Development of an environment-recruitment model for black bream: a case study for estuarine fisheries management.

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PROJECT 96/102

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

MARINE & FRESHWATER RESOURCES INSTITUTE

Fisheries Research and Development Corporation

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June 1998

ISBN: 0 7311 3183 5

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SUMMARY

Past studies on black bream in the Gippsland Lakes have shown that recruitment fluctuates from year to year (T. Gorman, unpublished data; Hobday and Moran, 1983) and that the 1987 and 1989 year classes have dominated catches for the last 5 years (CAF, 1996). For the sustainable management of the black bream fishery in the Gippsland Lakes and of similar estuarine fisheries in southern Australia, it is important to understand the extent and reasons for the fluctuations in recruitment success. In order to determine the relationship between recruitment and environmental variables, this study was designed to sample the age structure of black bream in the Gippsland Lakes and to correlate relative year class strengths with environmental conditions in the years prior to and proceeding spawning.

A representative sample of the black bream population was collected using a research beach seine. The age-length key was then applied to the length distribution of the sample to determine dominant year classes. The seven strongest year classes identified between 1971 and 1995 were 1973, 1974, 1979, 1981 (Hobday and Moran, 1983) and 1987, 1989 and 1995 from this study. A series of very low recruitment is evident during the early 1990s. A statistical rank method (Hobday and Moran, 1983) was used to model strong and weak year classes against October temperature and river flow. This method confirmed that dominant year classes were associated with high temperatures and low river flow in October at the start of the spawning season.

To develop a quantitative model, the age structure was back calculated to age 0+ using a range of natural and fishing mortalities, assuming a continuous fishery. Using dynamic regression modelling, monthly and seasonal environmental variables from the year prior to and proceeding spawning were modelled against relative year class strength (log transformed). The dynamic regression models found significant relationships between temperature and rainfall and relative year class strength. The three most significant models were between relative year class strength and February and summer temperature during the spawning season and May rainfall after the spawning season. No significant models were developed with river flow or Southern Oscillation Indices (SOI).

The two temperature models indicate that warmer temperatures may influence the year class strength perhaps by reducing larval mortality by increasing growth rates, reducing the duration of larval stages and by increasing the chances of encountering prey and avoid predation. The rainfall model may influence the relative year class strength by increasing the abundance of prey available through input of nutrients. High rainfall may also flush out stagnant water reducing the mortality of benthic prey items due to hypoxic waters.

These models can be used to predict relative year class strength at age 0+ for black bream in the Gippsland Lakes and together with information on growth and mortality rates can be used to simulate forecasts of future black bream stocks. This will allow managers to make educated changes to fishing pressure in response to feedback from the environment-recruitment models. The same methods used in this study can be applied to other estuarine fish species using either all or some of the existing assumptions depending on their applicability. However, a good knowledge of each species life history, the age structure of the population or a time series of catch-at-age data are required. These methods would most appropriately be used to determine if the environment-recruitment relationship found for black bream in the Gippsland Lakes is area specific or are the same variables influencing black bream stocks in bays and inlets across Victoria.

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BACKGROUND

Black bream (*Acanthopagrus butcheri*) are endemic to temperate Australia and occur in estuarine and coastal waters between Shark Bay (Western Australia) and Mallacoota (Victoria), including Tasmania (Munro, 1949; Hutchins and Swainston, 1986; Gomon *et al.*, 1994). They are fished throughout this range and are one of the most valuable commercial and recreational fish species in Victorian waters. In the Gippsland Lakes, black bream are the most targeted recreational species, providing over 90% of the State's annual commercial catch of this species (Conron and Coutin, 1995; Coutin *et al.*, 1997; Neira *et al.*, 1997).

Historically, there have been large variations in the annual commercial catches of black bream in the Gippsland Lakes (Fig. 1), but a continued decline over the last two decades has prompted concern. While overfishing was considered the most likely cause of this decline, recent investigations suggest other potential causes.

Research on the age structure of black bream in the Gippsland Lakes has revealed large fluctuations in the abundance of successive year classes and regular three to five year periods of very weak year classes (T. Gorman, unpublished data; Hobday and Moran, 1983; CAF, 1996). In the current stock structure, year classes spawned in 1987 and 1989 have dominated catches and there has been a four year sequence of low year class strengths since 1990 (CAF, 1996; Coutin *et al.*, 1997; Morison *et al.*, in press). This suggests that recruitment variation may be an important factor influencing black bream stocks.

Recruitment fluctuations are a characteristic of many fisheries (Sissenwine *et al.*, 1988). These fluctuations have generally been attributed to a number of environmental factors such as rainfall (eg. Crecco *et al*, 1986; Griffin, 1993), sea surface temperatures (SST) (eg. Helminen and Sarvala, 1994; Rutherford and Houde, 1995; Francis *et al.*, 1995), winds and currents (eg. Harris *et al.*, 1988; Thresher, 1994), river flow (eg. Harris, 1988; Harris and Gehrke, 1993) and El Niño events (eg. Kope and Botsford, 1990; Thresher, 1994). Any of these factors may affect recruitment by altering spawning time and location, distribution of eggs and larvae, production of larval food, and survival of larvae and juveniles (Hennemuth *et al.*, 1980). However, determining the underlying processes can be difficult due to the complex interactions of environmental conditions and different life-history stages.

For black bream, it has been suggested that spawning success requires specific environmental conditions (Potter *et al.*, 1996). In the Gippsland Lakes these conditions are warm, brackish waters of 19-21 ppt and 21 °C and occur during the spawning period between October and January (Butcher, 1945). Ramm (1986), however, reported that black bream spawned in all conditions and that year class strength was related to larval survival. In addition Ramm (1986) suggested that high river discharge in the spring would increase levels of nutrients and plankton in the lakes prior to spawning, and that high temperatures at the time of first feeding would reduce the rates of larval mortality. Whatever the process, it is apparent that environmental conditions in the Gippsland Lakes such as salinity, temperature and water quality play an important role in the recruitment success of black bream.

In an effort to determine this role, Hobday and Moran (1983) were the first to model the relationship between fluctuations in environmental conditions and the age structure of black bream stocks in the Gippsland Lakes. They developed an environment-recruitment model using the dominant year classes as indices of recruitment strength. Their results showed a positive relationship between a combination of low river flow from the Mitchell and Latrobe Rivers and high temperatures in October prior to spawning, and strong recruitment. They concluded that water conditions at the time of spawning (19-21 ppt and 21 °C) were critical for determining year class strength and that the low inflow of freshwater and higher temperatures at that time would provide these optimal environmental conditions.

NEED

Adoption of the precautionary principle in fisheries management implies the ability to act in advance to prevent or minimise negative impacts on stock abundance. Recruitment failure is one such impact which has been highlighted as a major reason for the collapse of many fisheries (Thresher, 1994). For example, overfishing of spawning stocks in major oceanic fisheries in the Northern Hemisphere is often attributed as one of the main causes of recruitment failure. Consequently, a range of models were developed to try to understand the relationship between spawning stock and recruitment so potential recruitment failure could be predicted and prevented (eg. Ricker, 1954; Beverton and Holt, 1957). These "stock-recruitment" models have been widely applied across many fisheries. More recently, it has become apparent that inclusion of environmental parameters into stock-recruitment models has significantly improved their predictive ability (Tang, 1985; Fogarty, 1993). In fact, for some inshore and estuarine fish stocks, the impact of environmental conditions on recruitment is often considered to be of greater importance than the spawning stock level (Hennemuth *et al.*, 1980; Harris *et al.*, 1988; Thresher, 1994). This is not to say that overfishing is not a problem: very low spawning stock levels can still reduce potential recruitment but it emphasises that other factors are involved. This is important because, typically, different harvesting sectors have blamed each other for declines in stock abundance. The black bream fishery in the Gippsland Lakes is no exception.

Industry and public awareness of the relation between environmental conditions and fluctuations in black bream recruitment in the Gippsland Lakes will result in a better understanding on the natural dynamics of these fish stocks, and perhaps help improve the understanding between the recreational and commercial sectors. It is often impossible to control fluctuations in environmental variables and the resulting size of the stock available for capture. Therefore, sustainable management of a fishery relies on the ability to make informed changes to fishing pressure in response to feedback from environment-recruitment modelling and/or pre-recruit monitoring (Walters and Collie, 1988).

Hobday and Moran (1983) provided a qualitative model that associated strong and weak year classes with environmental conditions. Whilst this was an important achievement, the next phase was to develop a predictive model that would help provide managers with a means of quantifying year class strength based on specific environmental variables. This was the main aim of the present study. The steps to achieve this aim required: (a) the determination of a time series of black bream catch-at-age data to provide an index of relative year class strength; (b) compilation of a time series of environmental parameters; and (c) the association of these two data sources in a quantitative model. These three steps are reflected in the project objectives.

OBJECTIVES

1. To determine the age structure and relative abundance of cohorts of black bream within the Gippsland Lakes.

2. To collate and analyse the available environmental data from the Gippsland Lakes and nearby regions.

3. To develop an environmental - recruitment model for black bream to forecast future stocks in the Gippsland Lakes.

MATERIALS AND METHODS

Study area

The Gippsland Lakes are a group of coastal lagoons in south-eastern Victoria separated from the sea by broad sand barriers (Bird, 1978), and connected to Bass Strait via a narrow channel at Lakes Entrance. The lakes include Wellington, Victoria and King covering an area of 400 km^2. They are fed by five main river systems: the Latrobe and Avon rivers which flow into Lake Wellington, and the Mitchell, Nicholson and Tambo rivers which flow into Lake King (Fig. 2). The Mitchell and the Latrobe rivers supply more than 50% of freshwater into the Gippsland Lakes (Latrobe Valley Water and Sewage Board, 1978).

Sampling methods

A small research beach seine and a standard commercial beach seine were used to sample the population of black bream in the Gippsland Lakes. The commercial beach seine was used to sample areas further offshore than the research beach seine (Table 1).

One week sampling sessions were carried out in December 1996 and February 1997. Inshore sampling was considered to be most effective during these months because black bream are distributed throughout the warmer shallow waters around the shoreline during the summer and autumn periods, and not in the deeper regions and rivers where they are generally found during winter and spring (B. McKenzie and A. Allen, Gippsland Lakes Commercial fishers, pers. comm.).

Sampling was undertaken in five of the six regions (2-6) sampled by Hobday and Moran (1983), each defined by their physio-chemical characteristics (Mobley *et al.*, 1982) (Fig. 2). No sampling was carried out in Region 1 (Lake Wellington) due to low catches of black bream from this area in December 1981 (Hobday and Moran, 1983) and low commercial catches in recent years (MAFRI, 1997). Due to the comparatively large area of Region 2 (Lake Victoria), this area was divided in two regions, ie. 2a and 2b.

Each region was divided into 1x1 nautical mile grids. The research beach seine was set at five sites located in randomly chosen grids, and at one site on a fixed location previously sampled by Hobday and Moran (1983). If conditions at random sites within a grid were impractical for sampling due to snags or thick seagrass, an alternate random grid was selected. The same sites were sampled in December 1996 and February 1997. In addition to the sites sampled by the research beach seine, one site was sampled with the commercial beach seine in December 1996 and a further five sites, one in each region (2a, 2b, 4, 5 and 6), in February 1997. Due to the large amount of seagrass in Region 3, sampling with the commercial beach seine was excluded from this area.

All commercial fish species caught with both beach seines in both months were identified and counted and the length frequencies and total catch weight were recorded (Tables 5 and 6). The fork length (FL) of all black bream were measured and rounded down to the nearest 0.5 cm. If catches were large (> 60 kg), a random subsample was measured and the length frequency distribution weighted accordingly to obtain total number and size frequency of black bream in the catch. Length-frequency distributions of black bream caught by the different gear and in different regions were compared.

Age structure

To determine the age structure and dominant year classes of black bream in the Gippsland Lakes, an age-length key was applied to a representative length-frequency distribution of the population. A total of 620 black bream were randomly sampled from catches by both beach seines during February 1997 to develop this age-length key. All unbroken otoliths were assigned a number, weighed, embedded in resin and later sectioned for ageing using standard methods (Morison *et al.*, in press). Black bream were assigned year classes based on the year in which it was spawned ie. black bream are assumed to have birthdate of January 1st, therefore a 2 year old black bream caught in February 1997 is from the 1995 year class.

The relative number of black bream in the different year classes was estimated using the following method (modified from Francis *et al.*, 1995):

1. The length-frequency distribution of black bream with 0.5 cm class intervals was recorded at each sampling site. If total catch was not measured, length frequencies were adjusted to represent total catch.

   If N_{ijkl} = number of fish *i* at length class *j* at the *k* th site in the *l* th region, then the total number of fish per length class *j* per site *k* per km^2 can be expressed as:

   $N_{ijkl} / AF * 10^6$

   where *AF* is the area fished (m^2).

2. The average number of fish per length class *j* in each region *l* is given by:

   $AV_{jl} = \Sigma_k \Sigma_i \, N_{ijkl} / n$

   where *n* is the number of sites per region, $j \varepsilon [1,45]$ and $k \varepsilon [1,6]$.

3. Therefore the number of black bream per length class *j* in each region *l* is calculated by:

   $AV_{jl} * SA_l$

4. So the sum across each length class *j* across the total sampled area (regions 2 - 6) is given by:

   $\Sigma_j AV_{jl} * SA_l$

   This provides a weighted length-frequency distribution for black bream in the Gippsland Lakes survey area.

5. The age-length key was then applied to the length-frequency distribution (step 4) to estimate the number of black bream in each year class present in the entire survey area.

This method assumes that:

- black bream were randomly distributed in each region during the sampling period;
- immigration and emigration during the sampling period were negligible;
- black bream from all length classes were equally vulnerable to capture; and,
- the catch was representative of the entire black bream population of the Gippsland Lakes.

To maintain the validity of the last two assumptions, it was necessary to consider whether the catches by the two sampling beach seines at different times were representative of the population. Catch rates during December 1996 were low and the sample caught by both beach seines was not considered large enough to be representative of the population. During February 1997, catches by the commercial beach seine undersampled fish < 13 cm FL probably due to either the mesh selectivity or the distance at which this net fished from the shore. Consequently, commercial beach seine catches were not considered to be representative of the black bream population in both sampling months. Samples caught in the research beach seine in February 1997 were considered to provide a better representation of the size structure of the black bream population in the Gippsland Lakes. The research seine caught a large number of black bream representing a broad size range and did not appear show mesh selectivity. Therefore, these samples were used to determine the age structure of black bream in the Gippsland Lakes and in the modelling.

Determination of relative year class strength

Ultimately, we were trying to determine the relative year class strengths of black bream when they were spawned, ie. at age zero. These would not be the same as the relative year class strengths observed in our samples because older year classes have been subjected to longer periods of fishing mortality (F), while younger year classes may have only been reduced by natural mortality (M). It was then necessary to use the current relative abundance of each year class and extrapolate them back to age zero so they could be compared with each other. Thus, to estimate the year class strength, we initially investigated the use of discrete and continuous models with different combinations of F and M. (Hilborn and Walters, 1992).

