Population dynamics and assessment of sand and rock flathead in Victorian waters

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State Government Victoria Department of Primary Industries

Australian Government Fisheries Research and Development Corporation

Project No. 2000/120

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February 2004

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Published by Primary Industries Research Victoria, Marine and Freshwater Systems, Department of Primary Industries, Queenscliff, Victoria, 3225.

ISBN 1 74106 555 0

Formatted/designed by Primary Industries Research Victoria Queenscliff

Printed by PIRVic Queenscliff, Victoria

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NON-TECHNICAL SUMMARY

2000/120 Population dynamics and assessment of sand and rock flathead in Victorian waters

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Objectives:

1. Determine the age structure and growth of sand and rock flathead in Port Phillip Bay and Corner Inlet.
2. Estimate biological parameters for sand and rock flathead.
3. Develop stock assessment models for sand and rock flathead.
4. Adoption of results by Fisheries Victoria.

Non Technical Summary:

OUTCOMES ACHIEVED

This project has addressed some of the main information gaps identified during assessment workshops for sand and rock flathead. It reports the basic biological parameters for sand and rock flathead in Port Phillip Bay and Corner Inlet respectively. Such information is essential for the assessment of fish stocks and was either missing or outdated for these species. A population model has been developed which can be used for other "data poor" species, that makes very few assumptions about parameter distributions or values. Recruitment to the sand flathead population in Port Phillip Bay has been shown to correlate strongly with environmental variables, demonstrating that recruitment is not closely linked to previous levels of fishing pressure. This relationship was incorporated into the population model. Recent data indicate that the abundance of sand flathead is declining for reasons that appear to be unrelated to fishing.

Deterministic models of the rock flathead population in Corner Inlet suggest that the minimum legal length (MLL) of rock flathead appears to be appropriate and that the current level of exploitation in Corner Inlet is not excessive. This information has been provided to Fisheries Victoria as part of formal and informal reporting arrangements. It has also been widely distributed to the public via media releases that were reported on in various magazines and news papers, and sent directly to the public in newsletters.

These results have provided Fisheries Victoria with evidence that stock sizes of both flathead species have been largely unaffected by fishing pressure under current fishery management arrangements. They will provide some ability to forecast future levels of recruitment and therefore a greater certainty of the outcomes of any proposed changes to management arrangements.

Sand flathead (*Platycephalus bassensis*) are a moderately long lived (23 years), slow growing species. They are distributed across southern Australia, and are the most abundant demersal fish in Port Phillip Bay. They are the most frequently caught recreational species in the Bay, and it was estimated that an average of 240 t were landed each year between 1990 and 1994. They also make up a small proportion of the commercial catch.

The recent declines in the abundance, average size and recreational and commercial catches have raised the question of the sustainability of sand flathead stocks in Port Phillip Bay. New information regarding the longevity of this species raises further questions as to their sustainability. It is expected that the introduced and expanding populations of exotic species (eg *Asterias*, *Sabella* and *Corbulla*) may also impact on sand flathead given the abundance and habitat requirements these invaders.

Rock flathead (*Platycephalus laevigatus*) are distributed across southern Australia, from northern NSW to WA. They are one of the major commercial species in Corner Inlet, however, between 1993 and 1998, commercial catches declined by 67% from 92 t to 30 t. The reasons for the decline are unclear, but may be related to the increase in mesh net fishing effort targeted at rock flathead during the early 1990's. This species is managed by both size limits (25 cm) and input controls in the commercial fishery. Although their common name would suggest otherwise, rock flathead live in close association with seagrass, and their populations may decline if the area of seagrass declines. It has been suggested that the decline in rock flathead catches in the 1970's was due to the loss of seagrass beds within Corner Inlet. The seagrass beds in Corner Inlet have recently been mapped, and information on the biology of rock flathead is required to enable the effects of habitat changes on rock flathead to be investigated.

The recent decline in the commercial catch of rock flathead has also raised the question of sustainability of the fishery within Corner Inlet. The suggestion that the decline in rock flathead catches in the 1970's was due to the loss of seagrass beds within Corner Inlet, highlights the need to understand the links between habitat and recruitment.

Surprisingly, there are few publications on sand and rock flathead and there is no information on the population dynamics of the local stocks of rock flathead. There has been a growing need to undertake research on these potentially vulnerable species because of their longevity and catchability, and to identify appropriate sustainability indicators.

There is also a lack of detailed analysis of catch and effort data for both species. Given the lack of preliminary data analysis, there have been no attempts at stock assessment of these important recreational and commercial species to support management strategies. This research addresses these information gaps and incorporates the biological data into an integrated age-based, population dynamic model. This model can be used for both the sand and rock flathead fisheries to inform managers, to assess management options, and to determine whether the current levels of fishing are sustainable.

Sand flathead from Port Phillip Bay grow quickly for the first 3 to 4 years. Growth slows after about 6 years of age, before reaching an asymptote at 26-28 cm in length. The asymptotic length is considerably smaller than that for sand flathead caught in offshore Victorian waters (38 cm) and Tasmanian waters (36-41 cm). These differences may be due to the heavy fishing pressure on sand flathead in Port Phillip Bay, or because of density dependent processes. The age structure revealed a large degree of recruitment variability, which was highly correlated with the southern ocellation index at the time of peak spawning and river discharge from the Maribyrnong and Yarra Rivers, which flow into the north end of Port Phillip Bay.

An age-structured population model was designed specifically for sand flathead, where accurate catch and effort data were not available because of the nature of the fishery. The model produced a reasonably close fit to the observed data with the exception of 2002. The model suggested that there were major ecological changes to Port Phillip Bay during the mid 1990s, coinciding with several potential triggers, including the cessation of scallop dredging and the invasion of exotic pests.

Age estimates for rock flathead are presented for the first time. Male and female rock flathead reach the minimum legal length (25 cm) as early as after 1.6 years and 1.9 years respectively, and their growth curves asymptote at about 52 cm and 55 cm respectively. The age structure of rock flathead also revealed variable recruitment which was significantly correlated with river discharge into Corner Inlet during the winter months (leading up to peak spawning) from the Franklin and Agnes Rivers.

Male rock flathead mature just below the MLL and females mature at a size just above the MLL. Because of the difference in growth rates, however, females mature at a younger age than males. The current MLL is probably appropriate for rock flathead at Corner Inlet because it gives about half of the population a chance to reproduce before being subjected to fishing mortality. At a length of 30 cm, nearly 100% of rock flathead are mature. Based on the length frequencies of commercial catches, very few fish are caught below this length. A yield per-recruit analysis indicated little benefit from an increase in the legal size. An eggs per-recruit analysis indicated that egg production is currently one quarter to one half that of an unfished population. While both male and female fish were found in spawning condition in most months of the year, most spawning probably takes place after October, when GSI peaked, and males in spent condition appeared in the samples in November.

Deterministic methods were used to model the rock flathead population. The models suggest that the current MLLs for rock flathead are appropriate, with adequate protection provided against growth and recruitment overfishing. Similarly, the current estimates of fishing mortality to appear to be sustainable. These findings indicate that current management arrangements are appropriate and do not need to be reviewed.

Keywords: Sand flathead, *Platycephalus bassensis*, rock flathead, *Platycephalus laevigatus*, age, growth, reproduction, assessment, population model, Port Phillip Bay, Corner Inlet.

Acknowledgments

We wish to thank Mr Neville Clarke (Corner Inlet commercial fisherman) for his collecting rock flathead samples and providing valuable insight into the Corner Inlet fishery. Acknowledgment must go to Greg Parry and the annual Port Phillip Bay trawl survey which provided most of the sand flathead samples used during this project. Thanks also goes to the technical staff (Dave McKeown, Pam Oliveiro, Ian Duckworth and Sean Brodie) for their assistance during laboratory work. KP Sivakumaran provided advise on staging and processing gonads. Leanne Gunthorpe ensured thorough distribution of results of this project to media outlets and stakeholders.

FINAL REPORT

2000/120 Population dynamics and assessment of sand and rock flathead in Victorian waters

Background

Sand flathead (*Platycephalus bassensis*) are a moderately long lived (23 years), slow growing species. They are distributed across southern Australia (Kailola *et al.* 1993), and are the most abundant demersal fish in Port Phillip Bay (Officer and Parry 2000). Sand flathead have been identified as the dominant predator throughout most of Port Phillip Bay (Officer and Parry 1996). They are the species most frequently caught by recreational fishers in Port Phillip Bay, and it was estimated that an average of 240 t were landed each year between 1990 and 1994 (Coutin *et al.* 1995). They also make up a small proportion (< 1%) of the commercial catch (Coutin 2000a). Both commercial and recreational fisheries for sand flathead are managed through minimum size limits (25 cm TL), and by input controls in the commercial fishery. Catches from both recreational and commercial fisheries, and catch rates from fisheries independent trawl surveys, all declined by about 50% during the early 1990s (Coutin 2000a; Coutin *et al.* 1995; Officer and Parry 2000). Anecdotal evidence also suggests that the average size of sand flathead caught by recreational fishers has decreased markedly. But the causes of the changes are unknown and prior to 2000 there had been no formal stock assessments. A further issue is the potential effect of the cessation of scallop dredging on the sand flathead population in Port Phillip Bay, which is thought to have made prey items more easily available to the fish (Greg Parry, pers. comm.). There have been three previous theses on sand flathead. Brown (1977) examined the sympatric relationship between 3 co-existing flathead species in Port Phillip Bay. His study included reproduction, abundance, feeding and age and growth. Andrews (1988) studied the feeding ecology of sand flathead in Port Phillip Bay to determine factors effecting prey selection. More recently, Jordan (1998) studied the age, growth, abundance and reproductive cycle of sand flathead from offshore and inshore Tasmanian waters to identify their life history strategies.

Rock flathead (*Platycephalus laevigatus*) are distributed across southern Australia, from northern NSW to WA (Kailola *et al.* 1993). They are one of the major commercial species in Corner Inlet, however, between 1993 and 1998, commercial catches declined by 67% from 92 t to 30 t (Anon 2000). The reasons for the decline are unclear, but may be related to the increase in mesh net fishing effort targeted at rock flathead during the early 1990's. This species is managed by both minimum size limits and (25 cm TL) and input controls in the commercial fishery. Although their common name would suggest otherwise, rock flathead live in close association with seagrass, and their populations may decline if the area of seagrass declines. It has been suggested that the decline in rock flathead catches in the 1970's was due to the loss of seagrass beds within Corner Inlet (MacDonald 1997). The seagrass beds in Corner Inlet have recently been mapped (Roob *et al.* 1998), but there is no information available on trends in seagrass cover within Corner Inlet over this period. Information on the biology of rock flathead is required for effective management of the fishery and to enable the effects of habitat changes on rock flathead to be investigated.

As part of a project funded by Fisheries Victoria, rock flathead had been routinely sampled from commercial mesh net catches since 1994. At the start of this study, over 1,500 otoliths had been collected and sampling was on-going. While other species of Platycephalids have been studied in other states (eg *P. speculator* in WA, (Hyndes *et al.* 1992)), no information was currently available on the biology or population dynamics of rock flathead in Victoria or elsewhere.

Stock assessment workshops were held at MAFRI in April 2000 to present and review the latest information on Victorian sand and rock flathead. These workshops involved representatives from MAFRI, Fisheries Victoria, the Co-Management Council, Seafood Industry Victoria, VR Fish, the VNPA as well as Alan Jordan from TAFI. It was clear at the workshop that some advances eg (Koopman Submitted) and (Jordan 1998) had been made in our knowledge of the biology of, and the fisheries for, these species, but that more work needed to be undertaken before the sustainability of the stocks can be assessed. The following research needs were recorded during the stock assessment workshops:

- Monitoring of recreational catches and catch rates,
- Continued monitoring of size and age structure,
- Estimation of fecundity,
- Representative sampling of fish to include small fish,
- Evaluation of the mortality of small fish released by recreational fishers,
- Continue to monitor age structure and mortality of sand flathead in Port Phillip Bay from annual trawl surveys,
- Development of an age-based stock assessment model.

Meeting these research needs would assist in identifying suitable reference points or "sustainability" indicators which could be used as performance criteria for ongoing assessment and management purposes.

Need

The recent declines in the abundance, average size and recreational and commercial catches had raised the question of the sustainability of sand flathead stocks in Port Phillip Bay. New information regarding the longevity of this species raised further questions as to their sustainability. It is expected that the introduced and expanding populations of exotic species (eg *Asterias*, *Sabella* and *Corbulla*) (Cohen *et al.* 1998) may also have impacted on sand flathead given their increasing abundance and the similarity in their habitat requirements to sand flathead.

The recent decline in the commercial catch of rock flathead has also raised the question of sustainability of the fishery within Corner Inlet. The suggestion that the decline in rock flathead catches in the 1970's was due to the loss of seagrass beds within Corner Inlet (MacDonald 1997), highlighted the need to understand the links between habitat and recruitment.

Surprisingly, there are few publications on sand and rock flathead and there is no information on the population dynamics of the local stocks of rock flathead. Research on these species, that are potentially vulnerable because of their longevity and catchability, would help to identify appropriate sustainability indicators.

There is also a lack of detailed analysis of catch and effort data for both species. Given the lack of preliminary data analysis, prior to 2000 there had been no attempts at stock assessment of these important recreational and commercial species to support management strategies. This research proposal addresses these information gaps and incorporates the biological data into an integrated age-based, population dynamic model that will assist in the ongoing assessment of the sustainability of fisheries for flathead.

Objectives

1. Determine the age structure and growth of sand and rock flathead in Port Phillip Bay and Corner Inlet.
2. Estimate biological parameters for sand and rock flathead.
3. Develop stock assessment models for sand and rock flathead.
4. Adoption of results by Fisheries Victoria.

Methods

Sample collection and biological parameters

Sand flathead

Between 1990-2002, samples of sand flathead were collected from research trawls (Officer and Parry 2000) conducted in six areas around Port Phillip Bay (Figure 1 and Figure 2). In each area two replicate 5 minute trawls were carried out at four depths (7 m, 12 m, 17 m and 22 m). Only two depths were sampled in the shallow Geelong arm (7 m and 12 m). Samples were taken using an otter trawl net (net specifications: 47 m long, 13 m wing spread, 5 m opening height, 45 m between trawl doors, 44 mm codend liner) towed behind RV Sarda (specifications; 19.8 m LOA, 5.9 m beam, 2.3 m draught) until 1997. Subsequent surveys were conducted using a commercial trawler (the Castella Rosa) which has similar dimensions to the RV Sarda. Once on board, fish were identified, sorted by species and placed into separate bins. The total weight and number of individuals of each species were recorded. When fewer than 100 sand flathead were caught in a shot all fish were measured (total length recorded to the cm below); when over 100 fish were caught, a sub-sample of approximately 100 fish were measured. The pair of sagittal otoliths from 50 randomly selected sand flathead at each station were removed, cleaned and placed into labelled envelopes. In addition, gonads from a sample of female sand flathead in spawning condition (based on the criteria of (Jordan 1998)) were taken from Port Phillip Bay near St Leonards in September 2001. Gonads were preserved in 10% vapour suppressed formalin (a solution containing 100 ml formaldehyde, 680 ml propylene glycol and 36 g hexamine added to 220 ml of filtered seawater to make 1 L). A 1 cm transverse section was taken from the middle of the largest lobe to eliminate possible bias in the size and development along the length of the ovary (Yuen 1955; West 1990). The maximum and minimum diameter of 100 oocytes from each fish were measured and the egg diameter calculated as the average of these two measurements. Differences between the length-weight relationships of males and females was examined with Analysis of Co-variance in Microsoft® Excel 97 SR-2.

Rock flathead

Rock flathead ‘frames’ have been routinely collected by MAFRI staff from fishers at Corner Inlet (Figure 1) since 1994 (frames are whole fish from which fillets have been removed but have the head and abdominal cavity intact). These frames were measured (total length), sexed and their sagittal otoliths taken and stored in a labelled envelope. These will be referred to as the commercial samples.

During the present project, research samples of whole rock flathead were purchased from a commercial fisher from Corner Inlet. Approximately 75 randomly selected fish were taken in each month between February 2001 and February 2002. For all samples, total length was measured, fish were sexed, gonads were macroscopically staged and otoliths extracted and weighed. For whole fish, total weight and gutted weight, body cavity and gonad lengths were also measured. Gonads were also staged macroscopically according to a modified criteria from Jordan (1998) (Table 1) and the gonad length and body cavity length were measured.

Gonads were preserved in 10% vapour suppressed formalin (a solution containing 100 ml formaldehyde, 680 ml propylene glycol and 36 g hexamine added to 220 ml of filtered seawater to make 1 l). After a period of at least 1 month, the preserved weight of the gonad was taken, and a 1 cm transverse section was taken from the middle of the largest lobe to eliminate possible bias in the size and development along the length of the ovary (Yuen 1955; West 1990). This sample was used for histological samples. If stage 5 and 6 gonads were present, 1 g of the sample was also taken and placed in ethanol for fecundity estimation.

Histology samples were staged according to standard criteria, based on the most advanced stage (West 1990). The maximum and minimum measurements of 5 of the most advanced oocytes was measured on each slide.

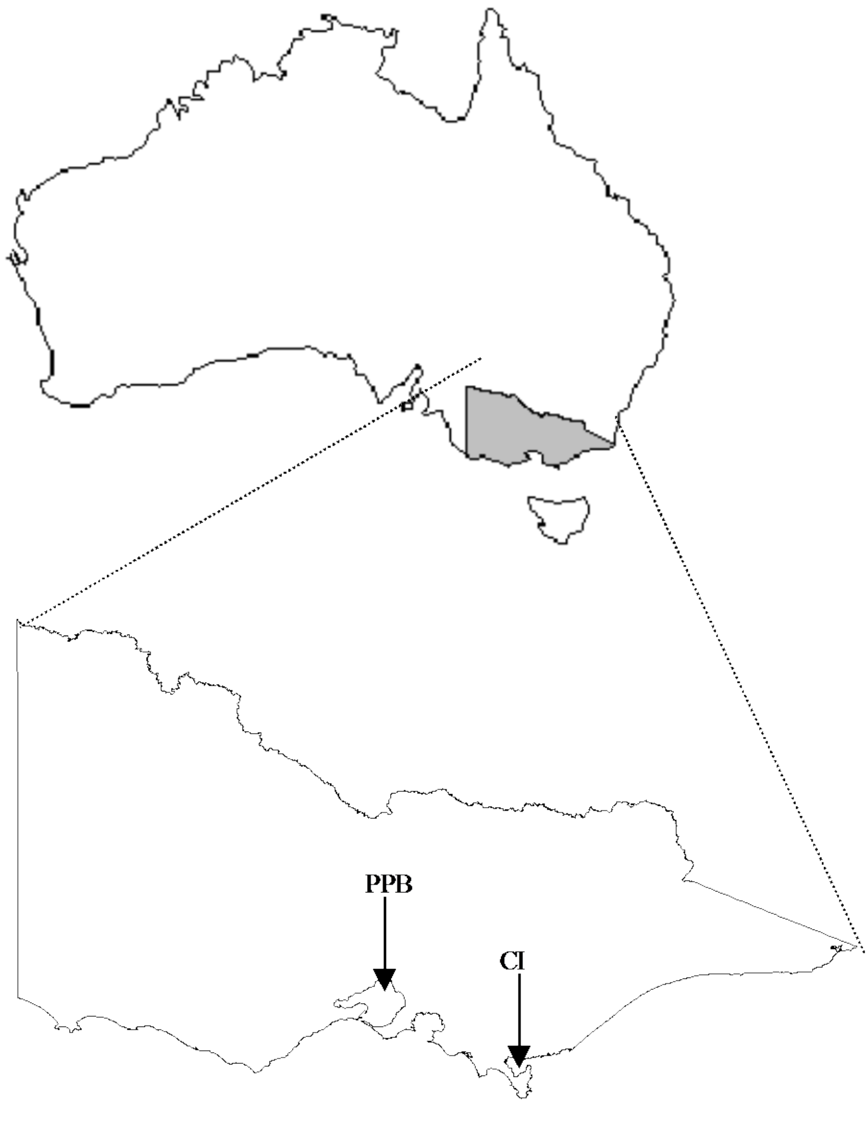


Figure 1. Map showing the location of Port Phillip Bay (PPB) and Corner Inlet (CI) within Australia and Victoria.

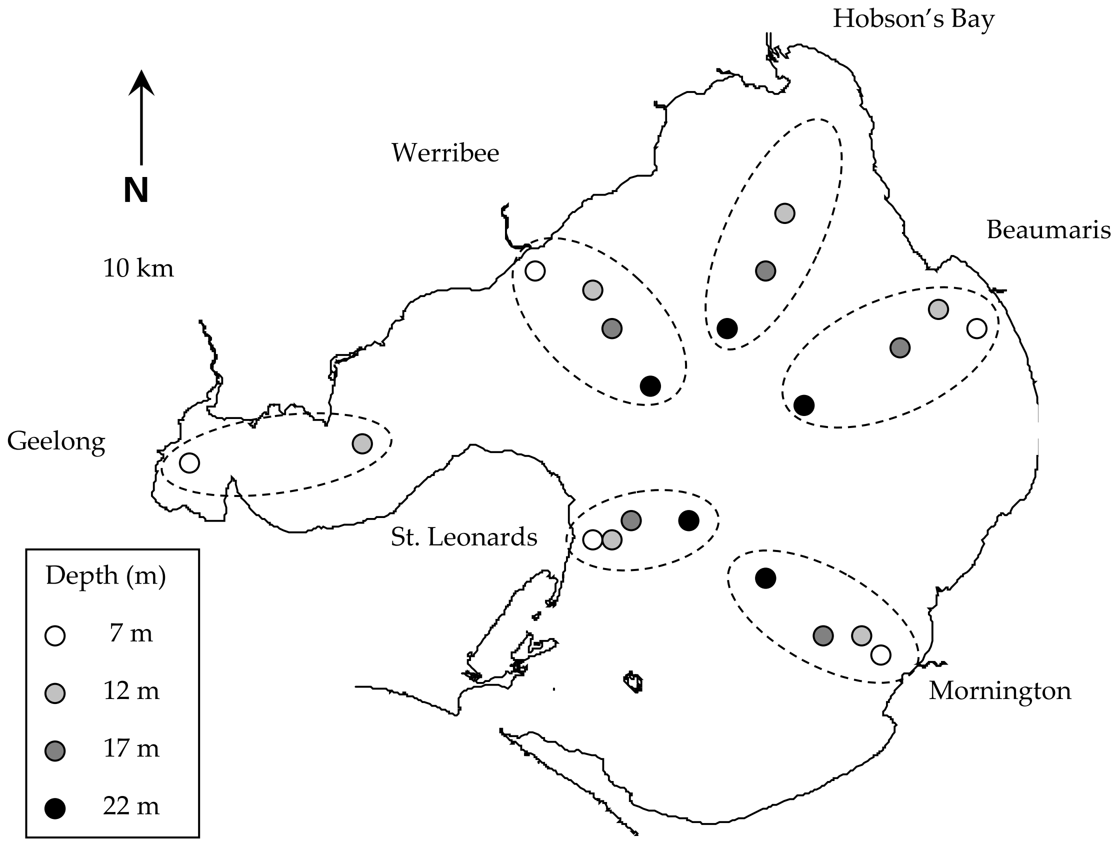


Figure 2. Map of Port Phillip Bay showing the 22 stations sampled during the 1990-2000 trawl surveys. Shading refers to station depths which are displayed in the depth key.

