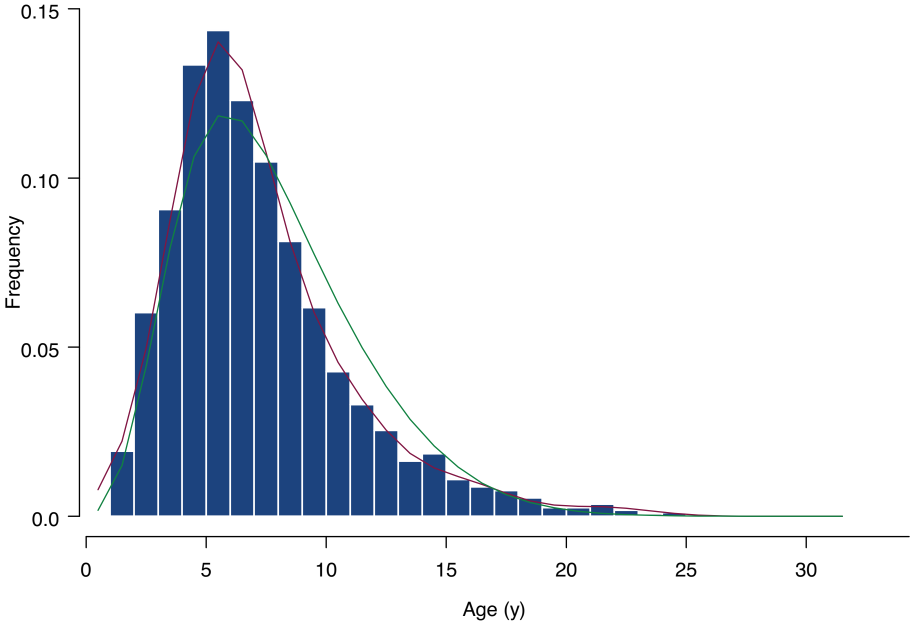


Figure 4.8 Histogram of actual age distribution obtained from sectioned otoliths for oceanic pink snapper, overlaid with age expected distributions determined from mixture (maroon line) and regression (green) analyses.

The examples above relate expected age distribution to the actual age distribution for the same set of data. That is, the expected distribution shown was generated from the same data set that provided the age distribution from sectioned otoliths. Because the oceanic snapper from Shark Bay had longer time series of age data, this provided the opportunity to partition the data, using data for some years to generate a relationship, which could then be tested against data from other years. This has been undertaken, with comparative examples provided below.

Figures 4.9 and 4.10 show the actual (sectioned otolith) age distribution for the two periods 1991-96 and 1999-2001. The data for two periods were subjected to both regression and mixture analysis to generate the relationships that were subsequently used to model expected age distributions.

Using the relationship generated using the 1991-96 data; the expected age distribution for 1999-2001 was better approximated using mixture analysis (Fig. 4.11), whereas regression analysis (Figure 4.12) failed to adequately represent the older age classes. In both cases there was considerable smoothing of the age distribution and hence loss of information for individual age classes.

This problem was also evident for the 2003 data. The actual age distribution for 2003 (Fig. 4.13) was considerably more complex than the expected distribution for both mixture analysis (Fig. 4.14) and regression analysis (Fig. 4.15). Mixture analysis again provided a better overall representation of the actual distribution, but regression analysis was able to better depict what appeared in Figure 4.11 to be a strong recruitment event.

Variability in the age distributions used during the development of relationships between proxies and actual age will affect the efficacy of the models. Examples of how expected (modelled) age distributions respond to such variability will be further investigated during this project, as this will affect how often the model needs to be recalibrated.

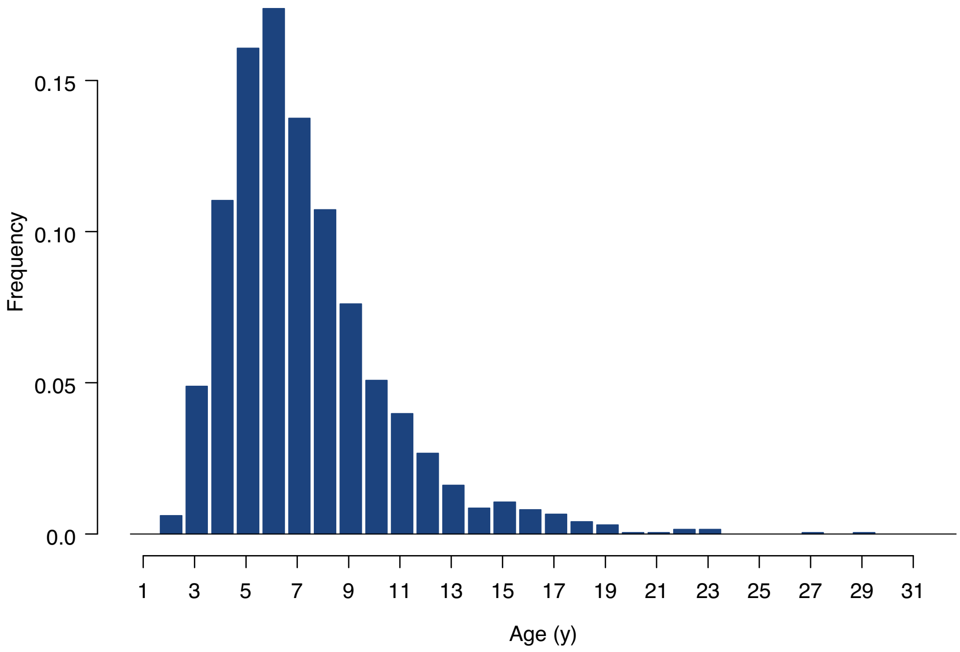


Figure 4.9 Actual age distribution for pink snapper from1991-1996.

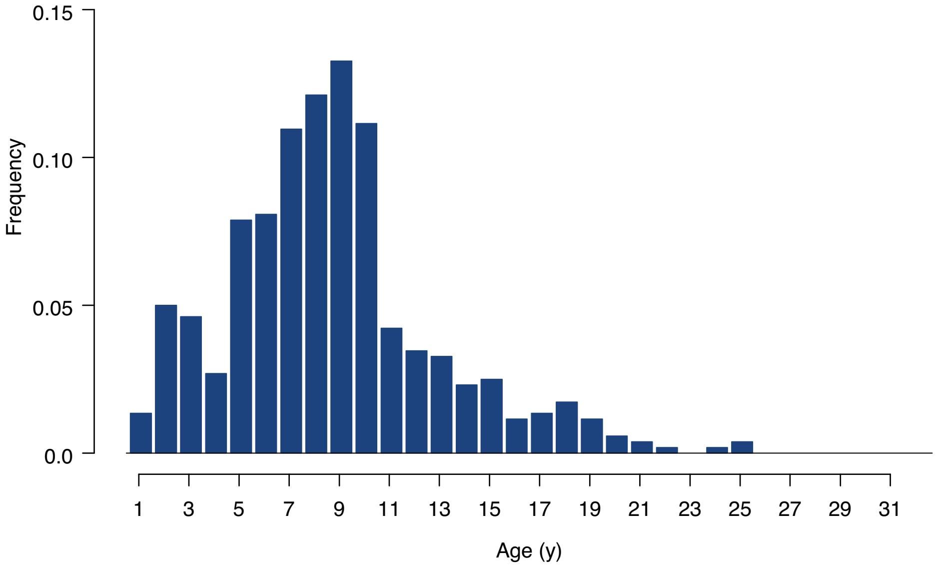


Figure 4.10 Actual age distribution for pink snapper from 1999-2001.

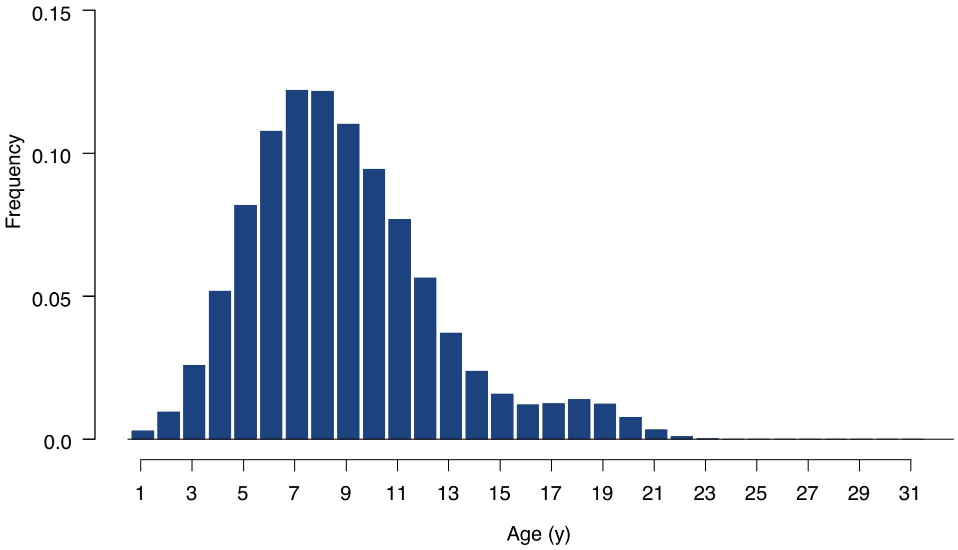


Figure 4.11 Forecasted age (expected) distribution for 1999-2001 for oceanic pink snapper using mixture analysis for the 1991-96 data.

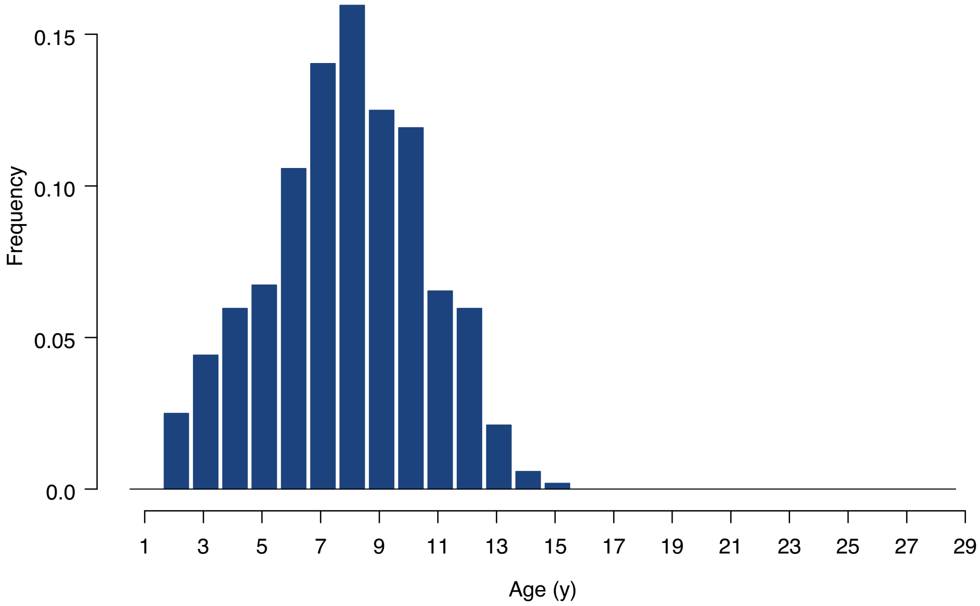


Figure 4.12 Forecasted age (expected) distribution for oceanic pink snapper from 1999-2001 using regression analysis for the 1991-96 data.

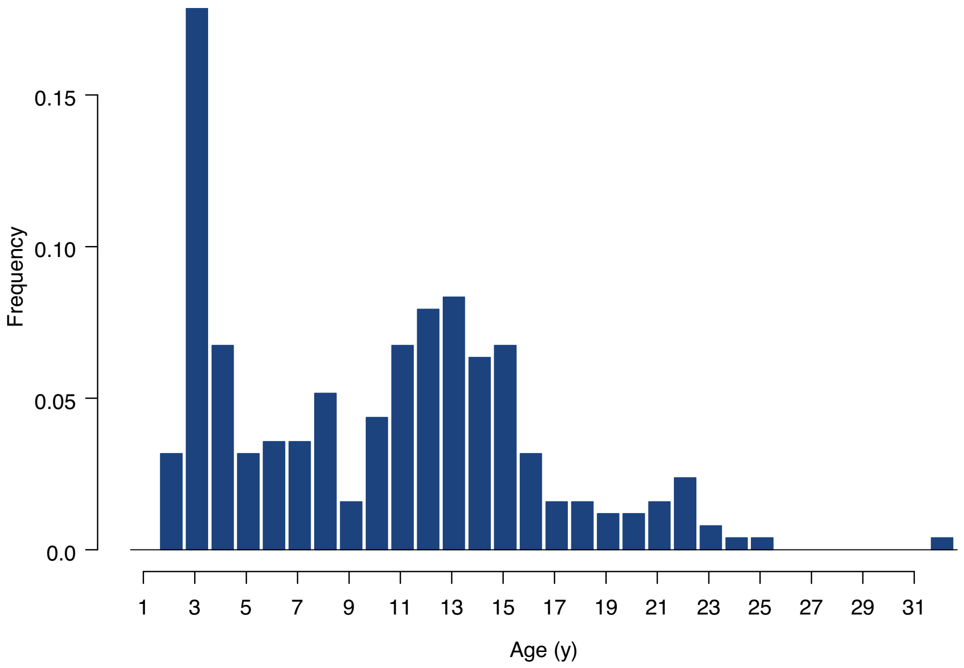


Figure 4.13 Actual pink snapper age distribution for 2003.

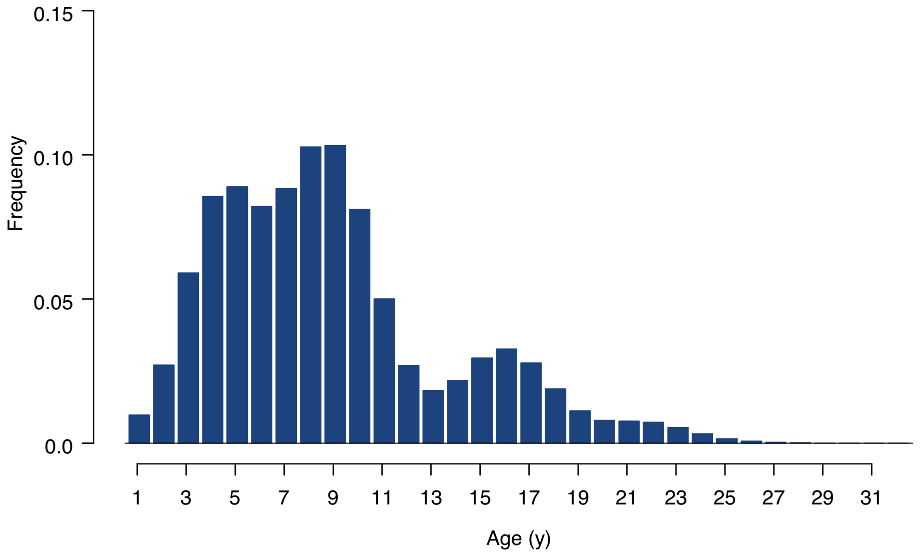


Figure 4.14 Forecasted (expected) age distribution for oceanic pink snapper in 2003 using mixture analysis derived from the 1999-2001 data.

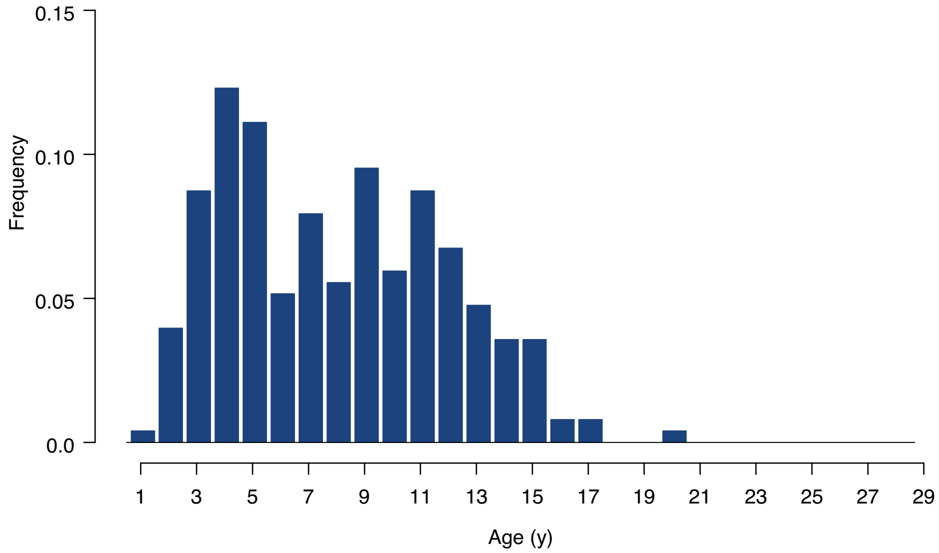


Figure 4.15 Forecasted (expected) age distribution for oceanic pink snapper in 2003 using regression analysis derived from the 1999-2001 data.

4.3.3 Sample sizes for sectioned otoliths

Using the age data, which was estimated using the annuli method, application of cumulative frequencies (see 4.1.1.1) determined that each of the precision levels had a unique sample size, which was is the same for all fish stocks (Table 4.3)

Table 4.3 Sample numbers required to achieve precision levels 0.04, 0.06 and 0.085 with 95% confidence by otolith section or whole otoliths.

Precision level	0.04	0.06	0.08
Sample size	1153	512	288

4.3.4 Sample sizes for proxy measures

The use of proxy measures introduces further imprecision requiring larger sample sizes to achieve precision levels between 0.04 and 0.08. The sample sizes required to achieve the predetermined precision levels for the proxy measures selected for each stock are shown in Table 4.4. This table can be used to provide a preliminary indication of what precision levels are achievable with current monitoring resources. For example, it can be seen that the yearly sample size required to achieve a precision level of 0.04 is not achievable for

- Shark Bay pink snapper (i.e. n = 48,618)
- Sea mullet (n > 19,000)
- Australian salmon (n > 76,000)

By contrast, if a precision level of 0.08 was acceptable, then half the stocks would need samples of < 500, and across all stocks the average number of samples required per year would be 616.

Table 4.4 Sample numbers required to achieve precision levels 0.04, 0.06 and 0.08 with 95% confidence by proxy measures of age for 23 stocks of scalefish in Western Australia.

Bioregion	**Species/ Stock**	**Method**	**Proxy**	**Precision level**		
				0.04	**0.06**	**0.08**
North Coast	Spanish Mackerel	Regression	Oto wt	2560	840	413
		Regression	Head length	3072	931	443
	Coral Trout	Regression	Total length	4665	1159	514
	Chinaman Cod	Regression	Oto wt	2848	893	431
Kimberley	Goldband Snapper	Regression	Oto wt	1521	614	329
		Mixture	Fork length	2701	1028	538
	Red Emperor	Regression	Oto height	2030	733	375
Pilbara	Red Emperor	Regression	Oto wt	4915	1190	523
	Rankin Cod	Mixture	Oto wt	15195	2766	1118
	Flagfish	Regression	Oto wt	4628	1155	513
	Rosy Threadfin Bream	Mixture	Oto wt	4410	1442	707
	Notched Threadfin Bream	Regression	Oto wt	N/A	4622	1154
Gascoyne	Pink Snapper (oceanic)	Mixture	Fork length	19949	3014	1161
		Regression	Oto wt	48618	2695	866
	Pink Snapper (Freycinet)	Regression	Oto wt	6260	1335	564
	Blue lined Emperor	Regression	Oto wt	5870	1296	553
	Western butterfish	Regression	Oto wt	12446	1782	678
West Coast	Australian Herring	Regression	Oto wt	6404	1349	568
	King George Whiting	Regression	Total length	3461	994	463
	Sea Mullet	Regression	Oto wt	19229	2078	744
		Regression	Total length	31864	2420	814
	Yellow-finned Whiting	Regression	Total length	6831	1390	579
	Black Bream	Regression	Standard length	3261	962	453
		Regression	Total weight	3438	990	462
	Dhufish (north)	Regression	Oto wt	2749	875	425
	Dhufish (metro)	Regression	Oto wt	2077	744	379
	Dhufish (south)	Regression	Oto wt	3098	935	445
South	Salmon	Regression	Total length	89247	3061	929
		Regression	Total weight	76286	2970	914
			Min	1521	814	329
			Max	89247	3061	929
			Mean	13530	1572	616

4.4 Discussion

The results of the analyses in this chapter indicate a considerable potential for using ageing methods other than the annuli method. The sample sizes required to achieve precision levels of 0.04 – 0.08 indicate that the annuli method is generally better for estimating age (for monitoring programs) than proxy measures; thus, the number of sectioned/whole otoliths required to achieve the required precision levels were much less than that required for the various proxy measures. Once the efficacy of using proxy measures for each stock has been assessed in Chapter 5, the relative costs of the different methods will be assessed in Chapter 6.

5.0 Assessment of performance of proxy age measures

5.1 Introduction

In Chapter 4 analyses were undertaken to ascertain which proxy measures of age provided the best fit to age structure determined from the annuli method. In this Chapter we assess the efficacy of using proxy measures of age for generating stock assessment advice. Ultimately, this aspect of the study is to determine whether using a proxy measure of age can provide an estimate of age structure sufficiently robust to be used as the basis for assessing stock status, either directly (catch curve analysis to estimate total mortality or age-structured model) or indirectly via examination of, for example, recruitment strength.

5.2 Methods

The efficacy of using proxy measures of age is first assessed by comparing the estimates of total mortality (Z) derived from catch curve analysis of age structure estimated using sectioned otoliths versus that estimated from the proxy measure. We do not investigate either natural mortality (M) or fishing mortality (F) in this exercise. All stocks were subjected to these comparisons. The age structures derived in Chapter 4 are presented in Figures 5.1 – 5.29. The value of Z is estimated using least absolute deviation regression, as follows, a method recognised for its inherent robustness (Li and Arce, 2004).

Fit $\log\left[\left(\text{Rel.frequency} + \frac{1}{\text{sample size}}\right) \times 100\right]$ v. age by least absolute deviation regression (with Laplacian errors)

Algorithm:

Select the LH abscissa to be the median of the age distribution.

Define the RH abscissa to be the knot value x^*, a parameter to be estimated.

Fit the regression line that minimizes the sum of absolute deviations.

The algorithm is performed on age distributions generated by (1) otolith section, and (2) competing proxies.

Once the point estimate for Z has been measured for each ageing method, the suitability of the proxy measure is assessed by objectively setting an acceptability criterion of $\pm 40\,\% \times \sqrt{\frac{288}{N}}$, , where N is the (proxy) sample size for the species. That is, proxies will only be accepted if the estimate of Z falls within the given bound of that obtained using ages from the annuli method. This criterion was developed as follows. The natural variability in Z was estimated by bootstrapping, with the square-root-of-N law applying, the proxy-measure data for each stock. The bound of 40% was identified as the worst-case acceptable to achieve 90% confidence estimates calculated from bootstraps of minimum sample size of 288 (K-S precision = 0.08, see Chapter 4) of the Z statistic for the annuli-method age distribution using the robust regression technique for each stock.

For those five stocks with an ASM, the estimated spawning biomass (median value) and variation (confidence intervals) derived using ages from the annuli method and those derived using the proxy measures are compared. Secondly, in order to later assess whether cost savings can be made through reducing sample sizes, a series of estimates are generated using relatively small sample sizes of the proxy measure drawn randomly from the real data. The acceptance or rejection of the proxy measure or reduced sample sizes of a proxy needs to be determined on a case-by-case basis for each stock. For example, for a stock below 40% B_0 an over-optimistic estimate of median spawning biomass should be treated with greater caution, whereas for a stock well above 40% B_0 there is scope to accept a higher level of discrepancy. Decisions regarding the confidence interval were likewise made depending on whether the stock was above or below 40% B_0[1]

5.3 Results

5.3.1 Estimates of total mortality (Z) - catch curve analysis

The catch curve analyses to estimate Z for the annuli method against proxy measures are shown in the lower panel of Figures 5.1 – 5.29. The Z-estimates are compared in Table 5.1. The proxy measures for 19 of the 23 stocks gave acceptable estimates of Z, i.e. within bounds determined using the square-root-of-N law. For some stocks, there was no discernible difference in the Z between the two methods, whereas in other the difference exceeded 50%. Large differences between the two methods that were acceptable (e.g. 37.2% difference for Australian herring) may seem counter-intuitive. However, the test is confirming that the proxy estimate is as reliable as the estimate derived from the annuli method but is not actually determining whether the estimate of Z is a true representation for the stock.