In the discrete model, it is assumed that fishing takes place over a relatively short time period within each year, and that the effects of natural mortality are negligible while fish are subjected to fishing mortality (Hilborn and Walters, 1992). Although the black bream fishery does not take place over a discrete time period, the reduction in numbers of black bream over the legal minimum size can be assumed to be mostly affected by the fishing mortality. Thus, numbers at time t_{-1} can then be back calculated using the equation :

$$N_{t-1} = (N_t\, p + C_t) / S \qquad 1.$$

Where N_{t-1} was the number alive after the fishery the previous year, $N_{t+}$is the number alive after the fishery the present year, C_t is the catch during the present year's fishery (equation 2), S is the survival rate (equation 3) and p is the proportion of black bream greater than legal minimum length within an age class.

$$C_t = N_t\ (1 - e^{-Ft}) \qquad 2.$$

$$S = e^{-M} \qquad 3.$$

In the continuous model, it is assumed that the survival of a cohort is governed by both M and F over a continuous time period. The numbers of fish in each year class at time t was calculated using the equation:

$$N_{t-1} = N_t\, p\ e^{M} + C_t\ e^{M/2} \qquad 4.$$

Natural mortality was assumed to be constant across and within year classes, while F was assumed to affect a proportion of black bream within each age class past the age of 5 years (Table 2). The methods for estimating of total mortality (Z) and M are given in Appendix A. Four scenarios of mortality estimates were used as described in Table 3. The relative year class strength was calculated from the ratio number of black bream in each year class to the average number of black bream in all year classes over the time period.

Preliminary results showed that the assumptions of the continuous model proved most appropriate for the black bream fishery in the Gippsland Lakes, therefore, the results and conclusions presented in this report are based on this method.

Environmental data

A fortnightly environmental monitoring program in the Gippsland Lakes was established in July 1996. Dissolved oxygen (DO) concentration, salinity and temperature were measured at selected sites throughout the lakes from Holland's Landing to Shaving Point, and in each of the three rivers flowing into Lake King (Fig. 3). These data were used to describe the seasonal changes in environmental conditions of the Gippsland Lakes for the duration of this project.

For modelling purposes, a longer time series of environmental data was required. Historic data on the long term changes in the environment of the Gippsland Lakes were obtained and collated from a variety of sources (Table 4). Since continuous data sets longer than 5 years were unavailable for salinity and water temperature in the Gippsland Lakes, data on river flows from the Mitchell River, and rainfall and air temperature from Bairnsdale were used as indicators of salinity (Mobley *et al.*, 1982) and water temperature, respectively.

The Southern Oscillation Index (SOI) (QDPI, Internet) was also used as a variable in the environmental modelling. The SOI measures the difference in air pressure between Tahiti and Darwin and ranges from +30 to -30. When the SOI is strongly positive (> +5), eastern Australia has a 75% probability of receiving greater than average rainfall whereas when the SOI is strongly negative (<-5), there is a 75% probability of below average rainfall in eastern Australia.

Development of environmental-recruitment model

Hobday and Moran (1983) developed a qualitative model linking dominant year classes of black bream in the Gippsland Lakes to environmental conditions. In their study, October river flow from the Latrobe and Mitchell rivers and mean October temperature were ranked and combined to give a score for a particular year. On a scale of 1 to 10, river flow was ranked from lowest to highest and temperature from highest to lowest. This method was repeated during the present study on a combined data set from 1972 to 1996, with river flow and temperature being ranked from 1 to 25, having a maximum score of 50. A score > 35 was considered to describe the environmental conditions suitable for a strong year class. A one way ANOVA was used to determine whether mean rank scores from strong year classes were significantly higher than those from weak year classes.

Dynamic regression models were used to obtain possible relationships between relative year class strength and environmental variables as in Sporcic *et al.* (1997). Two time series were analysed: from 1986 to 1995 only; and combined data from 1971 to 1995. As previously described, the relative year class strengths were estimated from the calculated abundance of those at age zero using the continuous model and a range of mortality estimates (Table 3). 1982, 1983 and 1984 year classes were assumed to be missing due to their absence from samples. Monthly and quarterly averages of temperature and SOI, and total monthly, quarterly and annual rainfall and river flow from the year prior to and after spawning were modelled against relative year class strength (log transformed) to determine possible significant relationships. These time intervals were chosen based on previous studies which suggest that months during the larval period, and when the fish are young-of-year, are the most critical for the survival of a year class (Cowan *et al.*, 1993; Rutherforde and Houde, 1994; Francis *et al.*, 1995). The environmental variables were highly correlated and therefore no models were developed using multiple variables.

Environmental variables associated with recruitment are often autocorrelated (Fogarty, 1993). After having modelled the variation with the environmental variables, the residuals may also exhibit autocorrelation. The Durbin-Watson statistic (D-W) was thus used to test for the presence of first and second order autocorrelations. The presence of autocorrelated residuals may be modelled using ARIMA (autoregressive integrated moving average) methods (Chatfield, 1989). The autocorrelation and partial autocorrelation function plots were used to detect the appropriate lag of the autocorrelation required to reduce the residuals to a random process.

RESULTS

Catch rates of black bream

In December 1996, black bream were caught at 25 of the 33 sites sampled by the research beach seine , most of which were in regions 2b and 5. Black bream was the third most abundant species caught, with a total catch of 36 kg, comprising 450 fish and a catch rate of 14 fish/shot with the research seine (Table 7). In February 1997, black bream was the most abundant commercial species with the highest catches in regions 2a, 2b and 4. A total of 624 black bream (19 fish/shot) were caught (73 kg) with the research seine at all 33 sites. 1122 kg of black bream were also caught from five commercial beach seines. Tables 5 and 6 outline the catch weight, number of fish and length range of all commercial species caught by both beach seines and the habitat type of the sites sampled.

Length frequency

In December 1996, the length frequency distribution of black bream caught in the research net ranged from 7.5 to 25 cm FL. The length distribution was bimodal with peaks at 11 and 18.5 cm FL (Fig. 5). Only 2% of fish sampled were greater than legal minimum length (eg. 23 cm FL, 26 cm TL). The length frequency distribution of black bream caught by commercial beach seine ranged from 11 to 37 cm FL. The distribution was also bimodal with peaks at 13 and 19 cm FL with 5% of the fish sampled being above size (Fig. 5).

In February 1997, black bream caught by the research beach seine ranged from 3 to 41 cm FL, and showed a bimodal distribution with a large peak at 13 cm FL and a smaller peak at 19.5 cm FL (Fig. 6). Only 7 % of the total black bream caught were over the legal minimum length. Although length frequency distributions varied considerably between regions, very few fish were caught south of Raymond Island (Region 3) and no fish > 17.5 cm FL were caught by research beach seine in Reeves Channel (Region 6) (Fig. 7). The length frequency distribution from the research seine (all areas combined) was assumed to be representative of the black bream population and further used to describe the age structure.

The length distribution of black bream caught in the commercial beach seine throughout the Gippsland Lakes in February 1997 was bimodal, with a minor peak at 13-15 cm FL and a major peak at 19 cm FL and (Table 8). Only 5% of black bream caught were over legal minimum length (Fig. 6). Commercial beach seine catches in eastern Lake Victoria (Region 2b), Jones Bay (Region 5) and Reeves Channel (Region 6) were bimodal, with peaks at 13 and 19-20 cm FL (Fig. 8). By contrast, catches from the west end of Lake Victoria (Region

2a) and Lake King (Region 4) were unimodal and dominated by a large number of fish at 17.5 and 18.5 cm FL, respectively. A single catch of 500 kg of black bream from Lake King (Region 4) dominated the length-frequency distribution of the commercial beach seine.

Age structure

Black bream sampled during the survey ranged from 2 to 21 years of age. The majority of black bream from 11 to 15 cm FL represented fish from the 1994 and 1995 year classes, while those of 16 cm FL were aged between 2 and 8 years of age (Table 9, Fig. 9). Black bream > 18 cm FL were generally from the 1987 and 1989 year classes.

The dominant year classes of black bream in the Gippsland Lakes were spawned in 1987 (age 10+), 1989 (age 8+), 1994 (age 3+) and 1995 (age 2+) representing 8.7, 25.5, 9.9 and 47.3% of the numbers of black bream, respectively. The 1993 year class was present in small numbers (6%), while the remaining year classes were poorly represented (Fig. 10). When initial numbers (ie. numbers of fish in year class at age 0) were back calculated assuming a continuous fishery, the relative year class strength of the 1987, 1989 and 1995 year classes were 2.8, 4.1 and 3.3, respectively. Therefore, 1989 was the strongest year class being 48% greater than the 1987 year class and 23% greater than the 1995 year class (Fig. 11).

Environmental conditions

Salinity

Salinity within the Gippsland Lakes varied with month, depth and distance from the lakes entrance. Mean surface salinities ranged from 0.6 ppt in the Mitchell river in October 1996 to 21.1 ppt at Shaving Point in February 1997. Bottom salinities reached a maximum of 32.5 ppt at Shaving Point in July 1996 and were lowest in the Nicholson river in October 1996. During the 1996/97 spawning period, optimal spawning salinity (19-21 ppt) was recorded in the bottom waters of the eastern end of Lake Victoria, Lake King (south of Raymond Island) and Reeves Channel (Regions 2b, 3 and 6 respectively) (Fig. 14).

Surface salinity was negatively correlated with the monthly river flow into the Gippsland Lakes lagged by one month during the study period (Fig. 12). The mean river flow between 1980 and 1996 into the Gippsland Lakes was generally lowest in February and March, and peaked in September and October. The Latrobe and Mitchell rivers had the highest mean freshwater flow into the Gippsland Lakes during September, while the Nicholson, Avon and Tambo rivers all peaked in October but at considerably lower flow rates (Fig. 13). Salinity decreased from July 1996 with the increase in river flow during the spring months and was lowest in October 1996. Bottom salinities were consistently higher than surface waters as the salt wedge from the entrance moved upstream into the lakes (Fig. 14). Bottom salinities were less affected by the freshwater flow into the lakes as freshwater generally forms a layer above the deeper saline waters. Salinity was generally lower in the surface waters of Jones Bay (region 5) where the Mitchell, Nicholson and Tambo Rivers discharge into the lakes, and near McMillan Strait at the west end of Lake Victoria (Region 2a), while the highest salinities were recorded in Reeves Channel (Shaving Point, Region 6). Salinity in Lakes King and Victoria east were similar across months and depths (Fig. 14).

Temperature

Water temperatures in the Gippsland Lakes varied by season, month and depth. Surface temperatures ranged from 10 °C at Shaving Point in July 1996 to 25.5 °C at the mouth of the Mitchell river in February 1997. Bottom layers were generally warmer than surface waters during autumn and winter, and cooler in spring and summer except in December 1996 when temperatures were up to 5 °C warmer at the bottom than at the surface (Fig. 15). Bottom temperatures ranged from 11 °C in July 1996 to 24.5 °C in February 1997, with both values being recorded in Jones Bay.

Dissolved oxygen

Dissolved oxygen (DO) concentrations varied markedly by month, depth and location. There were no seasonal trends in DO levels although low concentrations appeared to be associated with the warmer saline waters below the halocline. Surface concentrations ranged from 83.5 to 127% between October 1996 and January 1997 both extremes being recorded at Waddy Point (east Lake Victoria, region 2b)(Fig. 16). Bottom water of the Gippsland Lakes were often hypoxic. Levels $< 20\%$ DO were recorded in eastern Lake Victoria (region 2b) and Lake King (region 4) between July and October 1996 while the concentrations at the bottom in the west end of Lake Victoria (region 2a) were below 80% during the entire study period.

The lowest DO concentration (0.5 %) was recorded at Mick's Spit (Lake King, region 3) in September 1996 while the highest DO concentration recorded was 148% in Jones Bay (region 5) during a blue-green algal bloom in February 1997.

River flow, rainfall, temperature and Southern Oscillation Index (SOI)

River flow from the Mitchell River fluctuated considerably between seasons and years. Like rainfall, river flow tended to peak in the spring months and was lowest during autumn (Fig. 17). River flow peaked over 2 million ML in 1975, with flood years above 1.5 million ML occurring in 1971 and 1978 (Fig. 18). The lowest annual river flow was recorded in 1983 during an El Niño year, with only 0.21 million ML being discharged into the lakes. River flow from the Mitchell has remained comparatively low since the last flood in 1978.

Generally, rainfall at Bairnsdale peaks during spring and falls to a low in summer (Fig. 17), with February being the driest month. Total monthly rainfall varied considerably between seasons and years, with a mean annual rainfall of 718 mm from 1970 to 1996. The highest and lowest annual rainfall values recorded in the last 25 years were 1153 and 360 mm in 1978 and 1972, respectively (Fig. 18).

Extended periods of strongly negative (< -5 SOI) El Niño events occurred during 1972/73 (autumn to summer), 1977/78 (summer to summer), 1982/83 (winter to autumn), 1987 (summer to spring), and a very long period from spring 1991 to autumn 1995 except for the summers 1993 and 1994 (Fig. 17). Because El Niño events generally occur during winter and spring (QDPI, Internet), the resulting annual rainfall and river flows tends to be greatly reduced. A peak in river flow and rainfall in 1978 corresponded with the breaking of a drought. Periods when the SOI was > 5 for more than 12 months during the last 25 years included 1970/71 (summer to spring), 1973/74 (winter to spring), 1975/76 (autumn to summer) and 1988/89 (winter to autumn). These periods tend to correspond with periods of high river flow and rainfall.

Environment - recruitment model

Ranked model

The ranked model developed by Hobday and Moran (1983) was applied to the combined data from the present study and that collected in 1981. The seven dominant year classes from 1972 to 1996 were: 1973, 1974, 1979 and 1981 (Hobday and Moran, 1983), and 1987, 1989 and 1995 (present study). Our analysis showed a significant relationship between the combined ranks of low October river flow and high October temperatures and a strong year class (α = 0.05) (Table 10). With a score >35, the rank method successfully predicted four (1973, 1979, 1989 and 1995) out of the seven dominant year classes but failed to predict three dominant year classes (1974, 1981 and 1987). The model also predicted three year classes (1978, 1983 and 1992) to be strong but data from Hobday and Moran (1983) and our study suggests they are weak or absent (Table 11).

Dynamic regression model

Based on the continuous fishery model, the dynamic regression analysis for the period between 1971 and 1995 showed no significant correlations between river flow or SOI and relative year class strength. The analysis showed a significant positive correlation between the February temperature at the end of the spawning season and relative year class strength (α = 0.05) (Table 12). The model accounted for 41% of the variation of the relative year class strength (R^2 = 0.41), and predicted the relative strength of the 1979, 1989 and 1995 but underestimated the relative strength of the 1973, 1974, 1981 and 1987 year classes. The model also predicted a number of weak year classes including 1975, 1978, 1986, 1988, 1990, 1992 and 1994 (Fig. 19).