Fecundity was only estimated for gonads classified as stages 5 and 6, and where no postovulatory follicles were found. The 1 g sample (along with the ethanol) was diluted into 300 ml and the number of eggs in 5 subsamples each of 4 ml were counted. Fecundity was estimated by multiplying these counts by the ratio of the preserved weight to the sample weight.

The deviation of the sex ratio from 50:50 in the samples was examined using Chi-squared tests in Microsoft® Excel 97 SR-2. Differences between the length-weight relationships of males and females was examined with Analysis of Co-variance in Microsoft® Excel 97 SR-2.

Because a reliable estimate of relative abundance was available for rock flathead, the natural log of the percent frequency of 2 year-old fish was used as the index of recruitment. The correlation between various environmental parameters and recruitment was examined using regression analysis in Microsoft® Excel 97 SR-2.

Table 1. Macroscopic staging criteria used for rock flathead.

Stage/Category	Macroscopic criteria
Females	
1. Virgin	Small strap, less than ½ length of body cavity. Firm texture.
2. Maturing virgin	Virgin – Small strap with rounded body edge less than ½ length of body length, pink and transparent. Recovering – about ½ length of body cavity, bloodshot and flabby at posterior.
3. Developing	About ½ length of body cavity, opaque and becoming yellow. Ova not discernible.
4. Late developing	About ½ length of body cavity, opaque and yellowish pink. Ova discrete.
5. Ripe	About ¾ length of body cavity and swollen occupying all available space. Ovary and ova become translucent.
6. Running ripe	Eggs expressed with slight pressure. Ovary pinkish, clear and granular.
7. Spent	Slack and bloodshot. Few residual oocytes present.
Males	
1. Virgin	Small strap, less than ½ length of body cavity. Firm texture.
2. Maturing virgin	Virgin – Small strap with rounded body edge less than ½ length of body length, pink and opaque. Recovering – less than ½ length of body cavity, bloodshot and flabby at posterior.
3. Developing	About ½ length of body cavity, opaque and becoming larger.
4. Late developing	About ½ length of body cavity and larger.
5. Ripe	Greater than ½ length of body cavity and swollen occupying all available space. No milt expressed with slight pressure.
6. Running ripe	Milt expressed with slight pressure. Testes granular.
7. Spent	Flaccid and bloodshot.

Age and growth

One sagittal otolith from each fish was weighed to the nearest milligram. The otoliths were then embedded in clear polyester casting resin, sectioned and mounted using standard methods (Anderson *et al.* 1992; Morison *et al.* 1998a).

Otoliths were examined under a dissecting microscope (x25 magnification) fitted with a digital video camera connected to a computer running customised image analysis software (Optimate™) (Morison *et al.* 1998a). The number and radii of opaque zones along an axis from the primordium to the crista superior along the dorsal side of the sulcus (Figure 3) were recorded. All estimates were made by one person without knowledge of date of collection, size, or sex of the fish.

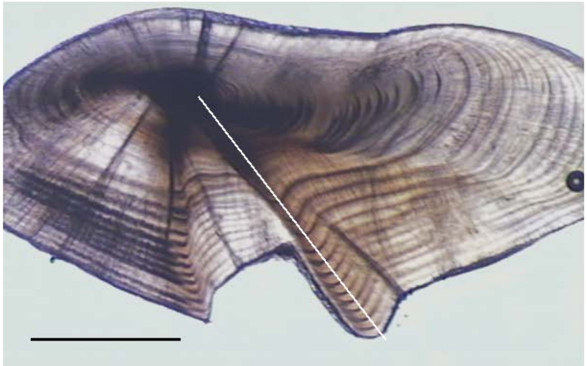
The periodicity of growth increment formation in rock flathead was examined by calculating the mean marginal increment ratio (MIR) of otoliths from the monthly samples. This analysis has already been performed for sand flathead by Koopman (Submitted) and so was not repeated. Marginal increment ratios were calculated using a variation of the relationship used by (Anderson *et al.* 1992):

$$MIR = \frac{(r_e - r_{e-1})}{(r_{e-1} - r_{e-2})} \times 100$$

where r_e is the total radius of the otolith from the primordium to the edge, r_{e-1} is the radius measured from the primordium to the penultimate growth increment, and r_{e-2} is the radius of the second last increment. The mean monthly MIRs (± 1 SE) were plotted separately for each age group that contained sufficient numbers of samples (2–6 years old), and plots of 7+ year old fish and all ages combined are also presented.

A length-weight relationship was described for male, female and both sexes combined using a power curve ($W=aL^b$; where W = weight (kg), L = total length (cm); a and b are constants). Differences between sexes were tested by Analysis of Co-Variance (ANCOVA) on data that were normalised through log transformation. The residuals had homogeneous variance after transformation.

A



B

Figure 3. Transverse sections of the sagittal otoliths of sand flathead estimated to be 13 years-old (A) and rock flathead estimated to be 8 years-old (B) at X25 magnification.

The white line marks the axis along which the growth rings were counted and the dark lines are scale bars of length 100 μm.

Age estimates from annual samples were adjusted to a birth date of 1 December, which corresponds to the mid-point of the reported spawning season of sand flathead (Jordan 1997). Rock flathead were also assigned this arbitrary birth date. Growth was described by the von Bertalanffy growth function (VBGF). This was fitted using a non-linear, least-squares procedure in SAS. The VBGF was fitted to both sexes combined, as well as for males and females separately. Data from immature fish were randomly allocated to the male and female data sets. The likelihood ratio test as applied by Kimura (1980) was employed to test for differences between growth curves.

Mortality and population modelling

Sand flathead

A population model of was developed for sand flathead that did not rely on catch-per-unit-effort (CPUE) data, but instead made use of the time series of fisheries independent catch-at-age data provided by the trawl survey results (Officer and Parry 2000). Only three age groups were used for simplicity: 2 year-old recruits, 3 year-old fish, and fish from 4 to 12 years-old inclusive (4+ year-olds). This data reduction to an intermediate level of complexity was used to remove the problem of "noisy" relative abundance estimates (Conser 1994 as cited by Panfili, 2002 ; Jacobson *et al.* 1994), and the addition of more age groups was did not improve the fit of the model to the observed data. Fish aged less than 2 years-old were not included because they were inadequately sampled by the gear, and fish greater than 12 years-old were inconsistently represented in the samples.

Since only three age-groups were chosen to represent the population dynamics, the model consists of three main functions; a recruitment function for the youngest fish, and survival functions for the 3 year and 4+ age groups. Earlier versions of the recruitment function were based on the Beverton-Holt recruitment function, however, linear regression of spawning stock abundance against recruitment revealed a very low R2 value (0.0181), and the plot did not suggest a relationship of any other form. After examination of a relationship between environmental variables within Port Phillip Bay, it became clear that recruitment would be more accurately described using a multi-parameter environmental-recruitment function. A linear function was derived using forward step-wise regression that produced a relationship with two independent variables. Initially a range of environmental variables the year before and during spawning were correlated with recruitment. The most highly correlated, significant variables were retained for further analysis and added to the step-wise regression one at a time based on the correlation coefficient. The highest added first followed by the second highest and so on until the addition of more parameters did not significantly increase the R2 of function. The same recruitment function was used for all model runs. The second function was a linear model with a random survival rate of 2 year-old fish. In the third function of the model, the 3 and 4+ year-old fish were assigned the same random survival rate. This simplification was necessary because of the limited time series of data.

The time series available for the population dynamics of sand flathead consists of only 12 points in time, from 1990 to 2002. This provides the minimum amount of information required for estimation of the population parameters for the three functions in the model. The equations have the form:

$$x_{2(ti)} = 4.5682 - 0.00003 \cdot Riverdischarge_{(ti-4)} + 0.02066 \cdot SOI_{(ti-3)} + \varepsilon$$

$$x_{3(ti)} = s_2 \; x_{2(ti-1)}$$

$$x_{4+(ti)} = s_{3+}(x_{3(ti-1)} + x_{4+(ti-1)})$$

where $x_{j(ti)}$ is the number of individuals in age j at time t_i, and

s_{j2}, s_{3+} are the random survival rates at age 2 and 3+.

The density functions of the parameters s_2, s_{3+} were chosen to be distributed according to the negative Log-Weibull function:

$$f(s_2) = ab^{-a} (-log(s_2))^{a-1} exp(-(-log(s_2)/b)^a)/ s_2$$

and

$$g(s_{3+}) = cd^{-c} (-log(s_{3+}))^{c-1} exp(-(-log(s_{3+})/b)^c)/ s_{3+}$$

Since $0 \leq s_2, s_{3+} \leq 1$ this ensures biological consistency of the random survival rates.

To estimate parameters a, b, c, d of the density functions of the survival rates, the method proposed by Troynikov (1998) was used. From the first and second model equations we have

$$s_2 = x_3(t_i) \, / \, x_2(t_{i-1}) \text{ and}$$

$$s_{3+} = x_{4+}(t_i)/(x_3(t_{i-1}) + x_{4+}(t_{i-1})).$$

Furthermore, by changing the variables in densities $f(s_2)$ and $g(s_{3+})$ we have the density functions accordingly for $x_3(t_i)$ and $x_{4+}(t_i)$, which are conditional on $x_2(t_{i-1})$ and $(x_3(t_{i-1}) + x_{4+}(t_{i-1}))$:

$$f(x_3(t_i)|\, x_2(t_{i-1}))=$$

$$ab^{-a}(-\log(x_3(t_i)/x_2(t_{i-1})))^{a-1}\exp(-(-\log(x_3(t_i)/x_2(t_{i-1}))/b)^a)/\, x_3(t_i)$$

$$g(x_{4+}(t_i)|\, (x_3(t_{i-1})+x_{4+}(t_{i-1}))) =$$

$$cd^{-c}(-\log(x_{4+}(t_i)/(x_3(t_{i-1})+x_{4+}(t_{i-1}))))^{c-1}$$

$$\times\exp(-(-\log(x_{4+}(t_i)/(x_3(t_{i-1})+x_{4+}(t_{i-1})).)/b)^c)/\, x_{4+}(t_i)$$

where $f(x_3(t_i)|\, x_2(t_{i-1}))$ is the transitional probability density from x_2 at (t_{i-1}) to x_3 in time t_i.

Let $\{ x_2(t_i), x_3(t_i), x_{4+}(t_i)\}, i=1,\ldots,N$ be time series data of the trajectory of the system, then the likelihood estimators for parameters a, b, c, d are

$$\mathscr{L}(\hat{a}, \hat{b}) = \max_{a,b} (\Pi f(x_3(t_i)|\, x_2(t_{i-1}))),\ i = 2,\ldots, N)$$

and

$$\mathscr{L}(\hat{c}, \hat{d}) = \max_{c,d} (\Pi\, g(x_{4+}(t_i)|\, (x_3(t_{i-1})+x_{4+}(t_{i-1})))),\ i = 2,\ldots, N)$$

The simplex method (Nelder and Mead, 1965) was used to approximate the maximum of the likelihood functions.

Number at each age was calculated by multiplying the proportions at age from age frequencies in each year by the average number of sand flathead caught per trawl during each year of the trawl survey. A selectivity function, calculated from covered cod-end experiments, was applied to account for gear selectivity. Selectivity was described by a logistic curve of the form:

$$P = 1/(1+\exp[-r(L-L_c)])$$

where P is the proportion retained by the gear, r is a constant, L is the length class and L_c is the mean length at first capture. The age selectivity function (Table 2) was estimated by applying an age-length key to the proportion of fish retained at each length. The numbers of fish in each age group are presented in Table 3.

Table 2. Age selectivity values of sand flathead for the trawl net in Port Phillip Bay.

Age	P
2	0.815929
3	0.930869
4	0.940886
5	0.970981
6	0.985569
7	0.985367
8	0.991041
9	0.988303
10	0.998073
11	0.989054
12	0.99691

Table 3. Relative catch-at-age for sand flathead between 1990 and 2002 (na = not available).

Year	2 years	3 years	4+ years
1990	66.196	29.877	83.435
1991	129.292	32.713	91.355
1992	94.206	59.453	100.233
1993	47.099	62.672	132.640
1994	50.631	38.396	145.750
1995	77.835	28.427	155.241
1996	59.538	44.245	166.858
1997	17.600	31.554	118.797
1998	na	na	na
1999	47.597	28.591	98.295
2000	11.570	23.861	158.923
2001	na	na	na
2002	25.084	12.992	41.941

Rock flathead

The trends in annual commercial CPUE data were different between gear types and, as it was not evident which, if any, of these time series of CPUE may have been a reliable measure of relative abundance of rock flathead, it was decided that they would not be used as an input into the stock assessment model. Deterministic methods of assessment were therefore used for rock flathead.

Natural mortality (M) of rock flathead was calculated using two different empirical methods. The equation incorporating water temperature and von Bertalanffy growth parameter from Pauly (1980) takes the form of:

$$\text{Ln}(M) = -0.0066 - 0.279 * \ln(L_\infty) + 0.6543 * \ln(K) + 0.463 * \ln(T)$$

Where M is natural mortality and T is the average water temperature.

Gulland's (1983) equation was also used and takes the form of:

$$M = -\ln(0.01)/t_{max}$$

Where t_{max} is the maximum age.

Total mortality (Z) was estimated using catch curve analysis and the Chapman-Robson estimator (Chapman 1960; Dunn 2002). For the catch curve analysis, all cohorts and ages were pooled and only ages 3 to 18 were used in the analysis. Z was estimated as the slope of the natural log of the total number of fish against age.

The Chapman-Robson estimator (Chapman 1960; Dunn 2002) takes the form of:

$$Z = \ln\left(\frac{1-\bar{a}-1/n}{\bar{a}}\right)$$

Where $\bar{a}$ is the mean age above recruitment and n is the sample size.

Fishing mortality (F) was calculated from the equation:

$$F = Z - M$$

The Beverton & Holt (1957) yield-per-recruit model was applied to rock flathead to examine optimum minimum legal lengths (MLLs) and yield at various levels of F. The two different rates of M were incorporated into the model. Egg-per-recruit analysis (Sluczanowski 1984) was conducted to examine the size and age at which maximum egg production occurred. All per-recruit analyses were carried out in Microsoft Excel ™ spreadsheets. The number of mature individuals at length was adjusted by the maturity ogive estimated in this study. Sensitivity to natural mortality was examined by using different values that were empirically estimated using the methods above. Values of fishing mortality between 0 and 1 were used to derive a response curve for yield-per-recruit and egg-per-recruit functions.

River discharge and SOI data were collected to determine if there was a correlation between recruitment and environmental variables. Discharge data from the Agnes, Franklin and Tarra rivers, which flow into Corner Inlet, were supplied by Melbourne Water. Southern Oscillation Indices (SOI) were down-loaded from the Queensland Department of Primary Industry's 'Long Paddock' web site. Regression analysis (Microsoft ® Excel 97 SR-2) was applied to the time-series of each environmental variable and recruitment to determine if there were significant relationships.

Results

Sand flathead

Age and growth

The within-reader precision of age estimates was measured using the Index of Average Percent Error (IAPE) (Beamish and Fournier 1981) for a sample of 200 re-read otoliths. Confidence intervals for the IAPE were calculated with a bias-corrected bootstrap technique (Efron and Tibshirani 1993) from a series of 6000 randomisations (Koopman Submitted). The IAPE was calculated to be 0.690%, with 95% confidence intervals of 0.143–1.237%. The largest difference between repeated readings was 1 year.

The annual periodicity of increment formation in sectioned sand flathead otoliths was established by means of the progression of strong and weak year classes over time and marginal increment analysis to an age of 11 years by Koopman (Submitted). This corresponds with level 1 validation (sensu Francis 1995) in that the first 11 increments are effectively annual, but there are insufficient data to determine the periodicity of the later increments or to make a quantitative estimate of the accuracy of the age estimation method.

The maximum estimated age of sand flathead in the samples was 23.25 years (Figures 4a and 5, Table 4), and was exhibited by three males (TL 26.8 cm, 27.2 cm and 28.0 cm) and one female (TL 29.4 cm). More males (9.0%) than females (2.9%) were assigned ages greater than 10 years. The minimum age of sand flathead in the samples was 0.25 years for three immature fish.

Both age-at-length and length-at-age showed a large degree of variability, particularly at young to intermediate ages (Figure 5). For example, the lengths of 7.25-years-old females ranged 22.3–37.0 cm, and the age of females greater than 30 cm ranged 3.25–23.25 years old.

The von Bertalanffy growth curves differed significantly between sexes ($\chi^2 = 530.80$, $P < 0.001$) (Table 5). L_∞ for male and female fish was estimates to be 26.0 and 27.7 cm respectively. K was also smaller for males (0.274 y^{-1}) than females (0.459 y^{-1}).

There was little difference between the sexes in the age structure of the sand flathead population (Figure 6), but there was a much greater difference in the length structure, reflecting the more rapid growth of females. Thus although there were slightly more females than males in the younger age groups (<8 years old) there were many more females in the larger length classes (>25 cm).

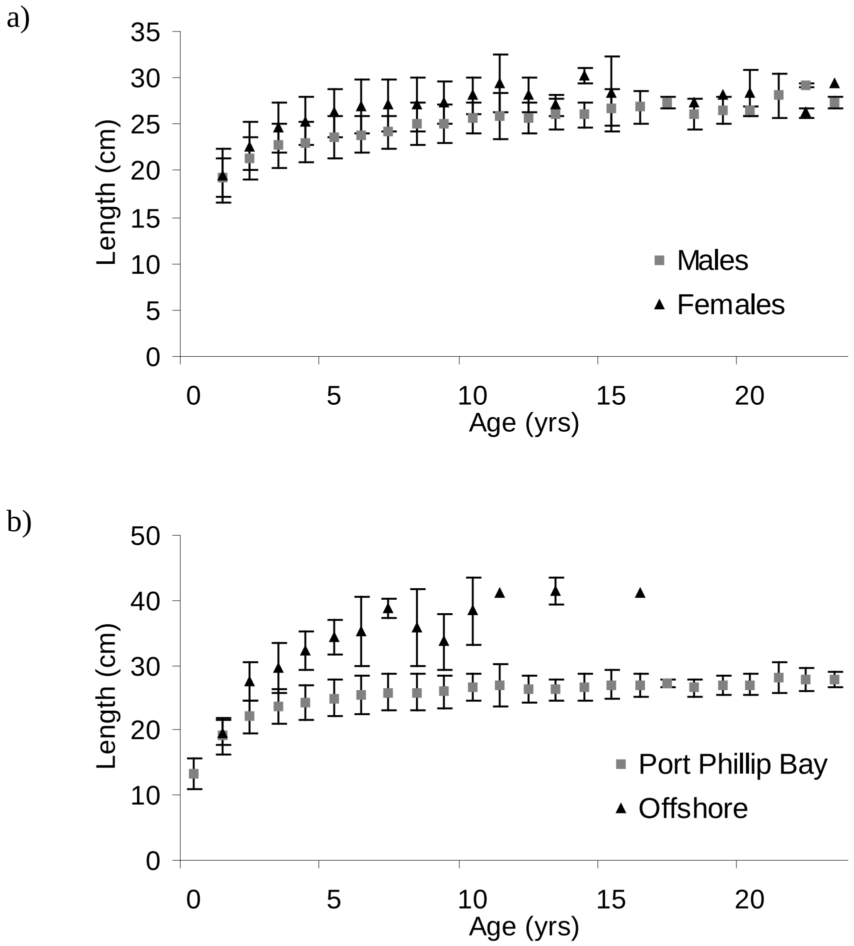


Figure 4. Mean length-at-age and standard deviation of a) male and female sand flathead from Port Phillip Bay and b) sexes combined from Port Phillip Bay and offshore Victorian waters.

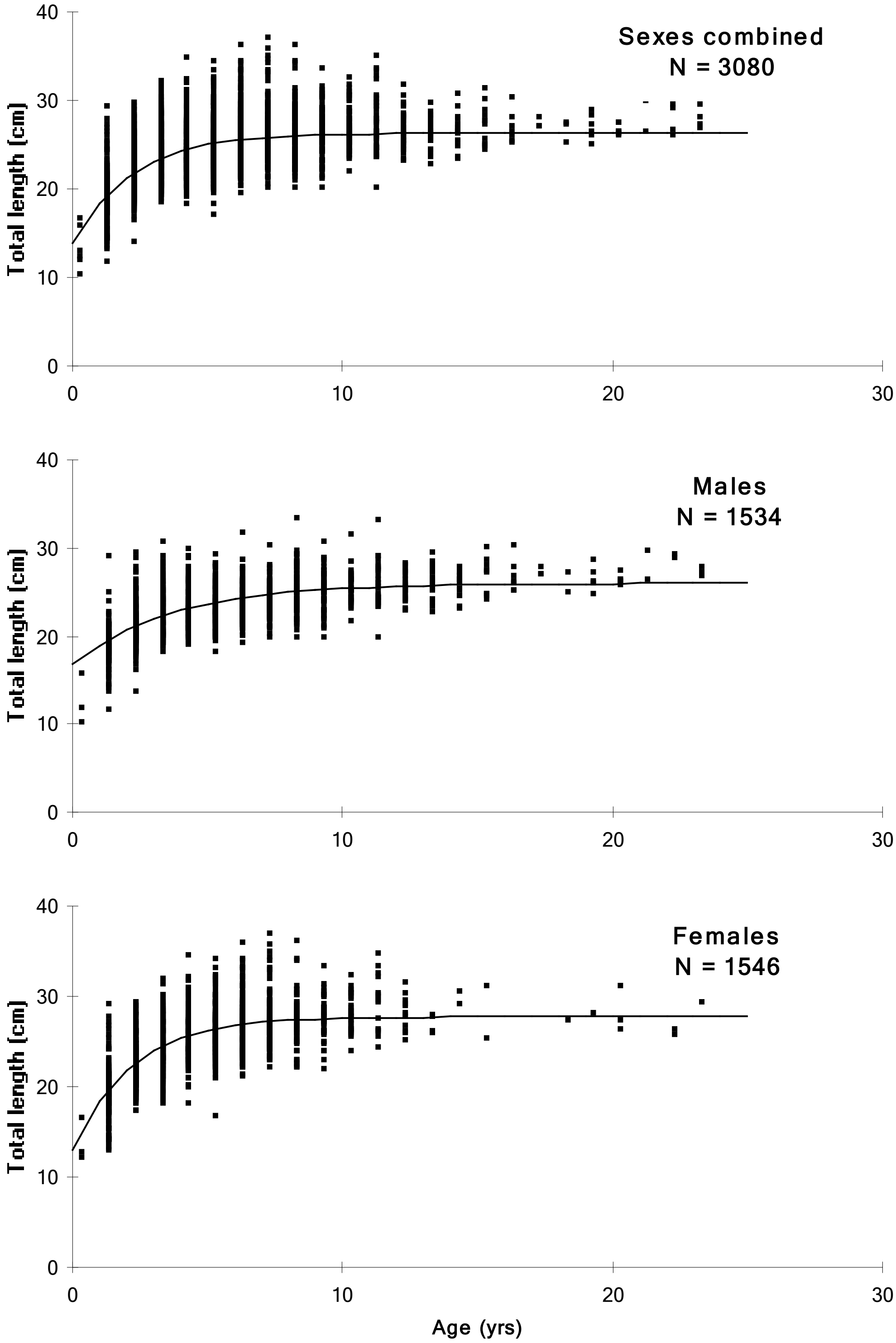


Figure 5. Von Bertalanffy growth curves fitted to length at age data for sand flathead caught in Port Phillip Bay.

Table 4. Mean length-at-age, standard deviation and sample size of sand flathead from Port Phillip Bay and offshore Victorian waters.