Table 5.1 Comparison of total mortality (Z) estimates derived using the annuli method and proxy measures of age. Sample size (N) refers to the data for proxies. For those species with two proxies, only the superior results are shown. TL, total length; OW, otolith weight. Dhufish are assessed as three stocks within the West Coast Bioregion (WCB).

Region	Species	Z sectioned otolith	Z proxy	% Difference	N	Acceptable
Kimberley	Goldband snapper	0.27	0.27	0	2417	YES
	Red emperor	0.19	0.19	0	1827	YES
Gascoyne	Pink snapper (Oceanic)	0.23	0.20	13.0	733	YES
	Pink snapper (Freycinet)	0.14	0.17	21.4	699	YES
	Blue-lined emperor	0.57	0.59	3.5	4172	YES
	Notched threadfin bream	0.80	0.76	5	362	YES
	Western butterfish	1.07	1.07	0	595	YES
Pilbara	Flagfish	0.46	0.52	13.0	1794	YES
	Red emperor	0.29	0.34	17.2	1827	YES
	Rankin cod	0.35	0.36	2.9	872	YES
	Rosy threadfin bream	0.85	0.85	0	1713	YES
North Coast	Spanish mackerel	0.26	0.26	0	1814	YES
	Chinaman cod	0.18	0.20	11.1	202	YES
	Coral trout	0.59	0.59	0	352	YES

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[1] B_0 as used here equates to the estimated spawning biomass at the start of the time period depicted in the ASM.

West	Australian herring	1.56	0.98	37.2	854	YES
	KG whiting	1.17	0.97	17.1	1378	NO
	Sea mullet (OW)	0.96	0.95	1.1	1212	YES
	Yellow-finned whiting	0.56	0.82	46.4	728	NO
	Black bream					
	Standard Length	0.60	0.58	3.3	1401	YES
	Total Weight	0.60	0.57	5.0	1273	YES
	Dhufish					
	North WCB	0.26	0.22	15.4	939	YES
	Metro WCB	0.16	0.23	43.7	802	NO
	South WCB	0.14	0.21	50.0	515	NO
South	Australian salmon (TL)	0.65	0.85	30.8	451	YES

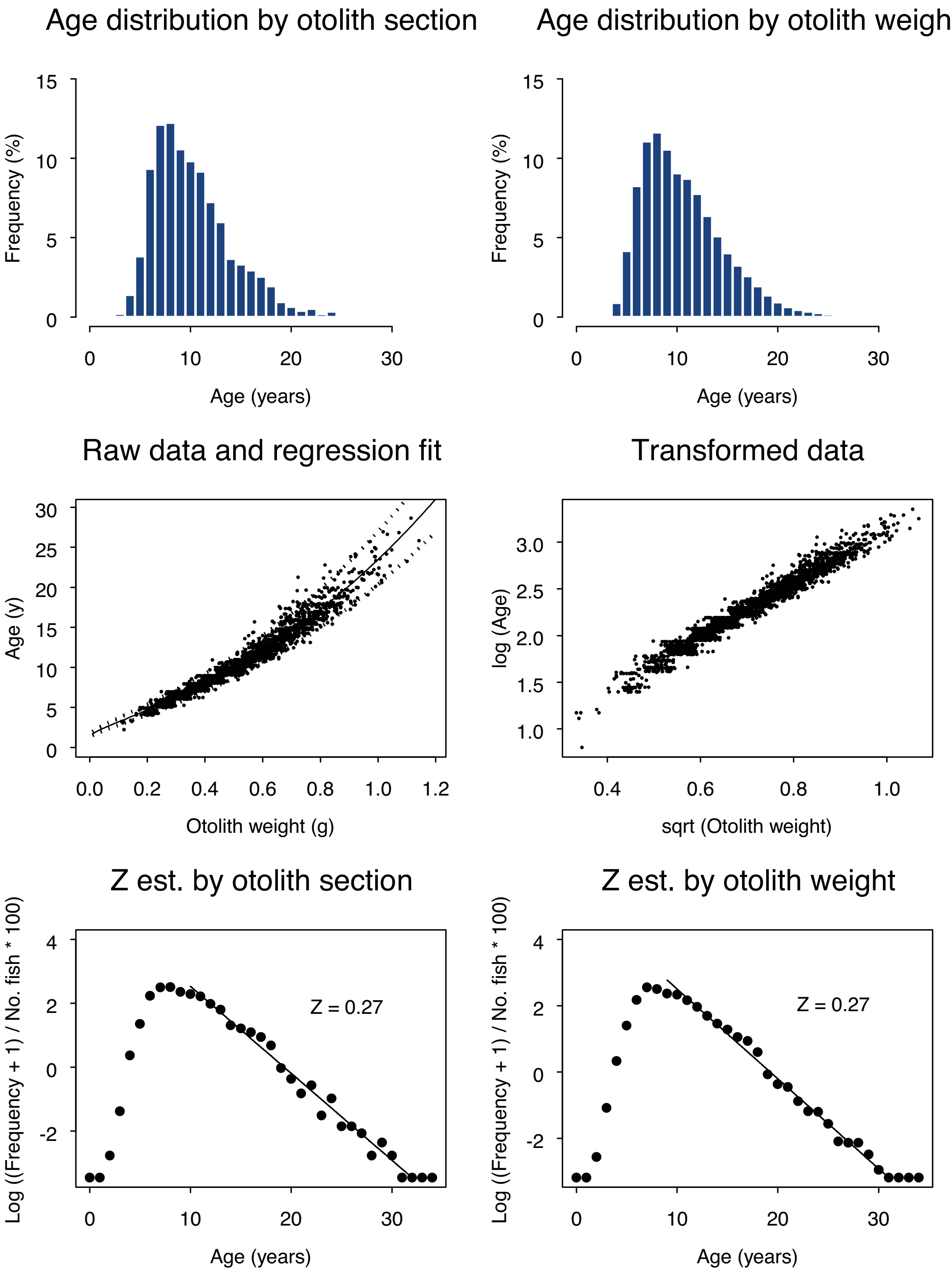

Figure 5.1 Goldband snapper (1) – by regression with otolith weight as proxy. Upper panels – age frequency distributions. Middle panels – otolith weight at age. Lower panels – catch curve analyses.

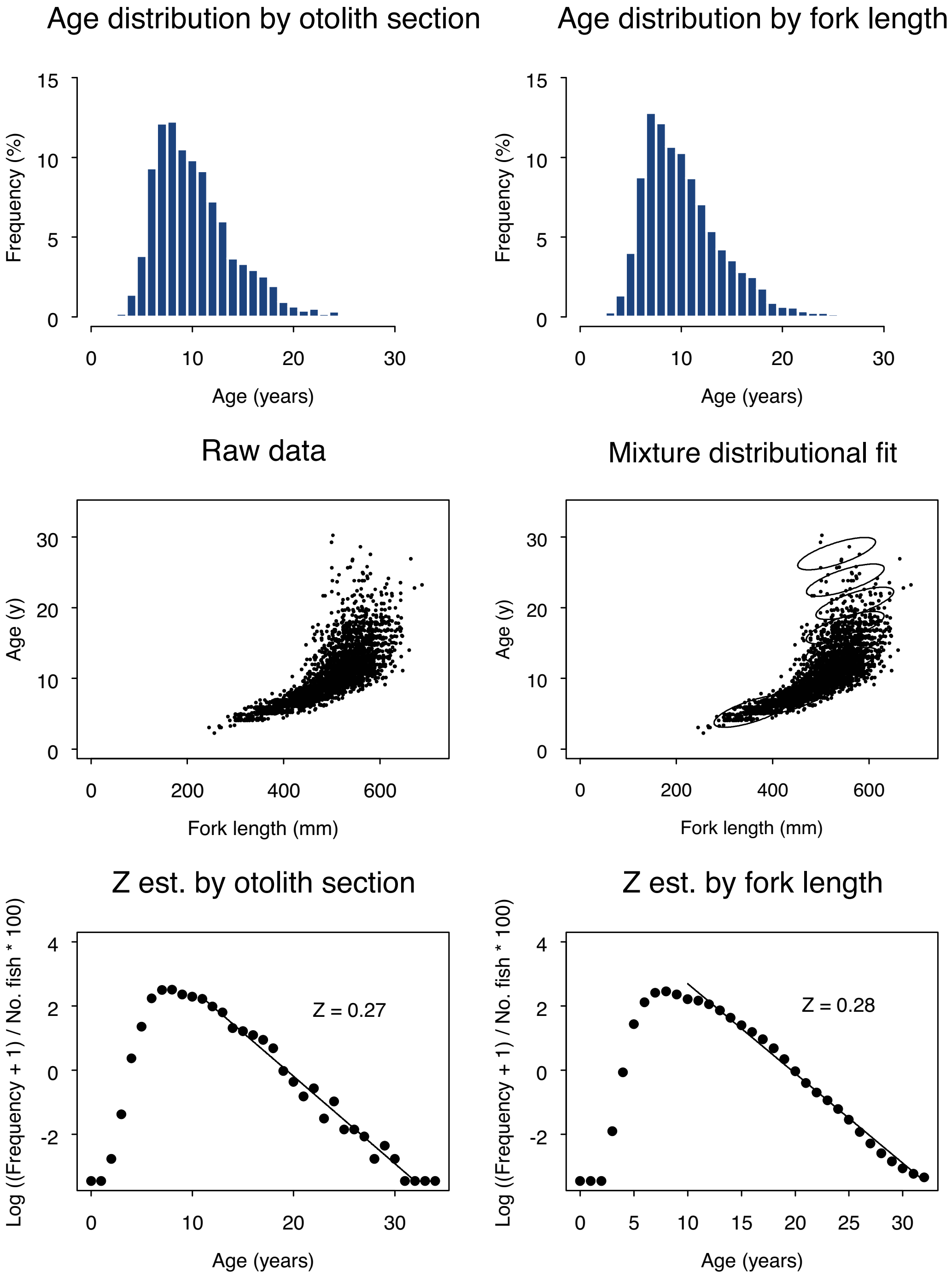

Figure 5.2 Goldband snapper (2) – by mixture with fork length as proxy. Upper panels – age frequency distributions. Middle panels – fork length at age. Lower panels – catch curve analyses.

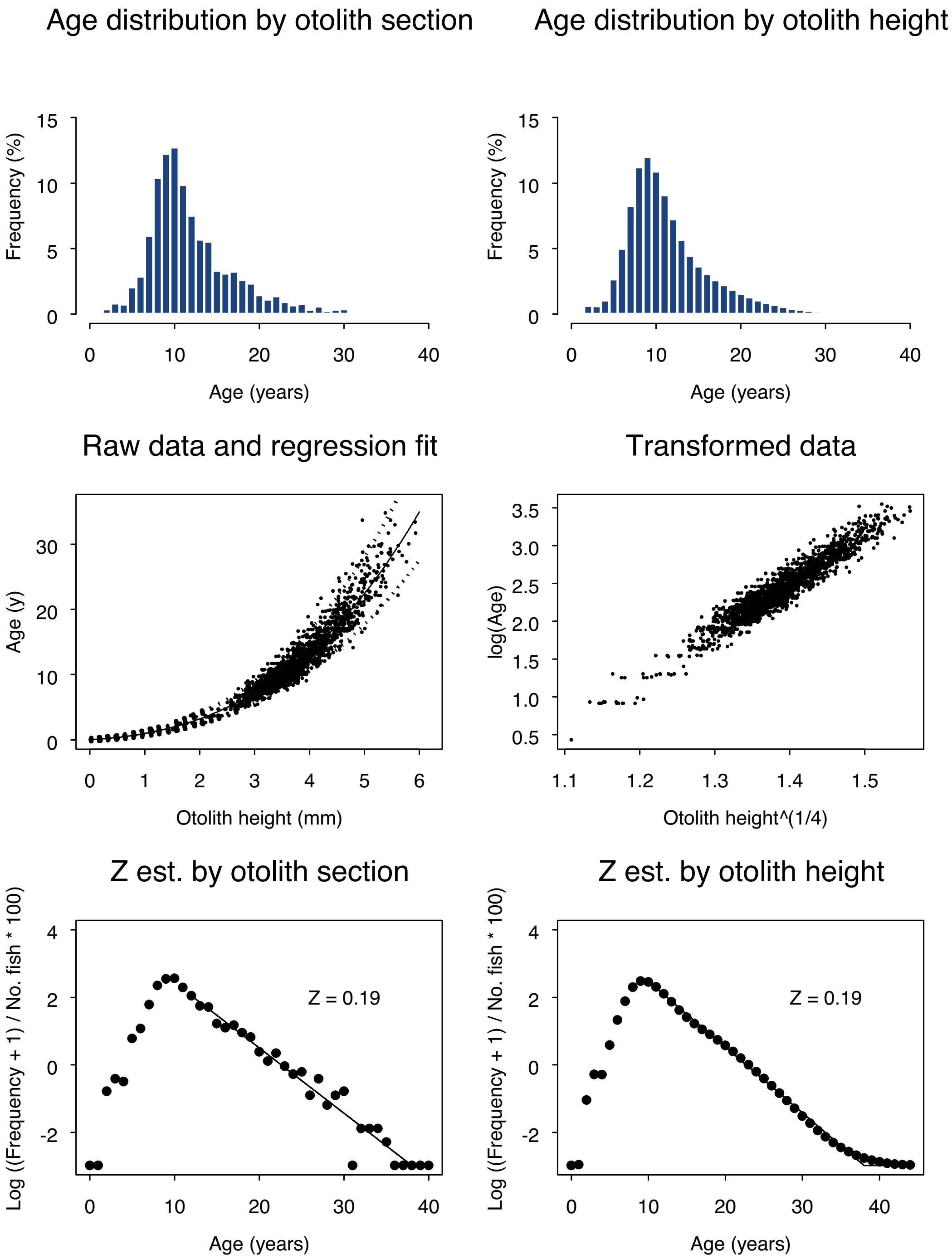

Figure 5.3 Red emperor (Kimberley) – regression with otolith height as proxy. Upper panels – age frequency distributions. Middle panels – otolith height at age. Lower panels – catch curve analyses.

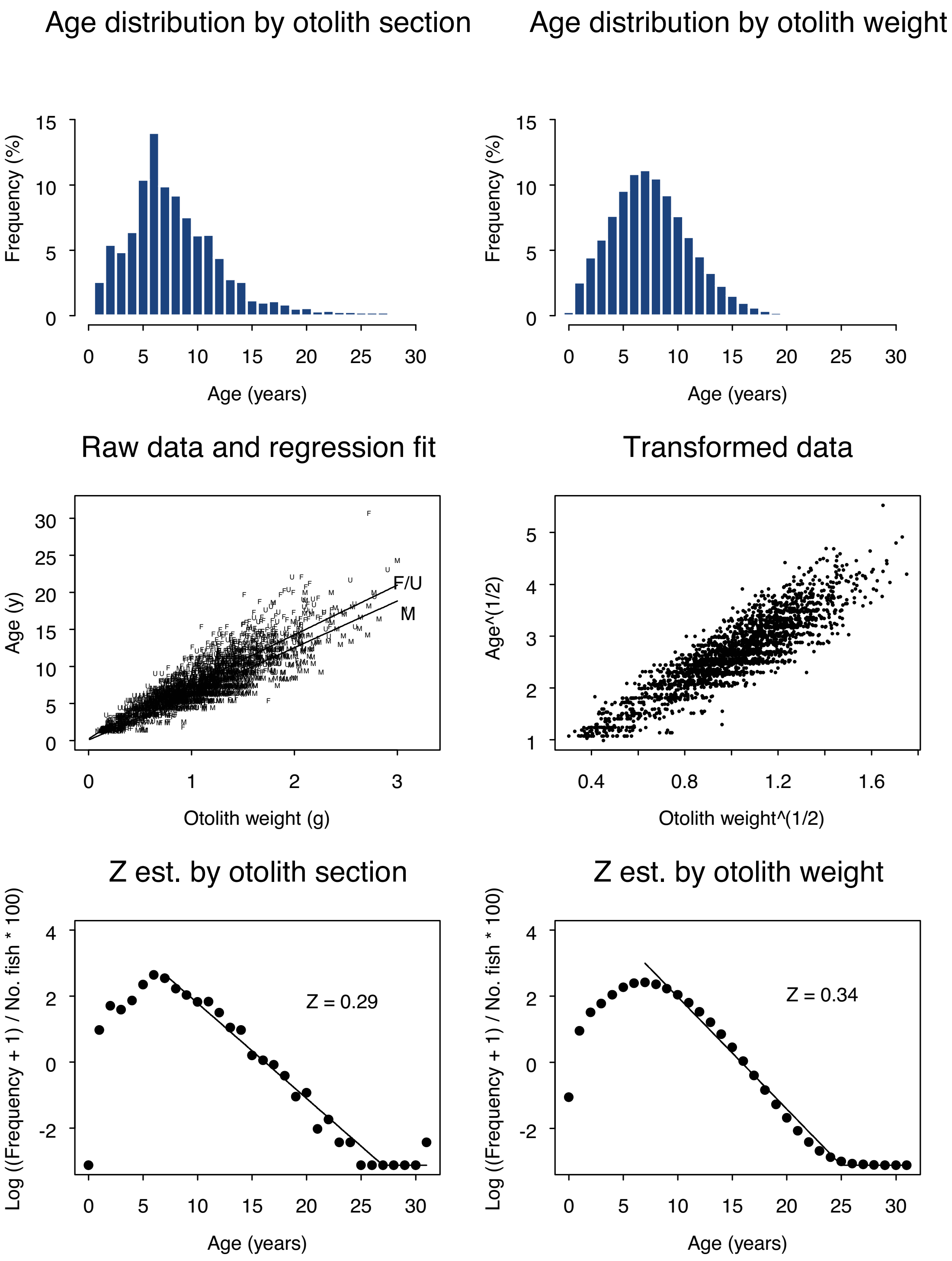

Figure 5.4 Red emperor (Pilbara) – regression with otolith weight as proxy. Upper panels – age frequency distributions. Middle panels – otolith weight at age. Lower panels – catch curve analyses.

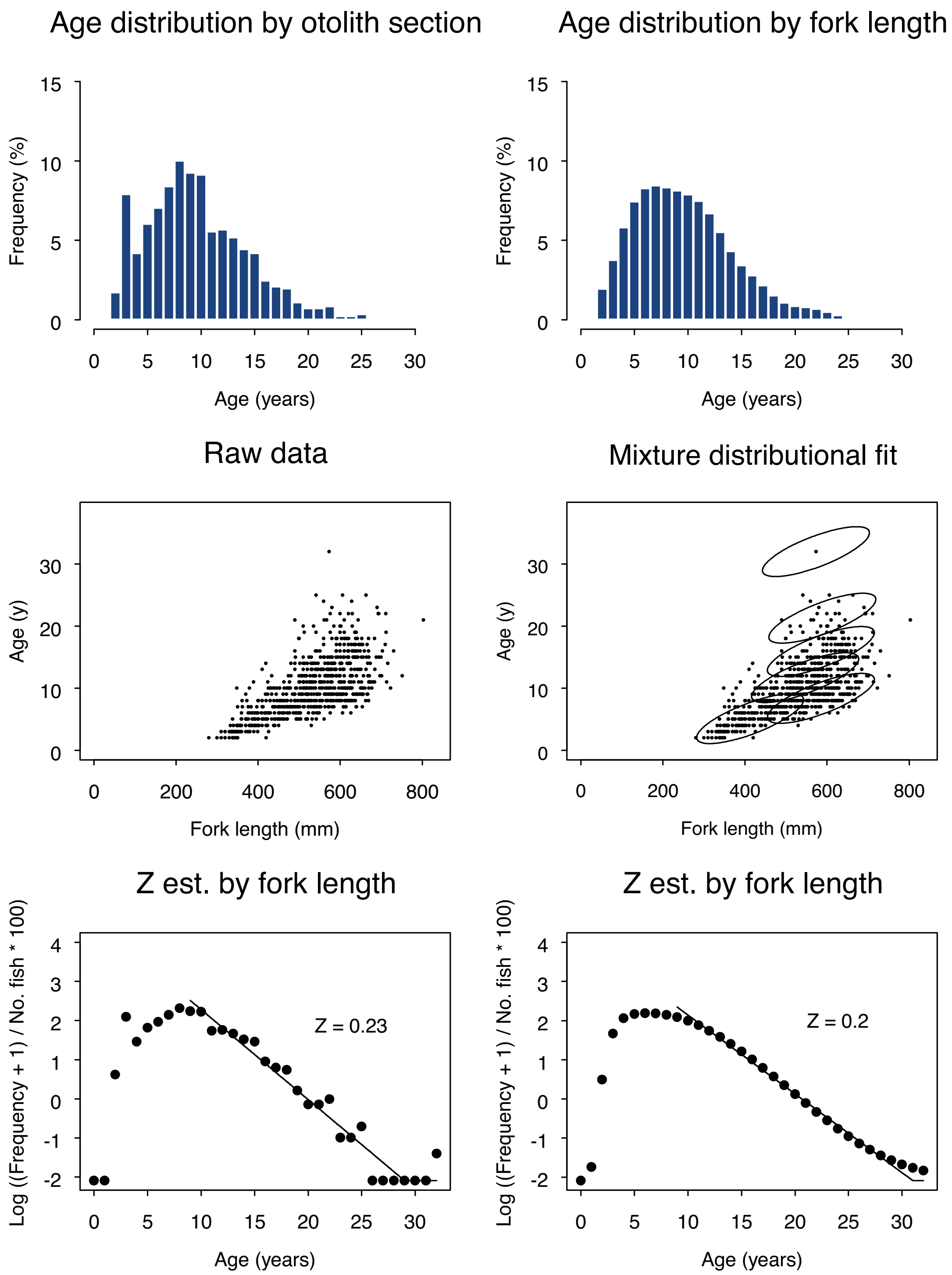

Figure 5.5 Pink snapper (Oceanic) – Mixture with fork length as proxy. Upper panels – age frequency distributions. Middle panels – fork length at age. Lower panels – catch curve analyses.