Three of the four mortality scenarios found that relative year class strength was significantly positively correlated with the August temperature of the previous year. Summer temperature and May rainfall were also found to be significantly positively associated with relative year class strength (Tables 12 and 13). Each of the three models developed for February temperature, mean summer temperature and May rainfall explained less than 50% of the variation of the relative year class strength (Table 14, Fig. 19).

When assuming a discrete fishery, the dynamic regression analysis found a statistically significant, positive relationship between the September temperature and relative year class strength (Appendix B). A significant positive relationship ($\alpha = 0.05$) was obtained between rainfall in November at the beginning of the spawning season and the relative year class strength (log transformed), which explained 89% of the variation in year class strength in the last 25 years (Appendix B).

DISCUSSION

Fluctuations in recruitment strength of black bream in the Gippsland Lakes between 1971 and 1995 were related to changes in the environmental conditions of the lakes and surrounding areas around the time of spawning. Significant relationships were found between recruitment and both temperature and rainfall. October temperatures prior to spawning, February and summer temperatures during the spawning season and rainfall in the May after the spawning season were the most significant in the prediction of black bream recruitment strength. No significant models were found using river flow or SOI as the predictive variable.

Temperature-recruitment models

Temperature may influence recruitment strength by either initiating spawning or affecting the survival of larvae (Sissenwine *et al.*, 1988; Harris and Gehrke, 1993; Helminen and Sarvala, 1994; Rutherford and Houde, 1994). Significant relationships were found between temperature and recruitment in the August and October prior to the spawning season and these models accounted for 25% of the variation in relative year class strength. Warm temperatures during these months may influence the start of spawning season because the onset of gonadal development for black bream in the Gippsland Lakes begins in October when temperatures rise above 15°C (Walker *et al.*, unpublished data). Potter *et al.* (1995) found that spawning of black bream in the Swan Estuary, WA was initiated when temperatures increased to 20°C. Harris and Gehrke (1993) also found that gonadal development of Australian Bass was influenced by temperature and thus influenced recruitment success. However, it is likely that the timing of gonadal development is not critical for successful spawning of black bream as it appears they are capable of spawning at a wide range of temperatures (Ramm, 1986; Walker *et al.*, unpublished data) and the strongest relationships between temperature and recruitment strength was found at the end of spawning during February (R^2=0.41).

Average summer temperatures during the last 25 years have been recorded at >26 °C in 1973, 1979, 1989 and 1995, all of which correspond with strong year classes. Very weak year classes were observed in 1986, 1992 and 1996 when the average summer temperatures were below 24 °C. Additionally, the presence of a strong 1981 year class (Hobday and Moran, 1983) coincided with high average February temperatures of 26.3°C, and the very low abundance of the 1996 year class corresponded with low average February temperatures of 22.1°C in 1996.

Thus, we considered that temperature in the Gippsland Lakes is most likely to influence the recruitment strength of black bream during February by increasing the survival during the early larval stages. During the larval and early juvenile stages, warm water temperatures increase growth rates, decrease the duration of the larval stages and enhance the ability of larvae to encounter prey items and avoid predation (Sissenwine *et al.*, 1988; Helminen and Sarvala, 1994; Rutherford and Houde, 1994). Francis *et al.* (1995) found a significant relationship between recruitment strength of snapper (*P. auratus*) and the mean February to June water temperatures in the Hauraki Gulf, NZ. Further studies to compare growth and survival of larval and juvenile black bream in the Gippsland Lakes will help determine if water temperature increases black bream growth and survival through the larval and juvenile stages.

Rainfall-recruitment model

The most significant relationship between rainfall and strong recruitment was a positive correlation with high rainfall in May after the spawning period. This was evident in the rainfall-recruitment model where the strong 1981 year class (Hobday and Moran, 1983) and very weak 1996 year class corresponded with very high rainfall (166.6 mm) and very low rainfall (39 mm) in May of 1981 and 1996 respectively. The model was also supported by the very low monthly rainfall during May of 1990, 1991 and 1992 which coincided with the series of low recruitment from those years.

Past studies have found that rainfall would either initiate spawning or increase food production for larvae and juveniles (Crecco *et al.*, 1986; Griffin, 1993) or it may increase the dissolved oxygen levels in the water column. Because no significant relationship was found to associate rainfall in the months prior to spawning with year class strength, it was considered that the initiation of spawning by rainfall was not a major factor. Higher rain in May, may induce an early winter flood bringing with it more nutrients and higher food production for the growing juveniles.

By May, black bream juveniles are between 5 to 7 months old, and can range in size from 5 to 8 cm FL. Major prey items for small black bream include copepods, amphipods and polychaetes (Rigby, 1984). The abundance of copepods is generally highest in summer but significant inflow of freshwater would be expected to increase zooplankton production as a result of nutrient input (Crawford *et al.*, 1992). As for benthic prey including amphipods and polychaetes, species diversity and numbers tended to be higher in May than in the warmer months in both seagrass and deeper regions of the Gippsland Lakes (Poore, 1982).

It may be possible that the May rainfall also influences the levels of dissolved oxygen in the water column. During summer and autumn, the Gippsland Lakes become vertically stratified and a salt wedge forms along the bottom of the lakes. In drier years, the salt wedge can intrude as far as Lake Wellington and into the Latrobe River resulting in a large area of low oxygenated water across the lakes (Poore, 1982). High river flow assists in the flushing of the salt wedge from the lakes and taking with it the stagnant deoxygenated water (Sherwood and Backhouse, 1982). Low dissolved oxygen levels are unlikely to directly effect the survival of black bream larvae and small juveniles because they congregate near the surface in shallow oxygenated waters and not at the bottom of deeper areas (Longmore *et al.*, 1990). However, low dissolved oxygen levels can result in high mortalities of benthic communities (Poore, 1982). The reduction in abundance of these benthic communities may lead to the reduction benthic prey available for juvenile black bream.

Comparison with other models

Hobday and Moran (1983) hypothesised that recruitment success of black bream in the Gippsland Lakes was related to a combination of low river flow and high temperatures during October at the beginning of the spawning period. They believed that these conditions would result in the onset of the specific salinity and temperature regimes required for successful spawning of black bream. The repeat of their methods during this study support this theory with the mean combined rank score of strong year classes being significantly higher than the mean rank score of weak year classes. However, this method was not quantitative and failed to take into account the combined effects of fishing and natural mortality on the strength of successive year classes. The rank model, therefore could only be used to predict the likelihood of a strong or weak year class but not the relative magnitude of the year class.

It appears that the models developed during this study help support Ramm's hypothesis (1986) that year class strength is related to larval survival. It follows that environmental conditions favourable for optimal food production and larval growth are critical in determining year class strength. Warm February temperatures can lead to faster growth of larvae and reduce the duration of the larval stages. A larger and/or older larvae may have a higher survival rate due to the increased ability to find and capture prey and avoid predation. The significance of high rainfall in May is to increase the food available for growing juveniles, by either increasing the nutrient loading of the lakes or by reducing the mortality rates of prey due to hypoxic waters by flushing out stagnant deoxygenated water.

Limitations and improvements

Overall even the best models only accounted for 41% of the variation in the relative year class strength. The variation between the estimates of relative year class strength and the models predictions in both the discrete and continuous fishery models could be due to a variety of factors. First, there are likely to be limitations in the models ability to back calculate to abundance estimates at age 0+. The use of empirical formulae to determine natural mortality of black bream, and the assumption that this mortality is constant throughout the various life history stages is an obvious oversimplification. Age-specific mortality is a characteristic of many fisheries (Goodyear, 1996) but is was unable to be incorporated into the present models. A long term program to monitor the age structure of black bream in the Gippsland Lakes prior to their recruitment to the fishery would be the most appropriate method for assessing such mortality.

Secondly, black bream are a pat of a complex ecosystem and modelling a few environmental variables is unlikely to capture many of the other biotic and abiotic factors which could influence year class strength, larval survival and recruitment to the fishery. Predicting recruitment strength from single environmental variables may be misleading (Walters and Collie, 1988) and needs to be taken into account when using such models for management purposes. It is not known what factors influence the survival of a year class of black bream between their first year and the time by which they reach legal minimum length. Survival through to legal size may be influenced by predation, unfavourable climate conditions and disease, bycatch and illegal capture of undersized fish. Density dependant factors, for example where the actual size of the year class is the limiting factor on the size of successive year classes, may also be important. These effects were not modelled in the current study.

Due to the short time series of our data, we are unable to determine the impact a strong year class, (eg. 1995) has on the future catches of black bream. Until we have monitored the progression of such a cohort throughout the prerecruit stages and movement into the fishery, there will always be difficulties in using such models for catch forecasting. An increased time series length may also accommodate more than one environmental variable in the dynamic regression models, and may strengthen the relationship of the environment and fishery variables. Also, long term cycles of the environmental conditions may be included in models and improve its predictive capabilities.

Application of the environment-recruitment models

These models can be used to predict the relative strength of a year class of black bream at age 0+ in the Gippsland Lakes. By comparing these year class strengths to that of strong year classes such as the 1989 year class, managers will be able to assess the future status of the black bream stocks in the Gippsland Lakes.

In conclusion, the same methods used in this study can be applied to other estuarine fish species using either all or some of the existing assumptions depending on their applicability. However, a good understanding of each species life history, the age structure of the population and time series of catch-at-age data are required. The age structure of the different species will directly determine the length of the time series used in modelling and hence provides a way to test this method. It would be most appropriate to apply these methods to the black bream populations within other Victorian coastal systems, such as Mallacoota Inlet and the Hopkins River, to determine if these relationships are area specific or are associated with the survival of black bream across all bays and inlets.

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BENEFITS

The main objective of this study was to develop an environment - recruitment model for black bream as a case study for estuarine fisheries. This study resulted in the development of three models that were statistically significant for predicting relative year class strength. However, the accuracy of these models for future predictions may only come in time. The knowledge of the dominant year classes and the presence of low, almost absent year classes within the fishery, as well as the large variation in the growth rates of black bream within age classes, has been conveyed to managers and industry. The notion that more than 80% of the numbers of black bream sampled from 1989 year class were below the LML has brightened the outlook on the black bream stocks in the Gippsland Lakes for the present time. Managers, commercial and recreational sectors, bait suppliers and the general public have been informed of the environmental conditions of the Gippsland Lakes and the relative importance of water quality to the health of black bream stocks. A model has been proposed to be developed over the next year that maps the progression of year classes through the fishery, with alternate scenarios of natural and fishing mortality that will allow managers to plan their response to environmentally forced variability in stock abundance.

INTELLECTUAL PROPERTY

The value of the intellectual property will be 61.72 % based on Part C of the FRDC project proposal.

FURTHER DEVELOPMENT

Sampling for black bream in the Gippsland Lakes will continue as a part of the Victorian Fisheries projects to monitor the age structure of black bream stocks and to develop a method for monitoring pre recruits. A time series of age structures will provide valuable information on the levels of natural and fishing mortality, which has previously been estimated from catch data and empirical formulae. The information gathered will be used to develop a dynamic management model based on the variation in growth rates between and within year classes, and the variations of natural and fishing mortalities. These models will then be used to follow single cohorts through the fishery using various levels of fishing pressure and initial abundance estimates to produce estimates of stock biomass and future catches.

PUBLICATIONS, CONFERENCES AND WORKSHOPS

Black bream stock assessment workshops, 1996 and 1997.

Coutin, P.C., Walker, S. and Morison, A. (eds) (1997). Black bream 1996. Victorian Fisheries Assessment Report. Compiled by the Bays and Inlets Stock Assessment Group. (Victorian Fisheries and Research Institute: Queenscliff)

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ACKNOWLEDGMENTS

We wish to thank Mr Barry McKenzie and Mr Arthur Allen (Gippsland Lakes commercial fishermen) for their assistance with the field sampling. Their knowledge of the Gippsland Lakes and the habits of black bream was invaluable. Appreciation to Graeme Bills for the collection of fortnightly environmental data and help during the sampling periods. Thank you to the Central Ageing Facility (MAFRI) for assistance in the ageing of black bream and cross checking of otolith readings. Many thanks to Ian Knuckey, Francisco Neira and David Smith for their assistance with the editing of the report. The project staff wish to thank the FRDC for funding the project and the Gippsland Lakes fishers for their support of this research.

FINAL COST (FRDC)

Item	Expenditure
Salaries	$59,125
Travel	$8,000
Operating	$16,000
Capital	$2,000
TOTAL	$85,125

DISTRIBUTION

A copy of the FRDC Final Report has been sent to the following:

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TABLES

Table 1 Dimensions of the research and commercial beach seines used for sampling in December 1996 and February 1997.

Net Dimensions	Research beach seine	Commercial Beach seine
Net length (m)	175	732
Haul rope length (m)	20	100
Mesh size wings (mm)	38	95
Mesh size bunt (mm)	16	38
Drop (m)	3	4.75
Distance set from shore (m)	approx. 50	approx. 200
Area fished (m^2)	4,750	57,057

Table 2. The proportion of black bream (p) to reach legal minimum length at a given age.

Age	p
12	0.87
11	0.8
10	0.68
9	0.5
8	0.34
7	0.22
6	0.07
5	0.05
4	0
3	0
2	0
1	0

Table 3. Mortality parameters (Z, M and F) used for the back calculation of relative year class strengths (YCS) for black bream in the Gippsland Lakes. See Appendix A. for details.

Relative YCS Scenario No.	Total Mortality (Z)	Natural Mortality (M)	Fishing Mortality (F)
1	1.1	0.27	0.83
2	0.9	0.27	0.63
3	1.1	0.14	0.96
4	0.9	0.14	0.76

Table 4. Environmental data used in modelling.

Source	Parameters	Units	Location	Time Period
THEISS Environmental Services	River flow	mL/day	Glenaladale, Mitchell River	1980 - present
		daily mean per month	Deptford, Nicholson River	1980 - present
			Ramrod Creek, Tambo River	1980 - present
			Stratford, Avon River	1980 - present
			Rosedale, Latrobe River	1980 -1988
State rivers and water supply commission	River flow	mL/day	Glenaladale, Mitchell River	1970-1980
		monthly discharges		
(data was supplied by Dave Hobday, MAFRI)			Rosedale, Latrobe River	1970-1979
EPA database	Salinity	ppt	Sites through out Lake King	Apr-89 to May-96
	Water Temperature	degrees Celsius	and Lake Victoria	Apr-89 to May-96
	Dissolved Oxygen	mg/L		Apr-89 to May-96
Bureau of Meteorology	Rain fall	Total per month (mm)	Bairnsdale	1984-1993
	Rain days	Total per month		1984-1993
	Air Temperature	Max, min degrees C		
	Air Temperature	Max, min degrees C	Bairnsdale (Historical)	1970 - 1983
Internet	SOI	monthly average		1970 to present
MAFRI	Dissolved Oxygen	% saturation	Sites throughout Lake King	Fortnightly from
	Salinity	ppt	and Lake Victoria (Fig. 3)	Jul-96
	Water Temperature	degrees Celsius		

Table 5. Catch composition of the commercial species caught by the research and commercial beach seines during sampling in December 1996 in the Gippsland Lakes. Catch weight, number of fish caught and length range are recorded, and the habitat of site is also provided.