Age (yrs)	Male			Female			Immature			All			Offshore		
	TL (mean, cm)	s.d.	n	TL (mean, cm)	s.d.	n	TL (mean, cm)	s.d.	n	TL (mean, cm)	s.d.	n	TL (mean, cm)	s.d.	N
0							11.47	1.04	3	13.27	2.43	6			
1	19.21	2.07	109	19.52	2.86	142	14.47	1.32	14	19.14	2.73	269	19.59	1.87	8
2	21.35	2.24	215	22.67	2.57	265	20.73	6.47	3	22.06	2.53	491	27.48	2.89	37
3	22.69	2.39	241	24.66	2.65	258	20.40		1	23.70	2.72	506	29.58	3.76	61
4	23.00	2.17	217	25.30	2.57	248				24.23	2.65	467	32.29	2.91	66
5	23.59	2.27	164	26.21	2.67	177				24.95	2.81	342	34.36	2.59	42
6	23.83	1.98	127	27.01	2.91	136				25.46	2.96	264	35.16	5.32	9
7	24.15	1.76	89	27.08	2.78	117				25.81	2.79	206	38.67	1.53	3
8	25.00	2.27	101	27.17	2.84	65				25.85	2.72	166	35.80	5.83	8
9	25.04	2.08	70	27.39	2.23	39				25.95	2.50	110	33.62	4.20	5
10	25.66	1.69	42	28.08	1.97	30				26.67	2.16	72	38.33	5.13	3
11	25.83	2.52	29	29.32	3.11	15				26.94	3.18	45	41.00		1
12	25.62	1.62	25	28.21	1.91	12				26.46	2.09	37			
13	26.09	1.66	25	27.05	1.10	4				26.22	1.61	29	41.50	2.12	2
14	26.02	1.39	17	30.20	0.87	3				26.65	2.01	20			
15	26.79	2.02	10	28.35	4.03	2				27.05	2.28	12			
16	26.86	1.80	7							26.86	1.80	7	41.00		1
17	27.33	0.58	3							27.33	0.58	3			
18	26.10	1.56	2	27.40		1				26.53	1.33	3			
19	26.60	1.45	5	28.20		1				26.87	1.46	6			
20	26.42	0.52	6	28.33	2.53	3				27.06	1.64	9			
21	28.10	2.40	2							28.10	2.40	2			
22	29.20	0.28	2	26.20	0.42	2				27.70	1.76	4			
23	27.33	0.61	3	29.40		1				27.85	1.15	4			

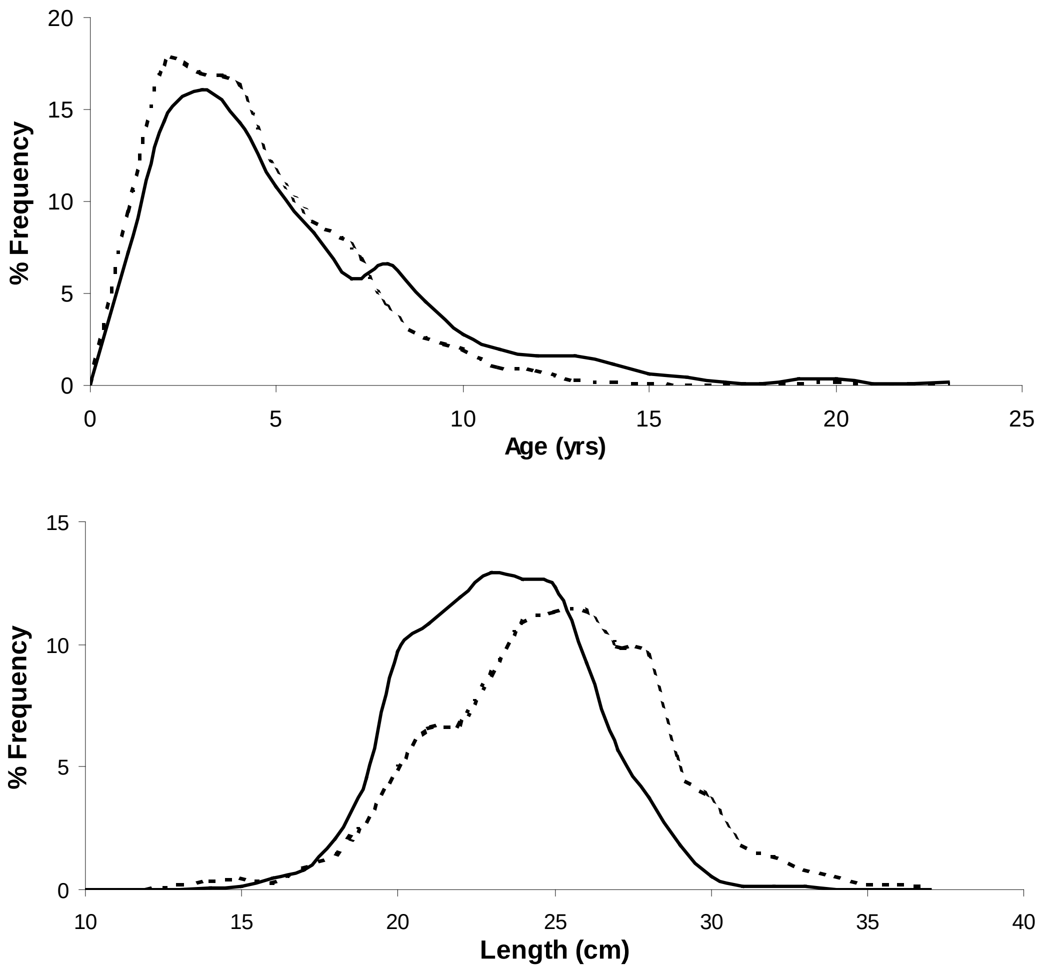


Figure 6. Age frequency and length frequency graphs for male (solid line) and female (broken line) sand flathead caught in Port Phillip Bay.

Recruitment of sand flathead varied considerably over the sampling period (Figure 7). A strong year class of 2 year old fish appeared in the samples in 1991 and another as 2 year olds in 1994. Both year classes can be tracked as distinct modes in the age distributions over the years sampled. A two parameter environmental-recruitment function was developed that explained 92% of the variation in recruitment (Figure 8). Average daily river discharge from the Yarra River for the February, March and April ($Riverdischarge_{(ti\text{-}4)}$) in the year prior to spawning and the Southern Oscillation Index ($SOI_{(ti\text{-}3)}$) in September of the year of spawning were the only two environmental variables that contributed significantly to the final model (Table 6). The models equation is as follows:

$$R_{2(ti)} = 4.5682 - 0.00003 \cdot Riverdischarge_{(ti\text{-}4)} + 0.02066 \cdot SOI_{(ti\text{-}3)} + \varepsilon$$

Comparison of growth between sand flathead caught in Port Phillip Bay and offshore Bass Straight revealed that those from offshore waters grow much faster (Table 5, Figures 4b and 9) and also attain a greater size. The difference between von Bertalanffy growth curves was significantly different ($\chi^2 = 887.18$, $P < 0.001$).

Table 5. Von Bertalanffy growth parameter estimates, standard errors and 95% confidence intervals for sand flathead from Port Phillip Bay, and offshore Bass Straight.

Sex	Parameter	Estimate	Asymptotic s.e.	95%-C.I Lower	95%-C.I Upper
Sexes combined	L_∞ (cm TL)	26.3	0.12	26.0	26.5
(n=3079)	K (y^{-1})	0.459	0.024	0.411	0.507
	t_0 (y)	-1.63	0.162	-1.95	-1.31
Males	L_∞ (cm TL)	26.0	0.20	25.6	26.4
(n=1533)	K (y^{-1})	0.274	0.023	0.229	0.318
	t_0 (y)	-3.79	0.411	-4.59	-2.98
Females	L_∞ (cm TL)	27.7	0.19	27.4	28.1
(n=1546)	K (y^{-1})	0.459	0.031	0.399	0.520
	t_0 (y)	-1.38	0.181	-1.731	-1.021
Offshore	L_∞ (cm TL)	38.0	1.01	36.0	40.0
(n=246)	K (y^{-1})	0.363	0.567	0.252	0.475
	t_0 (y)	-1.27	0.401	-2.061	-0.480

Table 6. Environmental and recruitment data used to develop the environmental-recruitment function. The predicted recruitment is also displayed.

Year	Average daily River discharge in Feb, Mar and Apr (ML/day)	SOI in September	Observed Recruitment (ln Relative number)	Predicted recruitment (ln Relative number)
1987	14763	-10.6	4.193	3.976
1988	17777	18.7	4.862	4.505
1989	12185	5.8	4.545	4.380
1990	29933	-7.3	3.614	3.660
1991	25681	-16.2	3.925	3.584
1992	14328	0.7	4.355	4.220
1993	18430	-7.0	4.087	3.958
1994	48122	-16.2	2.868	3.017
1995	44532	3.4		3.512
1996	26874	6.9	3.863	4.031
1997	73453	-14.1	2.448	2.420
1998	27152	12.1		4.132
1999	13532	0.2	3.222	4.230

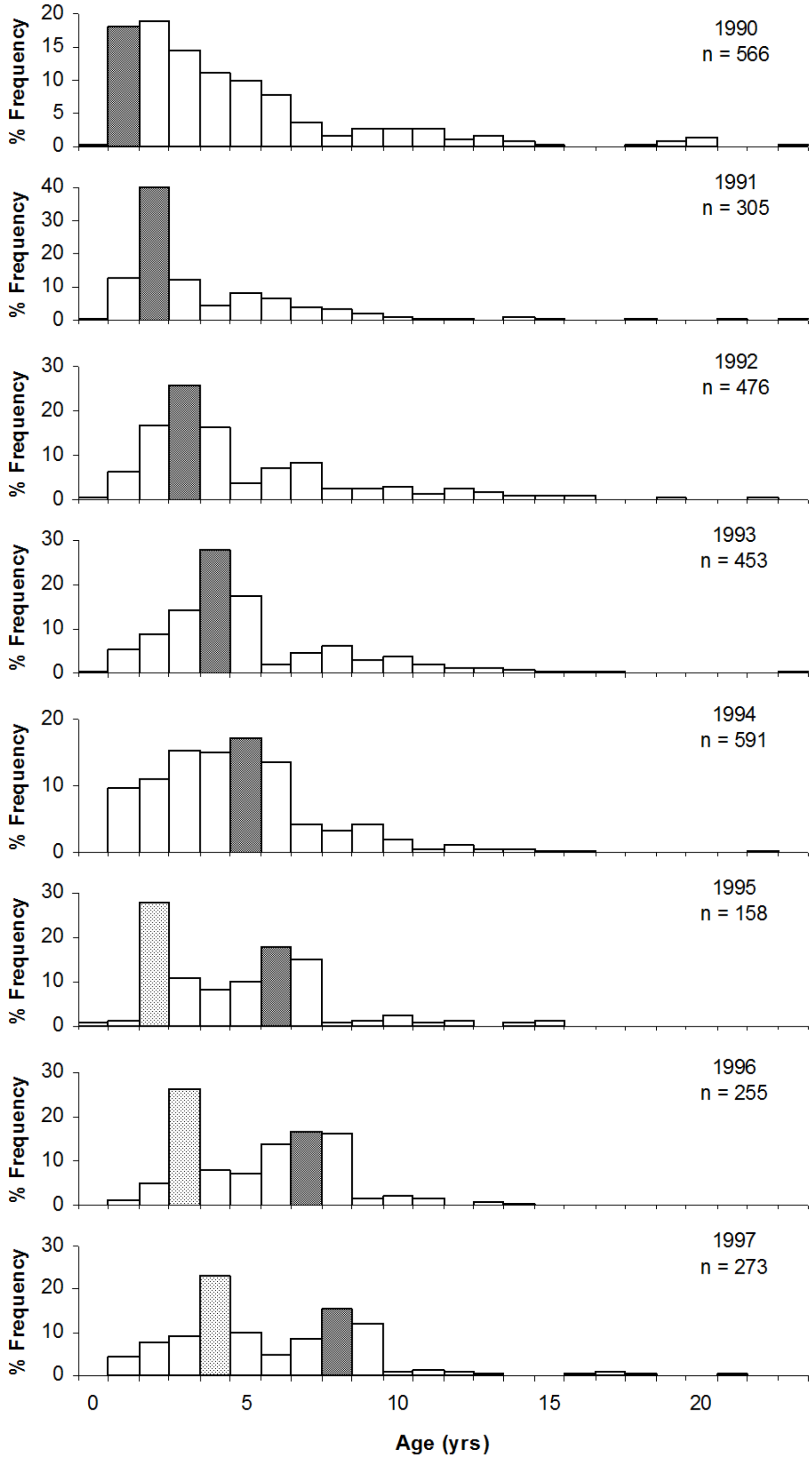


Figure 7. Age frequency of sand flathead caught in Port Phillip Bay between 1990 and 1997. Shaded blocks show strong year classes.

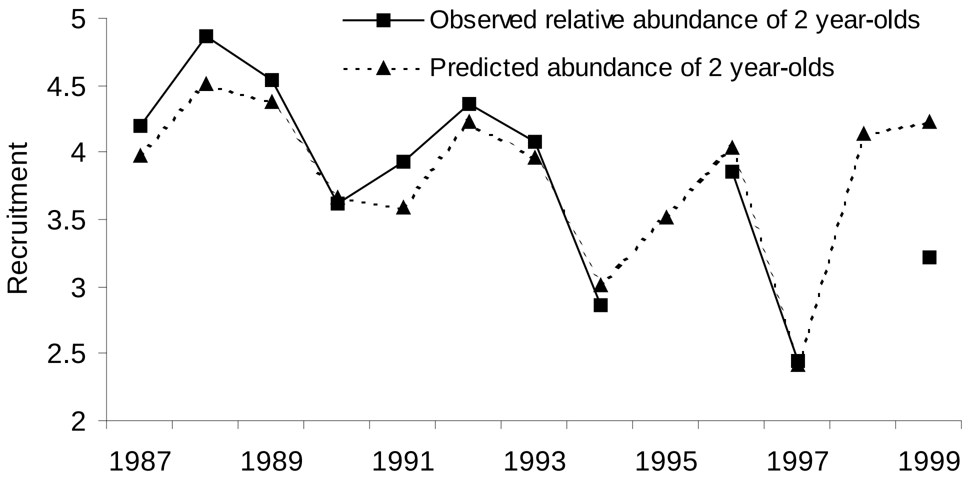


Figure 8. Environmental-recruitment model for sand flathead showing observed and predicted relative abundance of 2 year-old sand flathead in Port Phillip Bay.

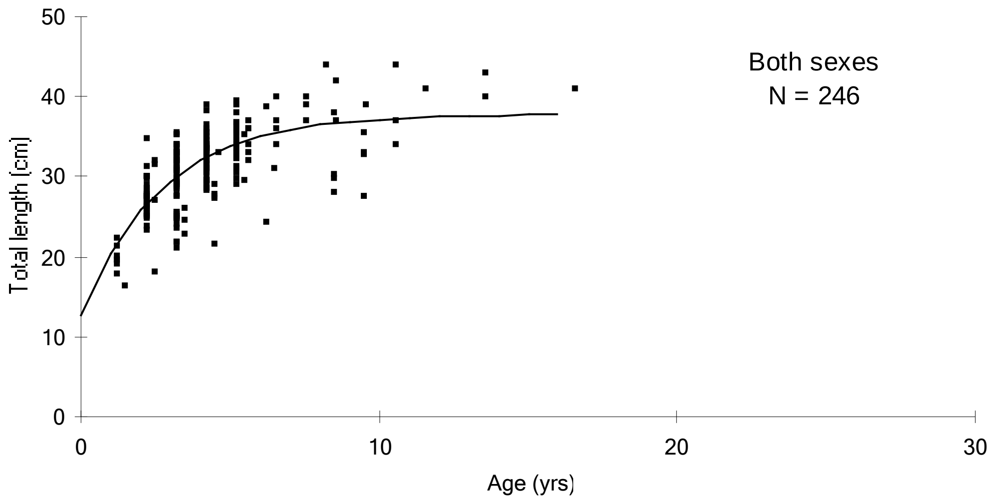


Figure 9. Von Bertalanffy growth curves fitted to length at age data for sand flathead caught from Victoria's offshore waters.

Biological parameters

A wide range of fish lengths and weights were present in the samples (Figure 10). Male sand flathead ranged in size from 17.5 to 33.4 cm (total length) and from 35 to 190 g (total weight). Females ranged from 12.8 to 37.0 cm in length and from 13 to 339 g in weight.

The ANCOVA revealed that the slopes of regressions of log weight against log length were not significantly different between male and female sand flathead ($F_{1,3009} = 1.991$, $p > 0.15$). However, the intercepts of these regression lines were significantly different ($F_{1,3009} = 63.618$, $p<0.01$). The parameters of the length-weight relationship are shown in Table 7.

Mean monthly GSI values for male sand flathead increased from less than 2% in January, March and May to over 3% in June and September, and had declined to less than 2% again by December (Figure 11). The pattern for females was similar but the highest mean GSI of over 6% was reached in September, and there was a secondary peak of 4% in January. This suggests a second major spawning event in late summer. The second spawning is supported by the egg frequency distribution (Figure 12) of fish caught in September that showed two distinct size groups, one with a mode of 0.75 mm (first spawning), the other had a mode of 0.30 mm (second spawning).

Table 7. Parameters of the relationship between total length and weight of sand flathead (weight = a*length^b).

Species	Sex	n	a	b	r^2
Sand flathead	Sexes combined	3800	0.0032	3.2221	0.9525
	Males	1513	0.0034	3.2095	0.9346
	Females	1501	0.0030	3.2477	0.9635
Rock flathead	Sexes combined	953	0.0019	3.3408	0.9747
	Males	664	0.0016	3.3994	0.9873
	Females	288	0.0032	3.1887	0.9574

Population Modelling

The stochastic model of sand flathead abundance was initially run for the years for which data on abundance was available, to check for closeness of fit. The predicted recruitment followed the observed recruitment extremely well for most years (Figure 13). Small deviations from the observed recruitment occurred for the 1994 and 1999 years. In 2002, however, the predicted recruitment was much greater than the observed recruitment. Similarly, the forecasted numbers of fish in the 3 year old and 4+ years old age groups followed the observed data reasonably well except in 2002. Observed abundance was lower than the predicted average abundance in all age classes for this year (Figure 13). Despite the discrepancies in 2002, the model did predict the gradual decline in the numbers of fish in the 4+-years-old age group after 1996.

Simulations were then run over the same period omitting the 2002 data from the parameter estimation process to determine wether the omission of the apparent outlier produced a better prediction of relative abundance (Figure 14). The recruitment model used was the same as that used to produce Figure 13, and so is not presented again. The discrepancy for 2002 was substantially less than when the full data set was used, but the observed relative abundance for the total population in 2002 was still well below that of the 5% quantile predicted by the model. The observed number of 3-year-old fish in 2002 was slightly under the 5% quantile, while the observed number of 4+-year-olds was between the 25% and 50% quantiles.

The time series of observed abundance suggests that the relative abundance of sand flathead in Port Phillip Bay was stable until the mid 1990s when abundance declined, despite recruitment not showing the same trend. Consequently, the use of data from the early 1990s in the estimation of population parameters to be used in later years may not be valid. To investigate this, estimates of survival distributions were produced for two different periods to compare the predictions using the survival rate estimated using data from 1990 to 1991 and survival using only data from 1995 to 2001. Survival differed substantially between the age groups and between the two time periods examined (Figure 15). Survival was lower for the 2-year-old group and the density distribution was positively skewed, while the 3+-year-old group had a density distribution that was negatively skewed. This pattern was consistent with both time periods, but the modes and variability of both survival distributions were different.

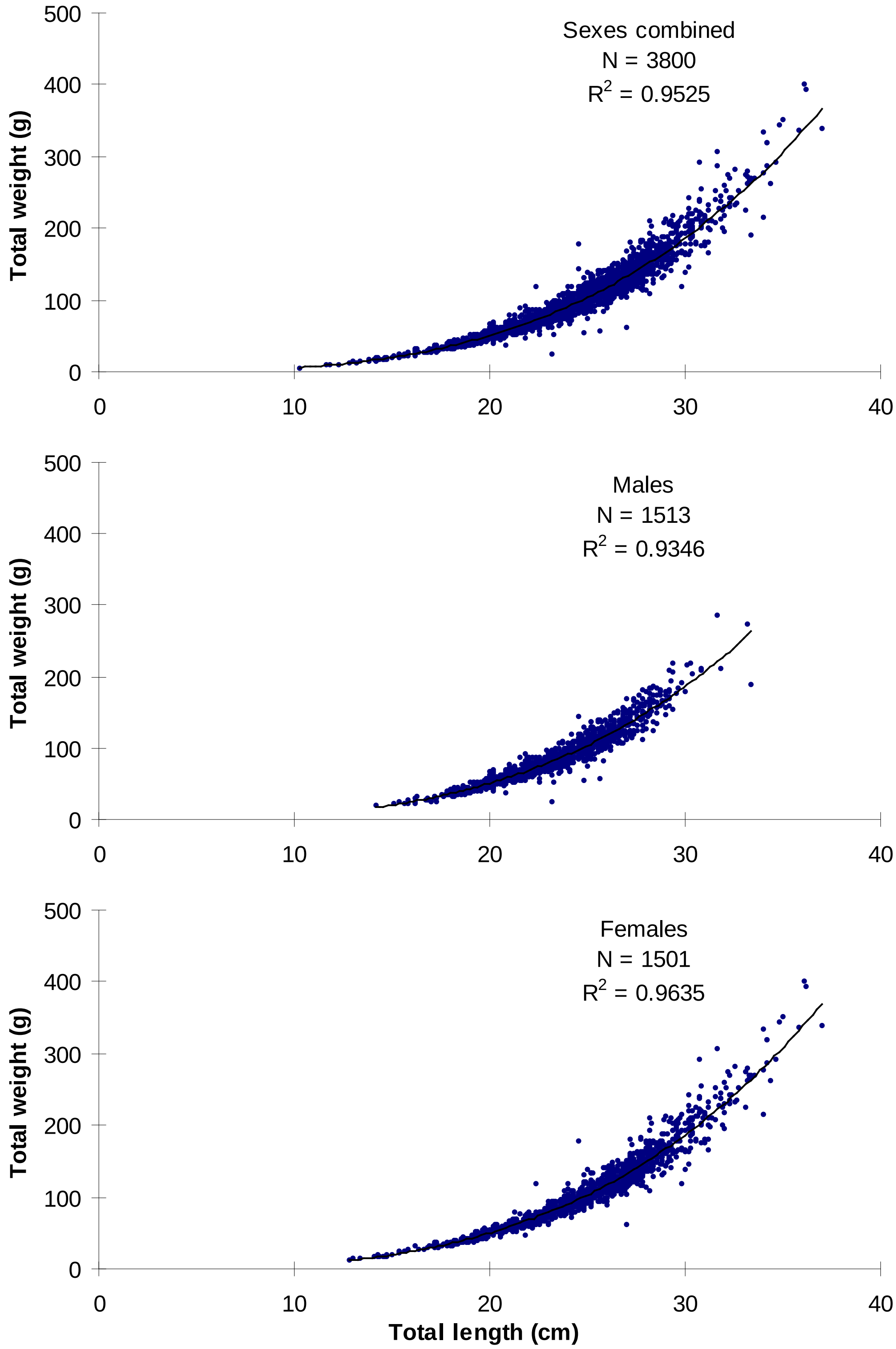


Figure 10. Relationship between total length and weight of sand flathead.