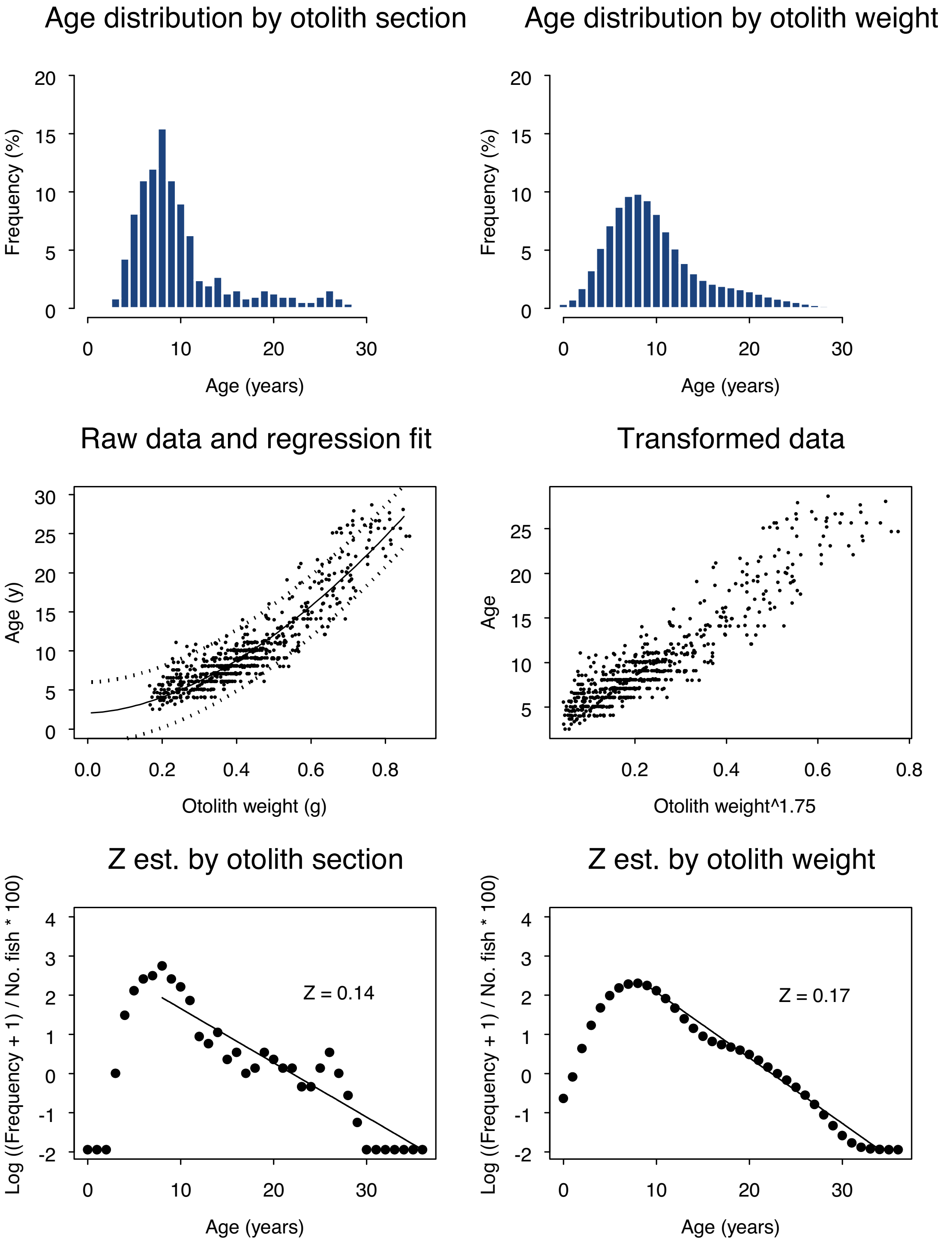

Figure 5.6 Pink snapper (Freycinet) – with otolith weight as proxy. Upper panels – age frequency distributions. Middle panels – otolith weight at age. Lower panels – catch curve analyses.

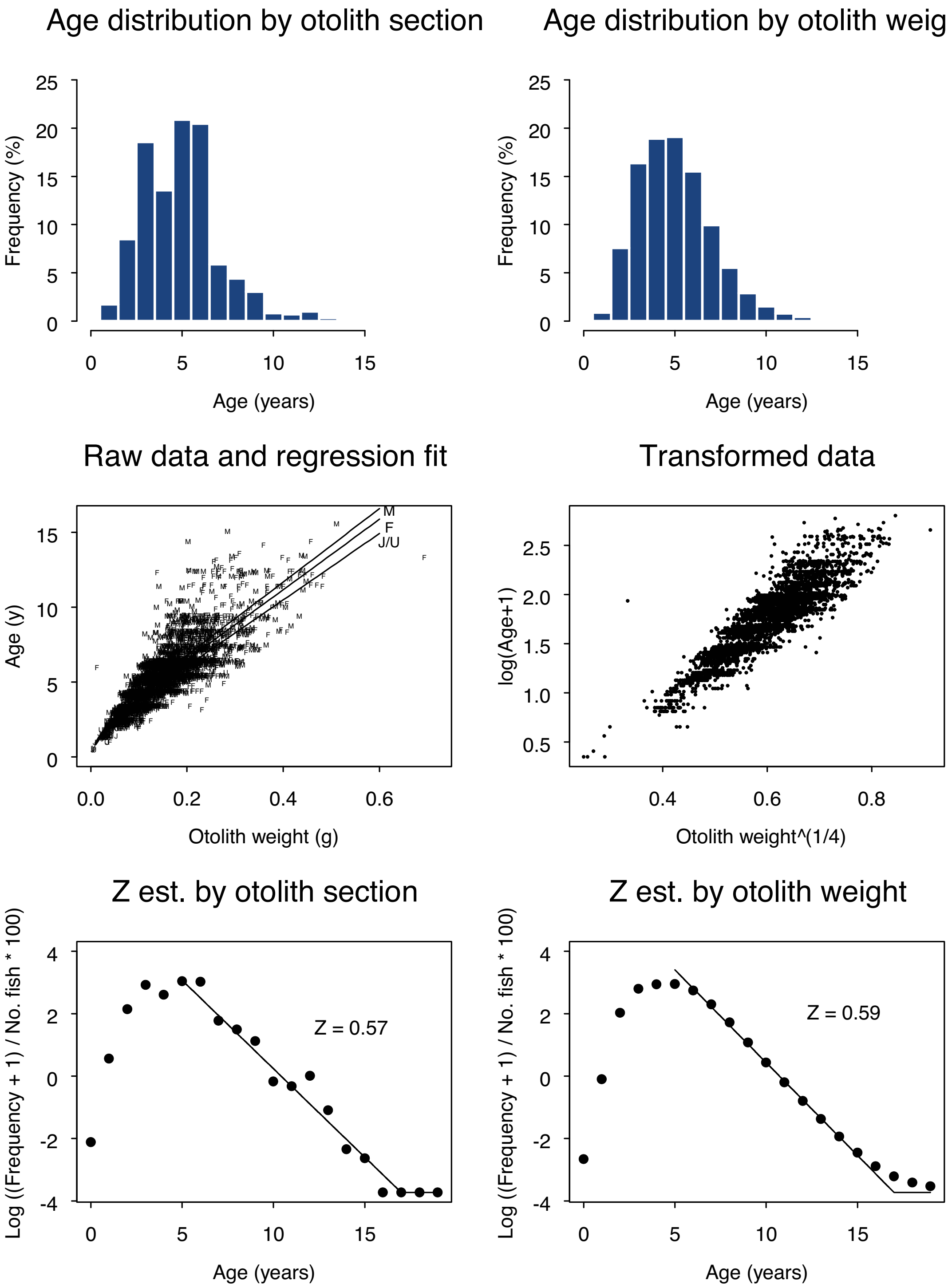

Figure 5.7 Blue lined emperor – by regression with sex differences and otolith weight as proxy. Upper panels – age frequency distributions. Middle panels – otolith weight at age. Lower panels – catch curve analyses.

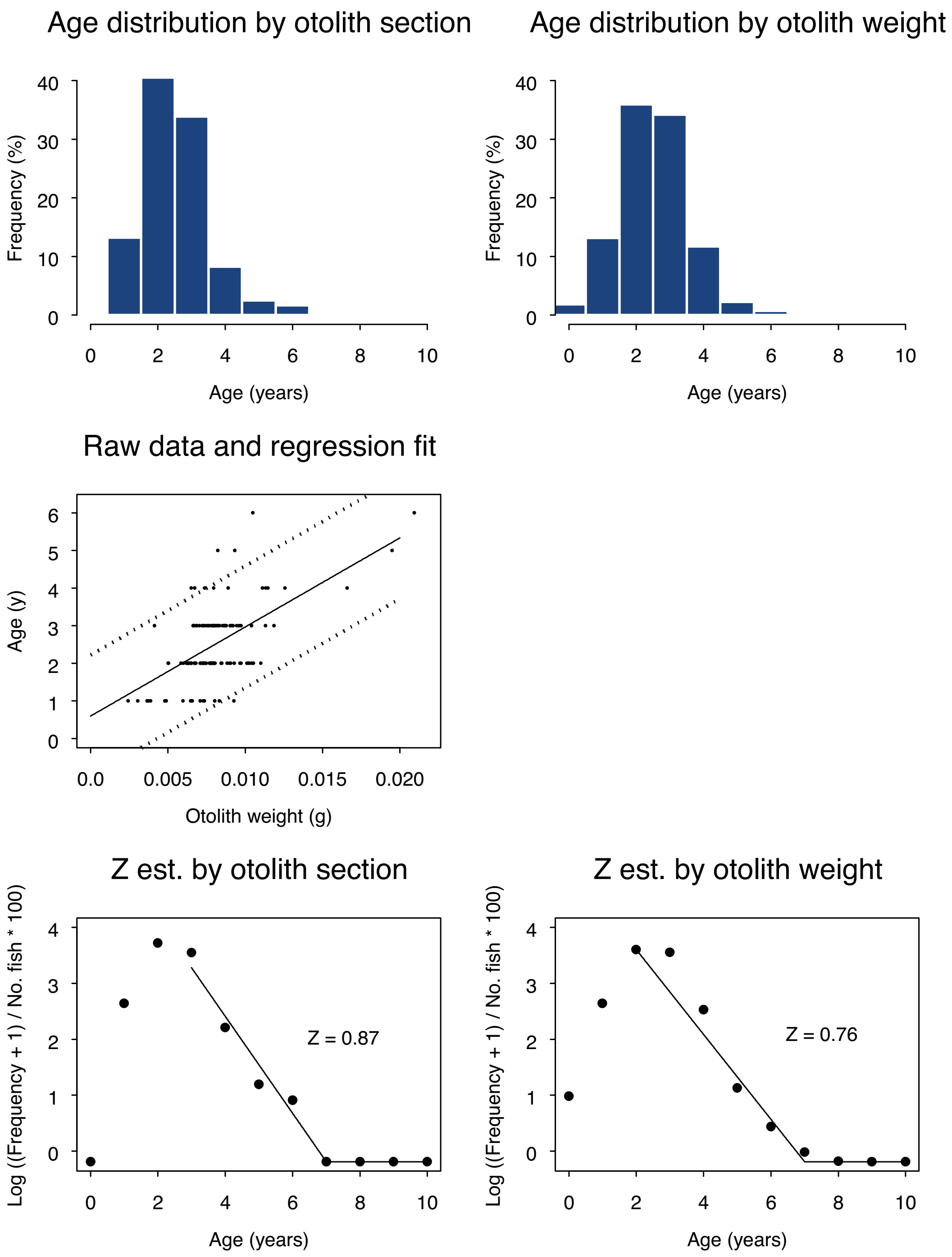

Figure 5.8 Notched threadfin bream – by regression with otolith weight as proxy. Upper panels – age frequency distributions. Middle panel – otolith weight at age. Lower panels – catch curve analyses.

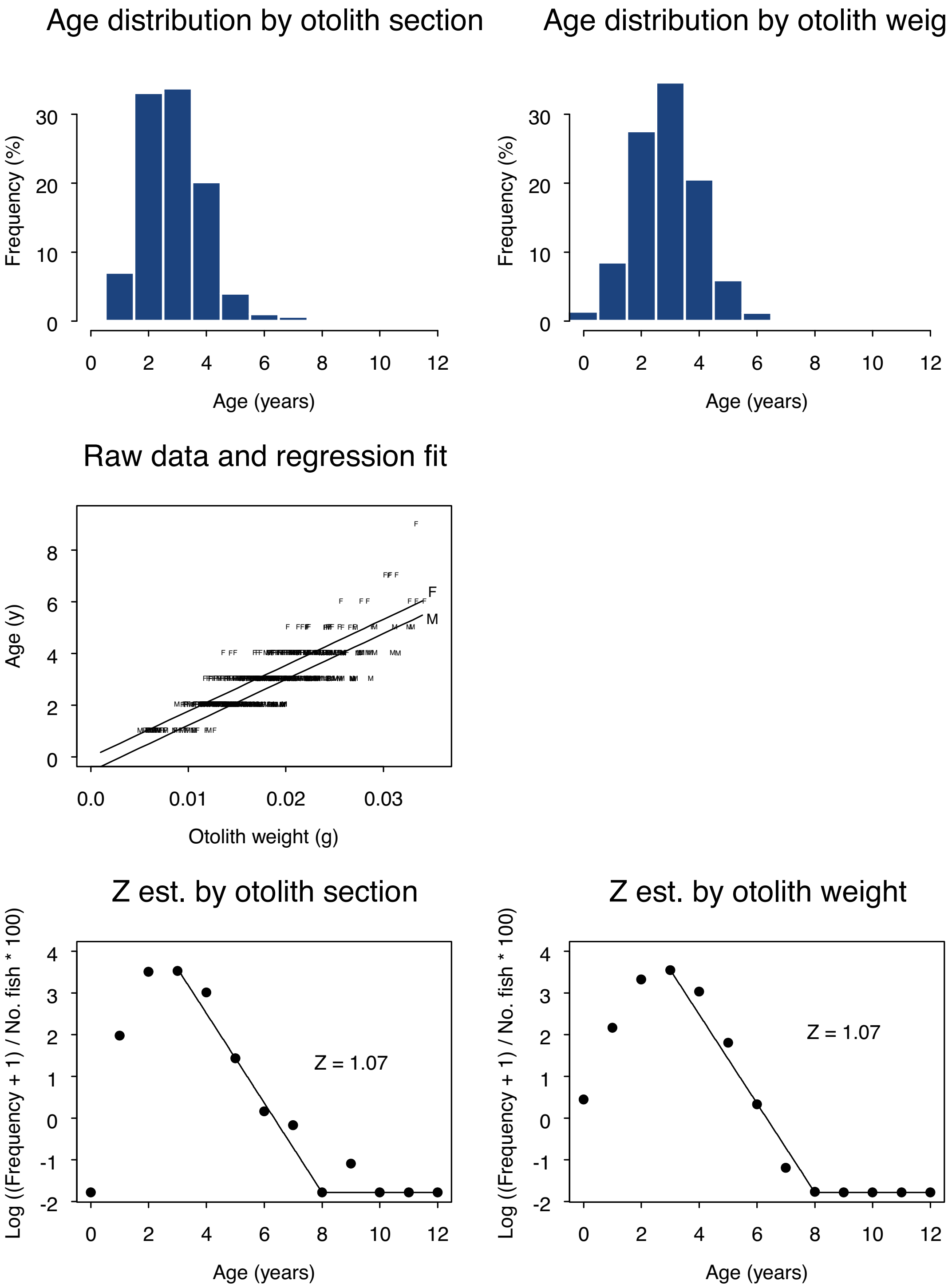

Figure 5.9 Western butterfish – regression with otolith weight as proxy. Upper panels – age frequency distributions. Middle panel – otolith weight at age. Lower panels – catch curve analyses.

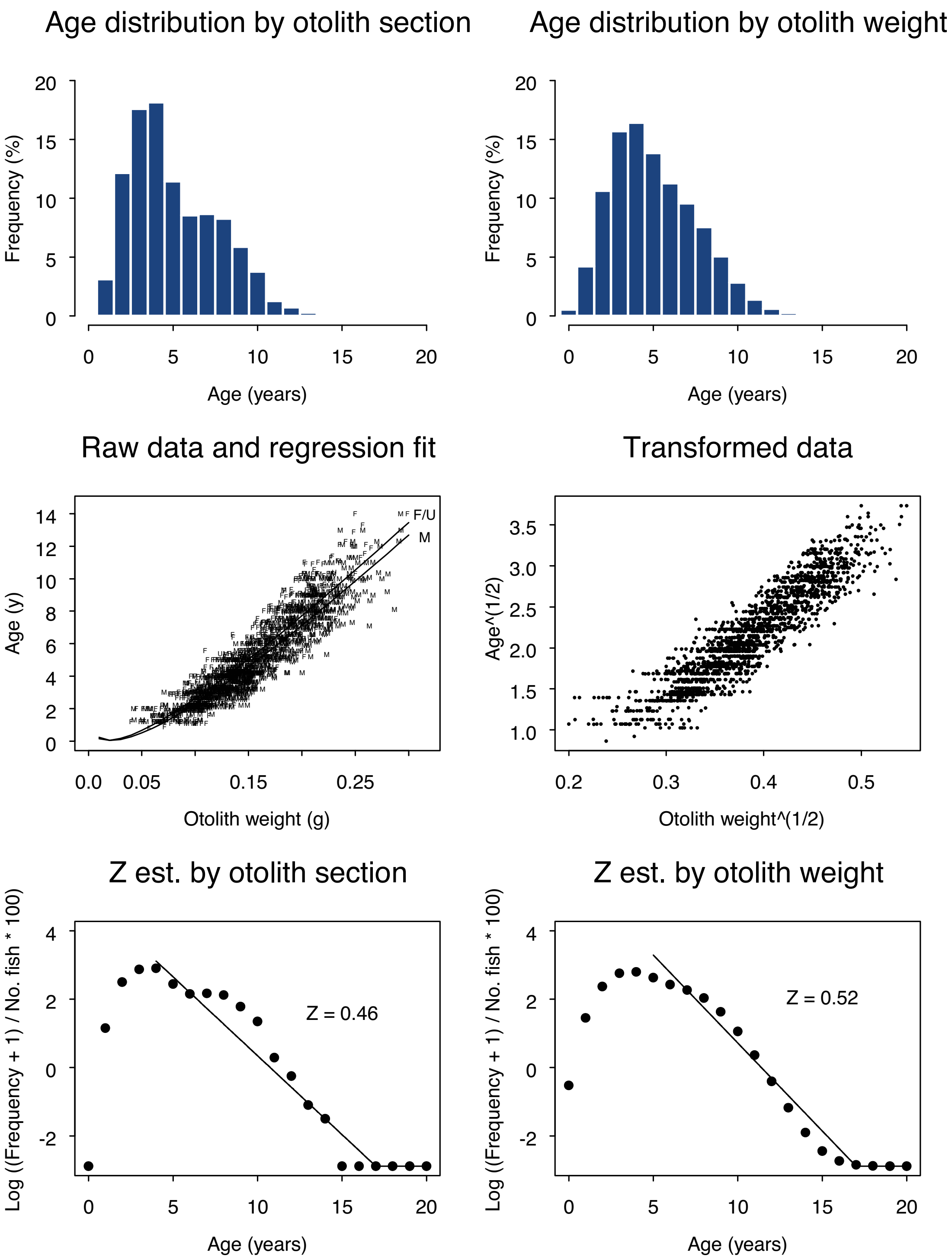

Figure 5.10 Flagfish – by regression with otolith weight as proxy. Upper panels – age frequency distributions. Middle panels – otolith weight at age. Lower panels – catch curve analyses.

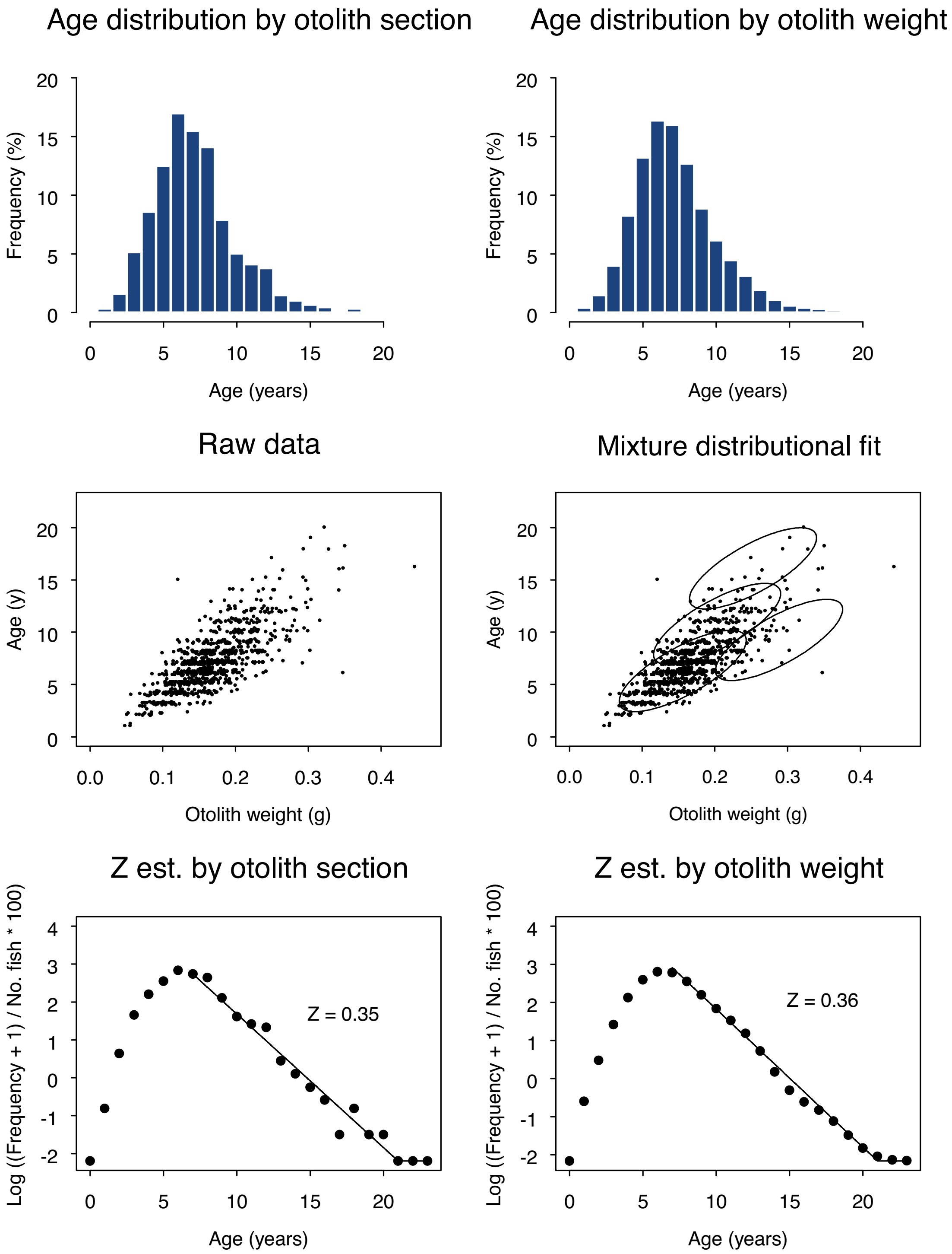

Figure 5.11 Rankin cod – mixture with otolith weight as proxy. Upper panels – age frequency distributions. Middle panels – otolith weight at age. Lower panels – catch curve analyses.

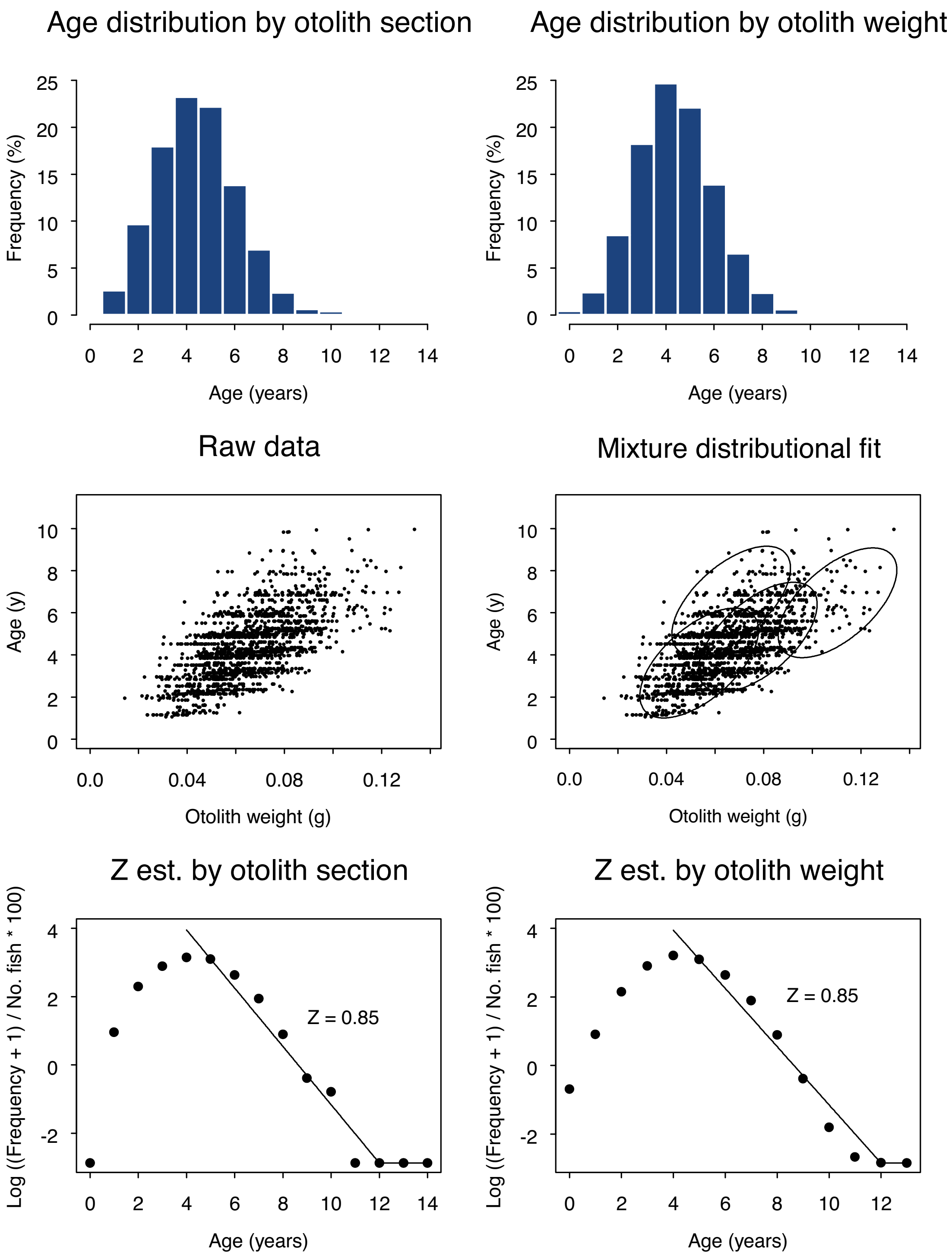

Figure 5.12 Rosy threadfin bream – mixture with otolith weight as proxy. Upper panels – age frequency distributions. Middle panels – otolith weight at age. Lower panels – catch curve analyses.