Site/Lake	Habitat	Species Common Name	Catch weight (kg)	Number of fish	Length range (cm FL)
2a.1 Lake Victoria	Sand	Black bream	0.08	1	16
		Australian salmon		1	10
		Yelloweye mullet	1.525	41	6.5 to 33
2a.2 Lake Victoria	Sand	Black bream	3.8	41	9.5 to 25
		Yelloweye mullet	1	7	10 to 31.5
		European carp	80	27	18.5 to 66
2a.3 Lake Victoria	Sand	Black bream	1.825	8	9.5 to 22.5
		Yelloweye mullet	3.825	14	17 to 33
		European carp		1	43.5
2a.4 Lake Victoria	Sand	Black bream	2.325	10	19.5 to 23.5
		Yelloweye mullet	1.725	29	6.5 to 30
		Australian salmon		2	10.5 to 11
		Silver trevally		1	13
		European carp	1.8	1	41.5
2a.5 Lake Victoria	Sand	Yelloweye mullet	1.5	13	9.5 to 29.5
		Australian salmon	0.1	4	9.5 to 12
		European carp	3.75	1	54.5
2a.6 Lake Victoria	Sand	Black bream	0.15	1	21.5
		Yelloweye mullet	2.85	29	8.5 to 31.5
		Australian salmon		1	10.5
2b.1 Lake Victoria	Sand	Black bream	0.06	2	11
		Yelloweye mullet	3.435	15	16 to 31
2b.2 Lake Victoria	Sand & 50% seagrass	Yelloweye mullet	9.00	48	16.5 to 28.5
		Australian salmon	0.9	3	10.5 to 27
2b.3 Lake Victoria	Sand & 50% seagrass	Yelloweye mullet	63.00	217	12.5 to 30.5
		Australian salmon	1.225	6	10.5 to 26
2b.4 Lake Victoria	Sand & 25% seagrass	Black bream	0.68	4	18 to 20.5
		Yelloweye mullet	20.00	130	16.5 to 27
		Australian salmon	3.285	36	10 to 26.5
2b.5 Lake Victoria	Sand & 50% seagrass	Black bream	12.00	149	9.5 to 23.5
		Yelloweye mullet	0.58	3	22 to 23
	Ruppia sp.	Silver trevally	0.10	1	19.5
	epiphytes on seagrass	Australian salmon		1	11.5
3.1 Lake King	Sand & 75% seagrass	Black bream	0.425	2	19.5 to 23
3.3 Lake King	Seagrass	Black bream	2.00	56	9.5 to 20.5
		Yelloweye mullet		2	11.5 to 12
		Luderick		2	3 to 5.5
		Silver trevally		1	18
3.4 Lake King	Seagrass	Black bream	0.5	2	19.5 to 25
	epiphytes on seagrass	Silver trevally			
3.5 Bunga Arm	Seagrass	Black bream	0.4	2	14 to 18.5
3.6 Bunga Arm	Sand bank & seagrass	Black bream	2.3	17	10 to 21.5
		Silver trevally	0.11	1	23
4.1 Lake King	Seagrass	Australian salmon	1.00	3	25 to 29
	Ruppia sp.				
	algae in shallows				

Table 5. Continued.

4.2 Lake King	Seagrass *Ruppia sp.*	Yelloweye mullet	0.875	3	24.5 to 29
4.3 Lake King	Seagrass	Yelloweye mullet	2.7	5	27.5 to 30.5
4.4 Lake King	Sand bank & seagrass algae in shallows	Black bream	0.08	2	11 to 12
4.5 Lake King	Sand & 75% seagrass *Ruppia sp.*	Black bream		1	11
		Yelloweye mullet	0.565	3	8.5 to 30.5
5.1 Jones Bay	Sand	Black bream	2.6	24	11.5 to 23
		Yelloweye mullet	0.5	8	12 to 20.5
		River garfish	0.07	3	17 to 18
5.2 Jones Bay	Rocky sand & seagrass algae in shallows	Yelloweye mullet	0.95	15	11 to 38.5
		River garfish		4	12.5 to 14.5
5.3 Jones Bay	Sand	Black bream	3.5	75	7.5 to 20.5
		Yelloweye mullet	1.8	37	11 to 20
		Australian salmon		3	10 to 12
		River garfish	0.5	23	12 to 24
		Tailor		3	15.5 to 17.5
5.4 Swan Bay	Sand & 75% seagrass *Ruppia sp.*	Black bream		1	11.5
		Luderick		2	5
5.5 Jones Bay	Rocky sand	Black bream	0.745	11	9.5 to 16.5
		Yelloweye mullet	2.025	25	13 to 27
		Luderick		1	6.5
		River garfish		15	13 to 17.5
		Australian salmon	0.68	18	9 to 13
5.5 Jones Bay		European carp		1	56
		Brown trout		1	22.5
5.6 Research seine Jones Bay	Rocky sand algae present	Black bream	0.55	11	10 to 22.5
		Yelloweye mullet	1.225	5	17.5 to 33
		European carp	8.8	2	
		Australian salmon		2	11.5 to 12
5.6 Commercial seine Jones Bay	Rocky sand	Black bream	115	392	11 to 37
		Yelloweye mullet	6	19	23 to 34
		Australian salmon	2.7	7	23.5 to 27
		Silver trevally		1	18.5
		Brown trout	0.975	2	22.5 to 37
		European carp	40.00	11	57.5 to 74.5
6.1 Reeves Channel	Seagrass epiphytes on seagrass	Black bream		2	16 to 18.5
		Yelloweye mullet	0.42	27	6.5 to 23
		Silver trevally	11.5	47	18.5 to 25
		Australian salmon	0.2	7	7.5 to 22.5
6.2 Reeves Channel	Seagrass *Ruppia sp.*	Black bream	0.725	17	9.5 to 21.5
6.3 Reeves Channel	Seagrass	Black bream	0.61	7	18.5 to 22
6.4 Reeves Channel	Sand & 75% seagrass *Ruppia sp.*	Yelloweye mullet	0.85	33	7 to 28.5
6.5 Reeves Channel	Sand & 50% seagrass	Black bream	0.388	3	12 to 20.5
6.6 Reeves Channel	Sand & 75% seagrass	Estuary perch	0.08	2	8 to 19.5
		Luderick		4	4 to 5
		Silver trevally		1	15.5
		Leatherjacket		1	19.5

Table 6. Catch composition of the commercial species from research and commercial beach seines during sampling in February 1997 in the Gippsland Lakes. Catch weight, number of fish and length range are recorded, and the habitat of site is also provided.

Site/Lake	Habitat	Species Common name	Catch weight (kg)	Number of fish	Length range (cm FL)
2a.1	Sand	Black bream	0.575	2	20 to 22
Lake Victoria		Australian salmon		1	16.5
		Yelloweye mullet	5.085	49	15 to 24
2a.2	Sand	Black bream	10.2	129	12 to 24
Lake Victoria	algae in shallows	Yelloweye mullet	9.77	59	10 to 29.5
2a.3	Sand	Black bream	5.6	51	11 to 24
Research seine		Yelloweye mullet	0.575	24	10.5 to 14
Lake Victoria					
2a.3	Sand	Black bream	136	545	12.5 to 40.5
Commercial seine		Yelloweye mullet	7.5	24	26 to 34
Lake Victoria					
2a.4	Sand	Black bream	2.43	12	16 to 24
Lake Victoria		Yelloweye mullet	1.75	14	16.5 to 25.5
2a.5	Sand	Black bream	0.16	1	19
Lake Victoria		Yelloweye mullet	10.05	58	18.5 to 32.5
		River garfish		15	9 to 23.5
2a.6	Sand	Yelloweye mullet	1.25	10	14 to 29.5
Lake Victoria		Brown trout	0.14	1	25
		Tailor	0.55	1	32
2b.1	Sand	Yelloweye mullet	4.725	23	22 to 29
Lake Victoria					
2b.2	Sand & 50% seagrass	Black bream	0.85	4	13.5 to 21
Lake Victoria		Yelloweye mullet	1.85	15	19.5 to 27
		Sole		2	9.5 to 12
2b.3	Sand bank & seagrass	Yelloweye mullet	0.115	7	9.5 to 12
Lake Victoria		Australian salmon		2	17.5 to 18
2b.4	Sand bank & seagrass	Black bream	0.378	7	12 to 14
Lake Victoria	*Ruppia sp.*	Yelloweye mullet	3.05	32	11 to 32
2b.5	Sand & 75% seagrass	Black bream	19.5	235	11 to 28
Research seine		Yelloweye mullet	3.55	56	9.5 to 31.5
Lake Victoria		Silver trevally	3.65	19	9 to 24.5
		Australian salmon	0.33	1	27
		Luderick	0.5	2	17 to 26
2b.5	Sand & 75% seagrass	Black bream	157	241	12 to 29
Commercial seine		Yelloweye mullet	5.65	18	25.5 to 33
Lake Victoria		Flounder	1.95	4	28.5 to 35.5
		King George whiting	1.2	6	29.5 to 32.5
		Australian salmon	1.1	7	17.5 to 19
		Silver trevally	14	130	9.5 to 27
2b.6	Sand & 75% seagrass	Black bream	1.125	5	14.5 to 24
Lake Victoria		Yelloweye mullet	0.825	14	11 to 26
3.1	Sand bank & seagrass	Black bream	0.18	3	3 to 19.5
Lake King	epiphytes on algae	Flounder		2	8 to 9
3.1	water column milky-green	King George whiting		3	8 to 9.5
Lake King	with blue green algae	Luderick		2	8.5
		Tailor		8	4.5 to 6
3.3	Seagrass	no fish			
Lake King	blue green algae in water				
	epiphytes on seagrass				

Table 6. Continued.

3.4 Lake King	**Seagrass** epihpytes on seagrass *Ruppia sp.*	Black bream Silver trevally	0.18 0.08	1 7	20 8 to 9.5
3.5 Bunga Arm	**Seagrass** *Ruppia sp.*	Black bream	0.18	1	19
3.6 Bunga Arm	**Sand bank & seagrass**	Black bream	0.155	1	18
4.1 Lake King	**Rocky sand & seagrass** blue green algae	Black bream Yelloweye mullet Tailor Silver trevally	0.13 0.13 0.13	1 7 2 11	19 10 to 17 5 8 to 9
4.2 Lake King	**Seagrass** epiphytes on seagrass blue green algae	Black bream Yelloweye mullet Silver trevally	0.48 0.89	3 1 97	13.5 to 23 14 5.5 to 10
4.3 Lake King	**Sand & 75% seagrass** blue green algae	Black bream Yelloweye mullet Silver trevally River garfish	2.35 0.155 0.04 0.13	13 6 5 23	17.5 to 22 10.5 to 14 7 to 8.5 8.5 to 15
4.4 Lake King	**Sand & 75% seagrass**	Black bream Yelloweye mullet Silver trevally Australian salmon River garfish	13 0.425 3.5 0.135 0.5	55 19 56 2 5	10 to 25 9.5 to 19 5.5 to 13 14.5 11 to 25.5
4.5 Lake King	**Seagrass** epiphytes on seagrass *Ruppia sp.* blue green algae	Black bream Yelloweye mullet Silver trevally Flathead King George whiting	0.23 4.00 	1 6 3 1 14	22 6.5 to 11 6.5 to 7 81 7 to 10
4.6 Commercial seine Lake King	**Sand & 50% seagrass**	Black bream Luderick Silver trevally	499.2 5.00	198 1 26	14 to 40.5 23.5 18 to 24.5
5.1 Jones Bay	**Sand bank & seagrass** algae present.	Black bream Yelloweye mullet	0.95	6 2	13 to 22 16.5 to 25.5
5.2 Jones Bay	**Rocky sand & 25% seagrass**	Black bream	0.725	6	13 to 23
5.3 Jones Bay	**Sand** algae in shallows blue green algae	Black bream Yelloweye mullet Silver trevally	8.5 0.625	40 13 3	14 to 25 13 to 21.5 9.5 to 10
5.4 Jones Bay	**Sand & 75% seagrass** blue green algae	Black bream Yelloweye mullet River garfish	3.6 1.15 0.5	11 52 26	14 to 41 9.5 to 18 8.5 to 19.5
5.4 Swan bay		Tailor	0.555	50	8.5 to 10.5
5.5 Jones Bay	**Sand** blue green algae	Black bream Yelloweye mullet River garfish	0.53 0.33 0.73	6 10 79	13 to 16.5 9 to 26.5 8.5 to 24
5.6 Research seine Jones Bay	**Rocky sand & seagrass** blue green algae	Black bream	0.205	2	13.5 to 19.5
5.6 Commercial seine Jones Bay	**Rocky sand & seagrass** blue green algae	Black bream	314	183	12 to 23.5
6.1 Reeves Channel	**Seagrass** epiphytes on seagrass	Black bream Yelloweye mullet Australian salmon King George whiting	0.355 0.405 0.04	5 10 7 12	13.5 to 17.5 14 to 32 13.5 to 17 7 to 9.5

Table 6. Continued.

6.2 Reeves Channel	Seagrass	Black bream	0.58	13	10.5 to 14
		Leatherjacket		1	9
		Luderick		1	13.5
6.3 Research seine Reeves Channel	Sand & 75% seagrass	Black bream	0.42	7	10 to 15
		Yelloweye mullet	0.28	3	16.5 to 17.5
		King George whiting	0.28	33	7.5 to 11
6.3 Commercial seine Reeves Channel	Sand & 75% seagrass	Black bream	15.31	151	11 to 24
		Yelloweye mullet	2.1	10	20 to 31
		Estuary perch		1	20
		Luderick		2	15.5 to 16
6.4 Reeves Channel	Sand & 75% seagrass; epiphytes on seagrass; blue green algae; *Ruppia sp.*	Yelloweye mullet	0.345	22	8.5 to 13.5
		King George whiting		11	7.5 to 9.5
		Tailor		22	4.5 to 6
6.5 Reeves Channel	Seagrass; epiphytes on seagrass	King George whiting		3	9 to 11.5
		Silver trevally		5	6 to 7.5
6.6 Reeves Channel	Sand & 75% seagrass; epiphytes on seagrass	Black bream		3	12 to 13.5
		Yelloweye mullet	0.25	19	8 to 10
		Silver trevally		1	6
		Leatherjacket		2	5 to 6

Table 7. Comparison of catch rates by the research beach seine between years and regions in December 1981, December 1996 and February 1997. Where **a** is the number of shots with research beach seine, **b** is the number of black bream caught and **c** is the CPUE. December 1981 data was obtained from Hobday and Moran (1983).