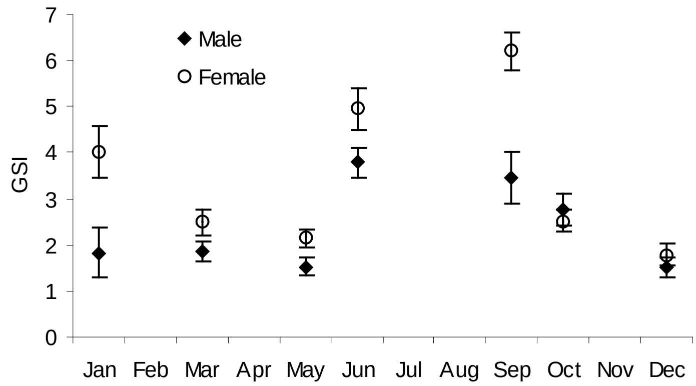


Figure 11. Mean monthly GSI (±S.E.) for male and female sand flathead caught in Port Phillip Bay.

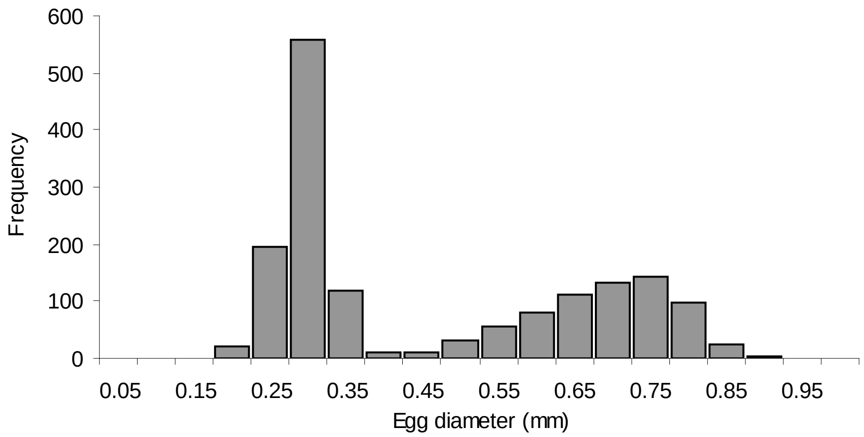


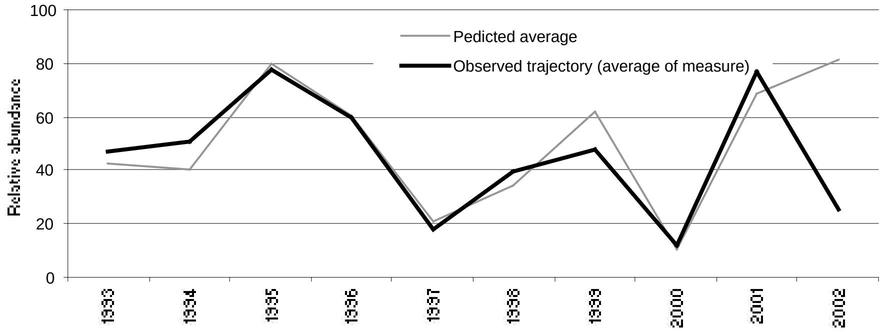
Figure 12. Frequency of egg diameters of sand flathead caught in Port Phillip Bay.

The estimated survival after 1995 exhibited wider distributions and lower means for both age groups. For the purpose of the following analysis, where these two survival distributions were used in predicting relative abundance, the survival distribution estimated using data from 1990 to 2001 is called the optimistic projection, while the projection using survival estimated from the 1995 to 2001 data is called the pessimistic projection.

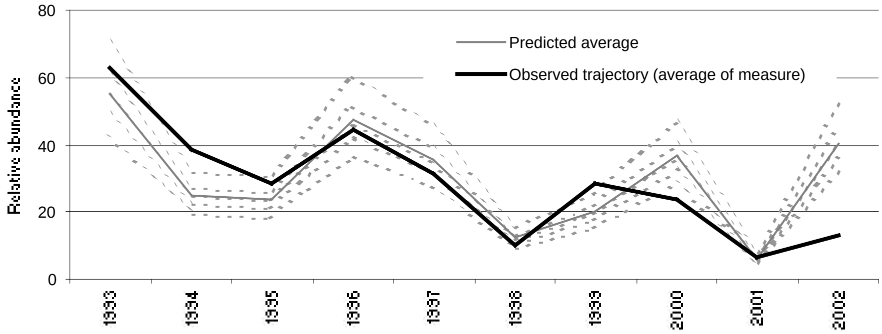
Projections can be made 3 years into the future because of the lag incorporated into the recruitment model. As with Figures 7 and 8, the same recruitment model was used in both analyses and so is only shown once. The projections of both scenarios for the total population size until 2005 was for increasing abundance (Figure 16 and Figure 17). Relative abundance increased until 2004 after which it declined slightly. The projections for both the 3-year-olds and 4+-year-olds increased throughout the simulated period, with the only significant decrease being in the number of 2-year-old recruits after 2004.

The patterns for the two different scenarios were similar, but the relative abundance estimates were slightly lower for the pessimistic projection. The choice of which estimate of survival was used also affected the size of the quantiles. The variation around the mean projection was much smaller for the optimistic scenario for all age groups.

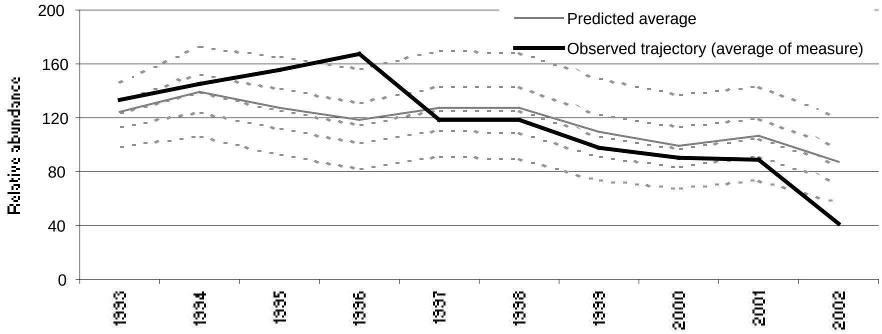
a)



b)



c)



d)

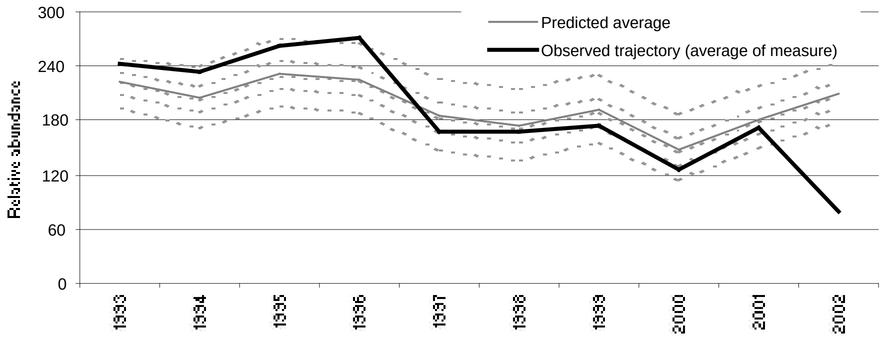


Figure 13. Observed and predicted relative abundance of a) 2-year-old recruits, b) 3-year-old fish, c) 4+-year-old fish and d) total population. Dotted lines are 5%, 25%, 50%, 75% and 95% quantiles.

d)

a)

b)

c)

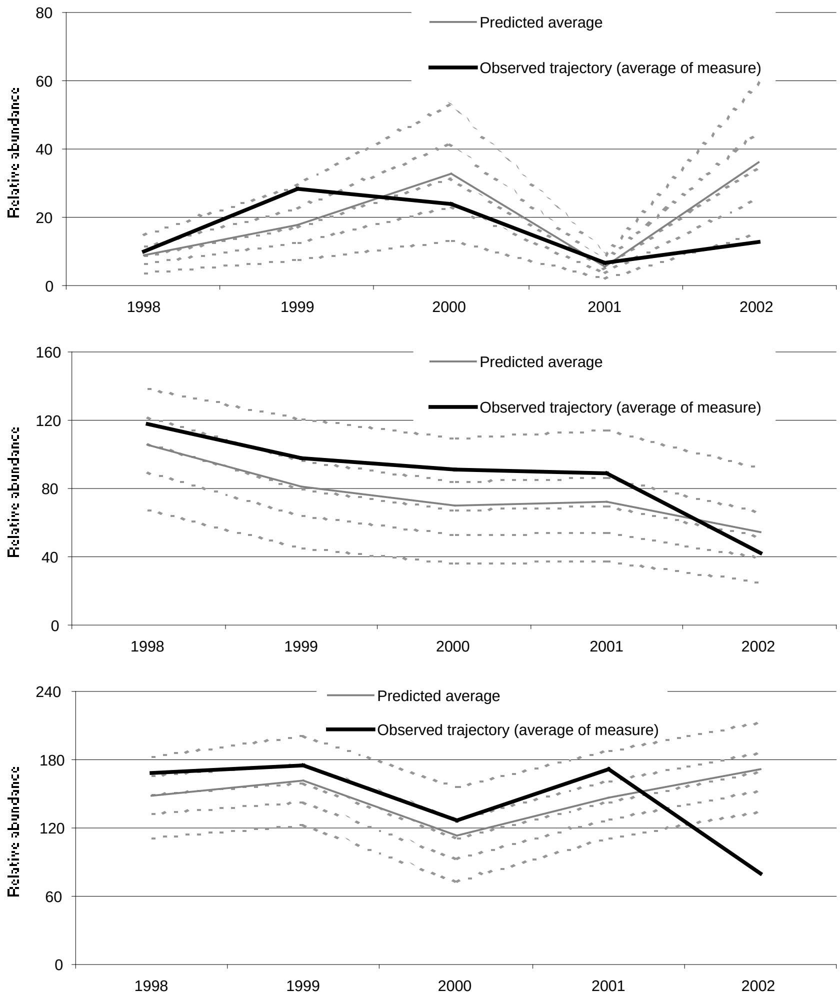


Figure 14. Observed and predicted relative abundance of a) 3-year-old fish, b) 4+-year-old fish and c) total population using data from 1995 onwards only. Dotted lines are 5%, 25%, 50%, 75% and 95% quantiles.

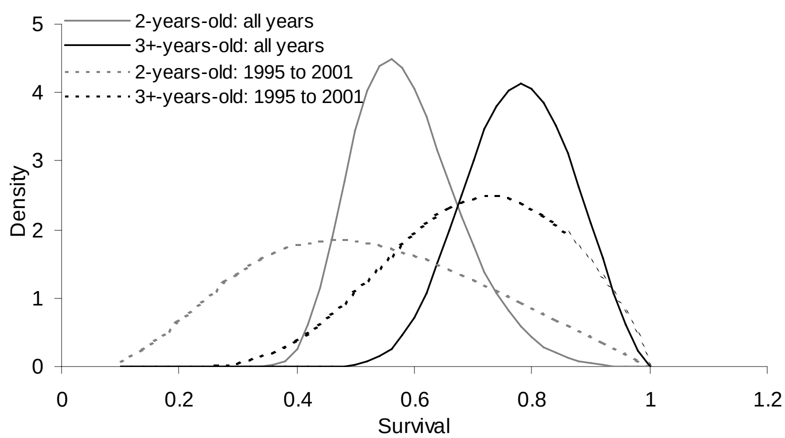


Figure 15. Log-Weibull distributions of survival for 2-year-old and 3+-year-old age groups estimated from the data.

a)

b)

c)

d)

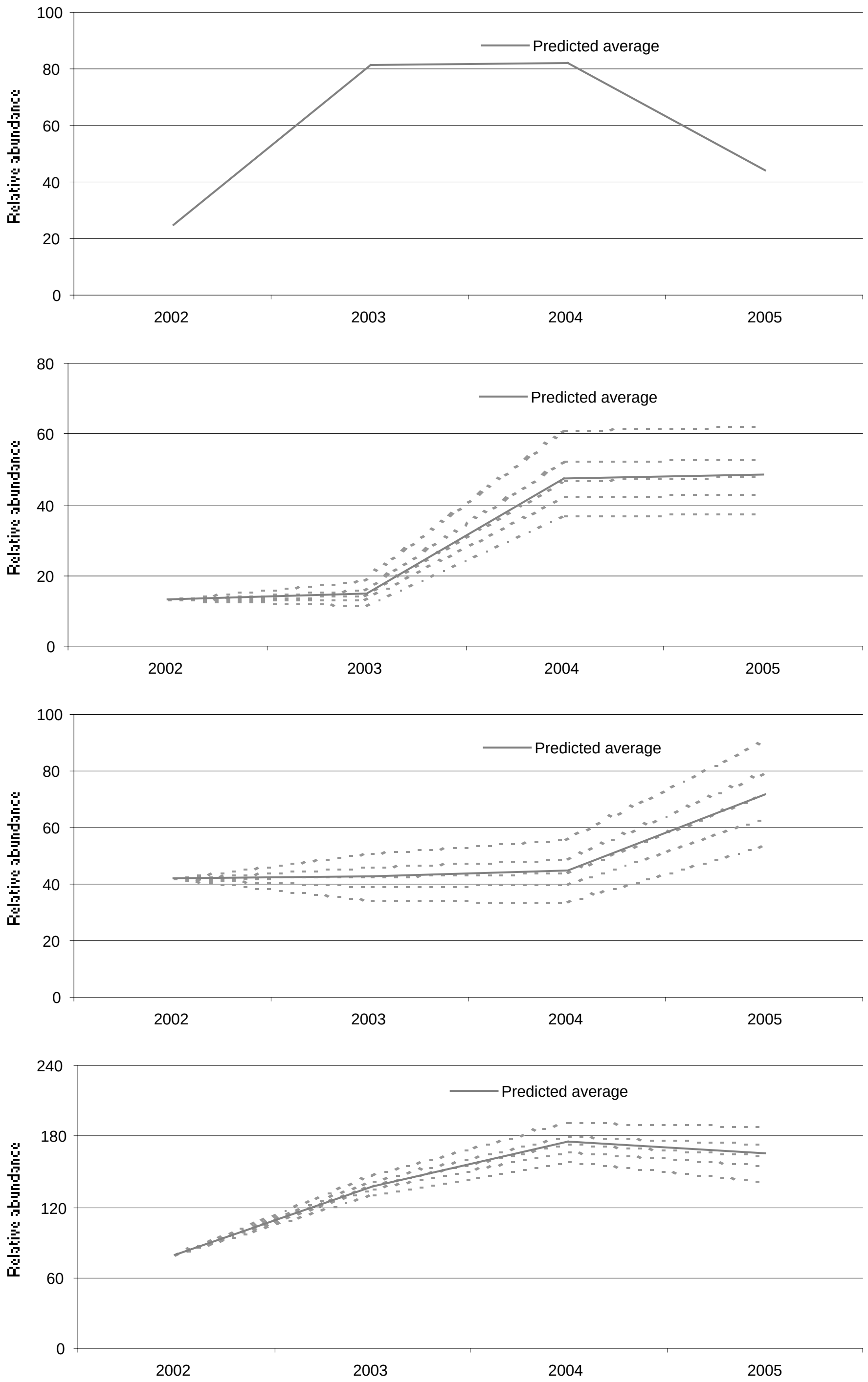


Figure 16. Forecasted relative abundance of a) 2-year-old recruits, b) 3-year-old fish, c) 4+-year-old fish and d) total population using the lower mortality rate. Dotted lines are 5%, 25%, 50%, 75% and 95% quantiles.

a)

b)

c)

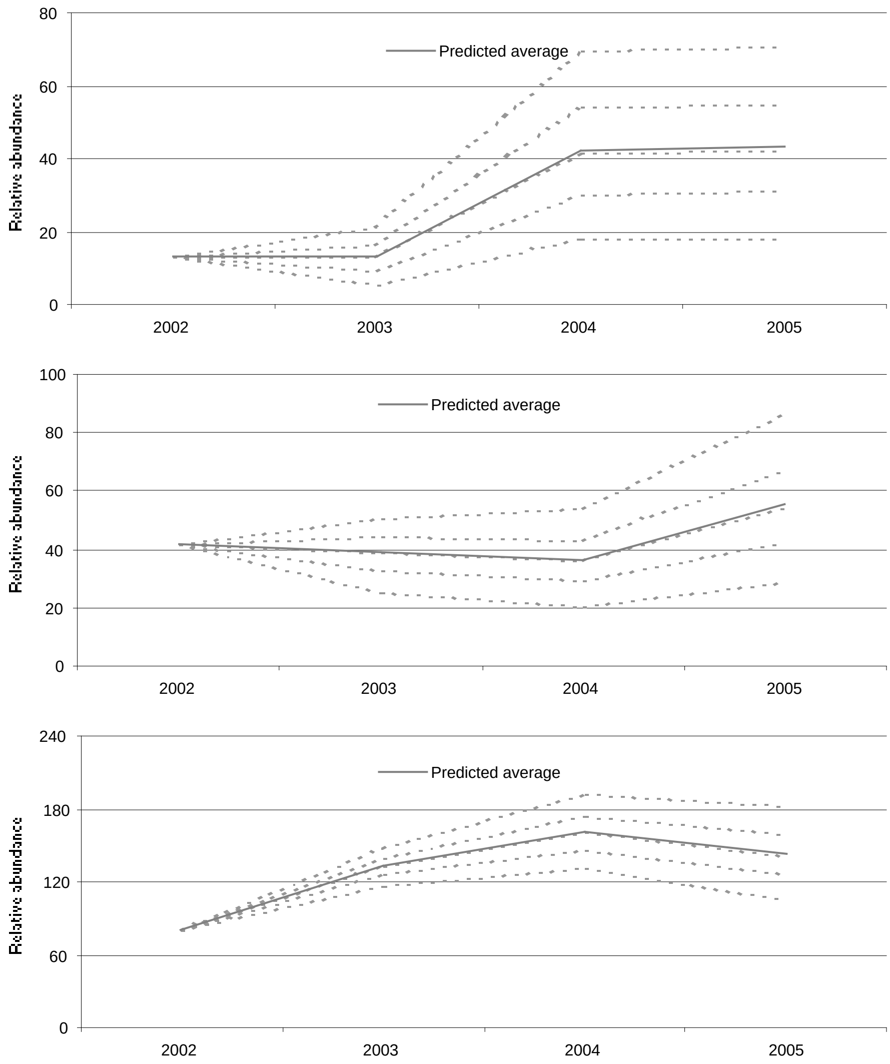


Figure 17. Forecasted relative abundance of a) 3-year-old fish, b) 4+-year-old fish and c) total population using the higher mortality rate. Dotted lines are 5%, 25%, 50%, 75% and 95% quantiles.

Rock flathead

Age and growth

The IAPE was 3.24%, with 95% confidence intervals of 2.65–3.79%. The largest difference between repeated readings was 2 years.

The general trend of mean monthly MIR for rock flathead otoliths was a rapid increase from less than 40% during January to about 80% in April, after which the MIR remained relatively constant until October or November when an opaque zone was deposited (Figure 18). The mean MIR decreased sharply to a low of less than 20% in December and then began to rise again quite rapidly in January and February to values similar to those in the previous January. This pattern was observed for all of the age groups that had sufficient numbers of samples during a month, and for all ages pooled. The annual trend for the 7+ age groups was inconclusive as data were missing for some months, but the same general trend was evident.

The pattern of MIR strongly suggests an annual periodicity for increment formation in sectioned rock flathead otoliths to an age of 7 years. This corresponds with level 1 validation (sensu Francis 1995) in that the first 7 increments are effectively annual, but there are insufficient data to determine the periodicity of the later increments or to make a quantitative estimate of the accuracy of the age estimation method.

The maximum estimated age of rock flathead was 21 years for a 56 cm female (Table 8). The maximum estimated age of a male fish was 16 years, for a fish 49 cm in length. More females (6.9%) than males (2.3%) were assigned ages greater than 10 years, while there were more males (70.1%) than females (54.7%) assigned ages less than 5 years.

Both age-at-length and length-at-age showed a considerable degree of variability (Figure 19). For example, the lengths of 5 year-old females ranged from 27–53 cm, and the age of females greater than 40 cm ranged from 4–21 years old.

The von Bertalanffy growth curves differed significantly between sexes ($\chi^2 = 846.78$, $P << 0.001$) (Figure 19). Estimates of L_∞ for males and females were 52.0 and 54.7 cm respectively (Table 9). Estimates of K were lower for males (0.098 y^{-1}) than females (0.170 y^{-1}).

The age frequency data revealed strong years classes for the 1990, 1995 and 1999 cohorts (Figure 20). They appear as 4 year-olds in 1994, and 2 year olds in 1997 and 2000, respectively. Few fish in the samples were less than 2 years or greater than 10 years of age.

Recruitment was significantly correlated with total discharge from the Franklin and Agnes rivers (Figure 21), the relationship particularly strong during winter ($F_7 = 8.475$, $p < 0.05$). The R^2 of the relationship was 0.5855 meaning that nearly 60% of the variation in recruitment could be explained by river flow. The relationship was negative, so that years of higher discharge also had poorer recruitment.

Biological parameters

Male rock flathead ranged in size from 17.6 to 42.6 cm (total length) and from 30 to 554 g (total weight). Females ranged from 20.5 to 54.0 cm in length and from 45 to 1592 g in weight (Figure 22).

The ANCOVA revealed that both the slopes ($F_{1,948} = 36.877$, $p << 0.0001$) and intercepts ($F_{1,948} = 91.839$, $p << 0.0001$) of the regressions of log weight against log length were significantly different between male and female rock flathead (Table 7). The relationship fits the data well apart from females greater than 48 cm, where weight is under estimated.

The sex ratio of the samples varied through out the year (Figure 23). Males were more common in the samples in most months, making up as much as 92% of the catch. Chi-squared tests confirmed that the dominance of males in the samples was significant ($p<0.05$) in all months except for April and May.