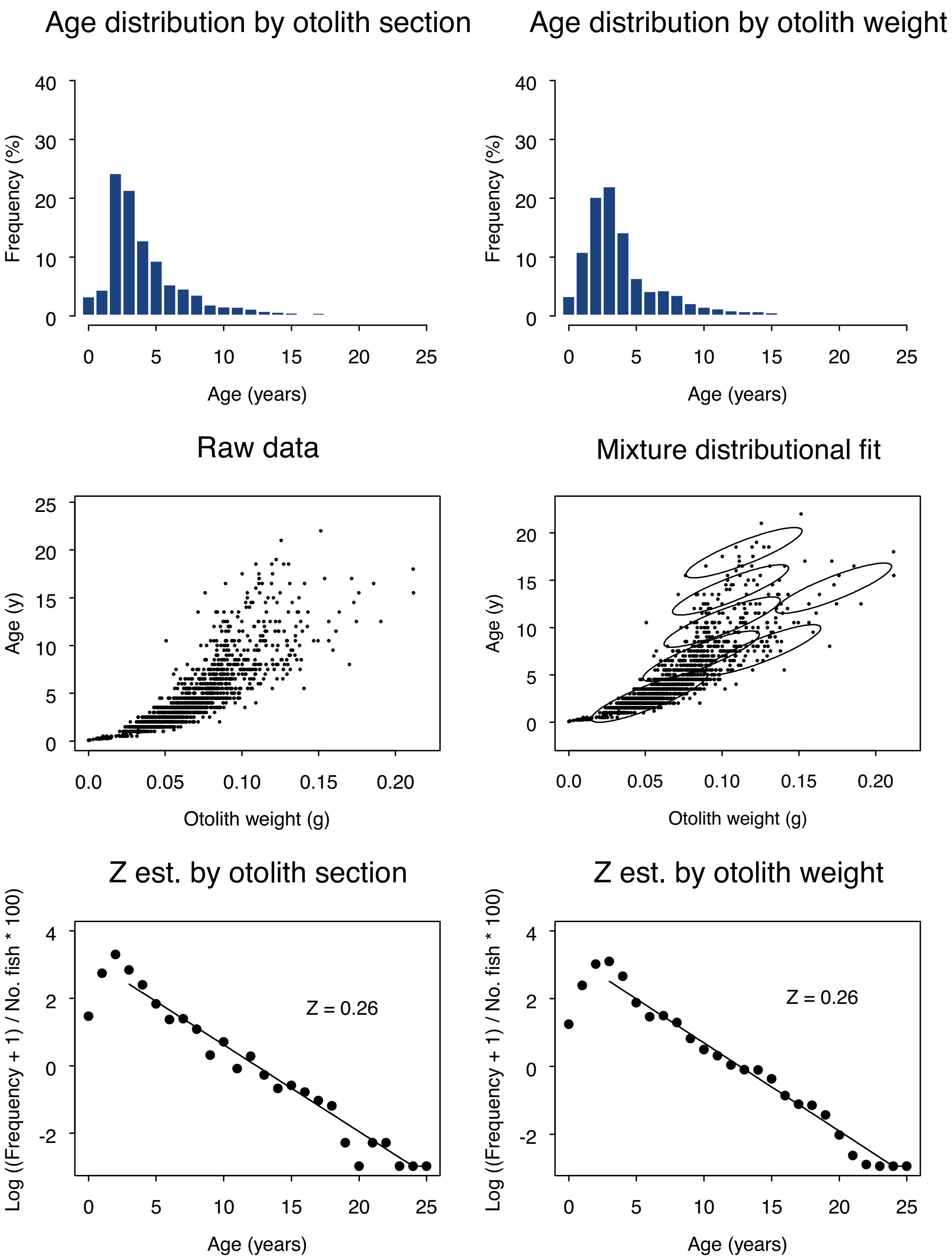

Figure 5.13 Spanish mackerel – mixture analysis with otolith weight as proxy. Upper panels – age frequency distributions. Middle panels – otolith weight at age. Lower panels – catch curve analyses.

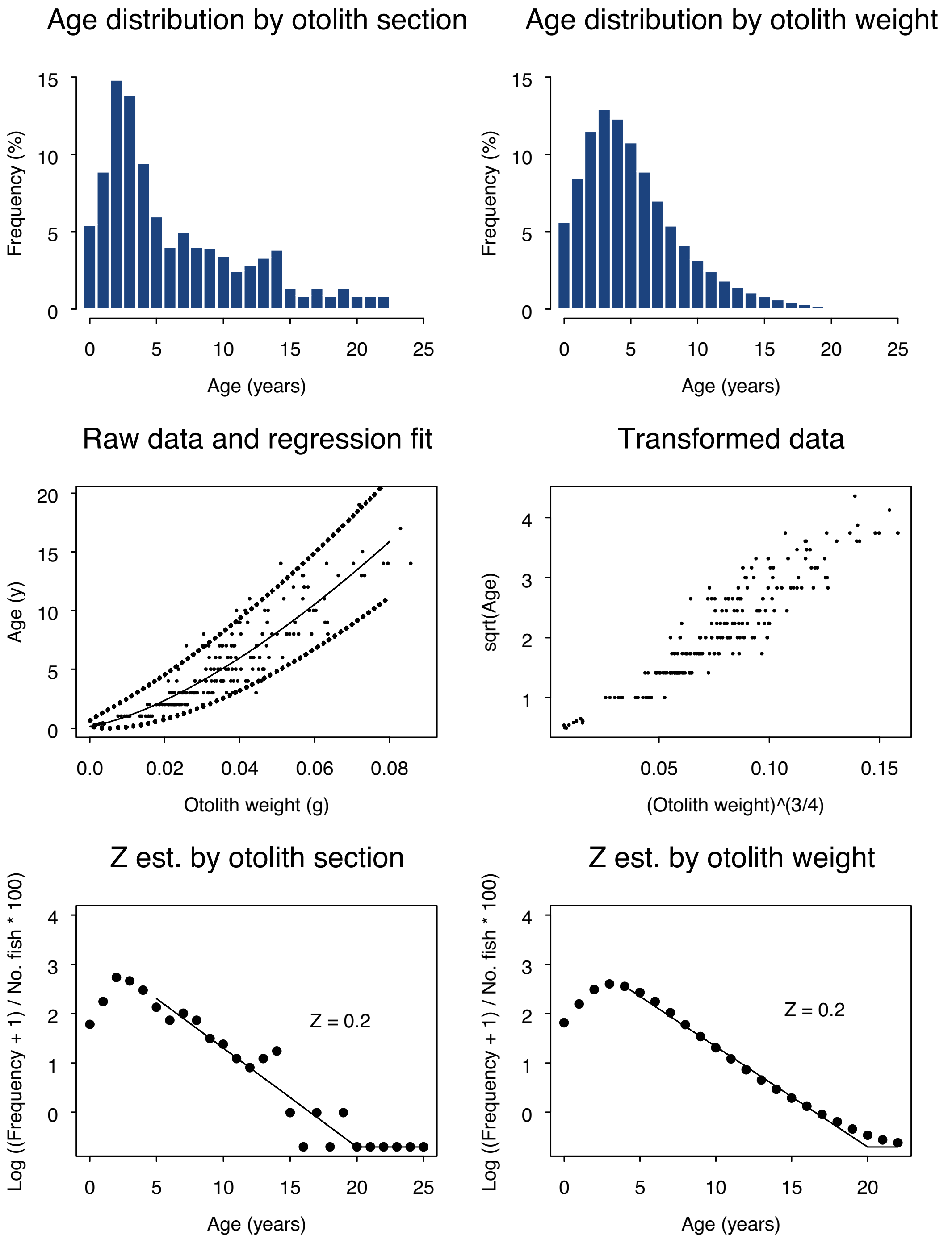

Figure 5.14 Chinaman cod – by regression with otolith weight as proxy. Upper panels – age frequency distributions. Middle panels – otolith weight at age. Lower panels – catch curve analyses.

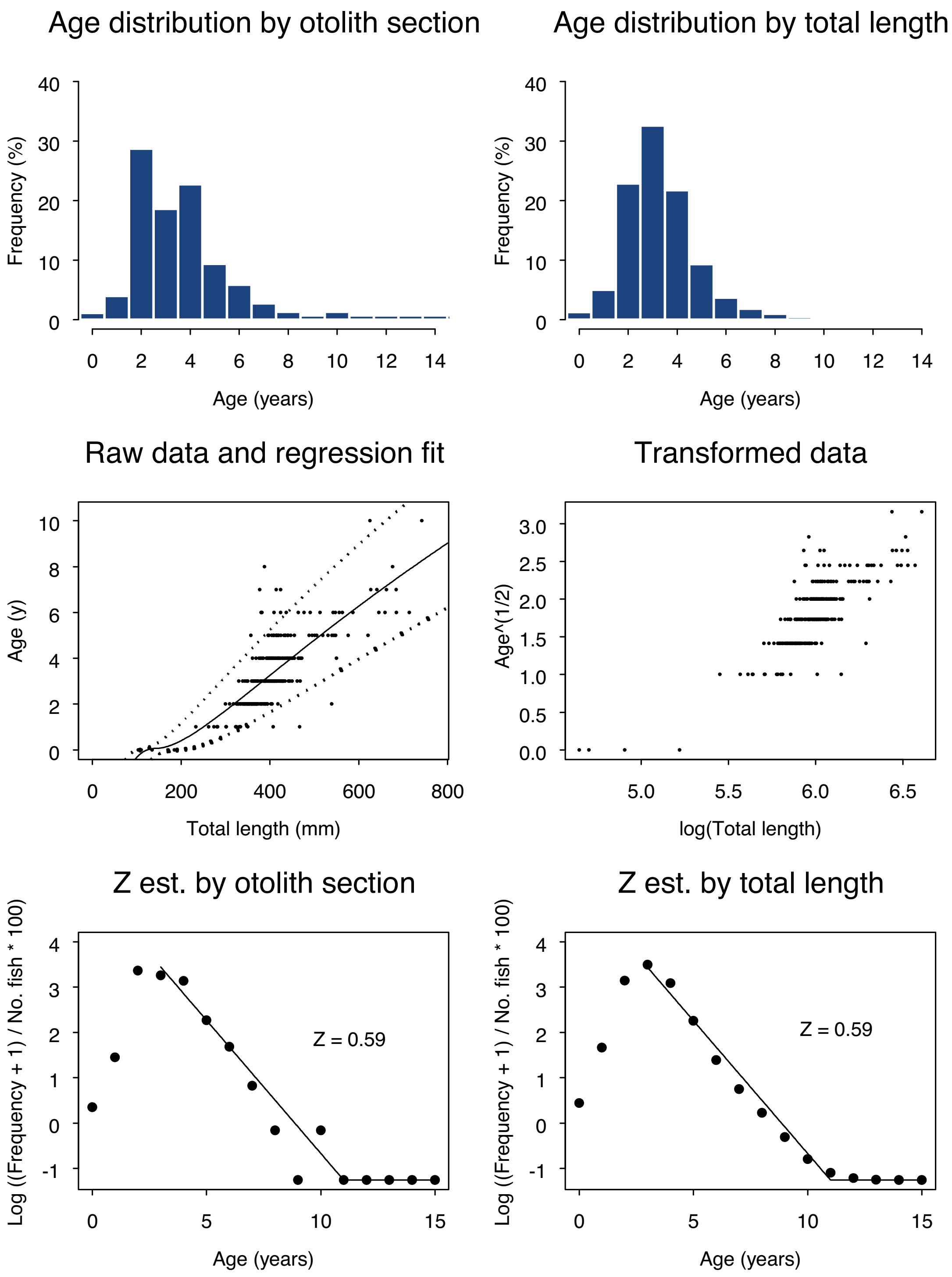

Figure 5.15 Coral trout – by regression with total length as proxy. Upper panels – age frequency distributions. Middle panels – total length at age. Lower panels – catch curve analyses.

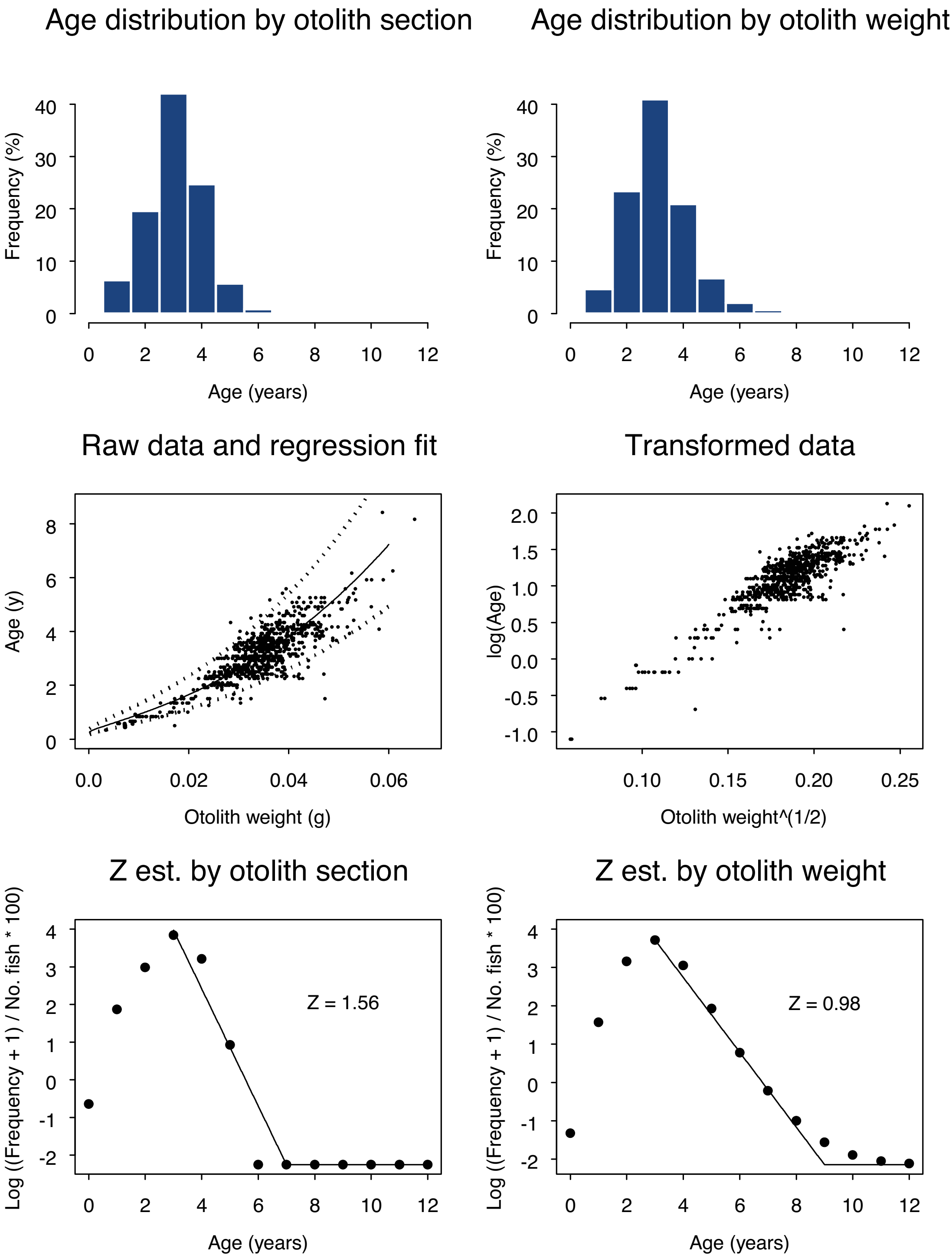

Figure 5.16 Australian herring – regression with otolith weight as proxy. Upper panels – age frequency distributions. Middle panels – otolith weight at age. Lower panels – catch curve analyses.

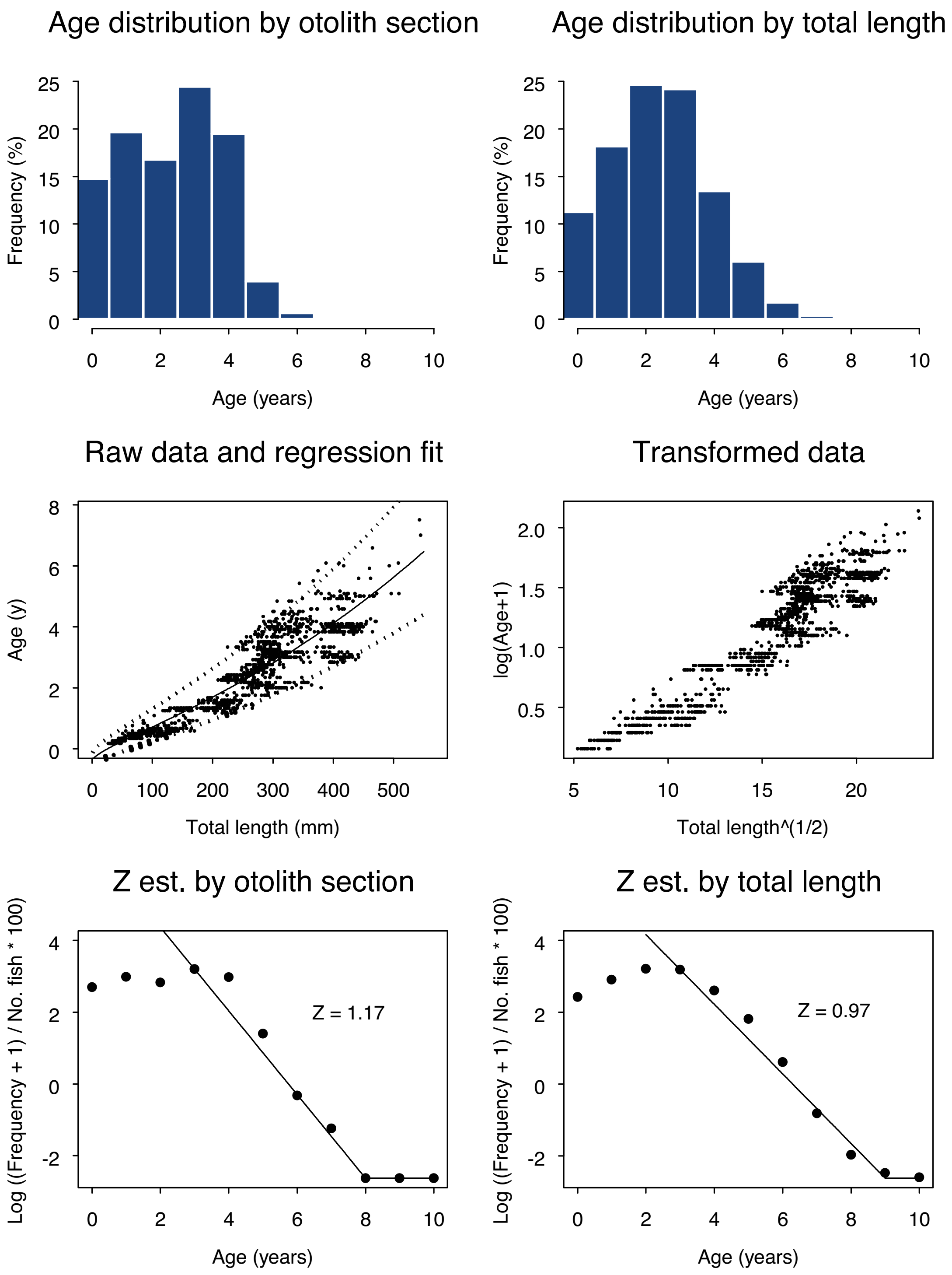

Figure 5.17 King George whiting – by regression and with total length as proxy. Upper panels – age frequency distributions. Middle panels – total length at age. Lower panels – catch curve analyses.

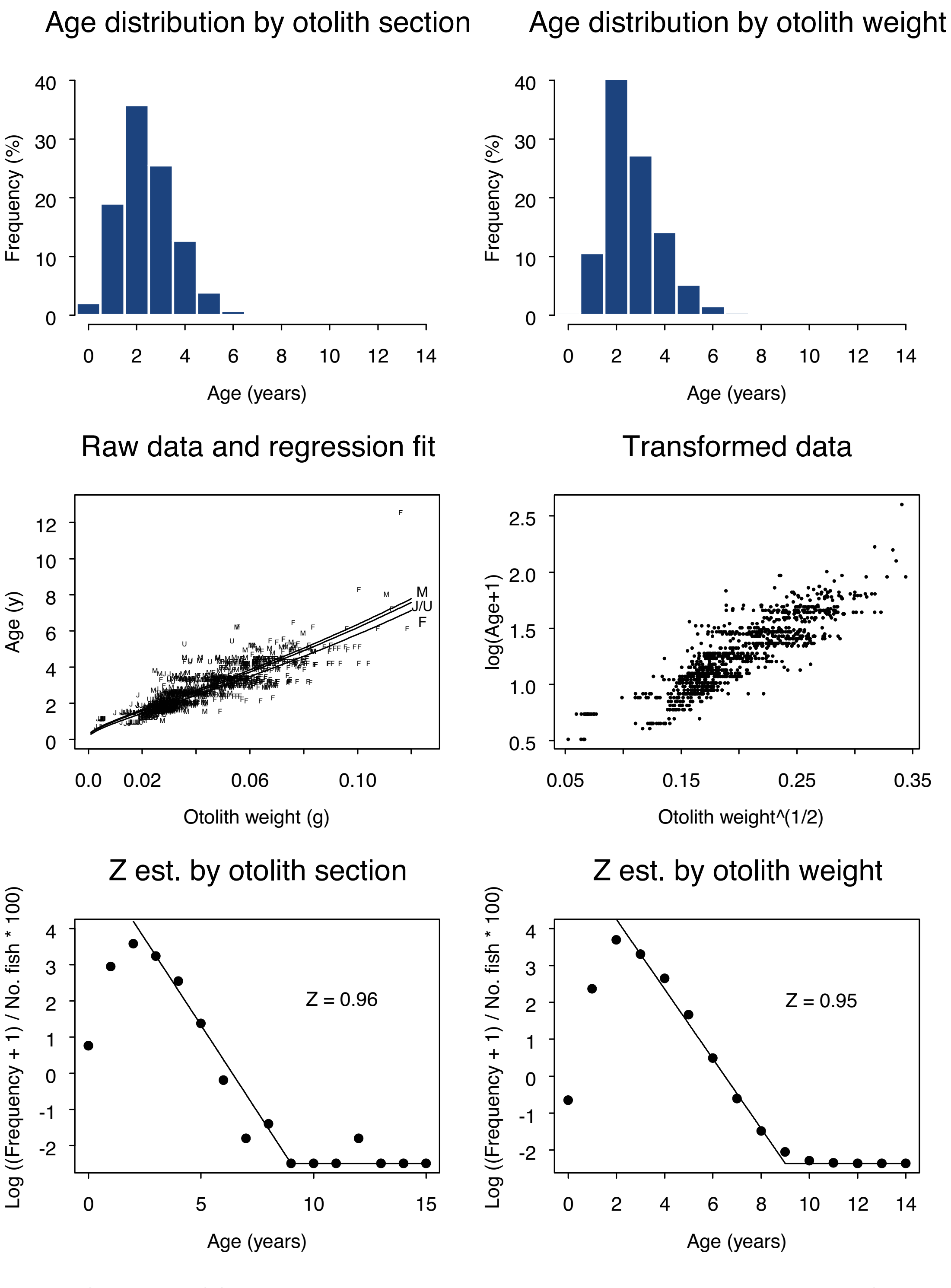

Figure 5.18 Sea mullet (1) – regression with otolith weight as proxy. Upper panels – age frequency distributions. Middle panels – otolith weight at age. Lower panels – catch curve analyses.