	REGION						
Dec-81	**1**	**2a**	**2b**	**3**	**4**	**5**	**6**
No. of shots	4	5		5	4	4	4
No. of black bream	77	473		1346	1047	1609	432
CPUE	19	95		269	262	402	108
Dec-96							
No. of shots	*n/a	6	5	5	5	6	6
No. of black bream	n/a	62	155	79	3	122	29
CPUE	n/a	10	31	16	1	20	5
Feb-97							
No. of shots	n/a	6	6	4	5	6	6
No. of black bream	n/a	195	251	6	73	71	28
CPUE	n/a	33	42	2	15	12	5

***n/a = not available**

Table 8. Comparison of length range and modes (cm FL) and percentage below legal minimum length (LML= 23 cm FL) of black bream caught in inshore and offshore regions of the Gippsland Lakes in December 1981, December 1996 and February 1997 (all regions combined). December 1981 data was obtained from Hobday and Moran (1983)

		Dec-81	Dec-96	Feb-97
Inshore	**Length range**	5 to 36	7 to 25	3 to 41
	Modes	9, 15, 22	11, 18.5	13, 19.5
	% below LML	91	98	94
Offshore	**Length range**	13 to 38	11 to 37	12 to 40.5
	Modes	16, 21	13, 19	15, 19
	% below LML	80	95	95

Table 9. Year class-length key combined for all catches of black bream from both research and commercial beach seine in the Gippsland Lakes in February 1997.

Fork length (cm)	95	94	93	92	91	90	89	88	87	86	82	76	Total
11	5	1	1										7
12	22	3					1						26
13	48	11	1										60
14	33	7											40
15	7	3	4										14
16	2	1	14	1			11						29
17	2		12	2	1		38		3				58
18		2	6	1	1	5	93	4	8				120
19	1			3			64	3	10	1			82
20						1	38		17				56
21						2	27		13	1			43
22							23	3	17				43
23							4	1	11				16
24									3				3
25							2		3				5
26									2				2
27							1		3				4
28									2				2
35											1		1
40												1	1
Total	120	28	38	7	2	8	302	11	92	2	1	1	612

Table 10. Summary of results from two single factor ANOVAs to test for a relationship between the combined ranked scores of October river flow and temperature and year class strength.

ANOVA 1.

H_0: The mean rank score from strong year classes is not significantly different to the mean rank score from weak year classes (1978 year class is considered weak).

Groups	*Count*	*Sum*	*Average*	*Variance*
Strong	6	214	35.667	130.667
Weak	19	427	22.474	167.819

ANOVA

Source of Variation	*SS*	*df*	*F*	*P-value*
Between groups	793.6898	1	4.968568	0.035868
Within groups	3674.07	23		
Total	4467.76	24		

ANOVA 2.

H_0: The mean rank score from strong year classes is not significantly different to the mean rank score from weak year classes (1978 year class is considered strong).

Groups	*Count*	*Sum*	*Average*	*Variance*
Strong	7	261	37.286	127.238
Weak	18	380	21.111	140.340

ANOVA

Source of Variation	*SS*	*df*	*F*	*P-value*
Between groups	1318.554	1	9.629961	0.005009
Within groups	3149.206	23		
Total	4467.76	24		

Table 11. Rank method for assessing relationship between dominant year class of black bream and environmental conditions. **YCS**: year class strength; **Oct RF**: river flow from the Mitchell river in the October prior to the January 1st birthdate; **Oct T**: temperature at Bairnsdale in October prior to spawning. **Rank RF**: rank of October river flow and **Rank T**: rank of October temperature. Data from 1972 to 1981 was obtained from Hobday and Moran (1983) Entries in bold italics refer to the dominant year classes and the asterisk scores refer to the years the model predicts to be strong.

Year	YCS	Oct RF	Oct T	Rank RF	Rank T	Score
1972	weak	190000	19.8	8	13	21
1973	***strong***	***21800***	***20.9***	***24***	***21***	***45****
1974	***strong***	***160000***	***20.1***	***11***	***16***	***27***
1975	weak	335000	18.9	1	4	5
1976	weak	184000	19.3	9	7	16
1977	weak	281000	18.0	3	1	4
1978	intermed	37200	22.3	22	25	47*
1979	***strong***	***92500***	***20.9***	***16***	***21***	***37****
1980	weak	141000	20.5	12	19	31
1981	***strong***	***50685***	***22.0***	***21***	***24***	***45****
1982	weak	92545	20.1	15	17	32
1983	weak	19278	20.2	25	18	43*
1984	weak	165048	18.3	10	2	12
1985	weak	91131	19.3	17	7	24
1986	weak	210620	19.3	7	7	14
1987	***strong***	***220814***	***19.4***	***6***	***11***	***17***
1988	weak	70835	19.3	19	7	26
1989	***strong***	***61166***	***21.4***	***20***	***23***	***43****
1990	weak	122598	19.2	13	6	19
1991	weak	223046	20.0	5	15	20
1992	weak	78497	20.7	18	20	38*
1993	weak	315590	18.9	2	4	6
1994	weak	227793	18.8	4	3	7
1995	***strong***	***31420***	***19.6***	***23***	***12***	***35****
1996	weak	109313	19.8	14	13	27

Table 12. Continuous fishery model including 1971 and 1995. Summary of results using dynamic regression models between relative year class strength (log transformed) of black bream in the Gippsland Lakes and environmental variables temperature and rainfall for the different scenarios of natural mortality (M) and total mortality (Z). Bold italics represent statistically adequate models at $\alpha = 0.05$. (+) month refers to positive coefficient for that month.

Scenario	**Temperature**	**Rainfall**	**Temp. (quarterly)**
1) M=0.27, Z=1.1			
no lag	***(+) Feb***	*(+) May*	***(+) Summer***
previous lag	***(+) Oct***	-	-
2) M=0.27, Z=0.9			
no lag	***(+) Feb***	*(+) May*	***(+) Summer***
previous lag	***(+) Aug***	-	-
3) M=0.14, Z=1.1			
no lag	***(+) Feb***	*(+) May*	***(+) Summer***
previous lag	***(+) Aug***	-	-
4) M=0.14, Z=0.9			
no lag	***(+) Feb***	*(+) May*	***(+) Summer***
previous lag	***(+) Aug***	-	-

Table 13. Parameter estimates of the regression model for scenario 2 (a) temperature model during February, (b) rainfall model during May, and (c) scenario 3 for summer temperature model.

	Parameter	Estimate	Standard error of estimate	T-ratio	*P*-value
a	intercept	-34.2737	9.3998	-3.646	0.0018
	temperature	1.2946	0.3673	3.525	0.0024
b	intercept	-2.4214	0.6250	-3.862	0.0011
	rainfall	0.0233	0.0089	2.615	0.0175
c	intercept	-28.4172	11.2289	-2.531	0.0209
	temperature	1.0842	0.4476	2.422	0.0262

Table 14. Regression equations describing the relationship between the three positive correlated variables from the continuous model. y_t: the relative year class strength (log transformed) at year *t*. D-W: the Durbin-Watson statistic is used to test for first order autocorrelation.

Environmental variable X_t	Lag	Regression Equation	R^2	D-W Statistic	*P*-value
February Temp	0	$y_t = -34.2737 + 1.2946X_t$	0.41	1.7597	0.2890
May Rainfall	0	$y_t = -2.414 + 0.023X_t$	0.27	1.6122	0.1857
Summer Temp	0	$y_t = -28.412 + 1.0842X_t$	0.25	1.6472	0.2119

FIGURES

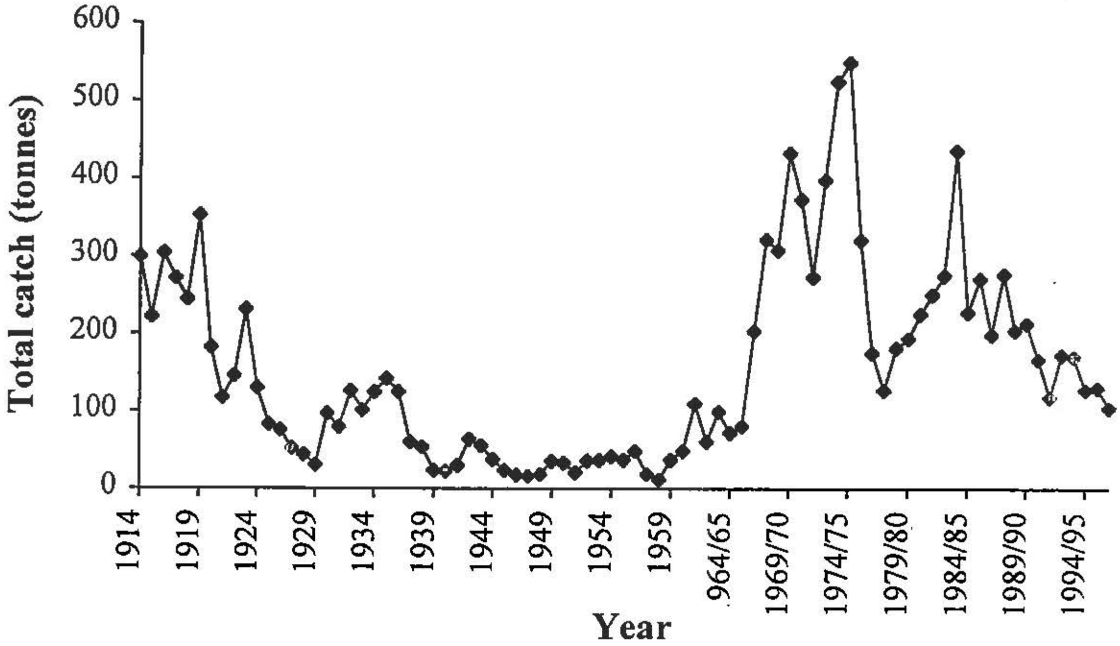


Figure 1 Annual total commercial catch of black bream in Victoria between 1914 and 1996/97.

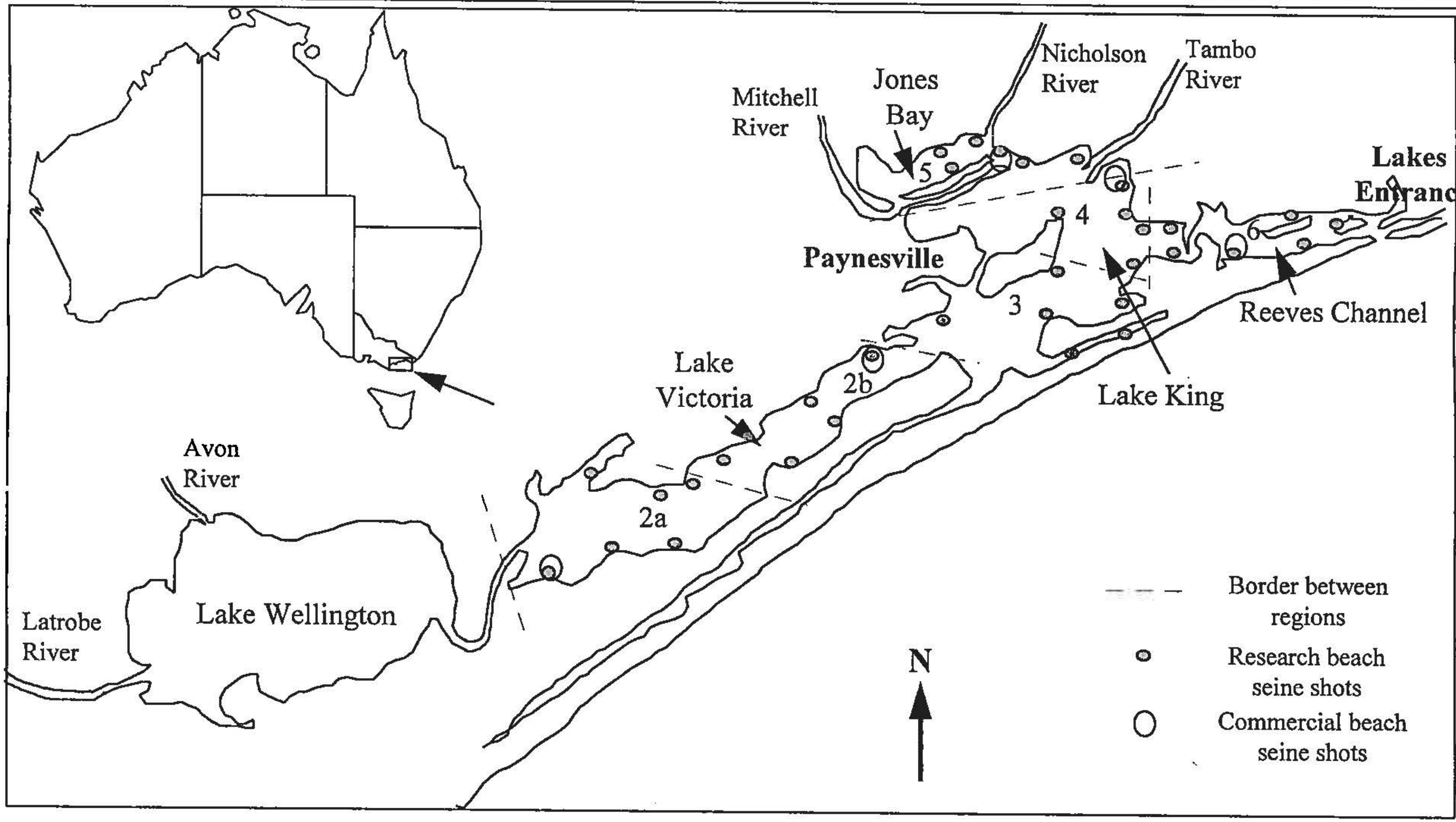


Figure 2. Map showing the division of the Gippsland Lakes into regions (2 to 6), and the sites sampled by the research and commercial beach seine nets in December 1996 and February 1997.