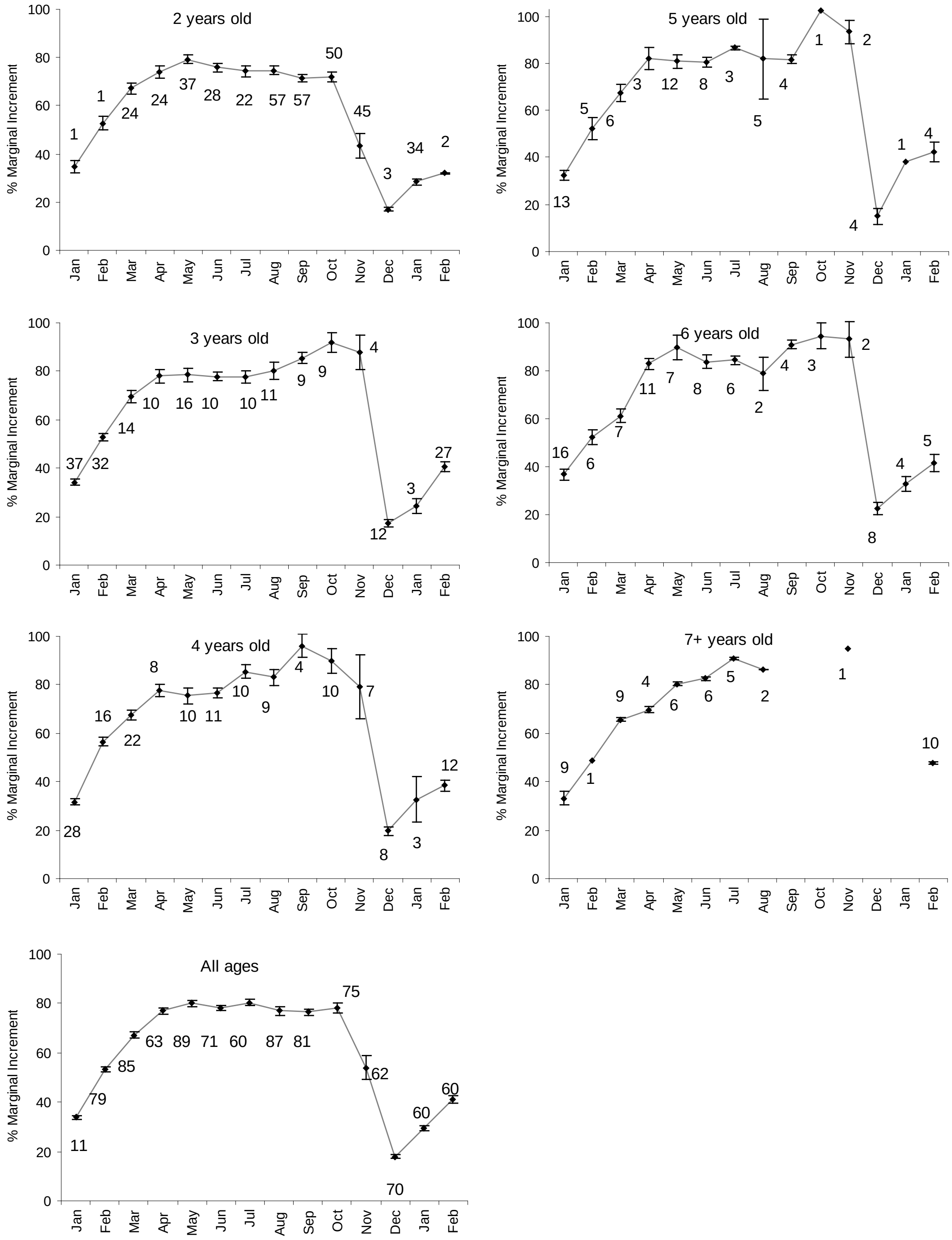


Figure 18. Mean marginal increments (+ SE) for rock flathead otoliths collected over a 14 month period in 2001/02. Separate graphs are displayed for each age group between 2 and 6 years and for the 7+ year old age groups and all ages combined.

Table 8. Mean length-at-age, standard deviation and sample size of rock flathead from Corner Inlet.

Age (yrs)	Male TL (mean, cm)	Male s.d.	Male n	Female TL (mean, cm)	Female s.d.	Female n	Immature TL (mean, cm)	Immature s.d.	Immature n	All TL (mean, cm)	All s.d.	All n
0							13.90		1	13.90		1
1	23.08	4.75	4	22.72	2.05	5	21.15	1.06	2	22.56	3.01	11
2	29.01	1.52	414	29.36	1.76	252	24.37	5.45	3	29.12	1.68	669
3	30.78	1.94	460	34.03	3.32	232	27.00		1	31.86	2.93	693
4	32.89	2.44	239	37.91	2.86	254				35.48	3.66	493
5	34.50	2.80	208	39.55	2.90	224				37.12	3.81	432
6	35.94	2.56	116	41.43	3.43	132				38.86	4.10	248
7	37.62	2.91	61	43.90	3.02	83				41.24	4.30	144
8	38.86	2.16	27	45.90	3.14	57				43.64	4.37	84
9	39.70	2.25	23	47.39	2.71	23				43.54	4.60	46
10	42.15	4.07	13	48.38	3.42	24				46.19	4.70	37
11	42.84	4.05	10	48.88	2.70	20				46.87	4.27	30
12	41.94	2.73	5	50.13	3.46	16				48.18	4.82	21
13	45.20	4.74	7	53.37	2.07	7				49.29	5.51	14
14	41.30		1	50.69	3.14	10				49.84	4.11	11
15	45.48	9.10	5	54.97	2.68	6				50.65	7.83	11
16	48.70		1	52.10	1.05	4				51.42	1.77	5
17				53.67	0.58	3				53.67	0.58	3
18				54.00		1				54.00		1
19				55.00		1				55.00		1
20												
21				53.60		1				53.60		1
22												
23												

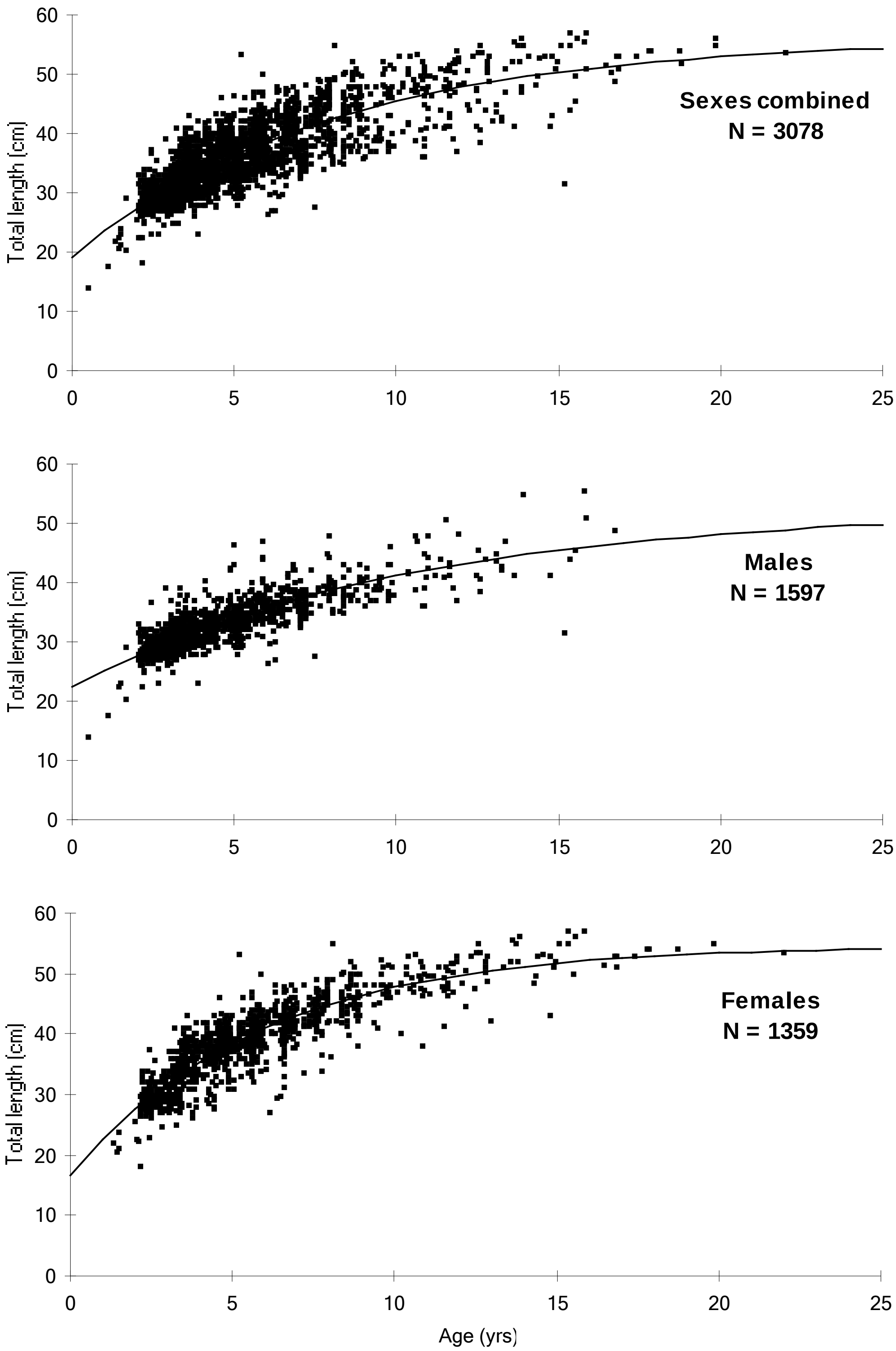


Figure 19. Von Bertalanffy growth curves fitted to length at age data for rock flathead caught in Corner Inlet.

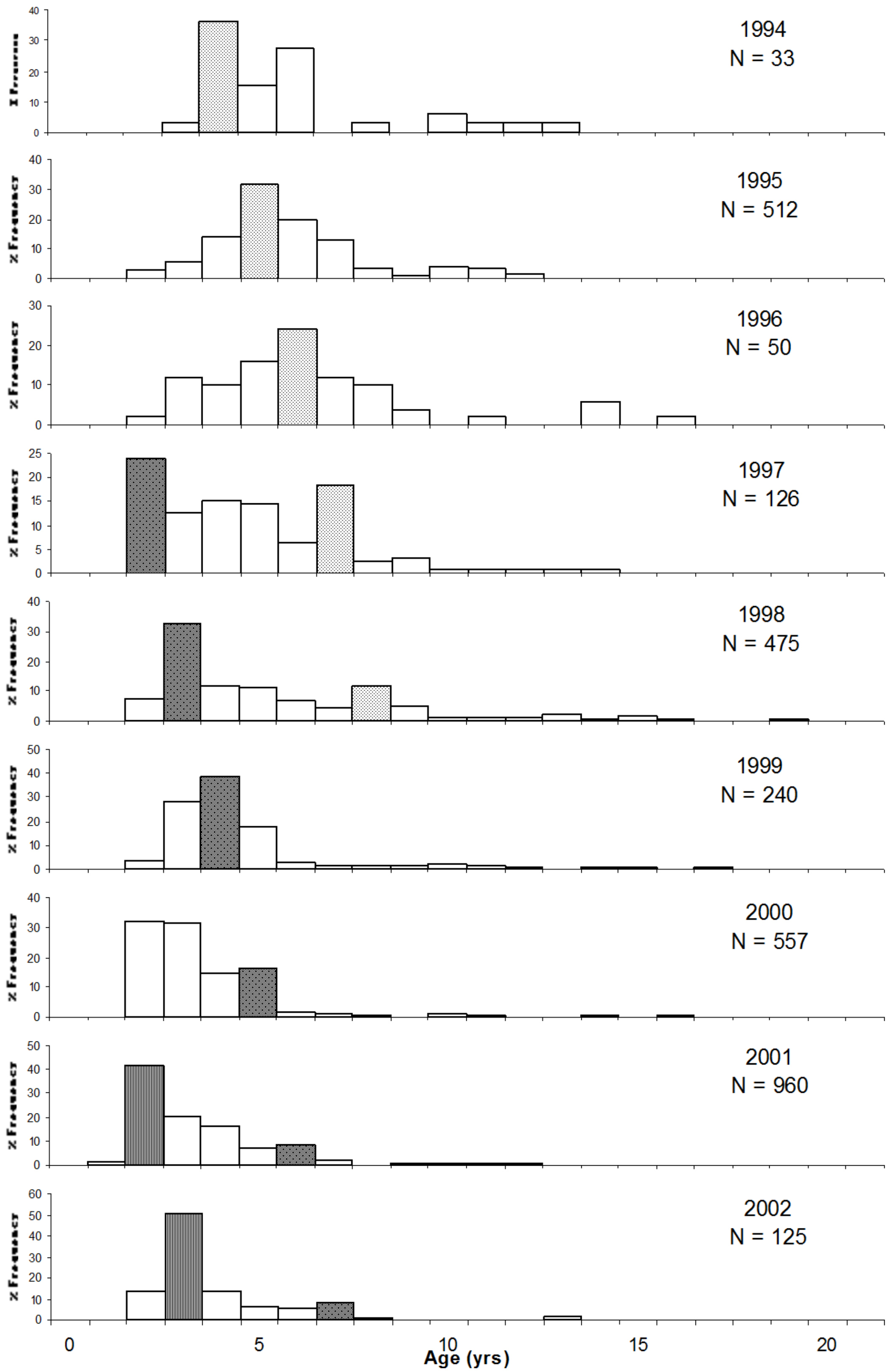


Figure 20. Age frequency of rock flathead caught in Corner Inlet between 1994 and 2002. Shaded blocks show strong year classes.

Table 9. Von Bertalanffy growth parameter estimates, standard errors and 95% confidence intervals for rock flathead.

Sex	Parameter	Estimate	Asymptotic s.e.	95%-C.I Lower	95%-C.I Upper
Sexes combined	L_∞ (cm TL)	55.9	0.95	54.1	57.8
(n=3078)	K (y^{-1})	0.125	0.007	0.112	0.139
	t_0 (y)	-3.35	0.197	-3.73	-2.96
Males	L_∞ (cm TL)	52.0	1.83	48.4	55.6
(n=1597)	K (y^{-1})	0.098	0.011	0.077	0.118
	t_0 (y)	-5.79	0.478	-6.73	-4.86
Females	L_∞ (cm TL)	54.7	0.70	53.3	56.0
(n=1359)	K (y^{-1})	0.170	0.08	0.154	0.187
	t_0 (y)	-2.14	0.167	-2.466	-1.812

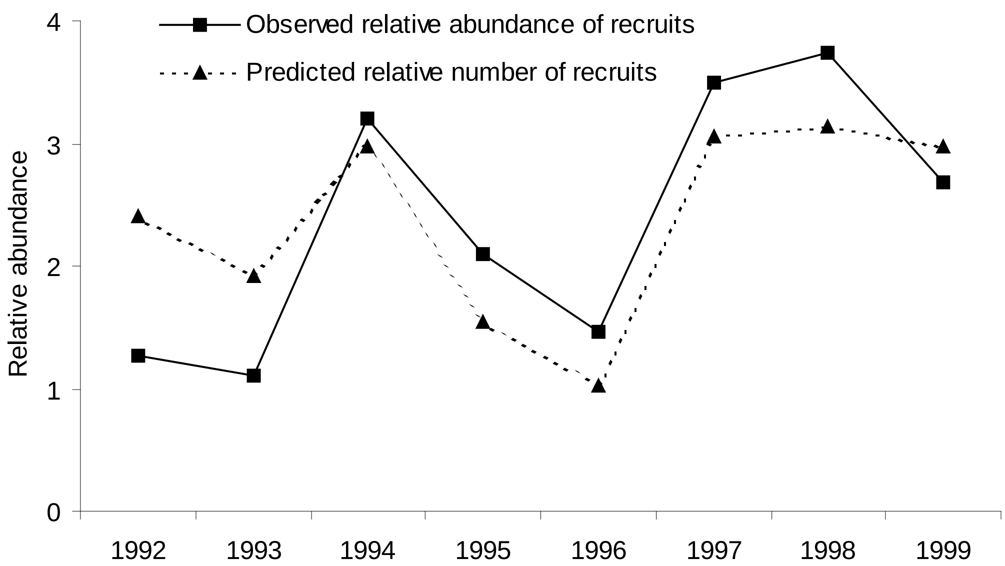


Figure 21. Environmental-recruitment model for rock flathead showing observed recruitment and recruitment predicted using winter flow from the Franklin River.

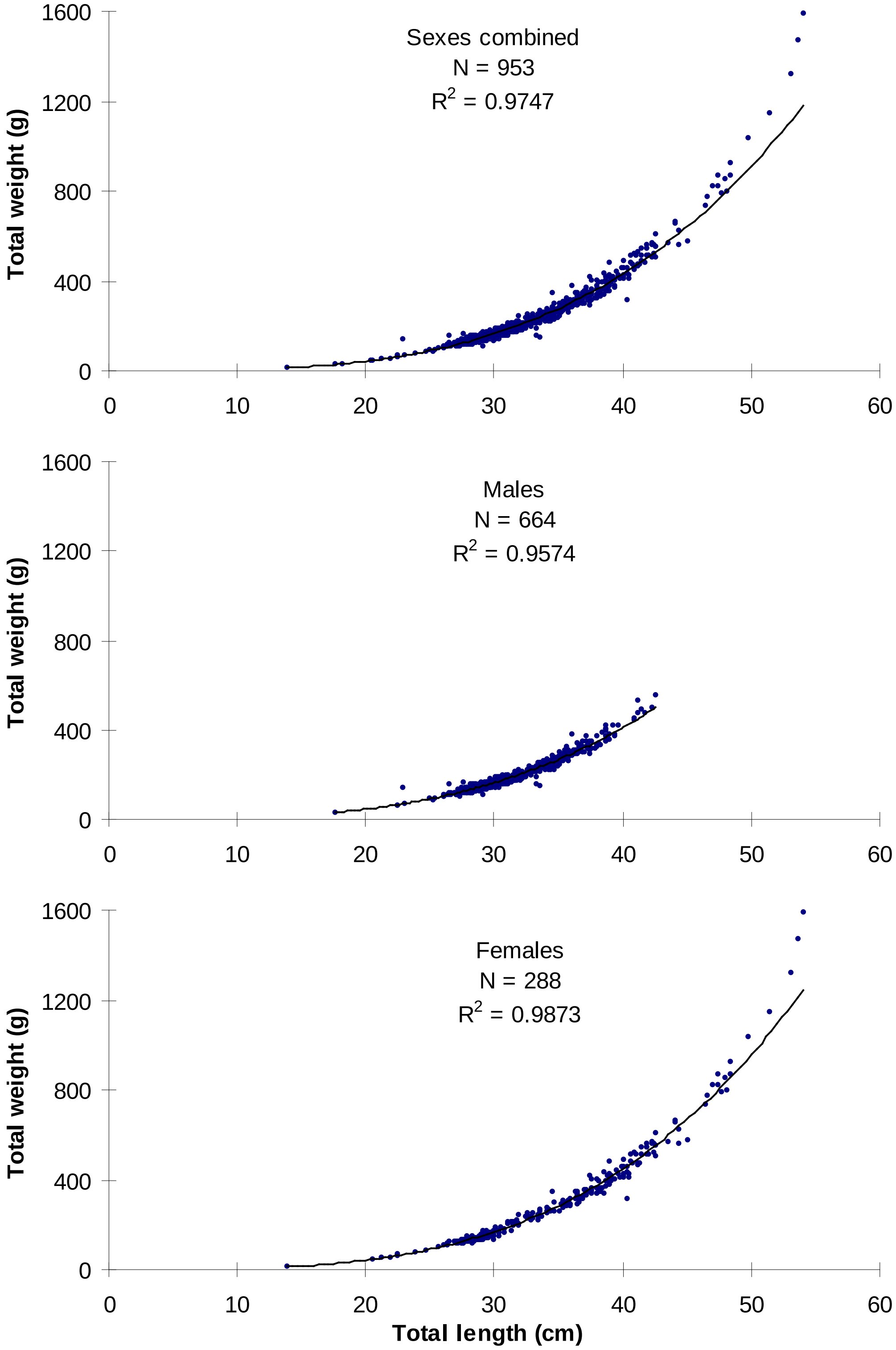


Figure 22. Relationship between total length and weight of rock flathead.

Although there were few small fish in the samples, it is clear that GSIs for male and female rock flathead was relatively low until the fish reached 26 cm and 28 cm respectively (Figure 24). Maturity ogives calculated by length and age provide estimates for 50% maturity of 23.1 cm and 1.8 yrs for male rock flathead (Figure 25). The estimated length at 50% maturity for female rock flathead (26.4 cm) was larger than for males, but this size is reached at a younger age (1.4 yrs) because of their faster growth rate (Figure 26).

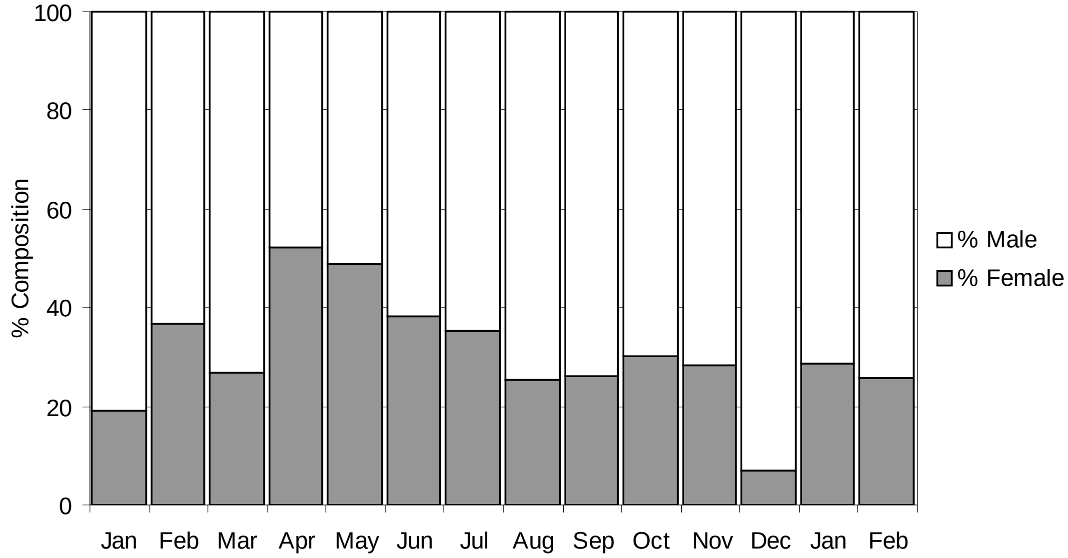


Figure 23. Sex ratio in rock flathead samples from Corner Inlet.

Male rock flathead in spawning condition (stages V and VI) were found in most months of the year (Figure 27), but comprised a majority of fish in the samples only between October and February. Small numbers of spent males were found in November and January, but the highest numbers were found in February. Female rock flathead were also found in spawning condition in most months of the year (Figure 27), with the peak spawning period also between September and February. No spawning females were present in the samples in December, but few females were caught at this time. Spent females were found in all months when spawning fish were present, but, as for males, comprised a greatest proportion of the sample in February.

GSIs for both males and females followed a similar pattern (Figure 28). GSI increased during winter and early spring to peak in October, the month in which the most males and females in spawning condition were found. GSIs began to decline in November and reached their lowest average value in March.

Stage II oocytes (Figure 29A) averaged 68 μm in diameter (range 40-120 μm) (Figure 30 and Figure 31). As the oocytes moved into stage III (Figure 29B), cortical alveoli and oil vesicles appeared and the eggs increased in size to an average of 162 μm (range of 120-280 μm). Oocytes had a wider range of size at stage IV (Figure 29C) as the cytoplasm filled with yolk granules and the cortical alveoli and oil vesicles increased in size. Mean oocytes diameter increased greatly to 354 μm (range 200-640 μm). At stage V (Figure 29D) the mean oocyte diameter was 450 μm (range 320-720 μm). During this stage the nucleus move towards the periphery of the oocyte and coalescence of the oil vesicles takes place. The oocytes are fully hydrated at stage VI (Figure 29E) and with a mean diameter of 508 μm (range 360-680 μm, but most frequently between 560-600 μm).

The plot of estimated fecundity against total length and age (Figure 32) showed a closer relationship between fecundity and fish length (R^2 = 0.83) than fish age (R^2 = 0.69). The empirical relationships are shown on the graphs.