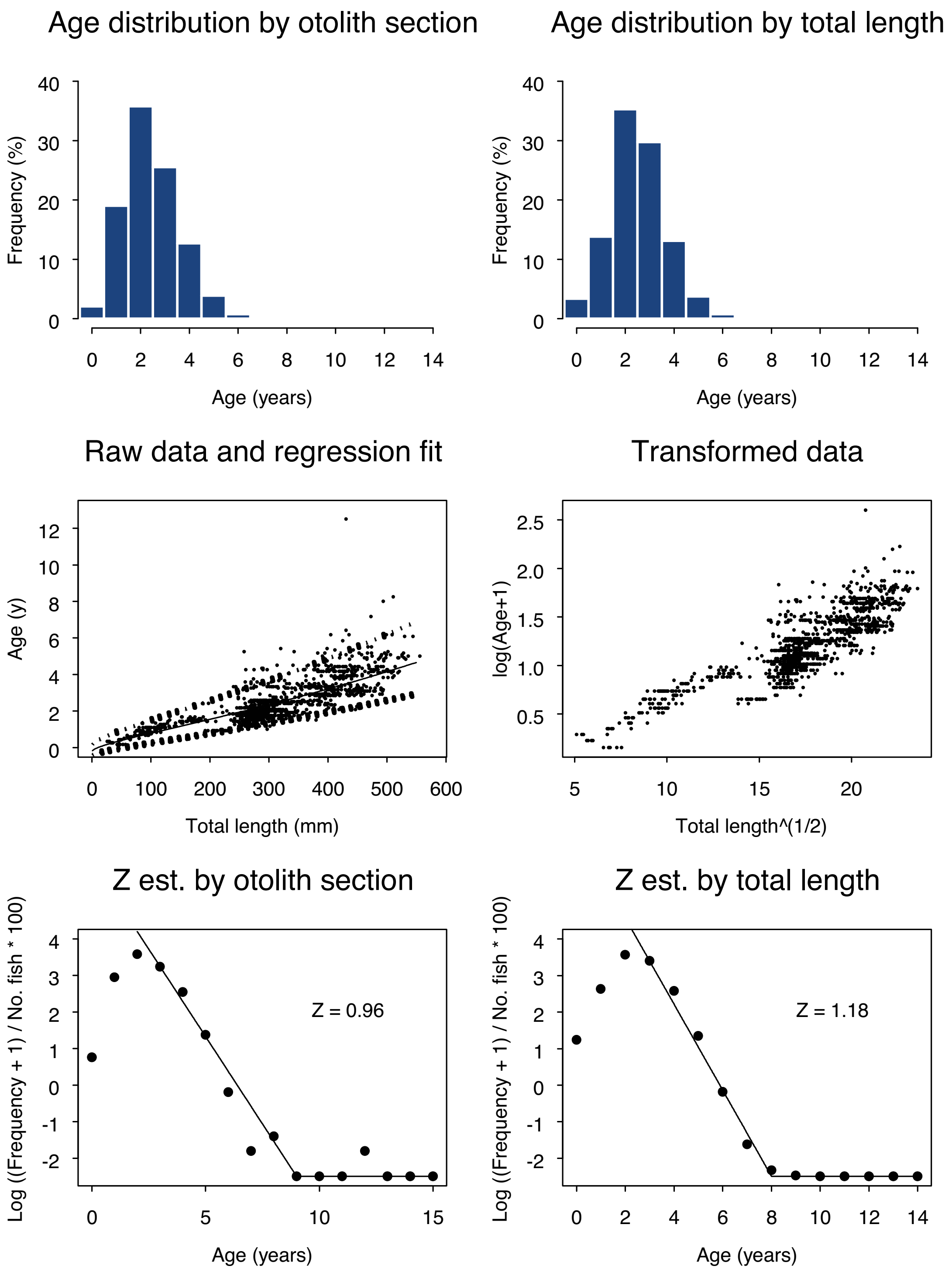

Figure 5.19 Sea mullet (2) – regression with total length as proxy. Upper panels – age frequency distributions. Middle panels – total length at age. Lower panels – catch curve analyses.

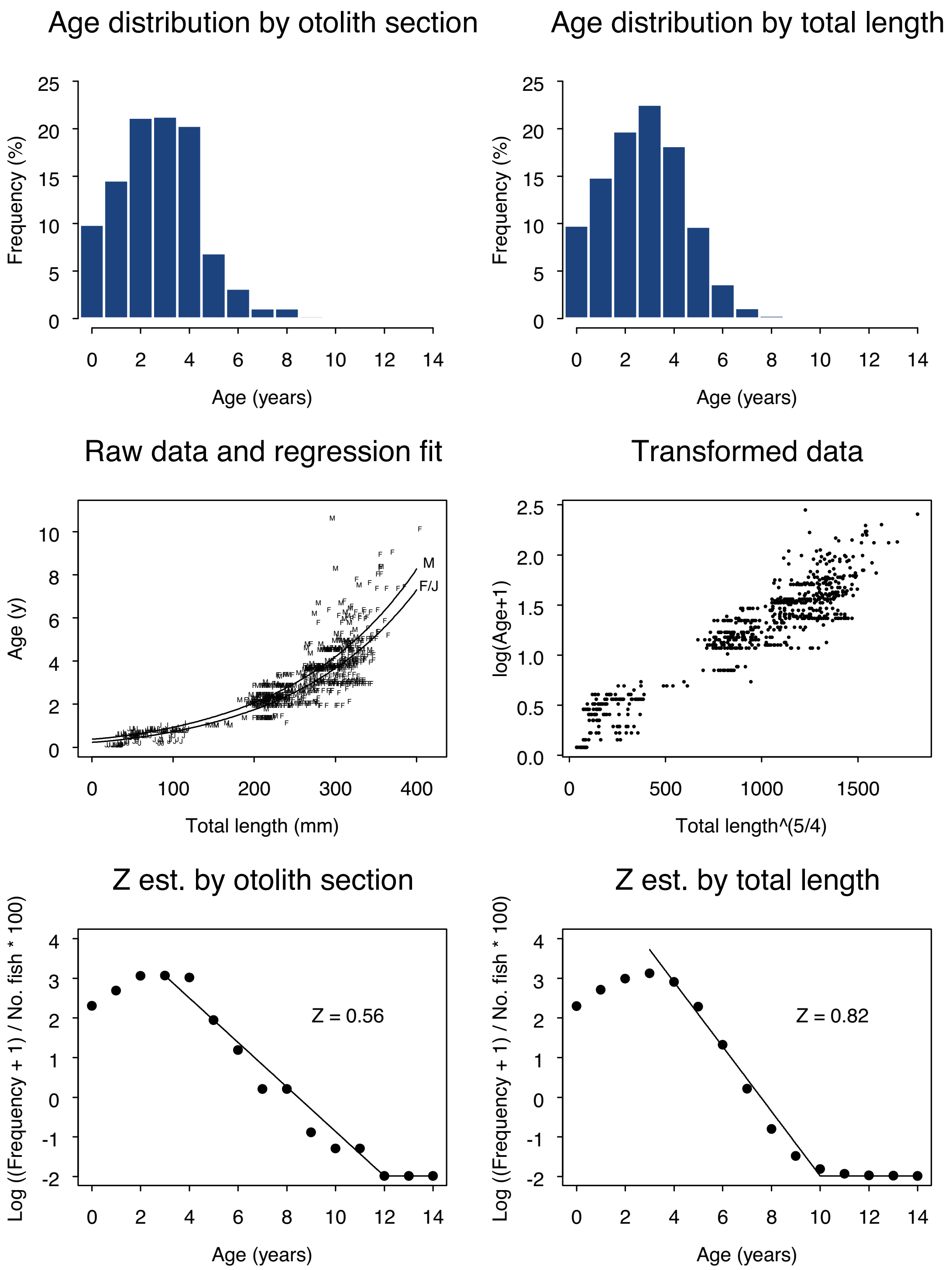

Figure 5.20 Yellow-finned whiting – regression with total length as proxy. Upper panels – age frequency distributions. Middle panels – total length at age. Lower panels – catch curve analyses.

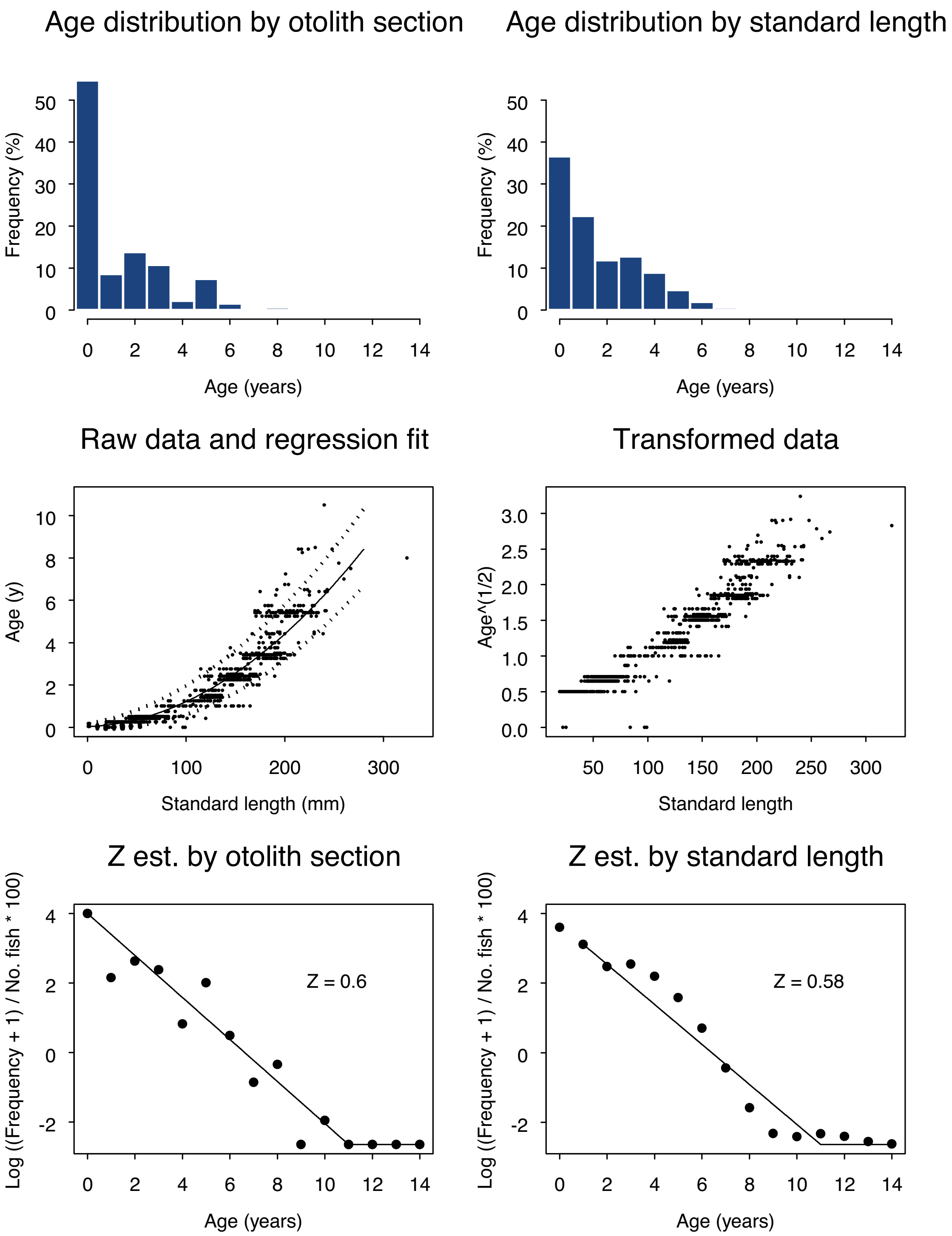

Figure 5.21 Black bream (1) – by regression with standard length as proxy. Upper panels – age frequency distributions. Middle panels – standard length at age. Lower panels – catch curve analyses.

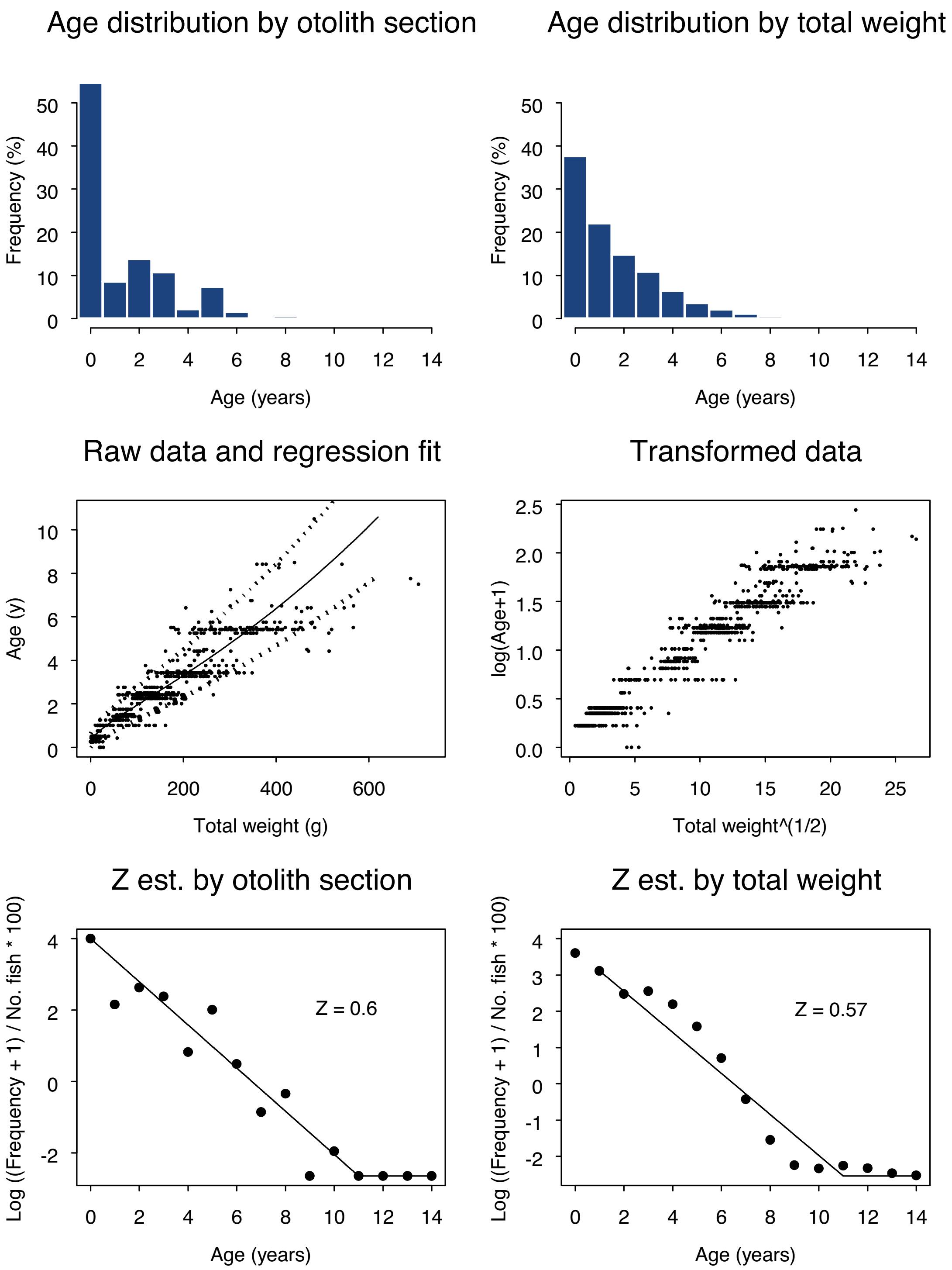

Figure 5.22 Black bream (2) – by regression with total weight as proxy. Upper panels – age frequency distributions. Middle panels – total weight at age. Lower panels – catch curve analyses.

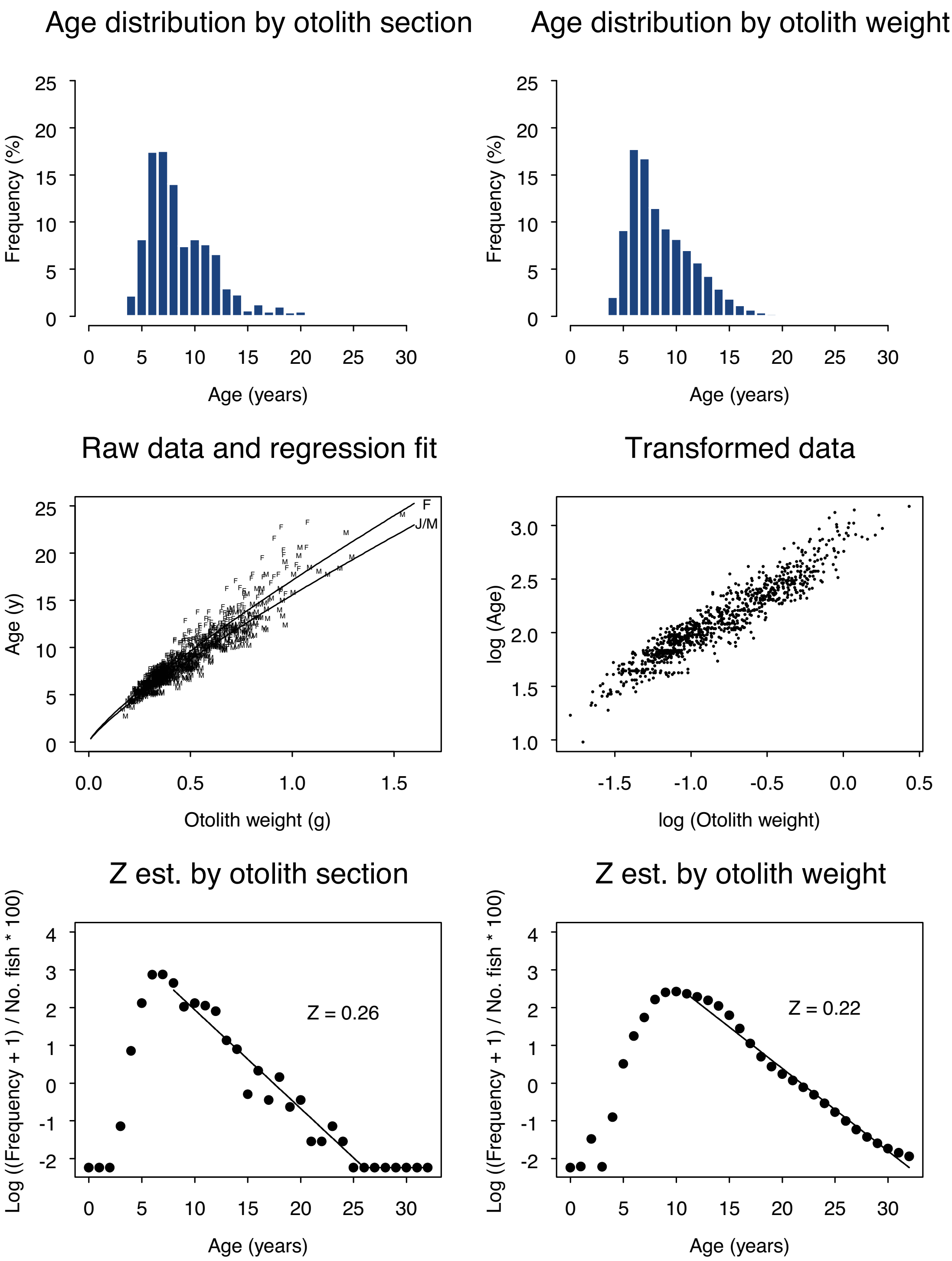

Figure 5.23 Dhufish – North WCB – by regression with sex differences and otolith weight as proxy. Upper panels – age frequency distributions. Middle panels – otolith weight at age. Lower panels – catch curve analyses.

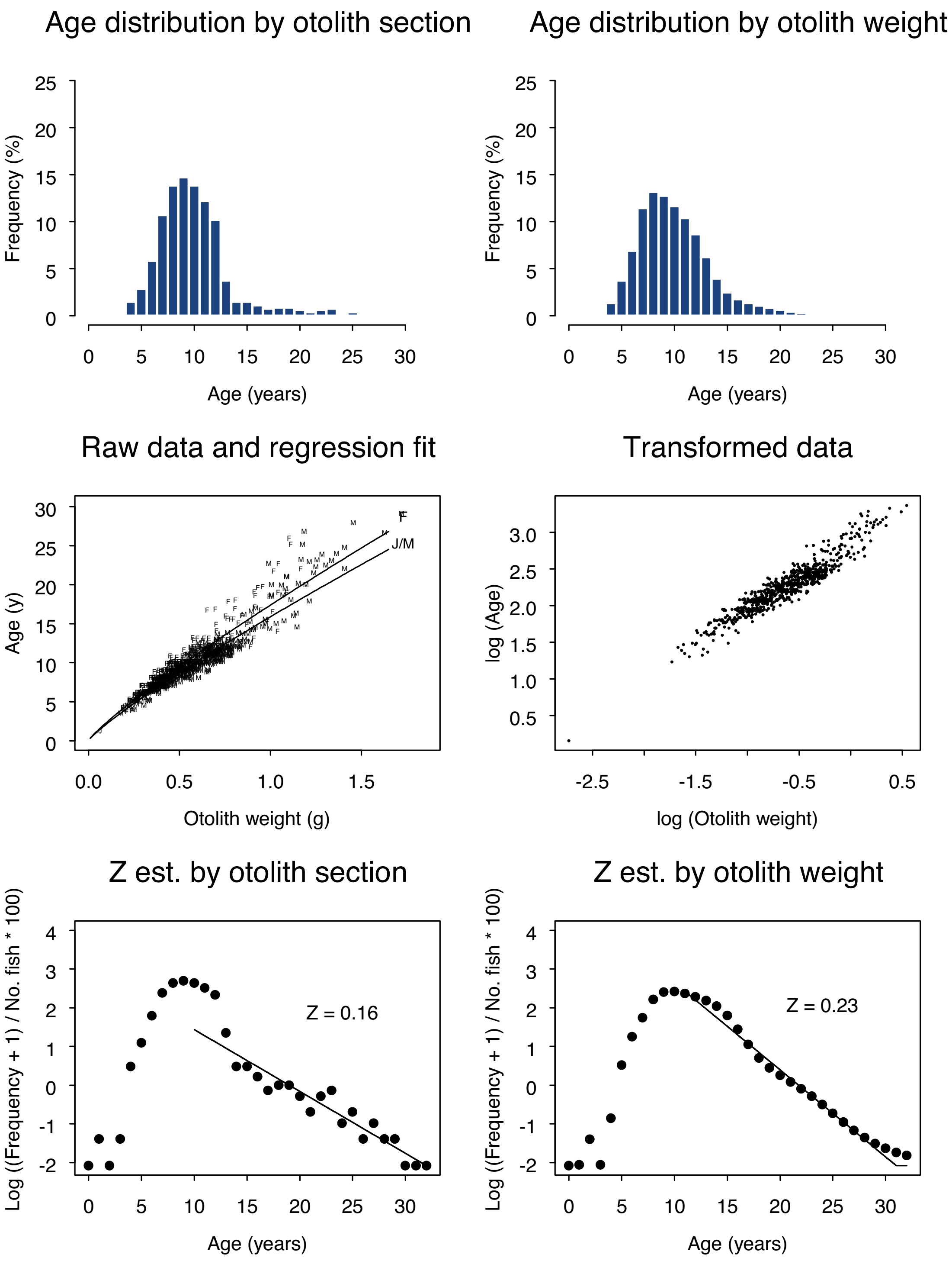

Figure 5.24 Dhufish – Metro WCB – by regression with sex differences and otolith weight as proxy. Upper panels – age frequency distributions. Middle panels – otolith weight at age. Lower panels – catch curve analyses.