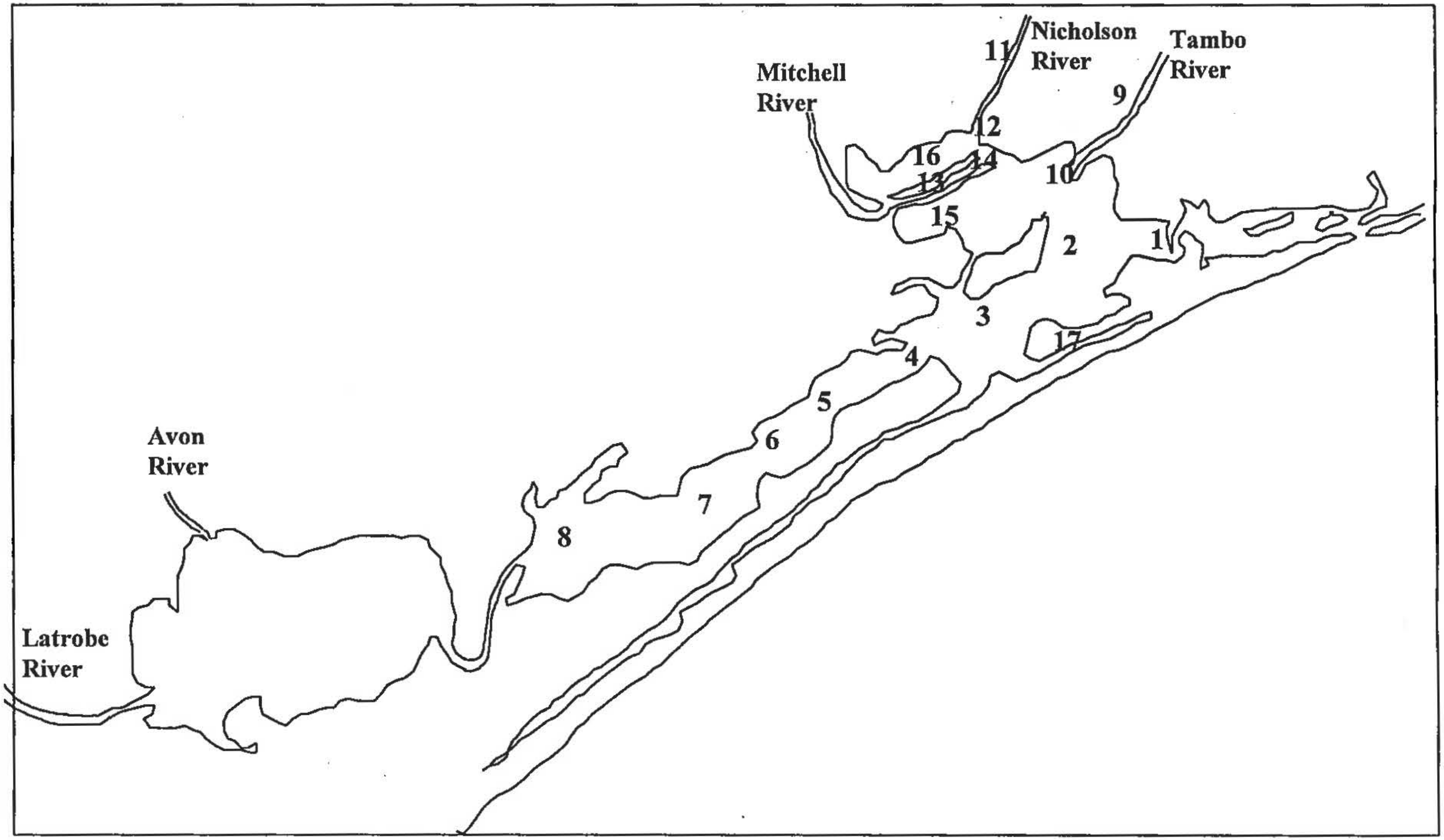


Figure 3. Map showing the location of the sites for fortnightly environmental monitoring of DO, salinity and temperature.

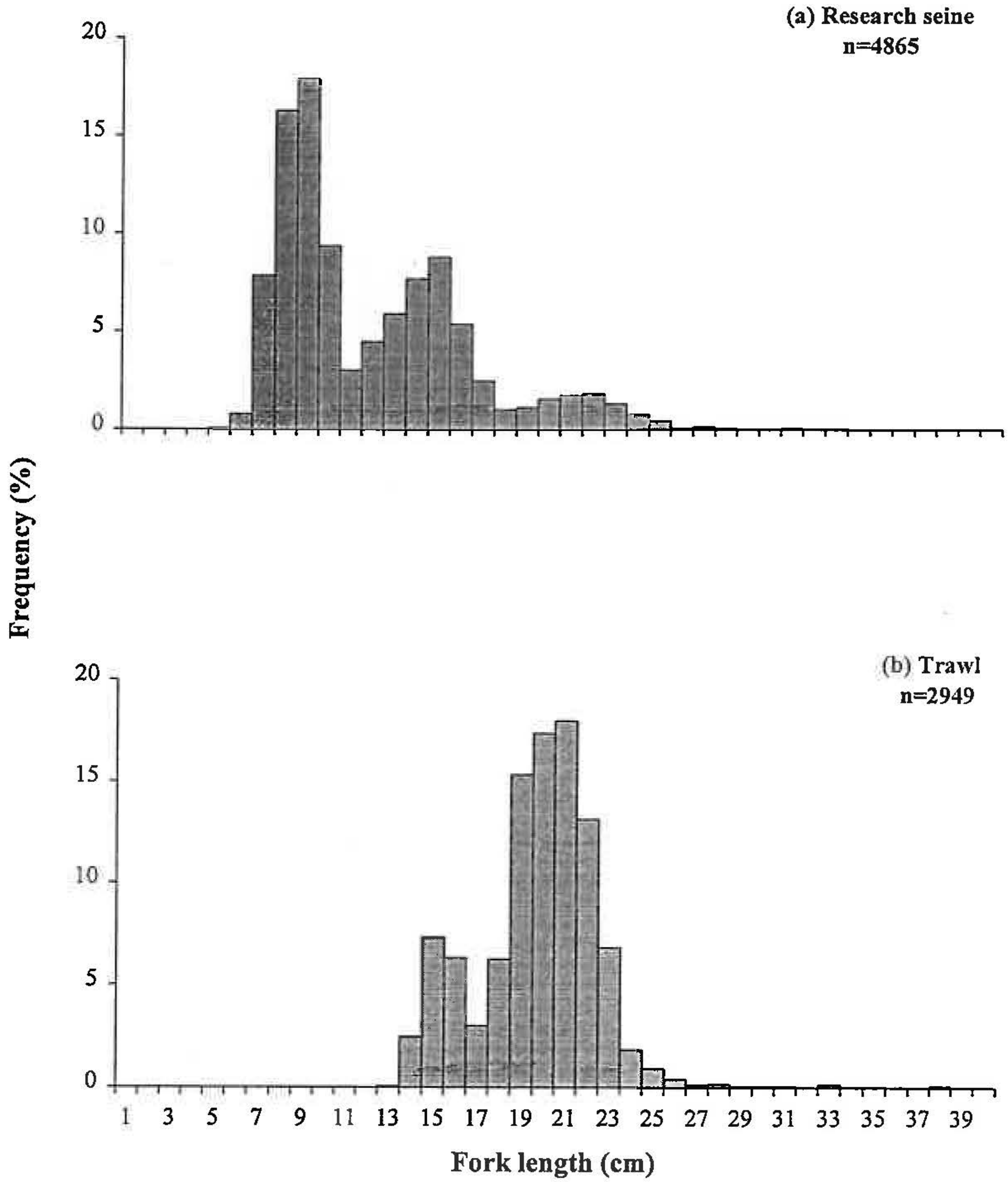


Figure 4. The length-frequency distribution of black bream, combined for all regions, sampled by (a) research beach seine and (b) board trawl in the Gippsland Lakes during the December 1981 (Hobday and Moran, 1983).

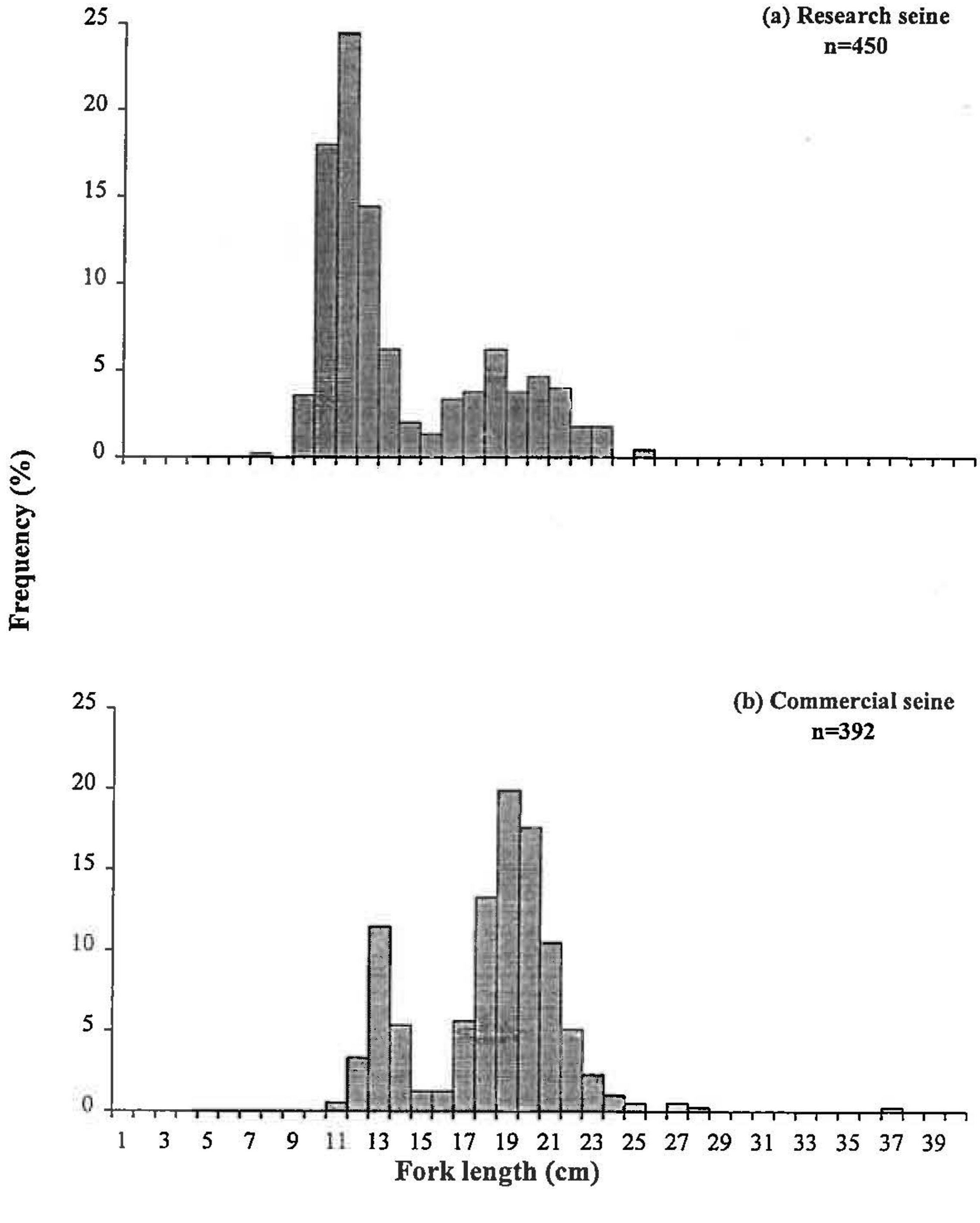


Figure 5. Length-frequency distributions of black bream caught by (a) research beach seine and (b) commercial beach seine, all regions combined, in the Gippsland Lakes in December, 1996.

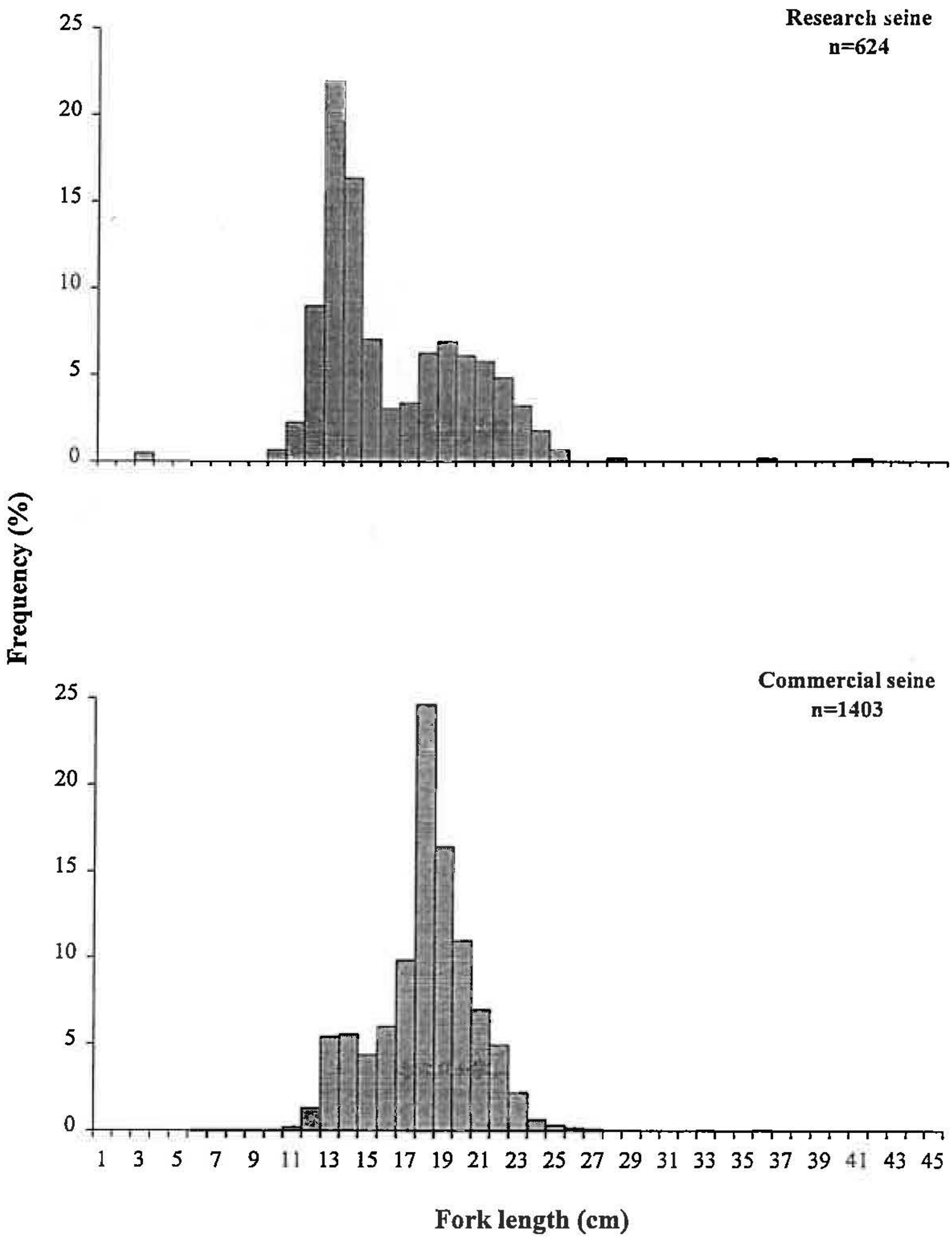


Figure 6. Length-frequency distributions of black bream caught by (a) research beach seine and (b) commercial beach seine, all regions combined, in the Gippsland Lakes in February 1997.