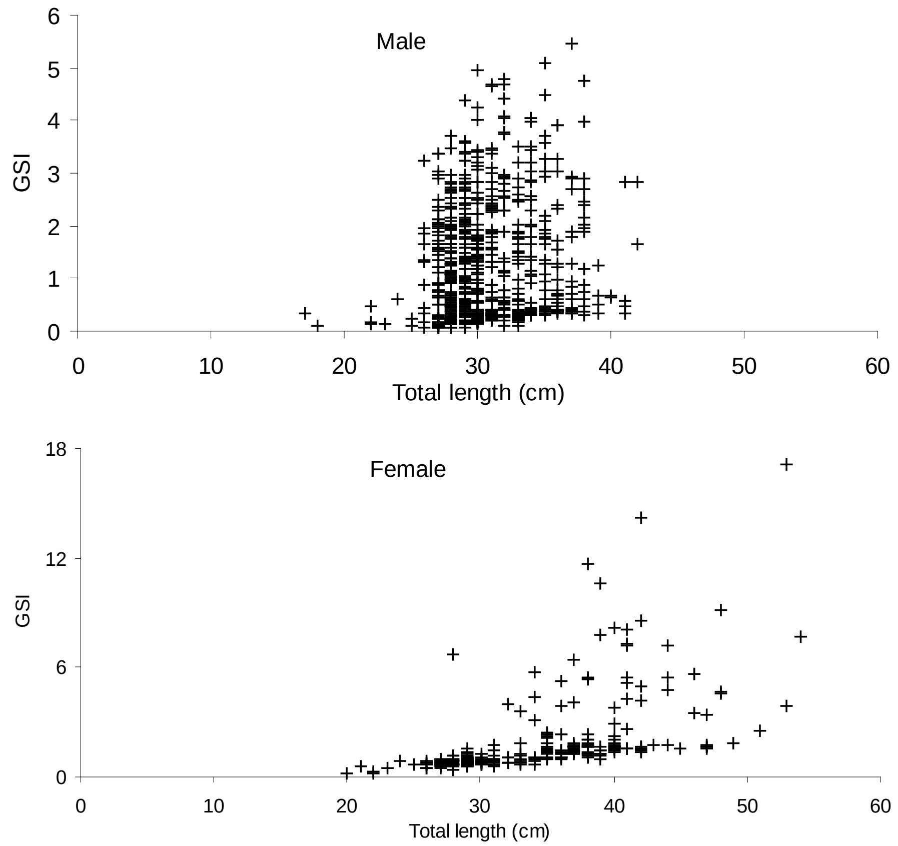


Figure 24. GSI of male and female rock flathead caught in Corner Inlet plotted against total length.

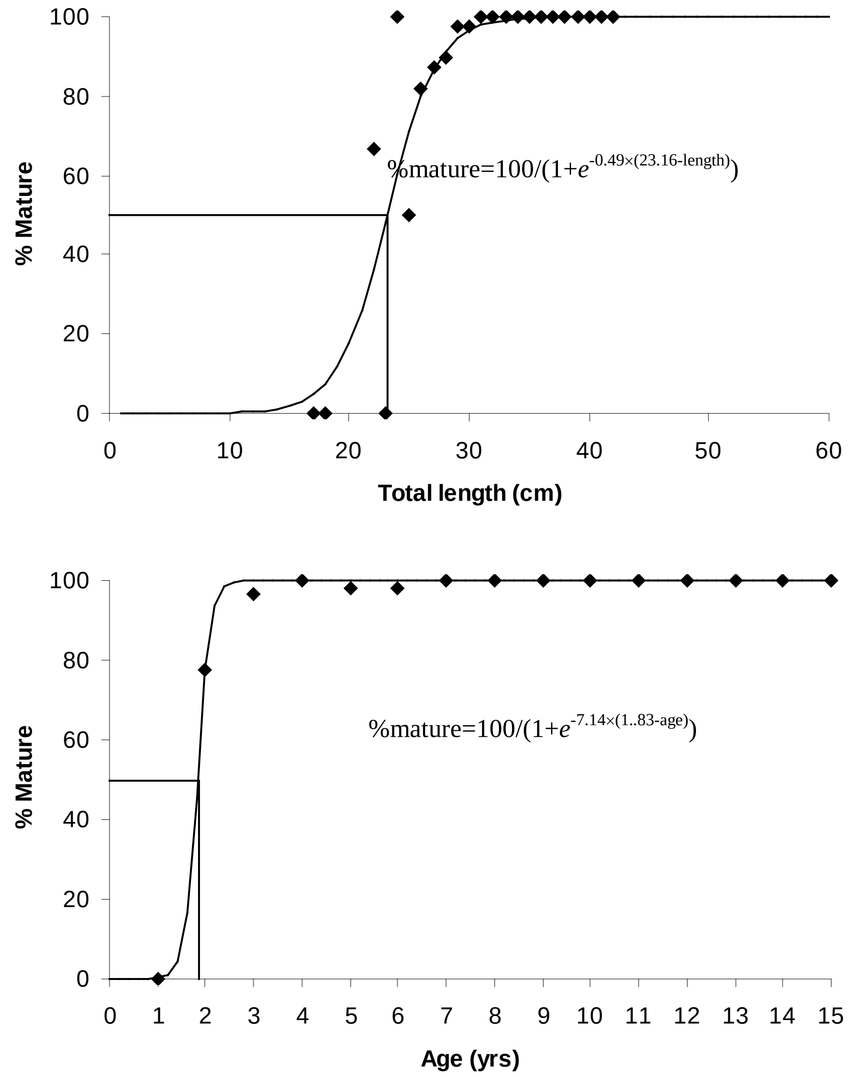


Figure 25. Maturity ogives for male rock flathead caught in Corner Inlet plotted against length and age. Diamonds represent observed data, solid curve represents the logistic regression fitted to the data and strait lines indicate length and age at 50% maturity.

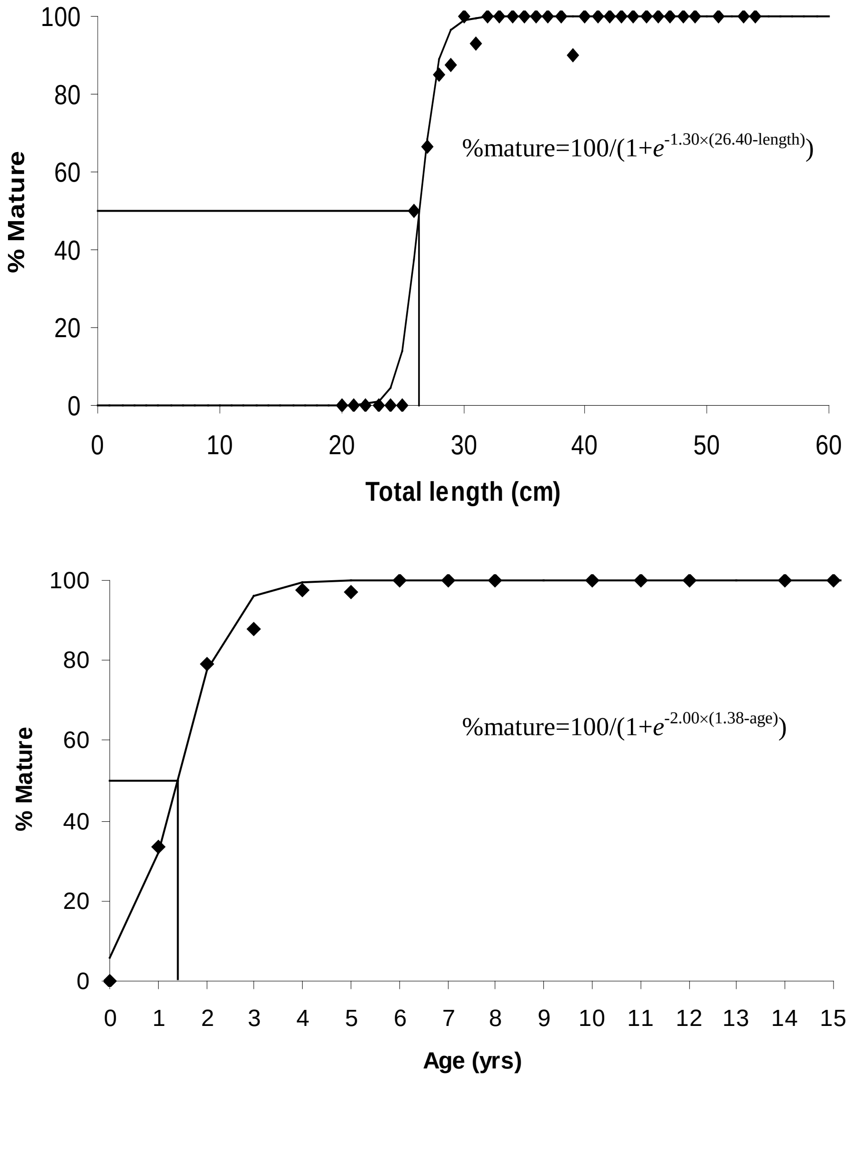


Figure 26. Maturity ogives for female rock flathead caught in Corner Inlet plotted against length and age. Diamonds represent observed data, solid curve represents the logistic regression fitted to the data and strait lines indicate length and age at 50% maturity.

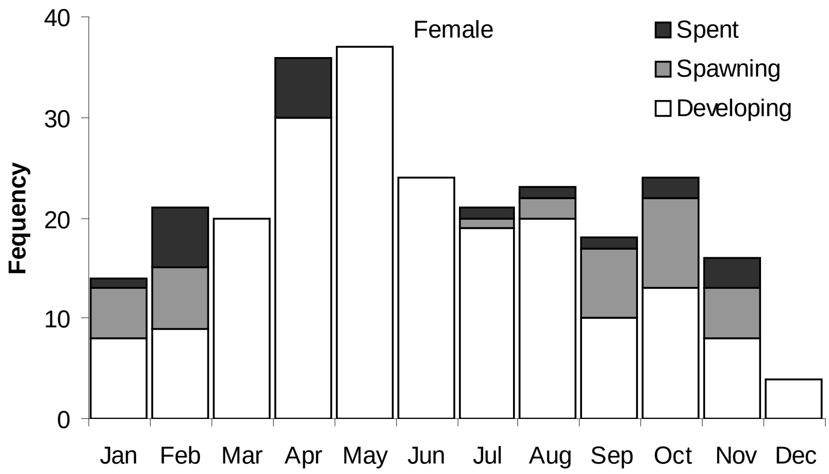


Figure 27. Frequency of mature male and female rock flathead from Corner Inlet in various stages of development (Developing = stages IIb, III and IV; spawning = stages V and VI; spent = stage VII).

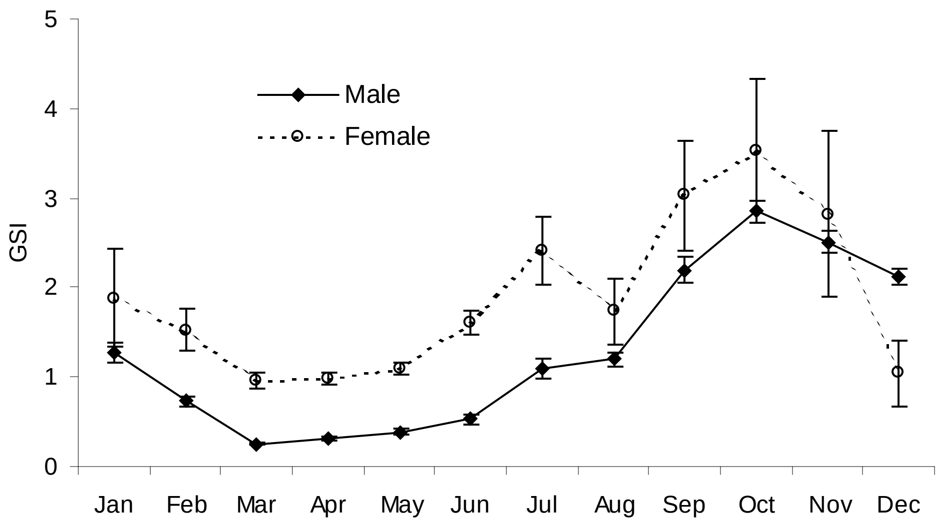


Figure 28. Mean monthly GSI (±S.E.) for male and female rock flathead from Corner Inlet.

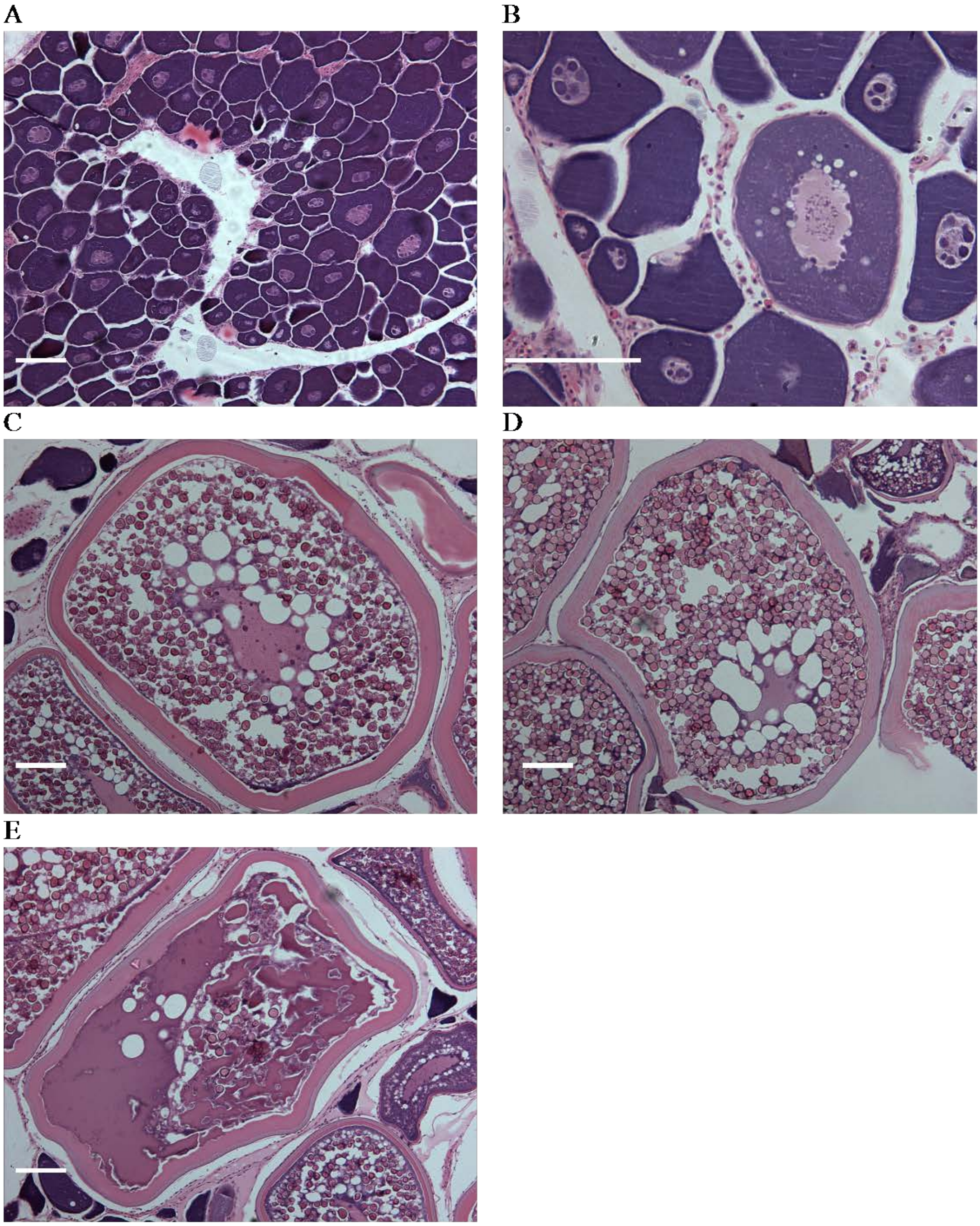


Figure 29. Histological sections showing the maturation of rock flathead oocytes from stage II (A) to VI (E) (Scale bar = 100µm).

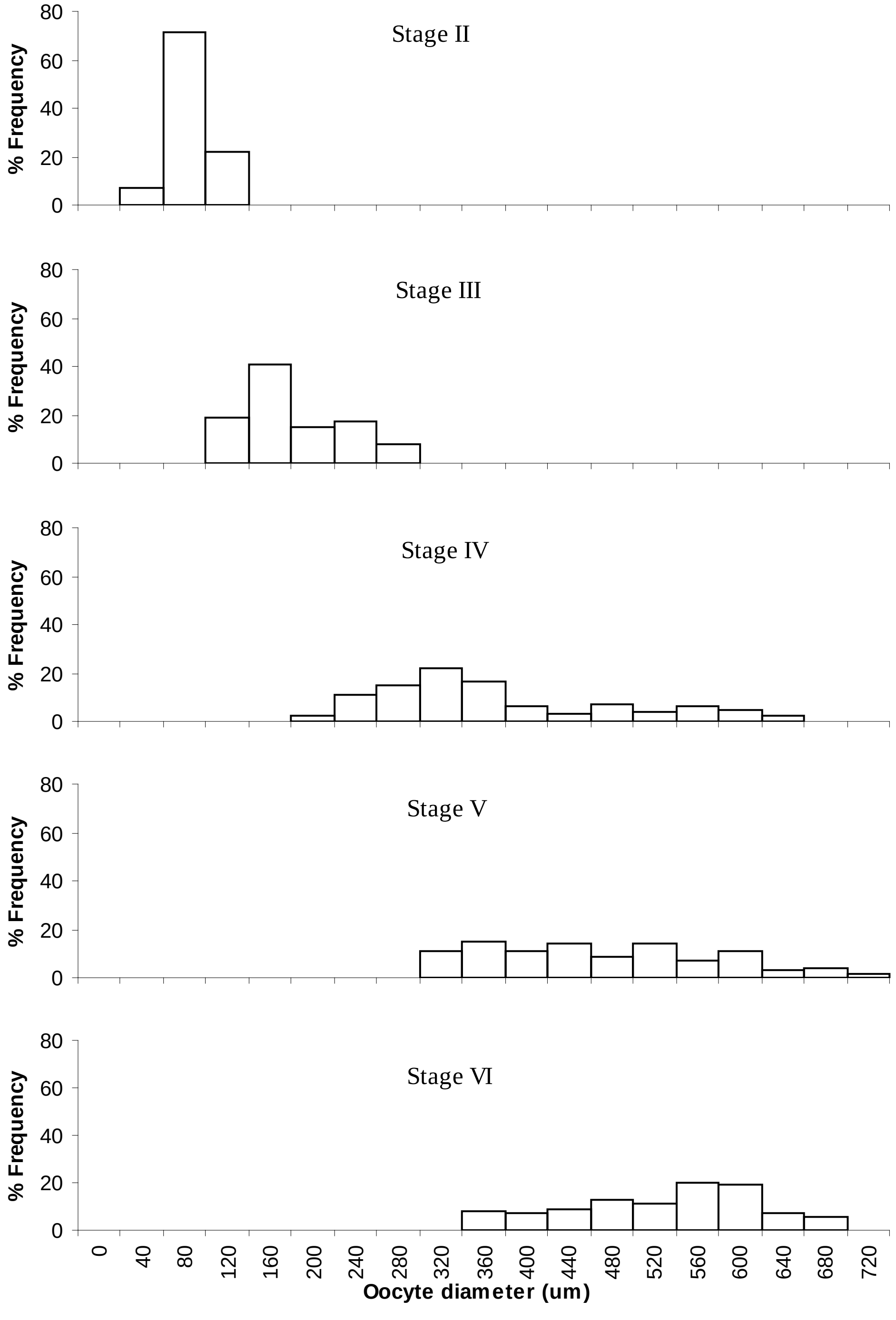


Figure 30. Frequency distribution of rock flathead oocyte diameter by developmental stage.

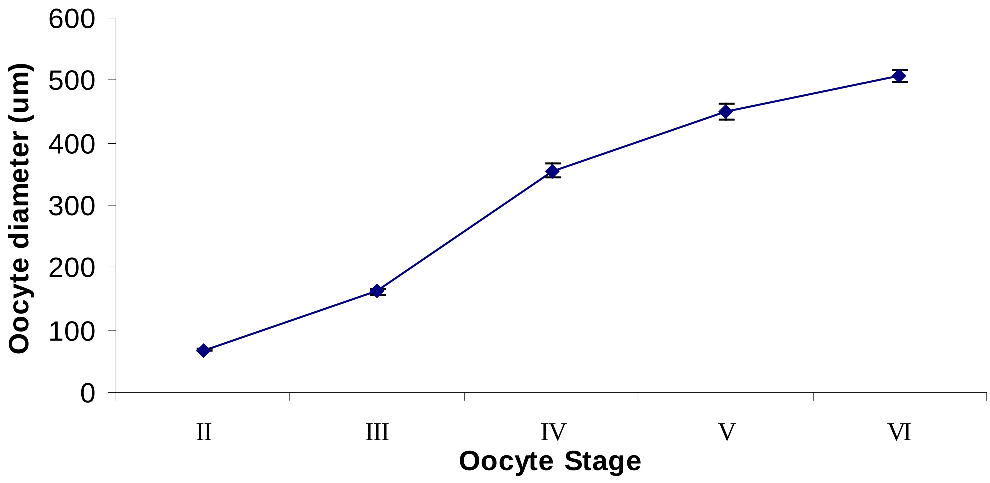
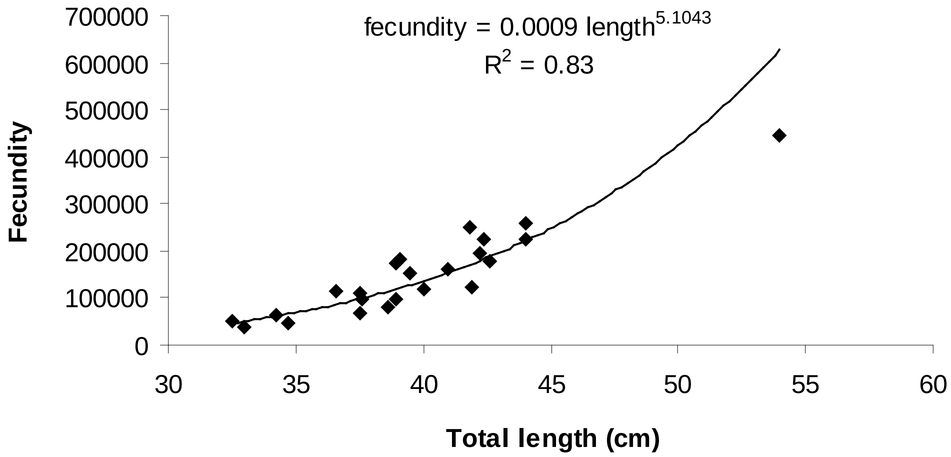


Figure 31. Mean diameter (± S.E.) of rock flathead oocytes measure from histological preparations.



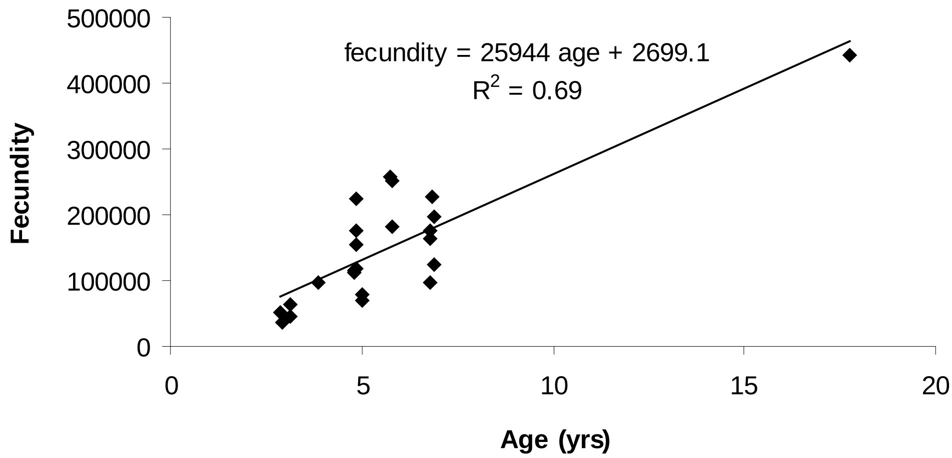


Figure 32. Fecundity estimates and relationship with a) total length and b)age for rock flathead caught in Corner Inlet.