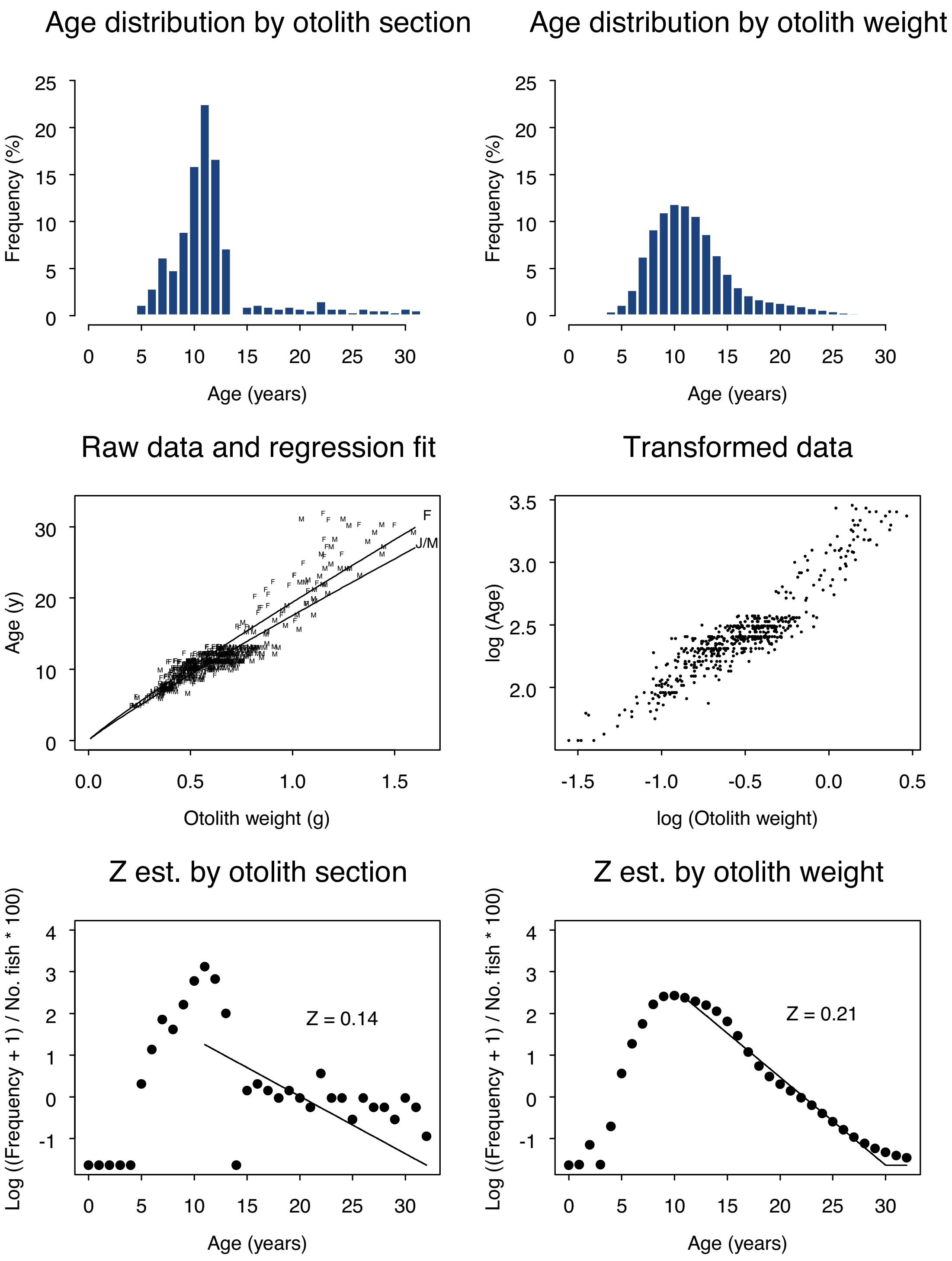

Figure 5.25 Dhufish – South WCB – by regression with sex differences and otolith weight as proxy. Upper panels – age frequency distributions. Middle panels – otolith weight at age. Lower panels – catch curve analyses.

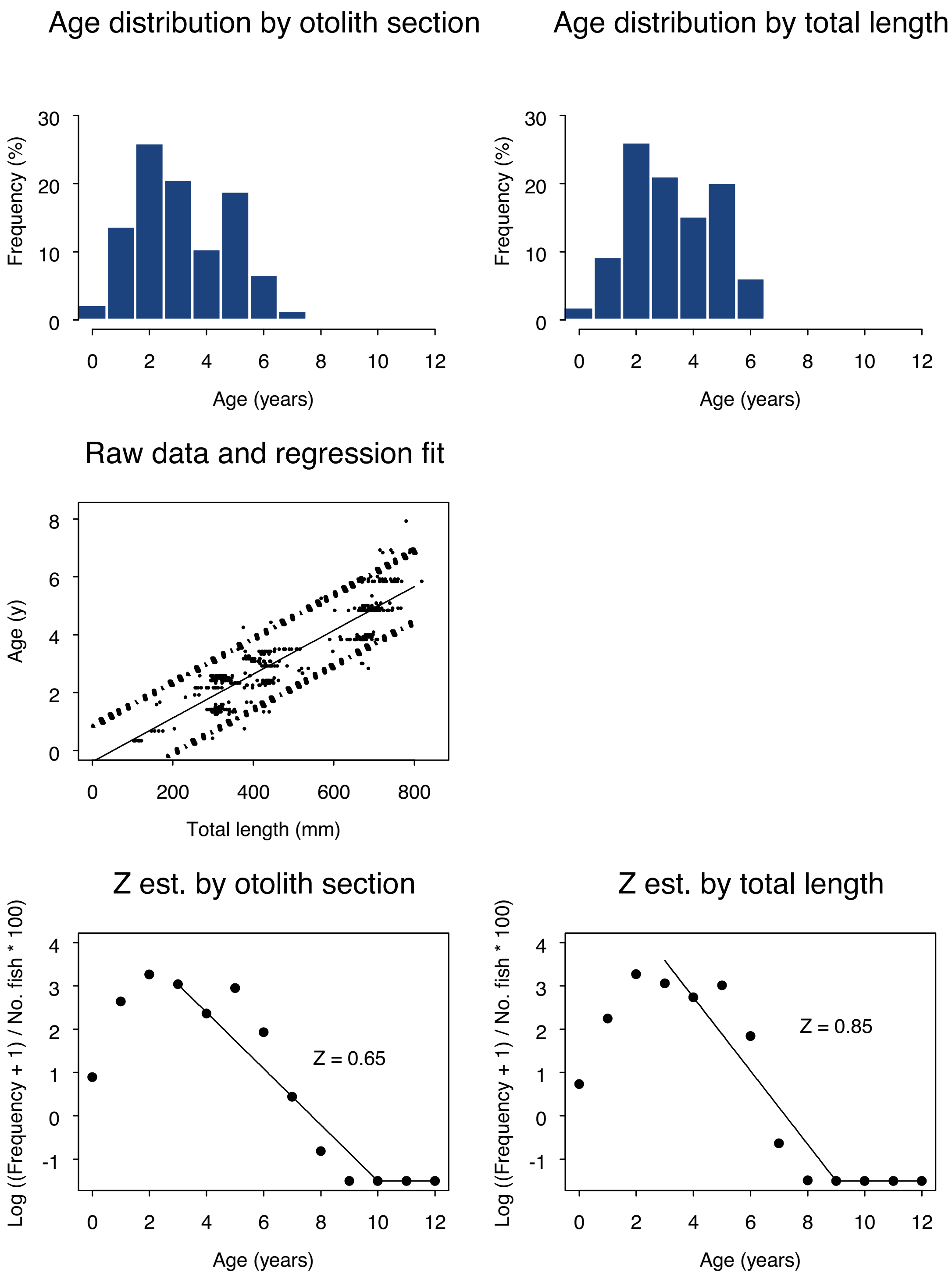

Figure 5.26 Australian salmon (1) – regression with total length as proxy. Upper panels – age frequency distributions. Middle panel – total length at age. Lower panels – catch curve analyses.

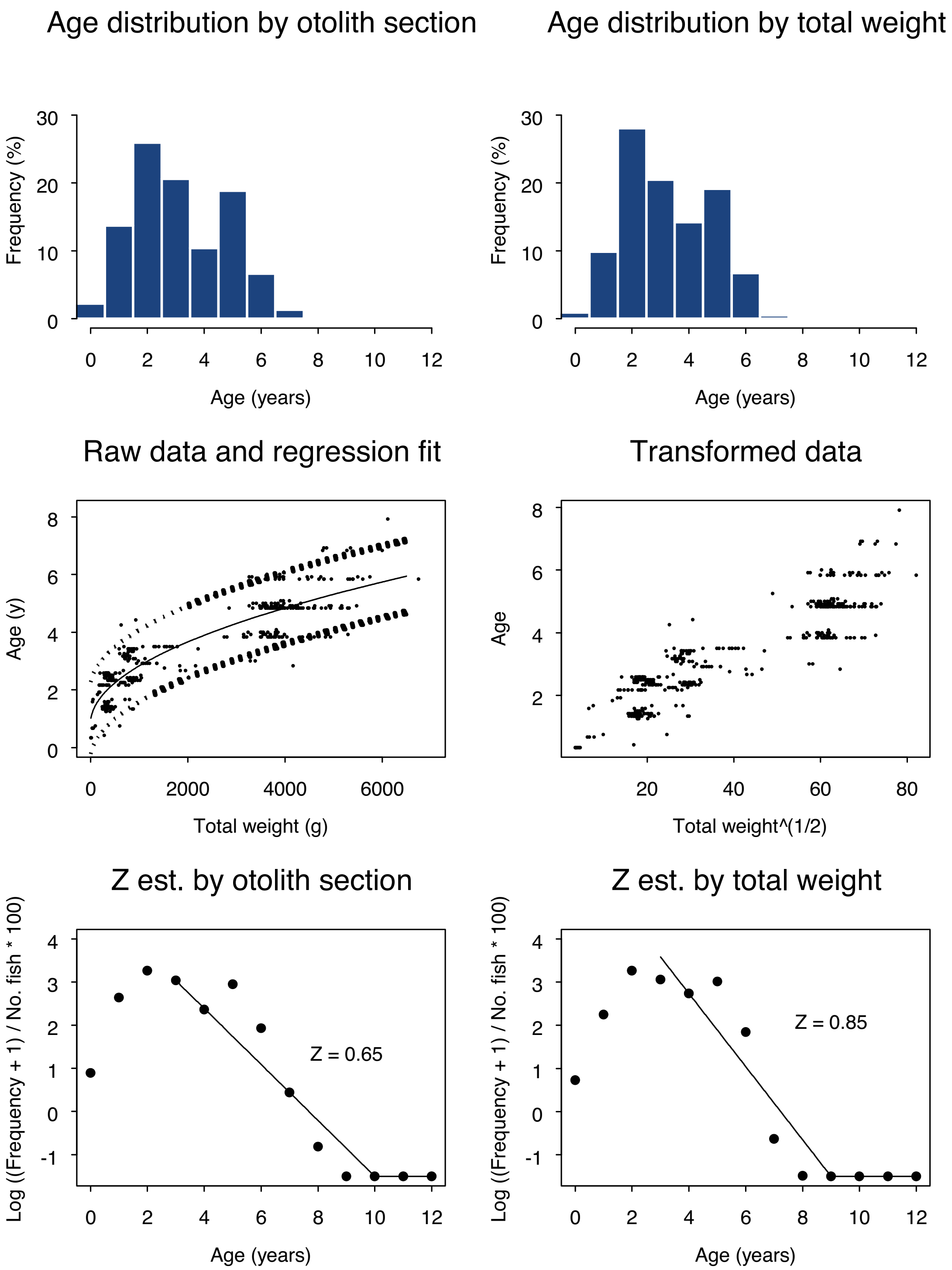

Figure 5.27 Australian salmon (2) – regression with total weight as proxy. Upper panels – age frequency distributions. Middle panels – total weight at age. Lower panels – catch curve analyses.

5.3.2 Application to age-structured models (ASMs)

Age structure derived from using alternatives to the annuli method were used in the ASM for each of 5 stocks to assess the difference in the key model output of median spawning biomass level, expressed as a percentage of estimated unexploited biomass (i.e. B_0), so as to align with the management indicators. The unexploited biomass level represents the pre-fished biomass, which is deemed the biomass at the start of the data set (e.g. 1980 for Kimberley goldband snapper, see Figure 5.28).

The additional runs of the ASMs were considered as sensitivity analyses to assess if smaller sample sizes (e.g. 100 – 350) could provide comparable estimates of spawning biomass, considering the magnitude of both the median value and the confidence intervals. The results shown for the sensitivity analyses are illustrative only in so far that only single realizations of 500 iterations are shown for each sample size.

Biomass plots are provided only for the first two examples (Kimberley goldband snapper and Kimberley red emperor), after which only the tabulated comparisons are shown (Pilbara Rankin cod, Pilbara red emperor, Shark Bay (Freycinet) pink snapper).

5.3.2.1 Kimberley goldband snapper

Kimberley goldband snapper were first assessed using data from 1997 to 1999. The spawning biomass estimated using sectioned-otolith ages was at 45% B_0 (Table 5.2A). Use of the full set of ages estimated using otolith weight from 1997 to 1999 (n = 481 – 784) provided an over-optimistic estimate of biomass in 2006, but fell within 10% of the sectioned-otolith method. Otolith weight therefore provided an acceptable alternative for use in the ASM for goldband snapper, despite that the confidence intervals (CI) for sectioned otoliths were wider than those for the sectioned-otolith method (Table 5.2B; Fig. 5.28). Smaller sample sizes of 200 and 350 also provided over-optimistic estimates of median biomass, and with considerably wider confidence intervals. The fact that the sample size of n = 200 otolith weights provided an estimate of median spawning biomass close to that for the full samples, highlights the need to consider both median values and the CIs when assessing the level of risk that might accompany the use of proxy measures. In this case the wide CIs provide a clear reason to reject the sample size of n = 200; the lower CI for n=200 extended well below 40% B_0 so this sample size is not acceptable.

The ASM was rerun with the inclusion of 2006 data (Table 5.2E, F). The sectioned-otolith and proxy methods again gave comparable results. The otolith weight method could therefore be used for goldband snapper.

Table 5.2 Estimates of spawning biomass (upper, median, lower) as a percentage of the 1980 level for Kimberley goldband snapper in 2006 using only samples from 1997 – 1999 (A – D) and all samples (E-F) in an updated run of the model. (A) & (E) all fish aged using sectioned otoliths (control), (B) & (F) ages derived from otolith weight (the best alternative aging method), (C - D) age samples of n=200 and n=350 otolith weights drawn randomly from the otolith weight data for 1997-1999.

	A	B	C	D	E	F
N (1997)	661	527	200	350	661	527
N (1998)	1126	784	200	350	1126	784
N (1999)	631	481	200	350	631	481
N (2006)					424	426
Upper % B_{1980}	53	61	66	63	54	53
Median % B_{1980}	45	49	48	50	47	46
Lower % B_{1980}	37	38	31	36	41	39

Table 5.3 Estimates of spawning biomass (upper, median, lower) as a percentage of the 1980 level for Kimberley red emperor in 2006 for (A) all fish aged using sectioned otoliths (control), (B) ages derived from otolith weight (the best alternative aging method), (C, D) samples of n=100 and n= 200 drawn randomly from the otolith weight data.

	A	B	C	D
N	322	308	100	200
Upper % B1980	51	49	65	57
Median % B1980	39	39	44	41
Lower % B1980	26	28	23	25

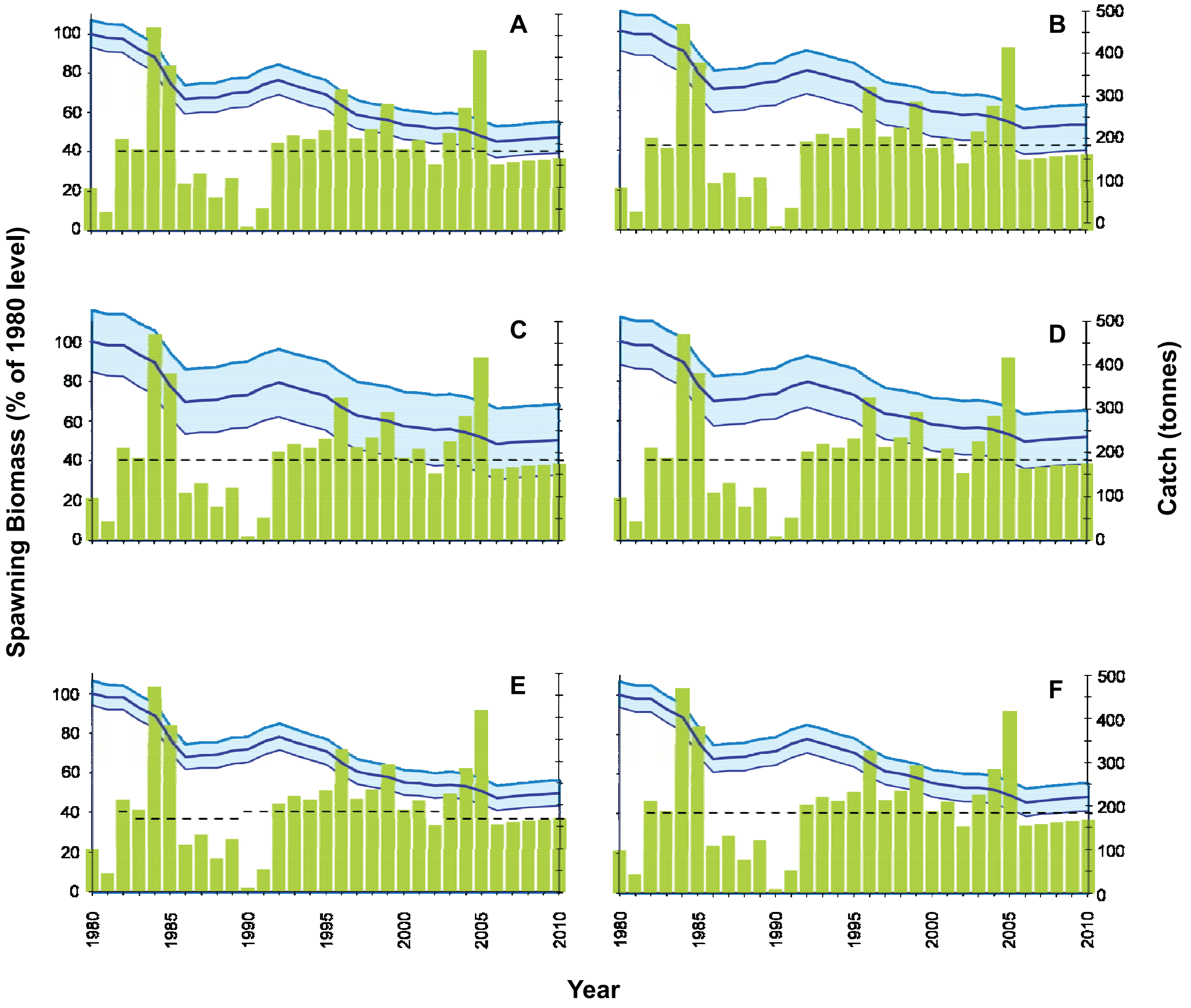

Figure 5.28 Outputs for the age-structured model for Kimberly goldband snapper with age inputs as described in Table 5.2. Spawning biomass = blue lines. Annual catches = green bars.

5.3.3.2 Kimberley red emperor

This stock had a strong relationship between age (sectioned-otolith method) and otolith weight (see Fig. 5.3). Estimating age using otolith weight provided an estimate of median spawning biomass the same as that derived from using sectioned-otoliths (Table 5.3, Fig. 5.29) and with similar CIs. A reduced sample of 200 otolith weights provides an over-optimistic estimate of spawning biomass with unacceptably wide confidence intervals. The example shown for a sample size of 100 (Fig. 5.29C) provided an over-optimistic estimate of median biomass and with unacceptably wide CIs; the lower CI extended well below the 40% B_0 level. Reduced sample size is therefore not an option for this stock but otolith weight is a useful proxy for estimating age. Furthermore, because the spawning biomass for this stock (in 2006) is just below the 40% B_0 reference point there is in fact a need to increase sample size to ensure that the results for otolith weight are robust.

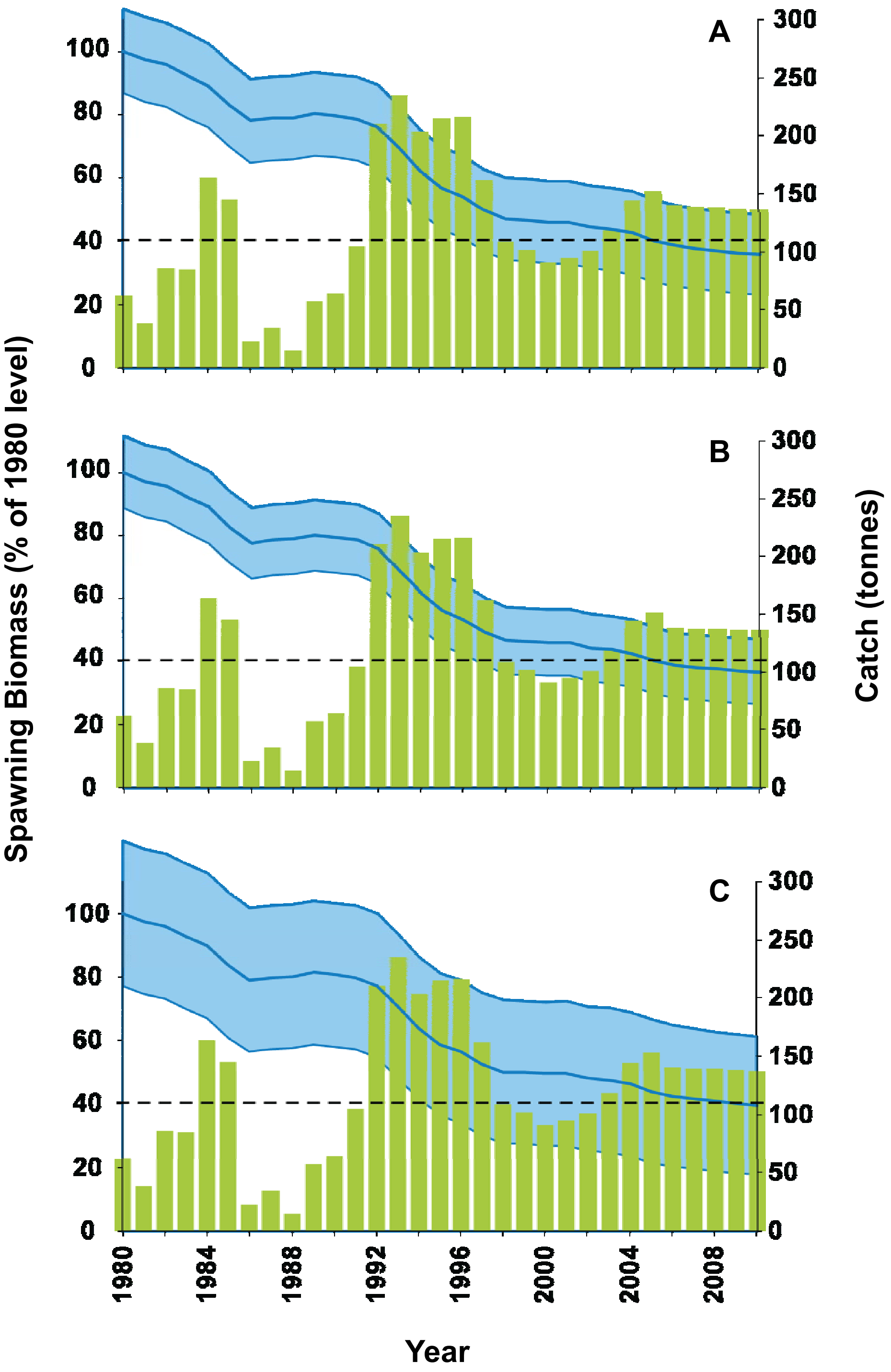

Figure 5.29 Outputs for the age-structured model for Kimberly red emperor with age inputs as described for A-C in Table 5.3. Spawning biomass = blue lines. Annual catches = green bars.