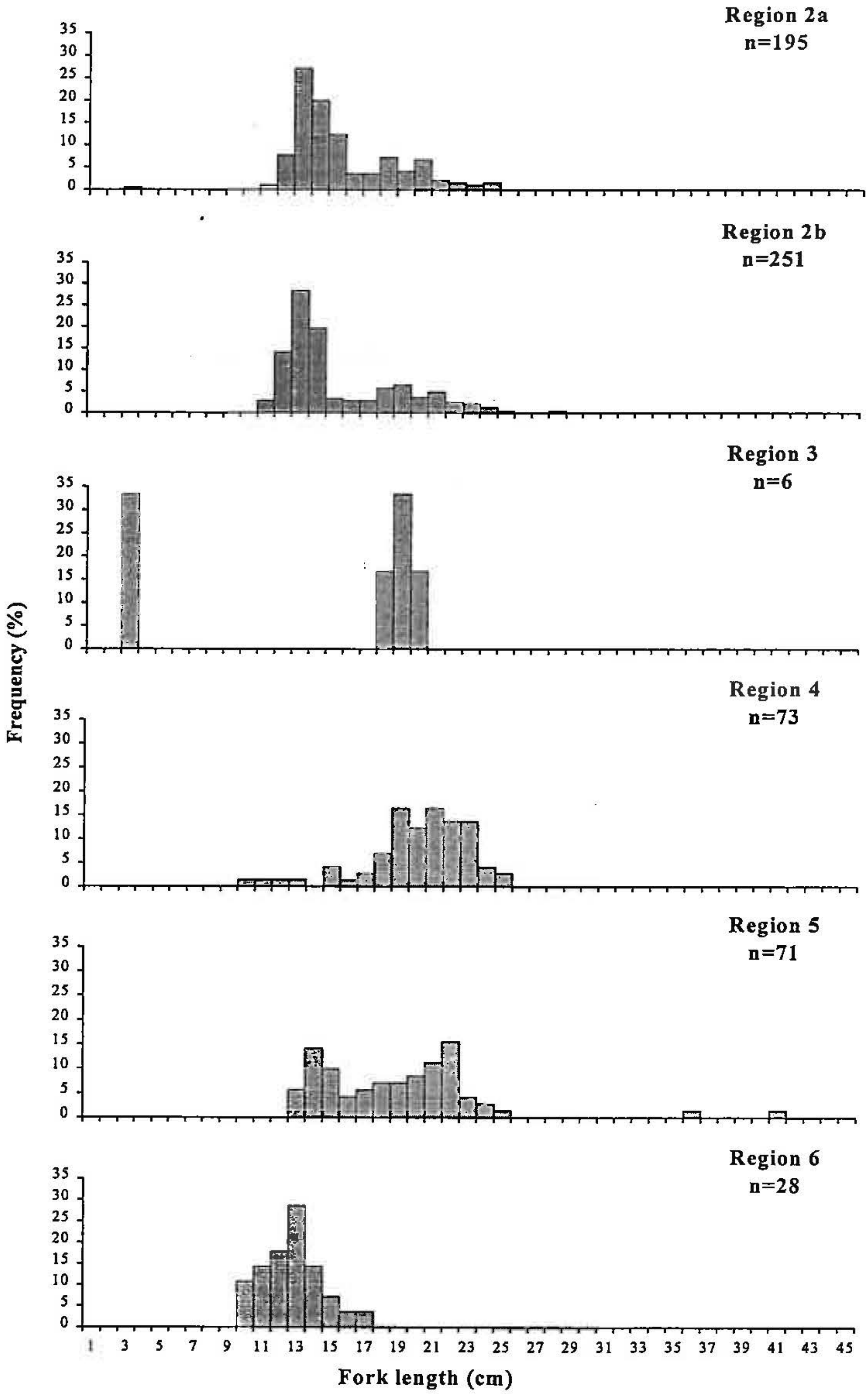


Figure 7. Length-frequency distribution of black bream caught by the research beach seine in each region of the Gippsland Lakes in February 1997.

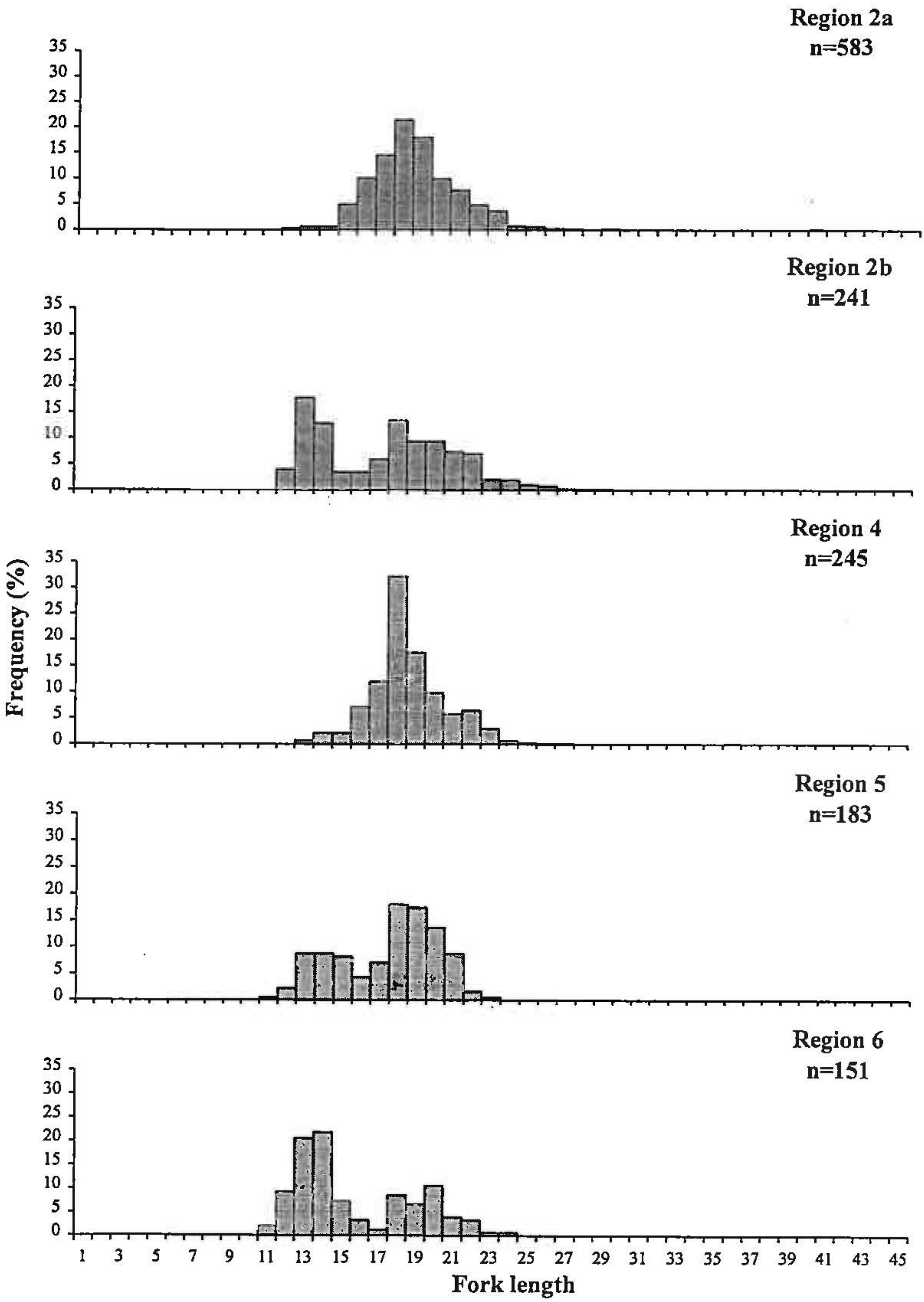


Figure 8. Length-frequency distribution of black bream caught by commercial beach seine in each region of the Gippsland Lakes in February, 1997.

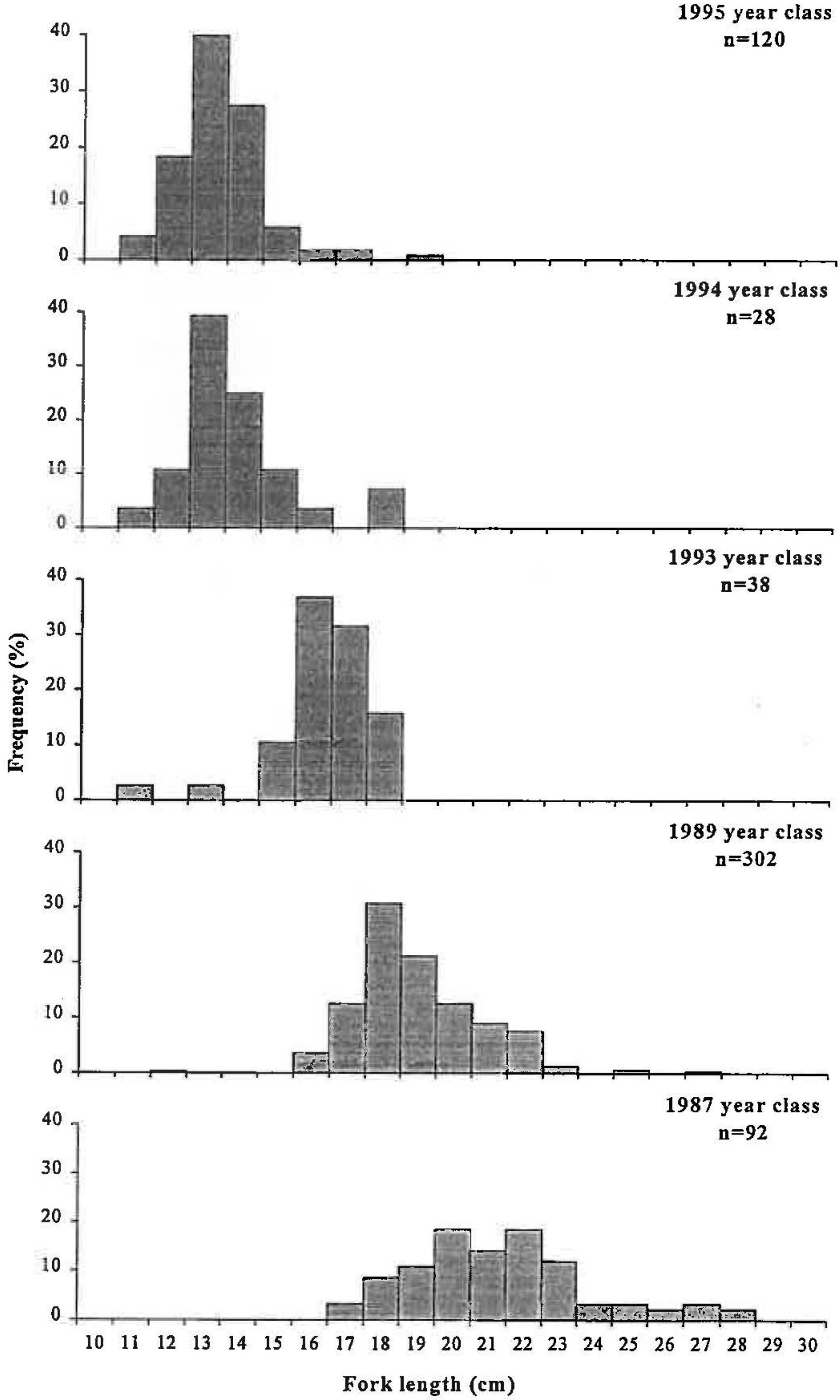


Figure 9. Length-frequency distributions of the stronger black bream year classes in the Gippsland Lakes (all regions combined) in February 1997.

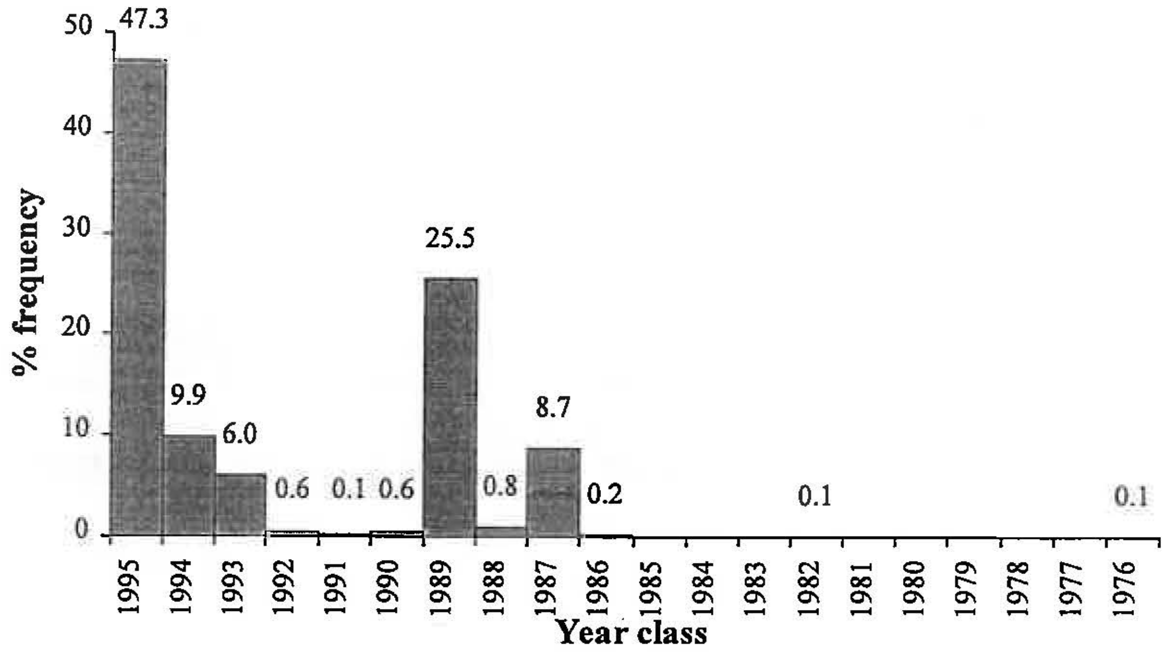


Figure 10. The age structure of black bream in the Gippsland Lakes in February 1997. Percent frequencies are calculated by applying the age-length key (Table 8) to the length-frequency distribution from research beach seine (Fig. 6).

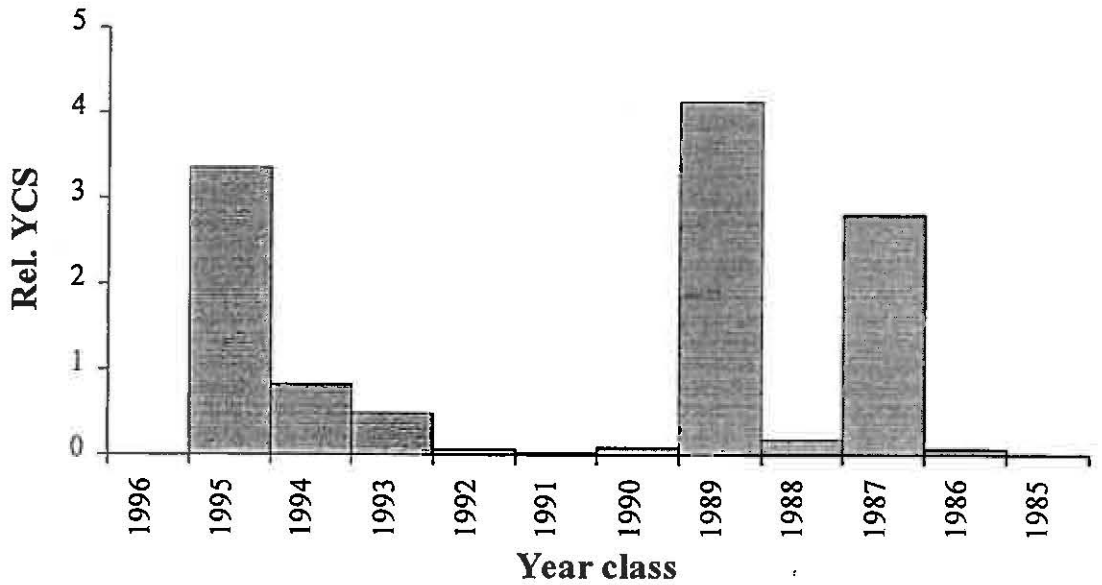


Figure 11. Relative year class strength (YCS) of black bream in the Gippsland Lakes in February 1997 obtained by the model assuming a continuous fishery.