Mortality and Modelling and the Fishery

Estimates of natural mortality (*M*) obtained using Pauly's and Gulland's equations were 0.27 yr^{-1} and 0.19 yr^{-1} respectively. The estimate of total mortality (*Z*) for rock flathead from the catch curve (0.38 yr^{-1}) (Figure 33) was very similar to that obtained using the Chapman and Robson estimator (0.37 yr^{-1}). Given the similarity in these estimates, only the Chapman and Robson estimate will be used in further analyses. Estimated fishing mortality (*F*) based on the estimates of *Z* and *M* were 0.10 yr^{-1} and 0.18 yr^{-1} respectively.

Yield-per-recruit (YPR) analyses revealed very different results for different estimates of *M* (Figure 34). For the lower estimate of *M*, YPR increased rapidly and peaked at 153 g per recruit at F = 0.35 yr^{-1} before declining slightly. The curve for the higher estimate on *M* did not peak over the range of *F* displayed, but reached an asymptote at about 130 g per recruit. For both scenarios, a reduction in *F* would not have increased the YPR, but an increase in *F* would be more productive if *M* = 0.27 yr^{-1}, and if *M* = 0.19 yr^{-1} then *F* was estimated to be at its optimum level.

YPR at the current estimates of *F* was nearly double at the lower estimate of *M* (0.19 yr^{-1}) than the higher one (0.27 yr^{-1}) (Figure 35). For the *M* = 0.19 yr^{-1}: *F* = 0.18 yr^{-1} scenario, the maximum YPR occurs at an age at first capture of 2.4 years, which corresponds to a length of 28.7 cm. This maximum YPR (144 g per recruit) was only sightly higher than the estimate for the current age/length at first capture (142 g per recruit). For the *M* = 0.27 yr^{-1}: *F* = 0.10 yr^{-1} scenario, YPR decreased over the entire range of age and length at first capture modelled.

The maximum number of eggs-per-recruit when *M* = 0.19 and *F* = 0 occurred at 4.5 years of age and 37 cm in length (Figure 36). Using the higher estimate of *M* the maximum eggs-per-recruit was much lower than when the lower estimated of *M* was used, and the peak occurred at a younger age and length (3 yrs and 33 cm). At the lower estimate of *M*, older fish continued to make a large contribution to egg production, with 14 year old fish producing 10% of the maximum egg number, while the corresponding age at the higher *M* was only 11 years. Depending on the estimate of *M*, the number of eggs per recruit at the current estimate of *F* was 55% (*M*=0.19) or 70% (*M*=0.27) of the level of the virgin population (Figure 37).

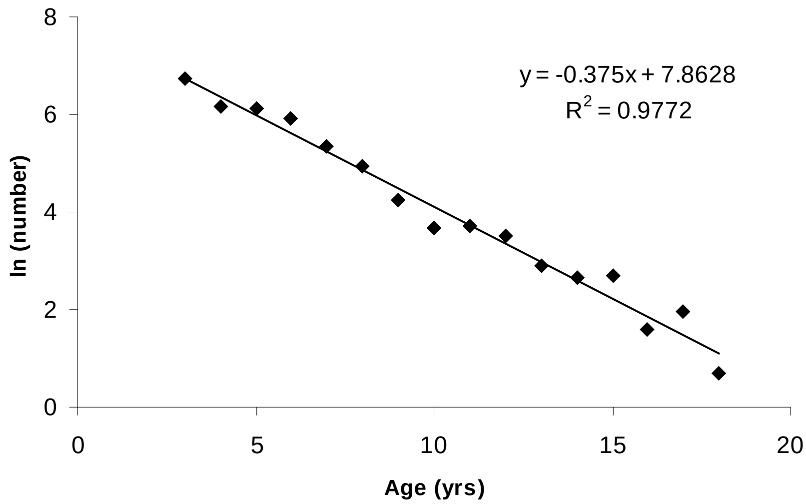


Figure 33. Catch curve analysis of rock flathead between the ages of 3 and 18 years inclusive. Regression function shown on chart estimates total mortality to be 0.375 y^{-1}.

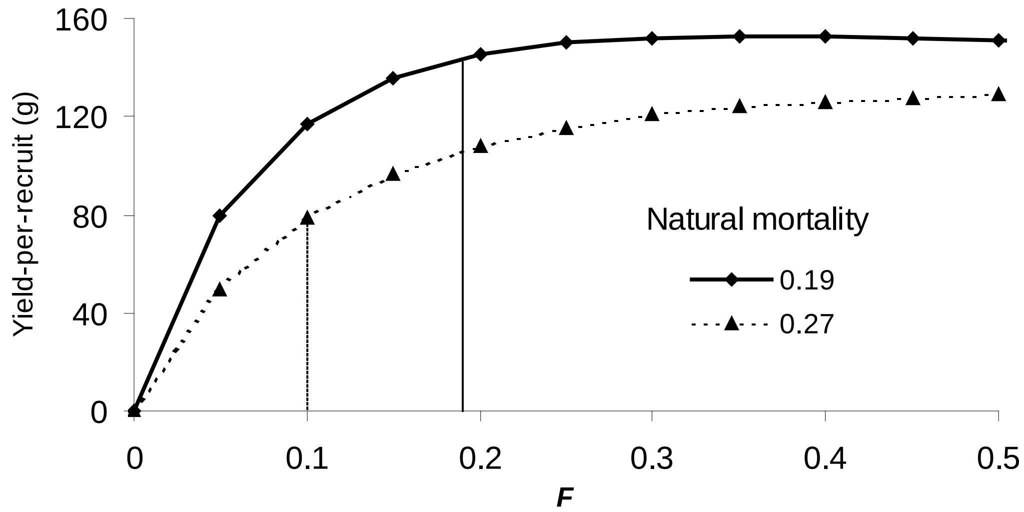


Figure 34. Yield-per-recruit of rock flathead for two different estimates of *M* over a range of values of *F*. Dotted and solid vertical lines are the current estimates of *F* if *M* = 0.27 yr^{-1} and 0.19 yr^{-1} respectively.

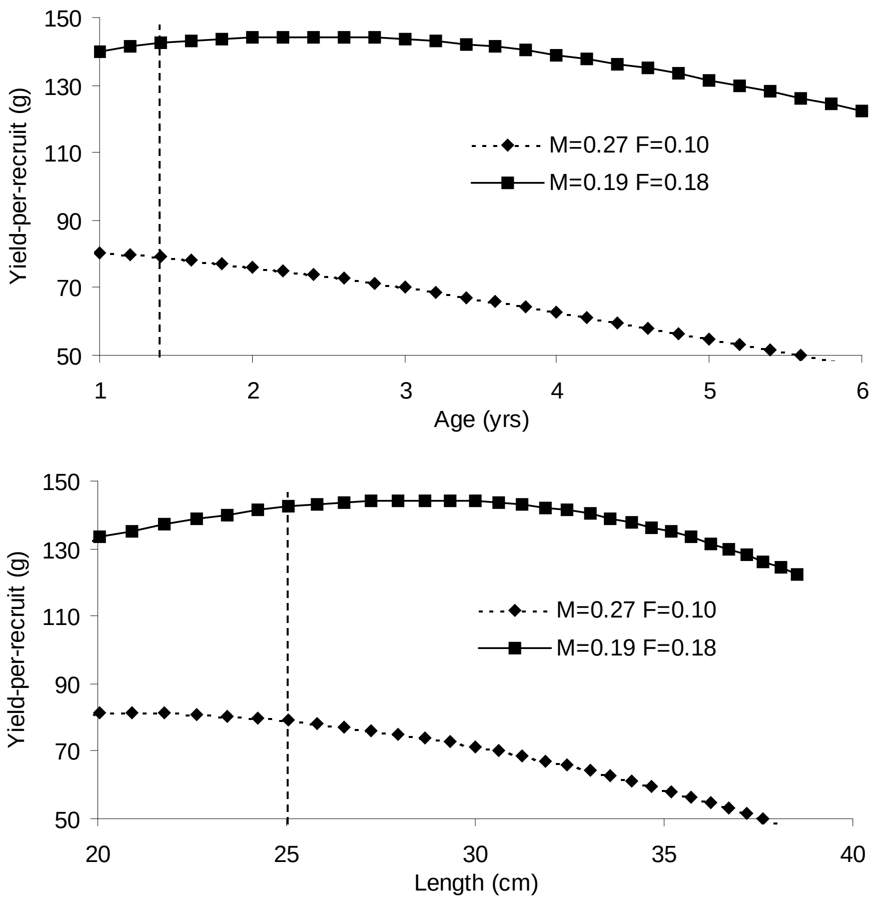


Figure 35. Yield-per-recruit of rock flathead for two different estimates of *M* and *F* over a range of age and lengths at first capture. Dashed lines are the current age and length at first capture.

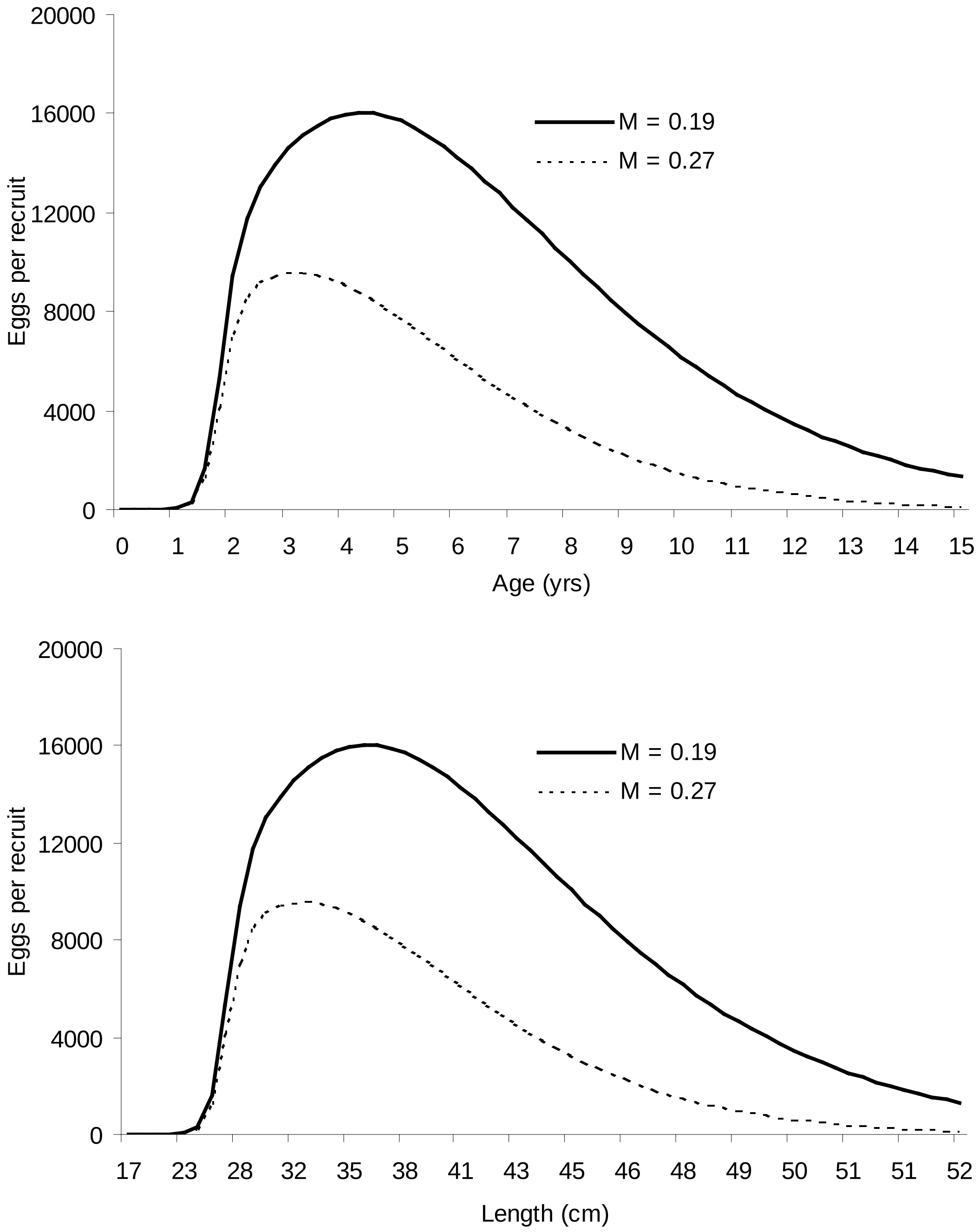


Figure 36. Eggs-per-recruit for female rock flathead plotted against age and total length for two different estimates of natural mortality. No fishing mortality has been incorporated into these analyses.

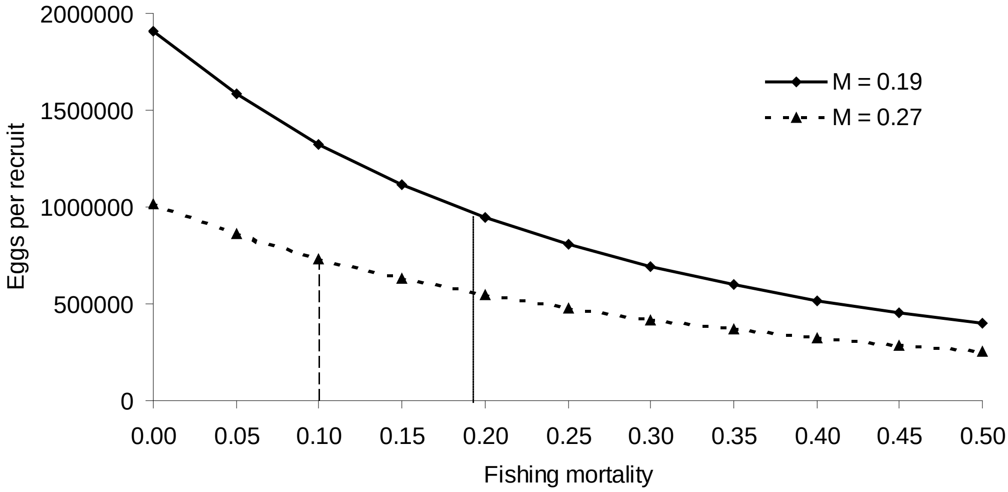


Figure 37. Eggs-per-recruit of rock flathead for two different estimates of *M* over a range of values of *F*. Dotted and solid vertical lines are the current estimates of *F* if M = 0.27 and 0.19 respectively.

Commercial Catch Statistics

The commercial fishery for rock flathead began about 145 years ago in Corner Inlet (MacDonald 1997). It is a multi-gear fishery that catches a variety of fin fish. Recent landings of all species have been between 225 t and 380 t per year (Anon 2000). Haul seines and mesh nets were the main fishing methods (Morison 2002) used until the late 1990s when ring seining became the most commonly used fishing method. The main species landed have been King George whiting, yellow-eye mullet, flathead (mainly rock flathead but also sand flathead), flounder (mostly greenback but also some long-nose), southern sea garfish, silver trevally and southern calamari.

Rock flathead catches by all gears were relatively low during the early 1980s before slowly increasing in the late 1980s, particularly as effort by seines increased (Figure 38 and Figure 39). Mesh net effort increased greatly in the early 1990s, however the greatest catches of rock flathead were not observed until 1993/94 when about 80 t were landed. The greatest catch rate was also observed in this year (1550 kg/km-lift). The catch has since fallen to about 20 t per year and effort has gradually declined in more recent years. The beach seine catch and effort peaked in 1990/91 at 11 t and 2750 shots respectively but both are now stable at around 2 t and 500 shots per year. Similarly, the catch and effort of garfish seines peaked in 1989/90 at 7 t and 2000 shots per year. While the effort fell in the following year and has remained at about 900 shots per year, the annual catch fell to only 2 t in 1996/97 before recovering to just under 5 t in 1999/2000. Ring seine effort and catch were very low until the method increased in popularity during the early 1990s. More than 1600 shots were made by ring seines in 1992/93 and 9 t of rock flathead were caught, which produced a peak in catch rate of 6 kg/shot. Catches and effort fell greatly until 1998/99 when both increased sharply and in 1999/2000, 8 t of rock flathead was landed from the 3000 hauls that were made.

Rock flathead catches by mesh nets are highest late spring and summer, and are smallest during winter and early spring (Figure 40). Catch rates follow a similar pattern to that of catch because of the relative uniformity of effort throughout the year. Catch rates of beach, garfish and ring seines are highest in late summer and early autumn. The catch rates are generally highest during this time as well.

Rock flathead caught at Corner Inlet using mesh nets have ranged from 26 to 66 cm in length since samples have been routinely collected since 1994 (Figure 41). The modal length was 36 cm and most fish were between 34 cm and 40 cm. Fish caught by haul seines in the same inlet had a similar length frequency distribution, however the modal size was smaller, 32 cm, and there was a smaller proportion of large fish caught.

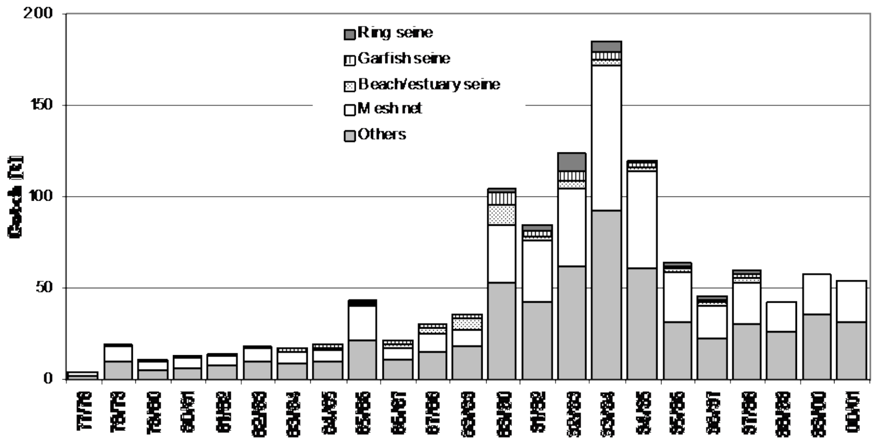


Figure 38. Total catch (t) of rock flathead from Corner Inlet by gear type.

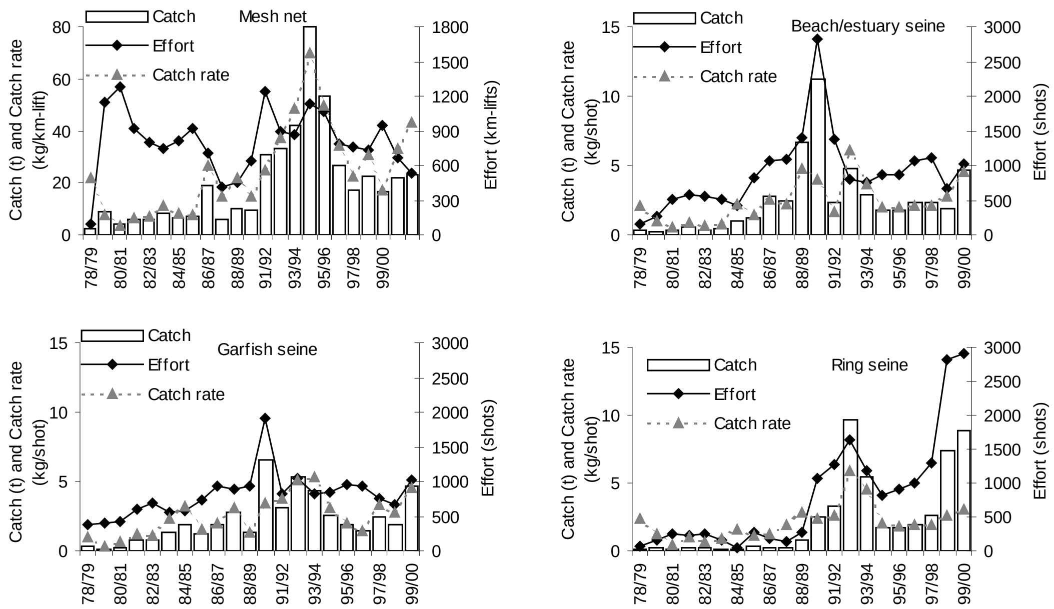


Figure 39. Total catch (t), effort (number of shots) and CPUE (kg/shot) of rock flathead from Corner Inlet by gear type.

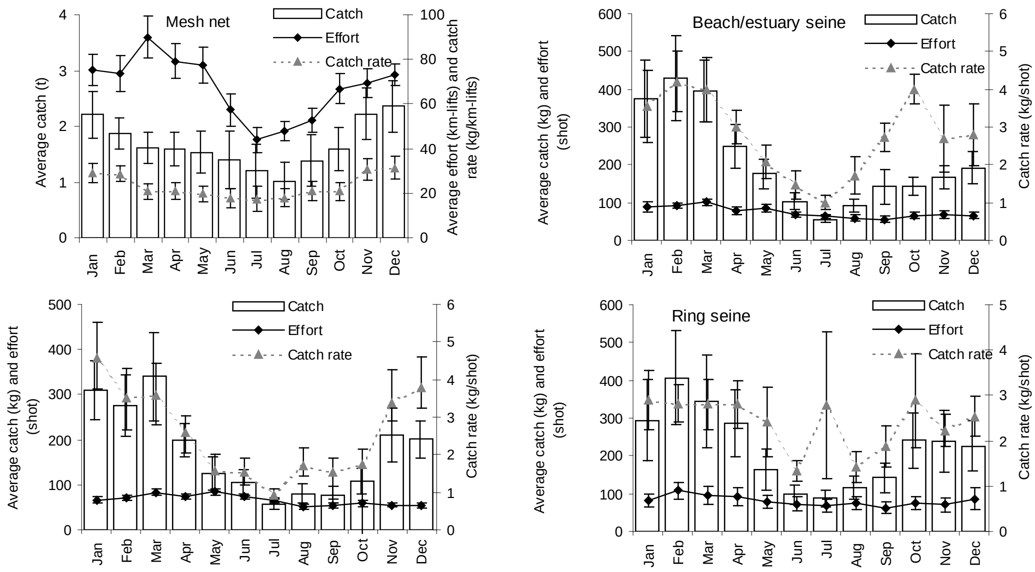


Figure 40. Average monthly catch (t), effort (number of shots) and CPUE (kg/shot) of rock flathead from Corner Inlet by gear type.