5.3.3.3 Pilbara Rankin cod

Otolith weight provided an over-optimistic estimate of spawning biomass for Rankin cod but was within 10% of the estimate derived using sectioned otoliths (Table 5.4A,B). The reduced sample sizes of otolith weights gave a reasonable approximation of median spawning biomass. Because the actual sample sizes available were small (< 300 for 2 of the 3 years), the CIs for the random selection of 200 otolith weights were comparable to those for the otolith weight data. Only a sample of 200 otolith weights appears to adequately represent the age structure of the stock. Given that the spawning biomass of Rankin cod is well above 40% B_0, otolith weight provides an acceptable alternative to sectioned otoliths but larger sample sizes are required because the age-otolith weight relationship was not strong (e.g. for a precision level of 0.06, n=2766 otolith weights).

Table 5.4 Estimates of spawning biomass (upper, median, lower) as a percentage of the 1990 level for Pilbara Rankin in 2006 for (A) all fish aged using sectioned otoliths (control), (B) ages derived from otolith weight (the best alternative aging method), (C, D) samples of n=200 and n=150 drawn randomly from the otolith weight data.

	A	B	C	D
N (1996)	176	175	200	150
N (1997)	433	431	200	150
N (1998)	263	261	200	150
Upper % B_{1990}	69	78	77	87
Median % B_{1990}	54	56	57	56
Lower % B_{1990}	41	39	42	30

5.3.3.4 Pilbara red emperor

Otolith weight provides an acceptable alternative to sectioned otoliths for the Pilbara stock of red emperor. Each sample size for otolith weight gave a reasonable approximation of median spawning biomass, but with wider confidence intervals for smaller samples. All reduced sample sizes provided slightly over-optimistic estimates of spawning biomass, but with wider confidence intervals than sectioned otoliths.

Table 5.5 Estimates of spawning biomass (upper, median, lower) as a percentage of the 1972 level for Pilbara red emperor in 2006 for (A) all fish aged using sectioned otoliths (control), (B) ages derived from otolith weight (the best alternative aging method), (C, D, E) samples of n=200, n=150 and n=100 drawn randomly from the otolith weight data.

	A	B	C	D	E
N (1996)	353	343	200	150	100
N (1997)	1091	455	200	150	100
N (1998)	834	832	200	150	100
Upper % B_{1972}	48	48	46	45	44
Median % B_{1972}	52	53	54	55	57
Lower % B_{1972}	56	58	63	67	73

5.3.3.5 Shark Bay (Freycinet) pink snapper

Ages derived using otolith weight provided an over-optimistic, but acceptable, estimate of spawning biomass (Table 5.6). However, all reduced sample sizes of otolith weights resulted in under-estimates of spawning biomass. These results indicate that a sample of only 100 otolith weights will provide a conservative estimate of spawning biomass. However, because the actual sample sizes were small (e.g. only 81 in 1998) larger sample size are required to better establish whether otolith weight can be used with confidence for ongoing monitoring of age structure.

Table 5.6 Estimates of spawning biomass (upper, median, lower) as a percentage of the 1980 level for inner Shark Bay pink snapper in 2006 for (A) all fish aged using sectioned otoliths (control), (B) ages derived from otolith weight (the best alternative aging method), (C, D, E) samples of n=200, n=150 and n=100 drawn randomly from the otolith weight data.

	A	B	C	D	E
N (1997)	172	148	200	150	100
N (1998)	81	61	200	150	100
N (1999)	170	154	200	150	100
N (2000)	276	157	200	150	100
Upper % B_{1980}	52	55	40	45	49
Median % B_{1980}	36	39	29	32	34
Lower % B_{1980}	20	23	19	19	19

5.4 Discussion

The ability to use alternatives (proxies) to counting annuli in otoliths to determine the age structure of scalefish species is dependent on establishing a robust model on a case-by-case basis. In this study, we attempted to establish such relationships using robust regression and mixture analysis. Regression was the best method in most cases when transformation of the data resulted in linearization of points around the line of best fit. In contrast, for stocks that exhibited substantial variability in the relationship between age and the proxy measure, and therefore did not respond well to transformation, tended to require mixture analysis to obtain a significant fit.

Proxy measures provided acceptable estimates of age structure for 19 of the 23 stocks examined in this study. In some cases, the relationships were particularly strong; those species whose proxy exhibited a good fit to the model, as seen by a relatively tight distribution around the line of bets fit, tended to be those for which estimates of total mortality were similar for both ageing methods. The ability for proxies to be used to estimate total mortality is partly dependent on the inherent variability of the relationships between the various proxies tested and the real age of the fish. However, the analyses undertaken in this study have indicated that potential alternatives to counting annuli should be investigated as a matter of course for exploited stocks of fish requiring estimates of age structure on a routine basis.

Age-structured models were used for goldband snapper, red emperor (2 stocks), Rankin cod and oceanic pink snapper to determine the level of spawning biomass using sectioned otoliths and the proxy otolith weight. Using otolith weights with the same (or similar) sample size as sectioned otoliths in the ASM for each stock provided good estimates of median spawning biomass, and with reasonable confidence intervals. As expected, confidence intervals generally became unacceptably wide as sample size decreased. Because the "true" spawning biomass may, by definition, fall anywhere within the confidence limits, small sample sizes should be avoided when the spawning biomass is below the management target level, i.e. 0.4 B_0. For stocks that require a high level of management input (e.g. frequent stock assessments for major target species) further investigation could be conducted into the probability of the proxy not meeting the acceptable biomass criterion in an effort to develop a stronger statistical basis for accepting or rejecting the proxy. For example, it is reasonable to expect that the spawning biomass has a 0.75 probability of being above 0.4 B_0 but the means of building such a criterion into the assessment has yet to be developed.

The results for this chapter will be used as the basis for specific recommendations in Chapter 6 for modifying both the numbers of fish sampled and the ageing methods used for 23 scalefish species/stocks in Western Australia. Given the sample sizes typically obtainable in current sampling programs, the sample sizes required to achieve precision levels of 0.06 and 0.08 will be considered in the cost benefit analyses undertaken in Chapter 6.

6.0 Cost analysis

6.1 Introduction

There are more than 150 species of scalefish in Western Australia that are subject to fishing mortality (Lenanton et al. 2007). The level of fishing mortality varies between species depending primarily on whether a stock is specifically targeted by fishers or caught incidentally; at the other end of the spectrum, some species are caught only rarely as bycatch. Risk assessment of the suite of all finfish species, i.e. including sharks, was undertaken in 2004 to determine research and management priorities with the aim to rationalize the monitoring programs being conducted by the Department of Fisheries. However, this assessment indicated that the number of species that required some level of monitoring to assess sustainability still exceeded the capabilities existing within current monitoring programs. The aim of this part of the project is to obtain a better understanding of the costs incurred in an age monitoring program. As such, to facilitate determination of the costs incurred to generate annual age composition for each species the following sub-components of the process were considered:

- Sampling/collection (e.g. at-sea sampling, market sampling, commercial or recreation fishers)
- Processing in the field or laboratory (including measurement of length and weight, removal of otoliths)
- Processing otoliths in the laboratory (measurement of otolith dimensions, embedding, sectioning)
- Reading otoliths (whole or sectioned)
- See other version for comment on analytical cost

The variety of stocks examined has allowed a range of different cost factors to be considered. For example, fishery-dependent vs. fishery independent sampling, commercially- vs. recreationally caught samples; shore-based vs. at-sea sampling.

6.2 Methods

The methods described focus on providing an overview relative to the determination of unit costs for (1) collecting and processing fish and (2) generating an estimate of age. More detailed descriptions of specific methods (e.g. sampling routines, otolith preparation can be found in Chapter 3 (and the literature cited therein). Ongoing collection and processing of fish and otoliths is expected to be predominantly undertaken by Level 2 and 3 Technical Officers; all costings are based on salaries and prices (e.g. fuel, travel expenses) as of September 2008. The unit costs are then used with the estimates of required sample numbers for appropriate precision levels to conduct the cost benefit analyses.

6.2.1 Sample collection

Many of the stocks sampled are fished commercially so samples can be obtained directly from fishers (e.g. onboard at sea, point of landing, processing facilities, fish markets). In some cases, the historic sampling was undertaken as part of a research project that employed fishery-independent sampling techniques (e.g. beach seining, research trawling, recreational fishing methods). Current sampling methods may not always reflect past practices but the range of potential sampling strategies covered here will allow a realistic representation of likely costs required to generate an age composition for a particular stock.

The following provides an overview of the resource requirements for alternative methods employed by Departmental staff to sample fish in Western Australia. A key consideration for any sampling program is that the samples are representative of the stock. In some cases, this required more than one sampling method to be employed.

The associated costs for sample collection include:

- Staff salaries
- Travel (e.g. airfares)
- Operational expenses (e.g. living allowances, vehicle lease, fuel, vessel charter, purchase of fish or fish frames).

6.2.2 Processor/market sampling

Fish of various stocks were collected directly from commercial fish processing establishments throughout the state, including *Lutjanus vitta*, *Epinephelus multinotatus*, *Nemipterus furcosus, Lutjanus sebae*, *Pristipomoides multidens, Arripis georgianus*, *Sillaginodes punctata*, *Mugil cephalus* and *Sillago schomburgkii*. Processing/distribution facilities occur in regional centres as well as the Perth metropolitan area, whereas major fish markets occur only in the latter.

6.2.3 Species sampling

6.2.3.1 Goldband snapper and Red emperor from the Kimberley region

Samples of *Pristipomoides multidens* and *Lutjanus sebae* were sampled by research staff aboard *RV Flinders* off the Kimberley coast of Western Australia. Two to three field trips were conducted each year, each with a duration of 15 days. At least two research staff was present on each trip, plus the vessel crew. The sampling costs for this fishery independent sampling included the costs of running the research vessel ($4200 per day)

Samples of these species were also collected from commercial vessels participating in the Northern Demersal Scalefish Fishery.

6.2.3.2 Pink snapper (Oceanic stock)

Samples of *Pagrus auratus* were collected directly from the commercial snapper fleet operating from Carnarvon, Western Australia. Each trip was of 7 days duration and consisted of sampling aboard commercial fishing vessels. A single DOF Technical Officer was required to collect the samples.

About six field trips were conducted each year and occurred between the months of March and October.

6.2.3.3 Pink snapper (Freycinet Inlet)

Pagrus auratus in Freycinet Inlet are only targeted by recreational fishers. Research staff collected frames from recreational fishers, as well as conducting their own opportunistic sampling. Normally, 4 research staff were involved in one field trip of 10 days duration, timed to coincide with large numbers of recreational fishers visiting the region to take advantage of high availability of fish during the pink snapper spawning season.

6.2.3.4 Blue-lined emperor

There is no commercial fishing for *Lethrinus laticaudis* in Shark Bay. Samples were collected from Fisheries Department research staff during research sampling programs and from recreational fishers. *L. laticaudis* samples were collected from both the western and eastern gulfs of Shark Bay. Sampling was conducted on a monthly basis by research staff and occasionally by collecting frames from recreational fishers. Fish were primarily caught by rod and line or through baited fish traps. Two Technical Officers attended each field trip. A research vessel was used for the collection of biological samples. The duration of each trip was 7 days.

6.2.3.5 Western butterfish

Samples of *Pentapodus vitta* were collected from four areas in Shark Bay as bycatch of a prawn trawl research program. Four field trips were conducted each year. Two technical officers were deployed for each trip. The duration of each trip was 14 days

6.2.3.6 Flagfish, Rankin cod, Rosy threadfin bream and Red emperor from the Pilbara region

Department of Fisheries staff collected samples of these species from commercial vessels participating in the Pilbara Trawl Fishery. Eight field trips were conducted each year. Each trip was of 7 days duration. Two Technical Officers attended each trip.

6.2.3.7 Spanish mackerel

Samples of *Scomberomorus commerson* were collected from onboard commercial, recreational and research vessels. Fish were collected from West Coast, Gascoyne and Northern (Pilbara and Kimberley) Bioregions. The number of research staff involved and the duration of each trip changed depending on where the sampling occurred. Therefore, the associated cost of sampling is different for each bioregion.

6.2.3.8 Chinaman cod

Samples of *Epinephelus rivulatus* were obtained from the Ningaloo reef system using a spear gun and hook and line techniques. Two research staff members attended each field trip. Normally, two field trips were conducted each year and the duration of these trips was 14 days.

6.2.3.9 Australian herring, Yellow-finned whiting, Sea mullet, King George whiting and Australian salmon

Monthly sampling was conducted in several different locations on the south coast and west coasts of Western Australia. Fish were obtained directly from the commercial sector and from fishery independent research sampling. Field trips usually lasted 5 days. Two Technical Officers were deployed for each field trip.

6.2.3.10 Black bream

The cost analysis for *Acanthopagrus butcheri* was based on sampling occurring on a monthly basis in the Swan River using seine nets. Two members of the research staff were required for two days each month to complete the sampling.

6.2.4 Sample processing

Sample processing, or biological processing, to generate data on fish length and weight, sex, reproductive condition etc. can occur either at field locations or in the fisheries laboratory in Perth. Processing costs include excision, cleaning and storage otoliths, and management of the data collected.

6.2.5 Otolith processing

Processing otoliths is undertaken only in the laboratory. Otoliths are routinely weighed, and in some studies, other dimensions (length, width, thickness) are measured. Otoliths to be sectioned are embedded in epoxy resin; transversally cut into thin sections (usually 3), mounted onto microscope slides and stored until ready to be read.

6.2.6 Otolith reading

Whole or sectioned otoliths were read under a microscope in the laboratory, with the optimal light conditions determined on a case-by-case basis. The ease with which the structures could be read (i.e. the readability) varied between species, hence the time required to obtain the age information from each otolith varies. Similarly, the number of times otoliths were read also varied with the ease of interpretation.

6.2.7 Sample size and cost estimates

To standardize the cost benefit analysis and to provide a stand-alone comparative summary of all species examined, the sample sizes required to achieve a precision of 0.06 and 0.08 were determined. For the otolith annuli method the sample sizes were n = 512 and n=288 respectively, while for the proxy measures the sample size varied (see Table 4.4). The decision to use the 0.06 and 0.08 precision levels was based on the historical inability to achieve the sample numbers required for a precision level of 0.04; that is, the costs required to collect the number of samples to achieve a precision level of 0.04 are prohibitive.

6.3 Results

6.3.1 Cost analysis – collection of fish

A detailed outline of the costs of collecting samples of fish is outlined in Table 6.1. This table accounts for the costs of salaries and field related costs of technical staff required to undertake the field sampling. This is calculated on the basis of Level 2 and Level 3 Technical Officers.

Sampling costs varied widely depending on the species and location of the fishery. In general, fish from remote regions or those that require considerable effort to obtain representative samples of (e.g. high-value, low volume species) were more expensive to collect. Inshore species that can be collected in relatively large numbers and/or from the southern half of the state (e.g. sea mullet, whiting) cost from \$22 – \$50 per fish to sample, whereas species from the Kimberley and Pilbara, mainly caught by trap and or line in relatively low numbers (e.g. goldband snapper, red emperor) and which required a dedicated cruise by a research vessel, cost up to $280 per fish. These costs included processing of fish (measurement of length, weight) and removal of otoliths, which was normally undertaken in the field to obviate the need to transport fish back to the laboratory. The costs in Table 6.1 assumed only one species is collected on any one trip. If for example, goldband snapper and red emperor otoliths are collected simultaneously, the field sampling cost for each species could be almost halved. Similarly, in the Pilbara Trawl Fishery several species could be collected simultaneously so the unit cost per fish of each species would decrease.

Market sampling was substantially more cost effective, with costs of only $9-13 per fish if otoliths are removed (Table 6.2). If otoliths do not need to be removed (e.g. if length is a suitable proxy for age), the costs for market sampling decrease significantly to around $2 per fish (Table 6.3). Market sampling was limited to commercial species, with some additional restrictions imposed for some stocks. For example, some species are required to be left whole for retail purposes so their otoliths could not be removed.

Table 6.1 Costs for collection by field sampling of fish from various scalefish stocks in Western Australia.

		Expenses										Unit Cost
Bioregion	**Species**	**Salaries**	**Overtime**	**Airfares**	**Accommodation + Food**	**Vehicle**	**Staff Allowances**	**RV Costs**	**Field Equipment**	**Annual Field Costs**	**No of otoliths collected**	**Cost per fish**
Kimberley	Goldband snapper	13,585	9,672	4,869	3,694	650	1,769	136,584		170,824	600	284.71
	Red emperor	13,585	9,673	4,869	3,694	650	1,769	136,584		170,825	600	284.71
	Spanish mackerel*	13,370	9,674	4,869	2,463		1,769			32,145	1409	22.81
Gascoyne	Pink snapper (ocean)	9,509	9,675	4,325	4,338	650	885			29,382	500	58.76
	Pink snapper (Freycinet)**	8,712	9,676		7,631					26,019	200	130.10
	Black snapper	21,278	9,677		31,870					62,825	1700	36.96
	Western butterfish	12,680	9,678	2,818	1,925		1,769			28,871	600	48.12
	Spanish mackerel*	10,028	9,679	2,163	5,054	650	774			28,348	669	42.37
Pilbara	Flagfish	25,360	9,680	14,708	12,661	1,734	3,035			67,178	1130	59.45
	Rankin cod	25,360	9,681	14,708	12,661	1,734	3,035			67,179	370	181.57
	Red emperor	25,360	9,682	14,708	12,661	1,734	3,035			67,180	928	72.39
	Rosy threadfin bream	25,360	9,683	14,708	12,661	1,734	3,035			67,181	1115	60.25
	Spanish mackerel*	20,056	9,684	5,515	16,572		1,548			53,376	1495	35.70
West	Australian herring	27,170	9,685		21,203					58,058	5107	11.37
	Chinaman cod	12,680	9,686		6,300					28,666	203	141.21
	Coral trout	34,010	9,687		1,084			54,200		98,981	400	247.45
	King George whiting	27,170	9,688		21,203					58,061	1654	35.10
	Sea mullet	27,170	9,689		21,203					58,062	2571	22.58
	Yellow finned whiting	27,170	9,690		21,203					58,063	1642	35.36
	Black bream	10,868	9,691							20,559	500	41.12
	Dhufish[1]	157,730	57,300		30,679	44,511	17,200		25,766	333,186		59.16
South	Australian salmon	3733	1400		2225	273				7631	500	15.26

[1] Costs for the three dhufish stocks in the West Coast Bioregion have been averaged.

Table 6.2 Sampling costs for market sampling for 12 scalefish species. These figures are based on visiting fish processing establishments or markets in the Perth metropolitan area. The costs include measurement of length and weight, and removal of otoliths when allowed.

Species	Frequency of sampling	Duration (hrs)	Wages ($)	Vehicle Costs ($)	Total Cost ($)	Unit Cost ($)
Goldband snapper	Monthly	8	476	56	532	10.64
Red emperor	Monthly	8	476	56	532	10.64
Australian herring	Weekly	7	417	225	641	12.82
King George whiting	Weekly	7	417	225	641	12.82
Sea mullet	Weekly	7	417	225	641	12.82
Yellow finned whiting	Weekly	7	417	225	641	12.82
Salmon	Monthly	7	417	56	473	9.45
Flagfish	Monthly	7	417	56	473	9.45
Rankin cod	Monthly	9	536	56	592	11.83
Rosy threadfin bream	Monthly	7	417	56	473	9.45
Pink snapper	Monthly	7	417	56	473	9.45
Dhufish	Monthly	10	595	56	651	13.02

6.3.2 Cost analysis –processing

Each age estimate from whole otoliths cost about $6-7 dollars and those from sectioned otoliths cost $10-18 (Table 6.4). The embedding time was consistent across species (3 hours for 50 otoliths) while the sectioning time was either 8 or 12 hours. Otoliths that were difficult to interpret incurred additional time to read and reconcile differences.

Each otolith costs $0.67 to weigh, or $1.12 to measure one linear dimension (length, height or breadth) (Table 6.5).

Table 6.3 Cost associated with collection of size data (total, caudal or fork length, weight) through market sampling for 15 scalefish species in Western Australia.

Species	Frequency of sampling	Vehicle Cost ($)	Duration (hours)	Wages ($/month)	Monthly cost ($)	Annual cost ($)	Unit Cost ($)
Goldband snapper	12	225	4	238	463	5,551	2.31
Red emperor	12	225	4	238	463	5,551	2.31
Pink snapper	12	225	4	238	463	5,551	2.31
Flagfish	12	225	3	179	403	4,837	2.02
Rankin cod	12	225	4	238	463	5,551	2.31
Rosy threadfin bream	12	225	3	179	403	4,837	2.02
Spanish mackerel	12	225	4	238	463	5,551	2.31
Chinamen cod	12	225	3	179	403	4,837	2.02
Coral trout	12	225	3	179	403	4,837	2.02
Australian herring	12	225	3	179	403	4,837	2.02
King George whiting	12	225	3	179	403	4,837	2.02
Sea mullet	12	225	3	179	403	4,837	2.02
Yellow finned whiting	12	225	3	179	403	4,837	2.02
Black bream	12	225	3	179	403	4,837	2.02
Dhufish	12	225	4	238	463	5,551	2.31

Table 6.4 Costs associated with the embedding, sectioning and age determination of otoliths for scalefish stocks in Western Australia. Hourly wages are calculated to be an average of a Level 1-research assistant (embedding and sectioning), and a Level 2/3 Technical Officer and a Research Scientist (reading and reconciliation).

Bioregion	Species	Sectioned/ Whole otoliths	Processing time (hours) for 50 otoliths							Hourly rate	Total Cost (first 50)	Cost per otolith
			Embed	Section	First read	Second read	Reconci-liation	Total	Readability			
Kimberley	Goldband snapper	Sectioned	3	12	6	6	3	30	Poor	30.31	909	18.19
	Red emperor	Sectioned	3	12	2	2	1	20	Good	30.31	606	12.12
Gascoyne	Pink snapper (oceanic)	Sectioned	3	8	6	6	3	26	Poor	30.31	788	15.76
	Pink snapper (Freycinet)	Sectioned	3	8	6	6	3	26	Poor	30.31	650	13.00
	Black snapper	Sectioned	3	12	2	2	1	20	Good	30.31	606	12.12
	Western butterfish	Sectioned	3	8	2	2	1	16	Good	30.31	485	9.70
Pilbara	Flagfish	Sectioned	3	8	4	4	2	21	Average	30.31	637	12.73
	Rankin cod	Sectioned	3	8	4	4	2	21	Average	30.31	637	12.73
	Rosy threadfin bream	Sectioned	3	8	4	4	2	21	Average	30.31	637	12.73
North	Spanish mackerel	Sectioned	3	12	6	6	3	30	Poor	30.31	909	18.19
	Chinaman cod	Sectioned	3	12	6	6	3	30	Poor	30.31	909	18.19
	Coral trout	Sectioned	3	8	4	4	2	21	Average	30.31	637	12.73
West	Australian herring	Whole			4	4	2	10	Average	30.31	303	6.06
	KG whiting	Sectioned	3	12	2	2	1	20	Good	30.31	606	12.12
	Sea mullet	Sectioned	3	12	6	6	3	30	Poor	30.31	909	18.19
	Yellow finned whiting	Whole			4	4	2	10	Good	30.31	303	6.06
	Black bream	Sectioned	3	12	2	2	1	20	Good	30.31	606	12.12
	Dhufish	Sectioned	3	12	6	6	3	30	Average	30.31	909	18.19
South	Salmon	Sectioned	3	12	6	6	3	30	Poor	30.31	909	18.19

Table 6.5 Unit costs for the measurement of otoliths.

Measurement Type	Measurement Time (per 50 otoliths)	Salary Rate ($ per hour)	Cost of Measurement (50 otoliths)	Cost per otolith
Weight	1.5 hrs	22.40	33.60	0.67
Length, Breadth or Height.	2.5 hrs	22.40	56.00	1.12

6.3.3 Cost benefit analyses

This section compares the costs required to generate age composition estimates. Total costs are a combination of fish sampling (or collection) costs and the costs to actually age each fish using sectioned otoliths or proxy measures.

Collection of the fish samples constituted the bulk of the total costs for stocks sampled in the field (Table 6.6), accounting for an average of 87% of total costs and in some cases 99% of the total cost. Collection of fish at the markets was considerably less expensive (Table 6.7), but still accounted for an average of 66% of the total costs. Although there was a good relationships between the otolith annuli method and proxies for several stocks, the numbers of proxy measures required were always considerably greater than the number of sectioned otoliths required. Therefore, because obtaining samples was typically the greatest part of the overall costs, in no cases were proxy measures found to be cost effective under the historical regimes of field sampling and determining age composition. By contrast, if representative samples could be obtained from market sampling then proxy measures provided a cost effective alternative to sectioned otoliths for many of the stock s examined.

Table 6.6 Cost analyses of acceptable ageing methods for 23 stocks of scalefish in Western Australia sampled in the field, which includes sampling in factories outside of the Perth metropolitan region. Sample sizes correspond to precision values of 0.06 and 0.08. Proxy measures that were not suitable (ns) are shown for completeness of the table; in these cases, only costs of the sectioned otolith method are shown. Note that for some stocks > 1 proxy is provided in those cases were one could not be selected over the other.

Species/ Stock	Ageing Methods	N (0.06 0.08)	Sample costs	Ageing Costs	Total costs
Spanish mackerel*	Annuli	512 288	18,278 12,202	9313 5239	27,591 17,441
	Otolith Weight	840 413	35,591 17,499	564 277	36,155 17,776
Coral trout	Annuli	512 288	126,694 71,266	6518 3666	133,212 74,932
	Total length	1159 514	286,795 127,189	579 257	287,374 127,446
Chinaman cod	Annuli	512 288	72,299 40,668	9313 5239	81,612 45,907
	Oto wt	893 431	126,100 60,861	600 290	126,700 61,151

Species/ Stock	Ageing Methods	N (0.06 0.08)	Sample costs	Ageing Costs	Total costs
Goldband snapper	Annuli	512 288	92,964 52,292	9313 5239	102,277 57,5301
	Oto wt	614 329	174,812 93,670	413 221	175,225 93,891
	Fork length	1028 538	186,654 97,685	514 269	187,168 97,954
Red emperor (Kimberly)	Annuli	512 288	37,064 20,848	6205 3491	43,269 24,339
	Oto weight	733 375	53,062 27,146	493 252	53,555 27,398
Red emperor (Pilbara)	Annuli	512 288	37,064 20,848	6205 3491	43,269 24,339
	Oto wt	1190 523	86,144 37,860	800 351	86,944 38,211
Rankin cod	Annuli	512 288	92,964 52,292	6518 3666	99,482 55,958
	Oto wt	2766 1118	502,223 202,995	1859 751	504,082 203,746
Flagfish	Annuli	512 288	30,438 17,122	6518 3666	36,956 20,788
	Oto wt	Ns	N/A	N/A	N/A
Rosy threadfin bream	Annuli	512 288	30,848 17,352	6518 3666	37,366 21,018
	Oto wt	1442 707	86,880 42,597	969 475	87,849 43,072
Notched threadfin bream	Annuli	512 288	30848 17352	6518 3666	37,366 21,018
	Oto wt	4622 1154	278,476 69,529	3106 775	281,582 70,304
Pink snapper (oceanic)	Annuli	512 288	30,085 16,923	8069 4539	38,154 21,462
	Fork length	ns	N/A	N/A	N/A
	Oto wt	2695 866	158,358 50,886	1811 582	160,169 51,468
Pink snapper (Freycinet)	Annuli	512 288	66,611 37,469	6656 3744	73,267 41,213
	Oto wt	1335 564	173,683 73,376	897 379	174,581 73,755
Black snapper	Annuli	512 288	18,924 10,644	6205 3491	25,129 14,135
	Oto wt	1296 553	47,900 20,439	871 277	48,771 20,716
Western butterfish	Annuli	512 288	24,637 13,859	4966 2794	29,603 16,653
	Oto wt	1782 678	85,750 32,625	1198 456	86,948 33,081

Species/ Stock	**Ageing Methods**	**N (0.06 0.08)**	**Sample costs**	**Ageing Costs**	**Total costs**
Australian Herring	Annuli	512 288	5821 3275	4035 2269	9856 5544
	Oto wt	1349 568	15,338 6,458	907 382	16,245 6,840
King George Whiting	Annuli	512 288	17,971 10,109	6205 3491	24,176 13,600
	Total length	ns	N/A	N/A	N/A
Sea Mullet	Annuli	512 288	11,561 6503	9313 5239	20,874 11,742
	Oto wt	2078 744	46,921 17,800	1396 500	48,317 18,300
	Total length	ns	N/A	N/A	N/A
Yellow-finned Whiting	Annuli	512 288	18,104 10,184	3103 1745	21,207 11,929
	Total length	Ns	N/A	N/A	N/A
Black Bream*	Annuli	512 288	21,053 11,843	6205 3491	27,258 15,334
	Standard length	962 453	39,557 18,627	481 227	40,038 18,854
	Total weight	990 462	40,709 18,997	495 231	41,204 19,228
Salmon	Annuli	512 288	7813 4395	9313 5239	17,126 9634
	Total length	3061 929	46,710 14,176	0 0	46,710 14,176
	Total weight	ns	N/A	N/A	N/A
Dhufish	Annuli	512 288	36,485 20,523	6205 3491	42,690 24,014
North WCB only	Oto wt	875 425	62,352 30,285	588 286	62,940 30,571

Table 6.7 Cost analyses of acceptable ageing methods for those stocks show in Table 6.6 if they could be sampled in a representative manner from markets in the Perth metropolitan region. Sample sizes correspond to precision values of 0.06 and 0.08.

Species/ Stock	Ageing Methods	N (0.06 0.08)	Sample costs	Ageing Costs	Total costs
Goldband snapper	Annuli	512	5448	9313	14,761
		288	3064	5239	8303
	Oto wt	614	6533	413	6946
		329	3501	221	3722
	Fork length	1028	10,938	514	11,452
		538	5724	269	5993
Red emperor (Kimberly)	Annuli	512	5448	6205	11,653
		288	3064	3491	6555
	Oto weight	733	7799	493	8292
		375	3990	252	4242
Red emperor (Pilbara)	Annuli	512	5448	6205	11,653
		288	3064	3491	6555
	Oto wt	1190	12,662	800	13,462
		523	5565	351	5,916
Rankin cod	Annuli	512	6057	6518	12,575
		288	3407	3666	7073
	Oto wt	2766	32,722	1859	34,581
		1118	13,226	751	13,77
Flagfish	Annuli	512	4838	6518	11,356
		288	2722	3666	6388
	Oto wt	1155	10,915	776	11,691
		513	4848	345	5193
Rosy threadfin bream	Annuli	512	4838	6518	11,356
		288	2722	3666	6388
	Oto wt	1442	13,627	969	14,596
		707	6681	475	7156
Sea Mullet	Annuli	512	6564	9313	15,877
		288	3692	5239	8931
	Oto wt	2078	26,640	1396	28,036
		744	9538	500	10,038
	Total length	ns	N/A	N/A	N/A
Yellow-finned Whiting	Annuli	512	6564	3103	9667
		288	3692	1745	5437
Dhufish	Annuli	512	6666	N/A	6666
		288	3750	N/A	3750
	Oto wt	875	11,393	588	11,981
		425	5534	286	5820

6.4 Discussion and conclusions

6.4.1 Overview

The tables showing comparative costs for obtaining age composition data for scalefish stocks represent the most important results this project. These results can be used to assist in the process of developing age sampling programs for a range of stocks.

The considerable costs incurred by using a research vessel to sample fish indicated that this method should only be used in those cases where no alternatives are available. In most cases, the use of research vessels has been for initial biological studies of oceanic "offshore" stocks for which commercial or recreational catches (i.e. fishery dependent) were inadequate to supply the required number of samples. While the research vessel can collect species vulnerable to trawl gear in large quantities, and hence be reasonably cost effective, other types of fishing gear that can be deployed from the research vessel only catch comparatively small numbers of fish on any one day. Market sampling or sampling directly from fishers is the preferred method, but this is only suitable in those cases where the samples are representative. For example, catches are often graded by size prior to delivery to markets.

6.4.2 Preliminary recommendations

In the Pilbara Trawl Fishery, research staff continue to collect at least 300 otoliths from red emperor and Rankin cod in each management area, similar to the number required for a precision level of 0.08 using the annulus method. Estimating age for these species using the otolith weight method required samples sizes of 523 and 1118 respectively, and does not represent a cost reduction over using the annulus method. In the case of flagfish, samples were easily obtained as this species is prolific in the catch and the otoliths are easily extracted. A sample size of 513 otoliths weights would be a cost saving of $3,000 over a sample size of 288 using the annulus method. If flagfish were collected from market sampling or collected from vessels in conjunction with other species, otolith weight may be a cost effective method of ageing this species.

For species which are not highly abundant or where it is difficult to obtain access to samples (e.g. dhufish, red emperor, goldband snapper, blue lined emperor) the collection of otoliths is the major cost, and there is no cost saving in collecting more otoliths (often twice as many) to use for the otolith weight method.

For species that are abundant in catches and easily obtained from markets (Australian herring, flagfish, yellow finned whiting, rosy threadfin bream, sea mullet) there can be cost savings in collecting sample sizes of 600 to 700 otolith weights rather than sectioning and aging 288 otoliths.

Cost savings of 20-30% for reading otoliths could be achieved if otoliths only had to be read once. Development of protocols for reading otoliths, including a scheme of training and testing would obviate the need for more than one read and subsequent reconciliation. Such a scheme would require the development and implementation of a training-reference collection along with standardized routines for estimating precision and bias.

Ultimately, these preliminary recommendations will need to be extended to fish biologists (or those responsible for generating annual age structure) so that they can fine tune sampling and processing methods with an understanding of both the risks to stock assessments for major target species and the savings that can be made to help address potential risks for some stocks that have hitherto not been subjected to regular assessments.

7.0 General Discussion

Determining the age structure of exploited fish populations remains one of the key tools used by fisheries science to provide advice on the status of exploited scalefish stocks for the purpose of fisheries management. Age structure information is used to generate estimates of total fishing mortality, from which the level of fishing mortality can be determined. Fishing mortality, in turn, is a metric that can be easily understood by stakeholders and managers. Age structure information also underpins the implementation of age-structured models, which constitute the most widely used type of model for stock assessment of scalefish.

In Western Australia there are > 150 spp. of scalefish captured (i.e. retained for sale or direct consumption) by commercial and recreational fishers. Twenty three stocks encompassing 18 species were assessed in this study to determine if age structure information could be obtained more cost effectively than is currently the case. Several phases of research were required to address this task.

The first step was to use available data to determine if an alternative (proxy) measure of age, i.e. an alternative to using the annuli method (counting internal "rings" on whole or sectioned otoliths), could be identified for each stock. The annuli method is widely accepted as the standard technique to determine age in scalefish, as it can be validated. Consequently, the annuli method was deemed the "control" against which the performance of proxy measures was assessed. The analyses to identify proxy measures of age consisted of two statistical methods, robust regression and mixture analysis, to assess if any of the available measures (e.g. fish length, otolith weight) could provide a reliable (statistically significant) depiction of the annual age structure. Application of both methods was required to account for the quite different relationships between age (as determined using the annuli method) and the proxy measures. No one of these methods was better than the other: the robust regression worked for relationships that responded positively to transformation whereas mixture analysis dealt better with relationships with considerable variability (e.g. highly variable otolith weights for any given age) and which did not respond well to transformation.

For some stocks more than one proxy was found to have a significant relationship with age; across all stocks examined, numerous proxy measures provided significant fits, of which 29 were optimal. Otolith weight was the chosen proxy measure for 17 of the 29 significant models, with length (standard, fork or total) accounting for a further 8 models. The remaining models used proxies including head length, otolith height and head length. While length is already measured for any study of fish biology, otolith weight should be routinely measured during any biological sampling program on exploited scalefish; this already occurs in Western Australia.

An ancillary step to identifying proxies was to determine the sample sizes for both the annuli method and for proxy measures that corresponded to K-S precision levels of 0.04, 0.06 and 0.08. A thorough examination of several statistical distributions showed that this range of precision levels was that most likely to provide acceptable estimates of age structure. With in this range, there is a guarantee that sufficient sensitivity to accurately estimate age compositions while still being cost effective. Nonetheless, once these precision levels were applied to the available data for the various stocks, we ascertained that the sample sizes required to achieve precision levels of 0.04 for the proxy measures were in most cases too expensive to collect. The subsequent cost benefit analyses therefore only considered precision levels of 0.06 and 0.08.

For 7 scalefish stocks in this report, the proxy modelling has poor levels of precision, i.e. K-S precision > 8%. The explanation is that the Kolmogorov-Smirnov precision has two components which sum together. The first depends on the sample size, while the second depends on the proxy relationship to age. While current sample sizes may be insufficient to achieve a K-S precision < 8%, the availability of larger sample sizes may make this bound achievable. Before attempting to use proxy measures in fisheries management, an external review of the age data used in the modelling would be undertaken to determine if the age estimates are suitable.

Once the best fitting proxy measures had been identified their performance in stock assessment techniques had to be ascertained. This step was crucial to ensure that any alternatives to the annuli method would be accepted by fishery biologists, who have a culture of relying on counting annuli on sectioned otoliths to estimate age structure. The ability for fishery biologists to ultimately undertake risk analyses when deciding on whether the additional uncertainty around using proxy is acceptable is dependent on them understanding the methods used to develop the proxy measures. The efficacy of the best proxy measure for all the stocks were assessed by comparing the estimates of total mortality using catch curve analysis against those derived using the annuli method; proxy measures for 19 of the 23 stocks examined were found to provide an acceptable estimation of total mortality.

In addition to the comparisons of total mortality using catch curve analysis, the proxy measures were compared to the annuli method for five stocks that had age- structured models. The age-structured models have been developed to integrate different sources of variability in the input parameters, such as that in age structure data, and to explicitly provide estimates of uncertainty around the median estimates of spawning biomass. The uncertainty for the spawning biomass estimates was depicted as confidence intervals around the median estimate; this was advantageous for testing proxy measures since the acceptability of the proxy could be better assessed by also considering this variability. We therefore conclude that the results from the age-structured models provided a superior indication of the efficacy of the proxy measures. Furthermore, the age-structured models also permitted testing of different sample sizes of proxies by randomly selecting from the actual proxy-measure datasets. These sensitivity analyses allowed further insight into the usefulness of proxy measures: whereas a random selection of at least 100 will adequately represent the median estimate of spawning biomass, significantly larger sample sizes (i.e. > 300) are required to provide sufficiently tight confidence limits.

The cost analyses reflect factors such as the need for either or both fishery dependent and fishery independent samples, sizes of catches on any one field trip (i.e. high for abundant species, low for less abundant species), level of industry contribution, number of staff required and distance from Perth, etc. The cost benefit analyses compared the annuli method and the proxy measures with sample sizes corresponding to precision levels of 0.06 and 0.08. 512 age estimates are required over a short-term timeframe (e.g. annually). For those stocks with age-structured models, this project has shown that in some cases fewer otoliths are required. As such, for many of the stocks examined here as few as ~288 age-estimates per year will suffice but samples of ~512 would be preferable for stocks near or below the accepted reference points of 40% of virgin biomass. These sample sizes will be further investigated as the program of adaptive implementation of the reduced sampling programs is developed.

Field sampling was by far the most expensive part of an age monitoring program, particularly in those cases were fishery-independent samples were required to obtain representative samples of fish. For many of the stocks, it is not possible to obtain representative samples from the Perth markets; this is due to a variety of reasons including direct sales or export from regional centres, marketing of processed fish only (e.g. trunked or filleted), and marketing of whole fish which cannot be damaged. Nonetheless, the costs for market sampling illustrate the substantial savings that could be made if representative samples could be consistently obtained.

Design of a monitoring program for future stock assessment

The comparative precision and costs for different (i) ageing methods and (ii) sample sizes will be used to develop a complete program of scalefish sampling. This program will align with priorities for management. However, it is not yet possible to complete the program until there has been a review of the priority management needs, on a stock-by-stock basis. Pending implementation of significant rationalization of the West Coast Demersal Scalefish Fishery, that has already involved protracted negotiations regarding management arrangements for both the commercial and recreational sectors of this fishery, there remains an urgent need for ongoing annual estimates of age structure for the following stocks in the West Coast Bioregion:

- North dhufish
- Metro dhufish
- South dhufish
- Abrolhos baldchin groper
- Kalbarri pink snapper.

The current need to focus on these species has not yet allowed development of a state-wide age monitoring program that would include consideration of the frequency with which age structure would need to be estimated.

8.0 Benefits and adoption

The critical results from this study are the relative costs of the different sampling and ageing methods, while the results for extending these cost-benefit analyses into actual age monitoring programs pertain to defensible statistical analyses used identify and test the proxy measures. The complete models for each of the five stocks with age-structured models were initially presented to staff of the Department of Fisheries' Research Division at a workshop in June 2006. This workshop was intended to be the precursor to developing a reduced program sampling/processing of fish otoliths for at least some stocks. The relevant fishery biologists were at that time not convinced that the suggested age monitoring programs were feasible. There was initially reluctance to try new methods of aging fish, particularly for stocks deemed to be below their biological reference point.

The analyses undertaken since the June 2006 workshop (e.g. to define the criteria for accepting/rejecting proxy measures of age) have alleviated the concerns of biologists so that there is now expected to be better take-up of the results. A key message of the study subsequent to that initial extension was that the implementation of any "new" sampling and ageing strategy had to be carefully considered in the context of the status of the stock in question. That is, the decision to change an age monitoring program would be based on a risk analysis to examine the cost benefits against the potential increases in uncertainty in the assessment, which in turn is a risk for sustainability of the stock in question.

These final results of the cost benefit analyses are now available for Departmental staff to revaluate the current age monitoring program, for scalefish. It is expected that the suggested changes to the sampling regimes will be enacted almost immediately, without having to await the development of the full program. In the interim, a program of adaptive implementation of the reduced sampling programs, whereby additional otoliths will be collected (and archived) in the first few years in the event that subsequent stock assessments need to be revisited.

9.0 Further Development

Sampling - Substantial savings could be made for age monitoring programs if representative (or random) samples of fish could be provided to researchers by industry. While this has worked for high-volume pilchard and sardine fisheries, for low-volume high-value fisheries more work is required to investigate potential systems for a structured sampling and delivery program. Such systems have been trialled in some fisheries but have typically not worked well unless (i) a research staff member accompanied the fishing operation, i.e. there was a need to revert to a field sampling program, or (ii) there was a particularly good relationship involving a high level of ongoing liaison, which requires fewer resources then regular sampling. Further education and provision of incentives may help to develop better partnerships, for more fisheries, between industry members and research staff to alleviate the high costs of field sampling. Fisheries that target multiple stocks, such as Goldband snapper and red emperor in the Northern Demersal Scalefish Fishery, already have sampling systems, including incentives, to encourage co-operation with field sampling programs.

Ageing methods - The sample sizes available for some stocks were marginal in terms of suitability for identifying potential proxies. Although significant relationship with age were found, these relationship need to be stronger and include a more representative distribution of age classes before the proxy measures can be used with confidence. If the re-assessment of scalefish management priorities[2] indicates that any such stocks with suspect relationships are currently in need of age monitoring then further sample collection and analysis will be required before the use of proxy measures can proceed.

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[2] To be undertaken by Department of Fisheries in 2009 following reviews of stock assessments for several species.

10.0 Planned outcomes

1. A schedule of assessments were completed to identify for each of 23 scalefish stocks the degree to which proxy measurements of age could be used to replace the annuli method. Regardless of what method is employed the minimum sample size required is ~300, whereas a sample size of ~500 is preferable. The proxy measures for several stocks had weak, albeit significant, relationships with age: in these cases the sample sizes required were much larger. Sample size required to obtain a precision level of 0.06 ranged from 814 to 3061.

2. Cheaper methods of ageing fish have been developed for 20 of the 23 stocks of Western Australian scalefish examined in this study. The costs of all aspects of the monitoring program for each stock were estimated and compared. The detailed tables of comparative costs will be provided to fishery biologist so that they have a basis for assessing were cost savings can be made. For all stocks the largest cost is to obtain the samples, particularly for those stock located in the northern half of the state (e.g. Goldband snapper, red emperor), and/or those which support a low-volume high-value fishery commercial fishery or a recreational fishery only (e.g. dhufish, inner Shark Bay pink snapper). The costs for processing samples for age determination and then the subsequent age determination are less than for the field sampling but nonetheless savings in these areas have also been identified.

3. Development of a full program of age monitoring for all scalefish stocks in western Australia awaits further liaison with fishery biologists and managers, who now need to consider the tradeoffs between cost and accuracy of the alternative methods

11.0 Conclusion

This study was designed to strategically evaluate the ongoing (and long-term) need to obtain estimates of the annual age composition of exploited fish stocks. The overall aim of the project was to reduce costs for individual stocks so that the sustainability status of more stocks could be assessed within the constraints of available funding. Biological databases for a variety of scalefish stocks, held at the Department of Fisheries, Western Australia, and Murdoch University, were interrogated to determine which held information that would allow examination of measures such as otolith weight or total length relative to ages estimated using the annuli method from either whole or sectioned otoliths. The amounts of data varied and depended somewhat on the current or historical value of the stock and on the timing of any focussed research. For example, the measurement of otolith weight was only taken up as a standard in the mid- to late 1990s.

The ability to use alternatives to counting annuli to determine the age of scalefish is dependent on establishing a robust model on a case by case basis. In this study we establish such relationships for 23 stocks. The statistical methods applied were robust regression and a modification of mixture analysis. Both methods are equally valid and were applied to each stock iteratively to all potential alternative measures available from the databases so as to determine candidate proxy measures of age. Otolith weight was the most common proxy chosen, followed by fish length.

Regardless of how well the robust regression or mixture analysis could model candidate proxy measures of age, the proxies had to be tested in assessments of stock status; this step was crucial for the project because of the longstanding belief that counting annuli on sectioned otoliths was the only method of aging scalefish. While this is true for the initial determination of age for the majority of scalefish species, there has remained an ongoing institutional bias against using anything but the annuli method for ongoing age monitoring programs. The selected proxy measure(s) for each stock were subjected to catch curve analysis to ascertain if they provided an estimate of total mortality comparable to that obtained using the annuli method. The proxy measures for 87% (20/23) of the stocks examined provided acceptable alternatives to the annuli method.

For the majority of the stocks examined there is scope to reduce sampling costs, in some case considerably. Given that the tests here confirm that the proxy estimates can be as reliable as the estimates derived from the annuli method but that neither method can be shown to be a true representation of the stock (as this is dependent on representative sampling), and not the ageing method; it is appropriate to spend less money to achieve a comparable level of ignorance. In the first instance the cost savings should be directed towards increasing the representativeness of the samples.

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13.0 Appendices

Appendix 1 Intellectual Property

The results of this research will be provided in the public domain.

Appendix 2 Staff

Staff who worked on the project were: M. Craine, D. Gaughan, R Lenanton, B. Rome, R. Steckis, P. Stephenson, B. Wise, I. Wright.