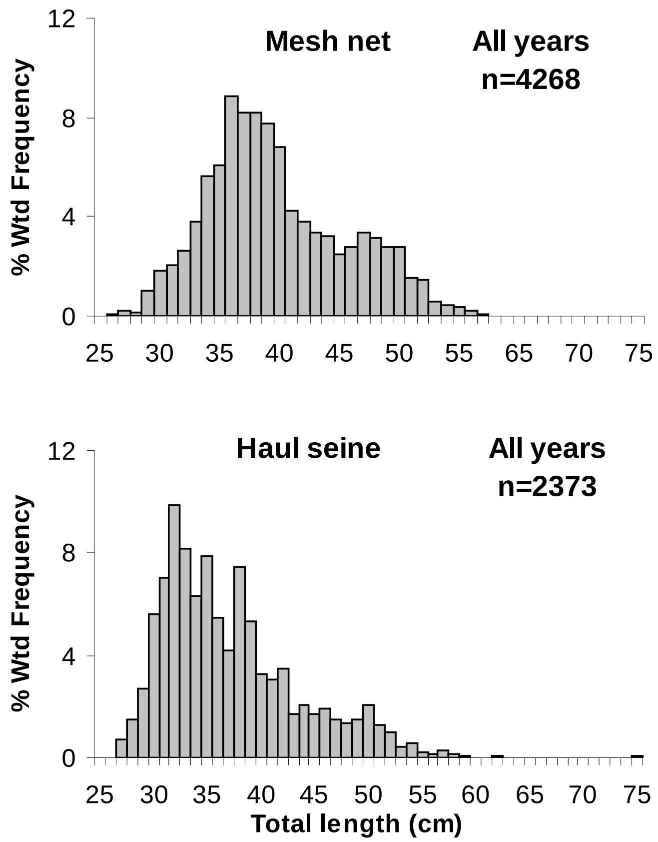


Figure 41. Weighted length frequency of rock flathead caught by mesh nets and haul seines pooled over years.

Discussion

Sand flathead

Growth of sand flathead in Port Phillip Bay was relatively fast for the first 3 to 4 years and then slowed after about 6 years of age. The estimated values of L□from the fitted growth curves (26.0 cm for males and 27.7 cm for females) were well below the observed maximum recorded lengths (33 cm for males and 37 cm for females). By comparison, sand flathead from offshore Victorian waters were substantially larger at all ages, and a much larger estimate of L□(38.0 cm). Port Phillip Bay sand flathead were also much smaller at each age than in Tasmania, where the estimated values of L□(36.6 cm for males and 40.5 cm for females) and the maximum lengths (46 cm for males and 51 cm for females) (Jordan 1998) were similar to those for the offshore Victorian samples.

There are several possible explanations for the slower growth rate of sand flathead in Port Phillip Bay compared to populations offshore and in Tasmanian waters including differences in habitat quality, density dependent effects on growth, potential genetic differences between stocks, and the effects of fishing pressure.

Density dependent growth is a well documented process whereby growth rate, maximum size and reproductive capacity are reduced as population size increases and resources become limiting (Ylikarjula *et al.* 2001). A comparison of the catch rates of sand flathead in Port Phillip Bay and the offshore waters of Tasmania (Jordan 1998) provides some basis for estimating the relative densities in the two areas. The maximum mean number of fish caught per 30 minute trawl was 18 in winter of 1993 at the inner-shelf strata off Storm Bay (Jordan 1998) and the mean catch rate for the entire Tasmanian survey was 2.25 fish per 30 minute tow. This compares with an average of 260 fish per 5 minute tow in Port Phillip Bay between 1990 and 1997 inclusive. The net used in Tasmania had a cod end liner with a mesh size half that of the net used in the Port Phillip Bay study, and, other things being equal, such a net would be expected to catch more small fish and hence have higher catch rates (the fish in the Tasmanian study ranged in size from 15.0 cm to 51.1 cm with an average of 28.8 cm). The Port Phillip Bay trawl survey, however, produced catch rates that were two orders of magnitude greater than the Tasmanian study with a shorter tow duration and larger mesh size. This strongly suggests much higher densities of sand flathead in Port Phillip Bay, and such a difference in density could be expected to be associated with differences in growth parameters.

In addition to the size differences between fish from Port Philip Bay and Tasmania, there were also differences in the variability of length at age between the two regions. Although the present study found length-at-age was highly heterogeneous in both sexes, this variability appeared to be highest in fish between one and eleven years old, and subsequently decreased. In contrast, Jordan (1998) reported that variability increased with age after maturity. Although this could have been an artefact of different sample sizes, the standard deviations of length-at-age suggest that the difference was real. The mean standard deviations of fish ≤ 10 years old and > 10 years old from Port Phillip Bay were 2.6 and 1.8 respectively, while the mean standard deviations for the same age groups in the Tasmanian data were 3.2 and 5.8 respectively. Possible explanations of these observations are that the faster growing fish may move outside the range of the Port Phillip Bay trawl survey, or that they become less abundant because they experience higher mortality rates (either natural or fishing mortality) than slower growing fish. Further research would be needed to investigate these possibilities.

The environment-recruitment model that was developed for sand flathead showed a very high level of association between average daily discharge from the Yarra River during February, March and April, the SOI index in September, and the level of recruitment of sand flathead. The strength of the association suggests a direct and causal relationship but the mechanisms by which these environmental variables could affect sand flathead recruitment are unknown. The river discharge variable incorporated discharges over a three month period in the year prior to spawning, suggesting a potential broad scale affect on the habitat of sand flathead that may affect adults. The SOI variable that contributed significantly to the model was for September, the month of spawning, suggesting that its influence was mainly on events close to the time of spawning. While it is not unusual for abiotic factors to affect recruitment in teleosts, the strength of the relationship is remarkable. The only relationship of similar strength known to us is the strong (but still lower) correlation that Francis *et al.* (1995) found between water temperature and spawning success of pink snapper *Pagrus auratus* in New Zealand. The dominant influence of these environmental variables in the relationship would also suggest that fishing mortality has little affect on the recruitment of sand flathead at current levels of fishing pressure.

An age-structured population model was designed specifically for sand flathead, where accurate catch and effort data were not available because of the nature of the fishery, but utilised the set of fishery independent catch-at-age and relative abundance data that were available over the time period from 1990 to 2002. The model can be described as one of intermediate complexity (Conser 1994; Jacobson *et al.* 1994) in that it uses some of the age composition information, but as a smaller number of age groups (three in this case) than there are age classes in the population.

Estimated mean survival was lower for the 2-year-old fish than the older age groups, although the distributions do overlap. This is not entirely surprising because smaller fish are usually subjected to higher rates of predation (Laevastu *et al.* 1996). The older fish would be subjected to a higher fishing mortality, but sand flathead below the current MLL may also experience significant post-release mortality after being discarded by recreational fishers (Conron, pers. com.). The estimates of survival also differed between the two time periods examined. The observations of lower abundance in the later time period when recruitment levels had not diminished, being reconciled in the model by a reduced level of survival.

The estimated survival was lower and more variable for the time period after 1995. This is a consequence of a decline in abundance in the second half of the 1990s which was particularly clear for the 4+-year-old age class. It is known that several major ecological changes occurred in Port Phillip Bay during the mid 1990s. These include the cessation of scallop dredging and the invasion and establishment of several exotic pests (Cohen *et al.* 2000; Parry and Cohen 2001), both of which could potentially have effected the survival and/or growth of sand flathead. There was no evidence of an increase in *F* in either the recreational or commercial fisheries. In fact, some data had suggested that the trend in recreational fishing in Port Phillip Bay in the early 1990s had been for a shift away from sand flathead to more desired species such as snapper and King George whiting (Conron, pers. comm.).

The population model fitted the observed data reasonably well for all age classes examined. The exception was for 2002 when the predicted abundance deviated significantly for all age classes, indicating a considerable reduction either in the numbers of fish in all year classes or in the catchability of sand flathead in Port Phillip Bay. Samples from the 2003 trawl survey may provide data that will confirm the trend or show the 2002 data to be aberrant.

The lower estimated survival after 1995, and the poor fit for data from 2002, may be an indication that trophic relationships among the Port Phillip Bay biota have been altered by the combined effects described above. If these are a long-term changes then the environment-recruit relationships may become less reliable, and other biological parameters may alter, reducing the accuracy of the model projections for sand flathead stocks.

Rock flathead

Age estimates for rock flathead are presented here for the first time. Increments in sectioned rock flathead otoliths were generally clear and unambiguous as evidenced by a low APE. Results of marginal increment analysis showed a clear cycle of increasing increment width through the year followed by a sharp decrease after new increments become visible on the otolith margin in December . There were insufficient data for separate analyses of each age group, but the uniformity of increment structure in larger otoliths suggests that the pattern of regular increment formation has continued in older fish. Although only 14 months of data were used for the marginal increment analysis, instead of the 24 months recommended by Campana (2001), the deposition of one growth increment per year in sectioned rock flathead otoliths was also supported by the progression of year classes through time. Three strong year-classes — 1990, 1995 and 1999 cohorts — progressed by one growth increment in each subsequent year. The most likely explanation for this is that one growth ring is deposited during each year of a fish's life (Morison *et al.* 1998b), at least until the age of 8 years. Examination of the otolith weight to age relationship provided further support that the number of increments increased regularly.

Rock flathead reached the MLL (25 cm) between the ages of 1.6 and 2.1 years for males and 1.9 and 2.4 years for females. By the age of two years, fish of both sexes average about 29 cm in length, after which females grow at a much faster rate and average 50 cm at an age of 12 years. Males are only 42 cm at this age. It is common for female fish to grow at a faster rate and to a larger size. This was found with sand flathead from Port Phillip Bay in this study, and has been well documented in many species from around the world (eg Horne 1997; Begg and Sellin 1998)..

An important finding of the present study was the clear patterns in year-class strength evident over the sampling period, which indicated that rock flathead recruitment in Corner Inlet varied considerably between years. Strong recruitment events occurred during 1990, 1995 and 1999, while poor recruitment occurred during 1991, 1994 and 1996. This variation in recruitment of rock flathead was found to be significantly correlated with river discharge into Corner Inlet during the winter months from the Franklin and Agnes Rivers. The peak river flow in both of these rivers occurs in July, August and September. Possible causal mechanisms for this relationship are, however, unknown. Variations in annual recruitment are not uncommon in fisheries (Sissenwine *et al.* 1988) and have been observed in several other Victorian marine species including sand flathead (this study), black bream (Morison *et al.* 1998b; Walker *et al.* 1998) snapper (Coutin 2000b) and King George whiting (Jenkins and Black 1994) and may be driven by a variety of biological or environmental factors including temperature, salinity or prevailing wind strength to name a few (eg. Kope and Botsford 1990; Thresher 1994; Jenkins and Black 1994; Francis *et al.* 1995).

Rock flathead are commonly recorded in the literature as growing to 50 cm in length, and to a weight of 2 kg (eg. Hutchings and Swainston 1986; Kailola *et al.* 1993; Daley *et al.* 1997). The largest fish obtained during the present study (a filleted frame) measured 56 cm TL and the largest whole fish (54 cm TL) weighed 1592 g. According to the length-weight relationship established in the present study, 50 cm male and female fish would weigh only 954 g and 836 g respectively. The largest fish recorded in length-frequency data from the commercial fishery was 75 cm. According to the length-weight relationship for sexes combined, a fish of this length would weigh approximately 3500 g. It must be noted however, that the length-weight relationship begins to under estimate the observed weight of female rock flathead at sizes above 48 cm TL.

Males were much more prevalent in the samples than females, however the proportion of females increased with size and age. Protandrous sex inversion is a possible explanation of this trend. This has been observed in other species of Platycephalids (for *P. indicus*; Lewis 1971) but no evidence of this was observed from the examination of gonads during the present study. The cause of the preponderance of males in the samples is unclear. It is unlikely that the main sampling method, ring seine, selects for the smaller males as this method encircles all fish within an area, trapping all those not small enough to fit through the mesh. Another possible explanation is that the large females may more likely to remain on the shallow mud flats as the tide lowers. The fishers shoot their nets just before low tide so as to catch the fish that are concentrated in the channels during the ebbing tide.

The data suggest that males mature just below the MLL and females mature at a size just above the MLL. Because of the difference in growth rates however, females mature at a younger age than males. The current MLL therefore gives about half of the population a chance to reproduce before reaching legal size.

The results of the YPR analyses indicated that there would be little increase in yield from an increase in the MLL. They suggested that increasing the MLL would either decrease the YPR, or slightly increase it depending on the estimate of M. Similarly, YPR would not be increased by a reduction in F, but may be improved by increasing F, again depending on the estimate of F used in the analysis.

At the current estimates of fishing mortality, the number of eggs-per-recruit (EPR) is about half of that which would be produced in an unfished population (for $M = 0.19$ yr^{-1}). If F was doubled, the EPR would be halved again. If $M = 0.27$ yr^{-1}, the EPR is only about 25% of an unfished population.

The buy-out of commercial fishing licenses in 2000 removed fishers that had contributed an average of 10% of the total fish catch in Corner Inlet over the preceding 5 years (Morison 2001). If it is assumed that this would produce a 10% reduction in F for rock flathead, then the EPR would increase by 6.17% and 3.05% for the $M = 0.19$ yr^{-1} and $M = 0.27$ yr^{-1} scenarios respectively.

These models suggest that the current MLLs for rock flathead are appropriate, with adequate protection provided against both growth and recruitment overfishing. Similarly, the current estimates of fishing mortality to appear to be sustainable.

Benefits

The project outcomes have provided immediate benefit to the management of sand and rock flathead stocks in Victoria. It is the first time that the biology of rock flathead has been studied and the first time that key biological attributes of sand flathead stocks have been evaluated using correct data on age and growth. The identification of the environmental variables that are highly correlated with recruitment is an important step in developing predictive assessment models that can be used for stock assessment.

This project will directly benefit both the recreational and commercial fisheries that target these stocks. The results have provided a sound scientific basis for assessing the current status of the resource and the future management of the fishery.

The results of the project will assist Fisheries Victoria in ensuring that the fisheries targeting sand and rock flathead are managed in a manner consistent with the principles of ecologically sustainable development. They indicate that at present population levels, current management arrangements have provided sufficient protection for the flathead stocks and that the fisheries based on these stocks are sustainable.

Further Development

The size frequency distribution of sand flathead in Port Phillip Bay shows that there is a high proportion of fish on the fishing grounds that are below the current MLL of 25 cm TL. These fish are frequently caught and discarded in the recreational fishery but their survival rate is unknown. An estimate of the mortality of these discards would give greater certainty to the estimates of mortality used in the current population model.

The reliability of the age estimates for both sand and rock flathead could be demonstrated by further validation work to confirm firstly that the first increment has been correctly identified, and secondly that the observed increments continue to be formed annually in older fish.

Investigation of the mechanisms by which the environment variables apparently control recruitment in sand flathead could give important insights into the ecology of sand flathead and the linkages between habitat quality and fish production. It would also be useful for assessing whether observed changes to the biota of Port Phillip Bay may have flow-on affects to sand flathead populations.

The deterministic modelling of rock flathead gave variable results because of the variability in estimates of M, and consequently also of F. A more accurate estimate of M would be useful for allowing a more reliable population model to be developed.

Planned Outcomes

This study addresses some of the main information gaps identified at the 2000 Sand flathead and rock flathead Stock Assessment workshops. Data on the age, growth and reproduction are fundamental in the management of the utilisation of fish stocks in a manner consistent with the principles of ecologically sustainable development. Further, a stochastic, age-structured, population model has been produced specifically for sand flathead, that makes no assumptions regarding catchability, mortality or recruitment. Relationships between recruitment and environmental variables have been identified for both sand and rock flathead that indicate that observed fluctuations in relative year-class strength or abundance are largely attributable to effects other than fishing pressure. These relationships will provide some ability to forecast future levels of recruitment to Victorian sand and rock flathead populations.

These results have been communicated to managers in Fisheries Victoria through informal discussions, through the extension material developed and distributed, and through half-year and annual reports on projects. They have provided Fisheries Victoria with evidence that the current management arrangements concerning sand or rock flathead have been consistent with the principles of ecological sustainability for these fisheries.

Results have also been incorporated into annual reports on the status of major fisheries and key species that have been provided to the Fisheries Co-management Council. The Council used these reports in their annual report to the Victorian Parliament.

Conclusion

Sand flathead from Port Phillip Bay grow relatively quickly for the first 3 to 4 years and growth then slows after about 6 years of age, before reaching an asymptote at 26-28 cm TL. The asymptotic length and growth rate was considerably lower than for sand flathead caught in offshore Victorian waters (38 cm) and Tasmanian waters (36-41 cm). There are several possible explanations for these differences including differences in habitat quality, density dependent effects on growth, potential genetic differences between stocks, and the effects of fishing pressure. The age structure revealed a large degree of recruitment variability, which was highly correlated with SOI at the time of peak spawning and river discharge from the Maribyrnong and Yarra Rivers, which flow into the north end of Port Phillip Bay.

Examination of GSI and egg diameters revealed that sand flathead in Port Phillip Bay probably spawned in two main batches. GSIs peaked in August-September, when there were two clear groups of egg size. One group had a mode of about 0.75 mm, the other 0.30 cm. GSI decreased to a minimum in December, however in January, GSI in female fish increased again, probably due to the batch of smaller eggs becoming mature. Fish spawned again in January or February, after which GSI decreased.

The environment-recruitment model described a very strong relationship between daily river discharge, the SOI for September, and sand flathead recruitment. This suggested that at current levels fishing pressure had a minimum role as a determinant of spawning success. Under current conditions, environmental factors apparently played an overwhelming role in this process.

An age structured population model was designed for sand flathead in Port Phillip Bay using a time series of data from fishery-independent trawl surveys. The model used data on catch-at-age and relative abundance for the time period from 1990 to 2002. The model fitted closely to the observed data prior to 2002, duplicating the decrease in abundance during the late 1990s.

Age estimates for rock flathead are presented for the first time. Male and female rock flathead in the samples were found to reach the MLL of 25 cm TL as early as 1.6 years and 1.9 years respectively, and their growth curves asymptote at about 52 cm and 55 cm respectively. The age structure of rock flathead also revealed variable recruitment which was significantly negatively correlated with river discharge from the Franklin and Agnes Rivers into Corner Inlet during the winter months prior to spawning.

Male rock flathead reached 50% maturity just below the MLL and females just above the MLL. Because of the difference in growth rates, however, females matured at a younger age than males. Approximately half of the population of rock flathead in Corner Inlet reproduced before reaching the current MLL which therefore provides some protection against recruitment overfishing. At a length of 30 cm, nearly 100% of rock flathead are mature. Very few fish are caught below this length in the commercial fishery. Although both male and female fish were found in spawning condition in most months of the year, most spawning probably takes place after October, when GSI peaked, and males in spent condition appeared in the samples in November.

Yield-per-recruit and egg-per-recruit models applied to the rock flathead population suggested that the current MLL for rock flathead provided adequate protection against growth overfishing. Similarly, the current estimates of fishing mortality appeared to be sustainable. These findings indicated that current management arrangements are appropriate and do not need to be reviewed.

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Appendix 1: Intellectual Property

The intellectual property from this project will be shared between the Fisheries Research and Development Corporation and the Marine and Freshwater Resources Institute as outlined in the project contract. The Fisheries Research and Development Corporation will be acknowledged in all publications arising from the project.

Appendix 2: Staff

Matt Koopman	Fisheries Scientist (MAFRI)
Alexander Morison	Senior Fisheries Scientist (MAFRI)
Vladimir Troynikov	Modeller (MAFRI)
David McKeown	Technical Officer (MAFRI)
Sean Brodie	Technical Assistant (MAFRI)
Ian Duckworth	Technical Assistant (MAFRI)
Pam Oliveiro	Technical Assistant (MAFRI)

Appendix 3: Publicity Material

Copies of Fisheries Notes (numbers 527 and 529) written and distributed to communicate outcomes of the project to stakeholders and the public.

Fisheries Notes

MAFRI Research & Education

11 August 2002
FN 0527
ISSN 1329-8062

Sand flathead - a bread and butter catch.

Matt Koopman and Sandy Morison, Marine and Freshwater Resources Institute

Sand flathead are the species most commonly caught by recreational fishers in Port Phillip Bay, making up about 60% of the total recreational catch by number. While they are not the most desired species, they are a "bread and butter" catch, providing an easy feed for boat anglers. In comparison, the commercial catch is only about 10% of the recreational catch.

During the 1990s, there were concerns that sand flathead numbers were in decline and that the average size of the fish had decreased. These concerns prompted a MAFRI scientists to examine the population dynamics of sand flathead in Port Phillip Bay.

To gain basic biological information, the age of many thousands of fish was determined by examining growth rings on their ear bones. These data has revealed that sand flathead live for a lot longer than previously thought. The maximum estimated age for sand flathead is 23 years old.

MAFRI scientists have also found that the growth of sand flathead is highly variable meaning that big fish are not necessary old fish. For example the study revealed that a 7 year old female fish could be anything between 22 and 37 cm long and a female fish, measuring 30 cm could be 3 years old or it could be 23 years old.

The size of sand flathead was also influenced by its sex. Female sand flathead, the study showed, are larger on average than male sand flathead. Average size of male and female flathead were 23 cm and 25 cm respectively. The minimum legal size limit for sand flathead is 25cm.

The study has shown that sand flathead are most common in the central basin of Port Phillip Bay, in waters with at least 17 m depth and become less abundant in shallower areas. Large female sand flathead, the study revealed, are most abundant in the shallower areas, while smaller male and female sand flathead are most common in the deeper regions of the bay.

Annual trawl surveys conducted by MAFRI have also revealed interesting patterns in the biology of sand flathead. Recruitment of sand flathead within Port Phillip Bay appears to be highly variable from year to year. Fish abundance can vary by as much 200% between years depending on the success of recruitment in previous years. MAFRI scientists found that recruitment is highly correlated with environmental variables such as river discharge and long-term climate fluctuations predicted by the southern oscillation index, influences recruitment success and are collecting data to validate this theory.

The project is funded by Fisheries Victoria and the Fisheries Research and Development Corporation.

For more information about sand flathead research, contact Matt Koopman at MAFRI on 52580342.

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19 August 2002
FN 0529
ISSN 1329-8062

MAFRI Research & Education

The life and times of rock flathead under investigation.

Matt Koopman, Marine and Freshwater Resources Institute

Little information exists on the life history of rock flathead. This is despite this species being a mainstay of the commercial fishery in Corner Inlet. The annual catch in Corner Inlet in recent years has averaged about 30 t, and is worth approximately $75,000. MAFRI's fisheries scientists are undertaking a two-year research project aimed at collecting some basic biological data on this species.

Matt Koopman, with the help of local fishers, has obtained approximately 1200 rock flathead from Corner Inlet between February 2001 and January 2002. These fish were measured, aged, sexed and their reproductive organs taken for analysis. His work has revealed that on average female rock flathead appear to grow faster and attain a greater size than males. At 5 years old female rock flathead have reached 39 cm on average, whereas males are only 34 cm. At 10 years old females are on average 48 cm and males only 40 cm. The oldest rock flathead found in Corner Inlet was 19 years old. This was a female fish with a length of 55 cm. The largest fish caught from Corner Inlet measured 57 cm in length, and previously the species was thought to reach only 50 cm.

MAFRI scientists have also found that the growth of rock flathead is highly variable meaning that big fish are not necessary old fish. For example the study revealed that a 4 year old male fish could be anything between 28 and 39 cm long and a female fish, measuring 40 cm could be 4 years old or it could be 10 years old.

Rock flathead spawn from September through to February with the maximum spawning effort occurring in October. The reproductive data obtained by MAFRI scientists suggests that rock flathead aggregate according to sex, with some of the catches being heavily dominated by males, and others by females. Similar patterns of aggregation have been observed in sand flathead from Port Phillip Bay and tiger flathead in offshore waters.

These data will be used to develop a stock assessment model for this commercially important species in Corner Inlet. The stock assessment model will provide information to fishers and Fisheries Victoria which will be crucial for the management of a sustainable rock flathead fishery.

The project is funded by Fisheries Victoria and the Fisheries Research and Development Corporation.

For more information about rock flathead research, contact Matt Koopman at MAFRI on 52580342.

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