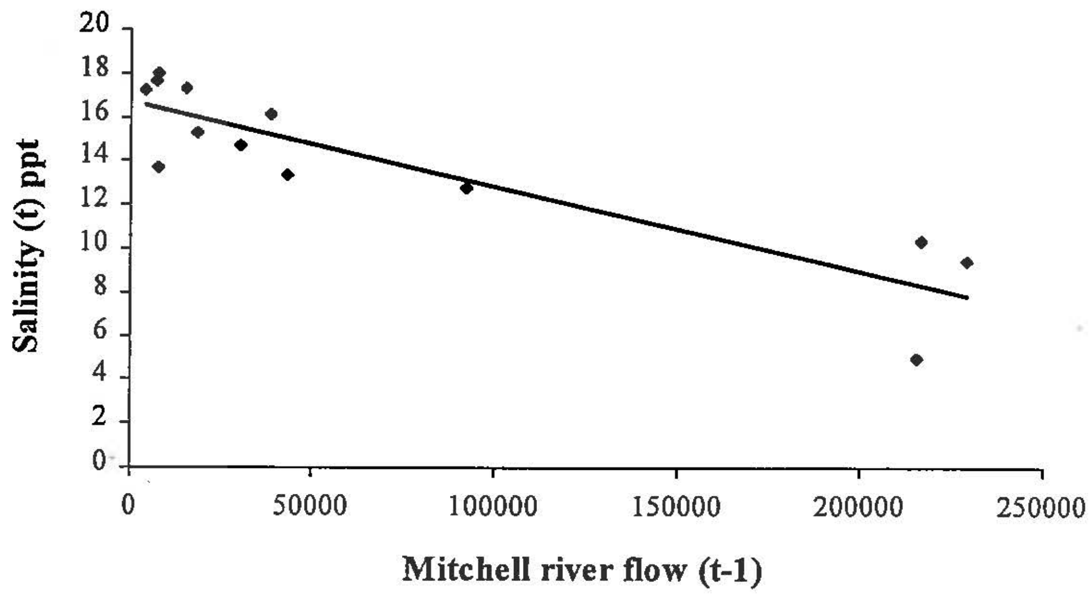


Figure 12. Relationship between surface salinity in Lake Victoria in month t and river flow from the Mitchell river in the previous month (t-1) ($R^2 = 0.80$)

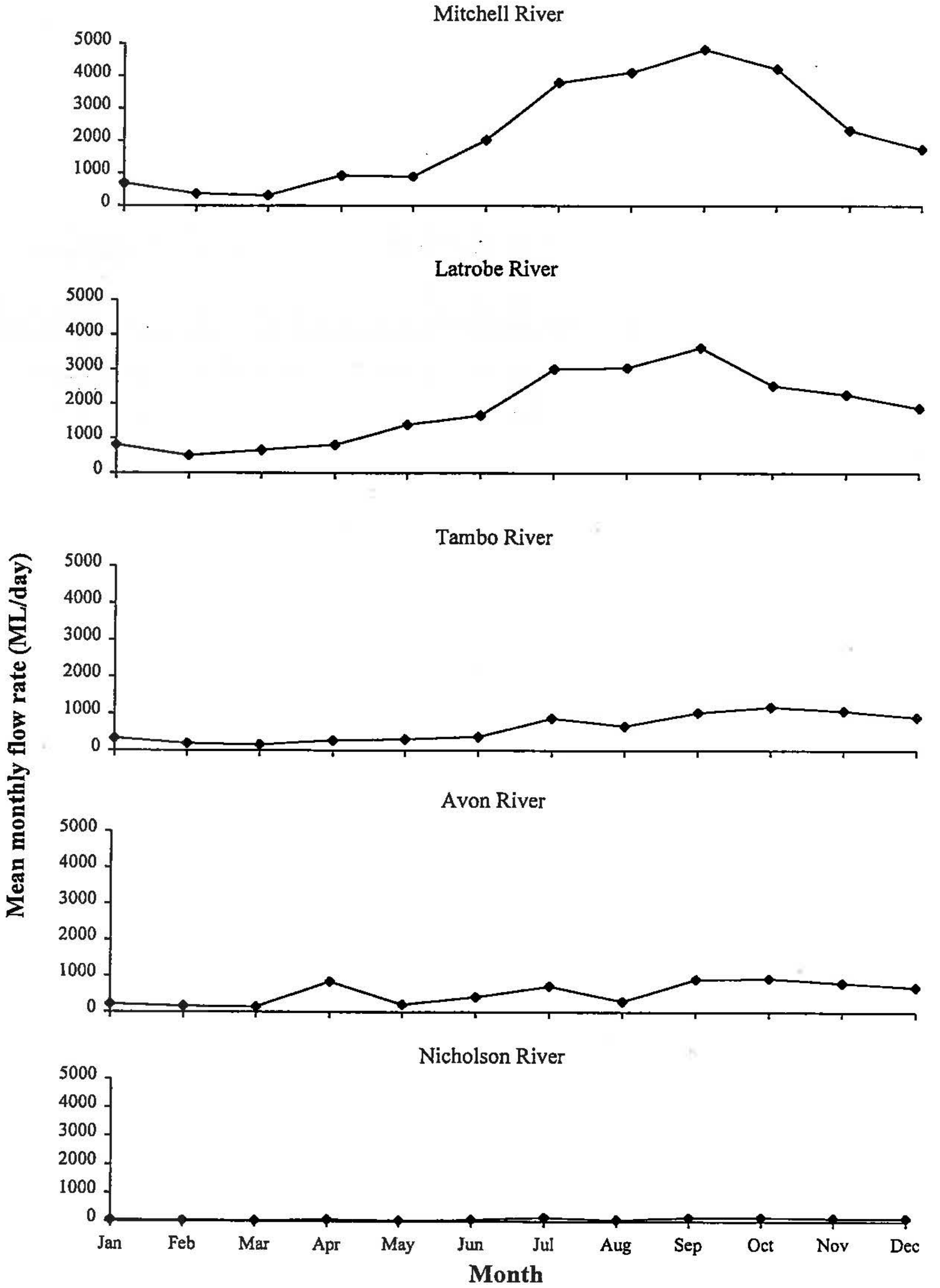


Figure 13. Mean monthly flow rate (ML/day)(1980-1996) from the Mitchell, Latrobe, Tambo, Avon and Nicholson rivers.

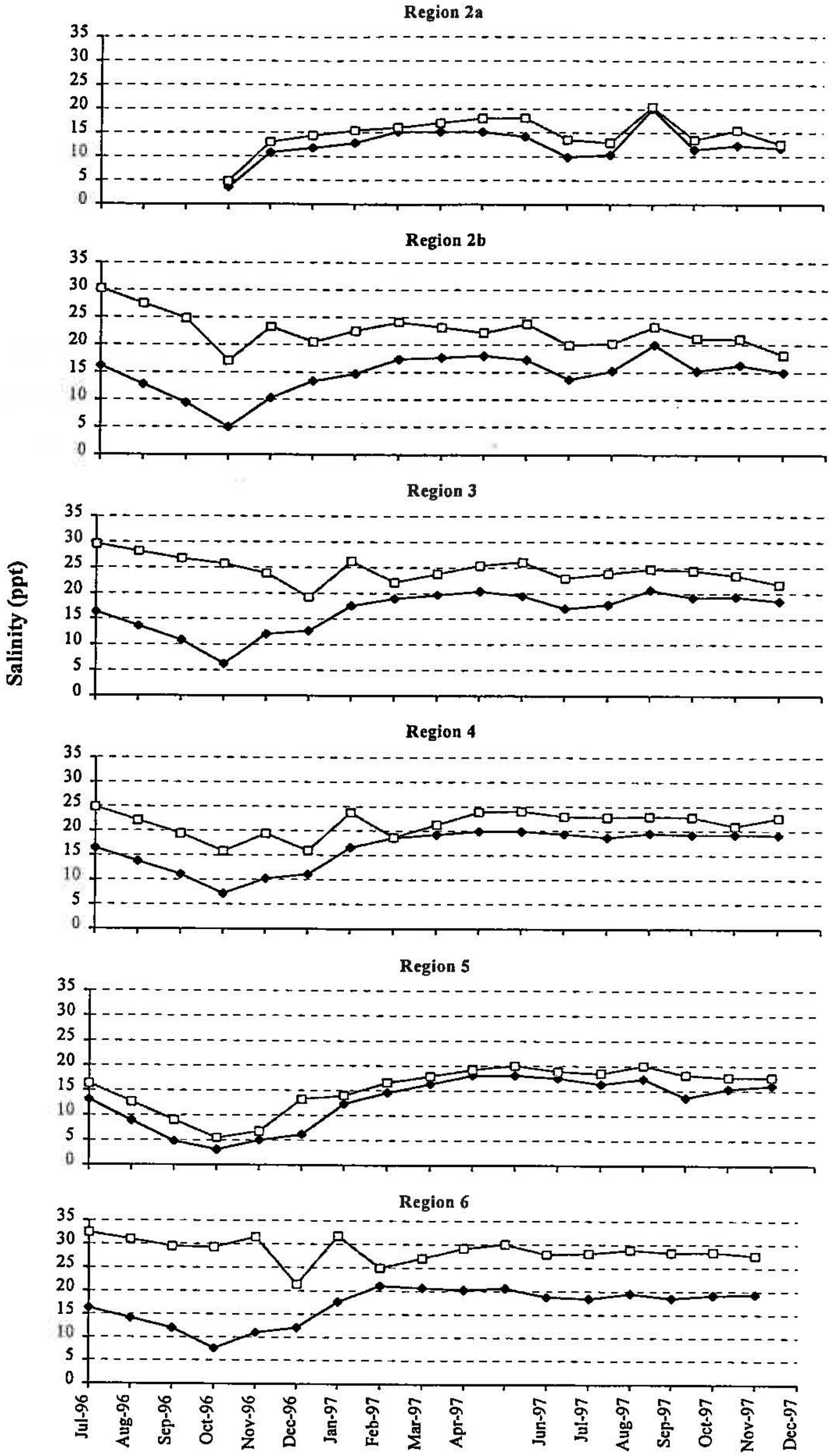


Figure 14. Mean monthly surface (◆) and bottom (□) salinities (ppt) for each region in the Gippsland Lakes between July 1996 and November 1997.

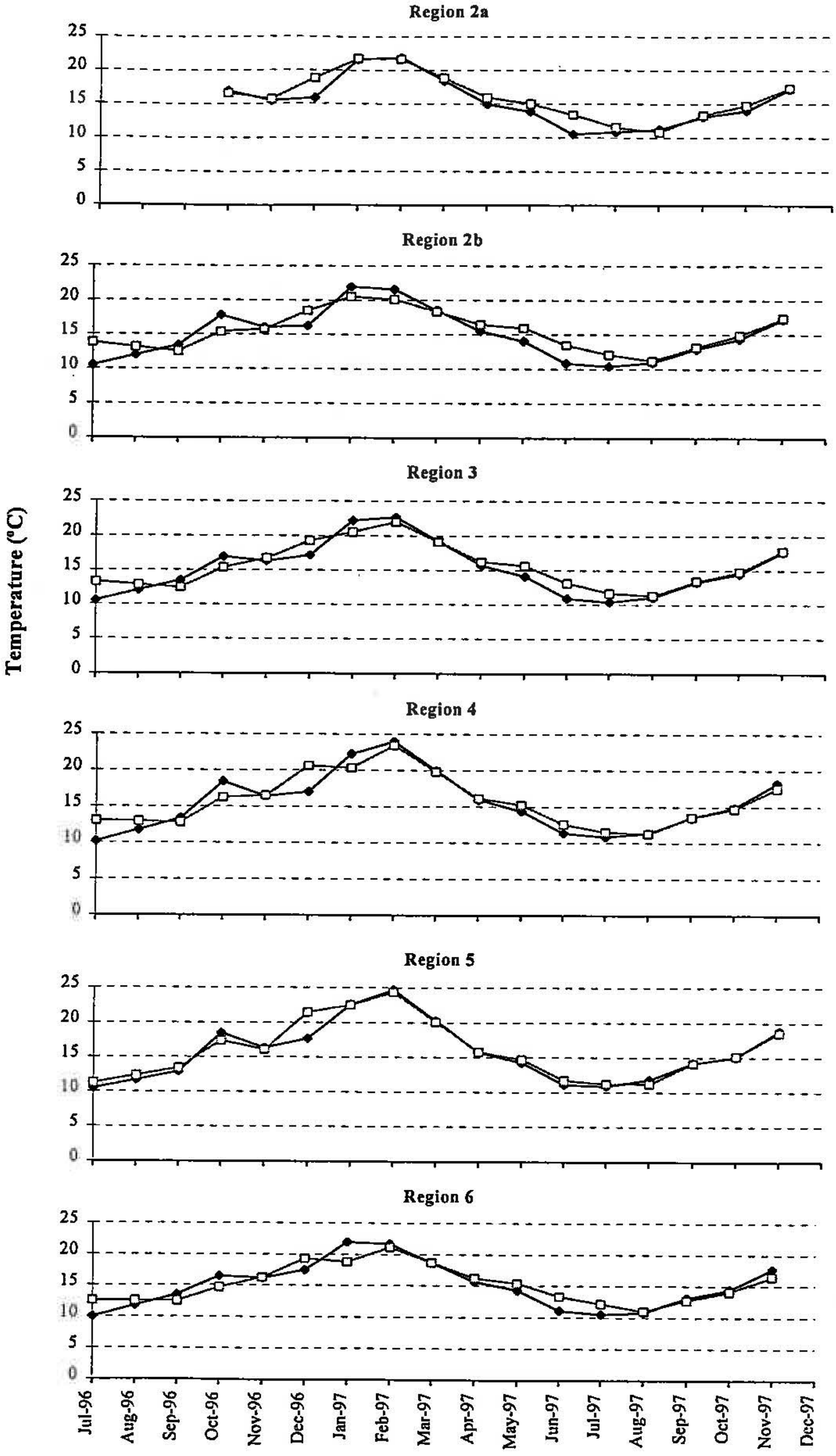


Figure 15. Mean monthly surface (◆) and bottom (□) water temperature in each region of the Gippsland Lakes between July 1996 and November 1997.

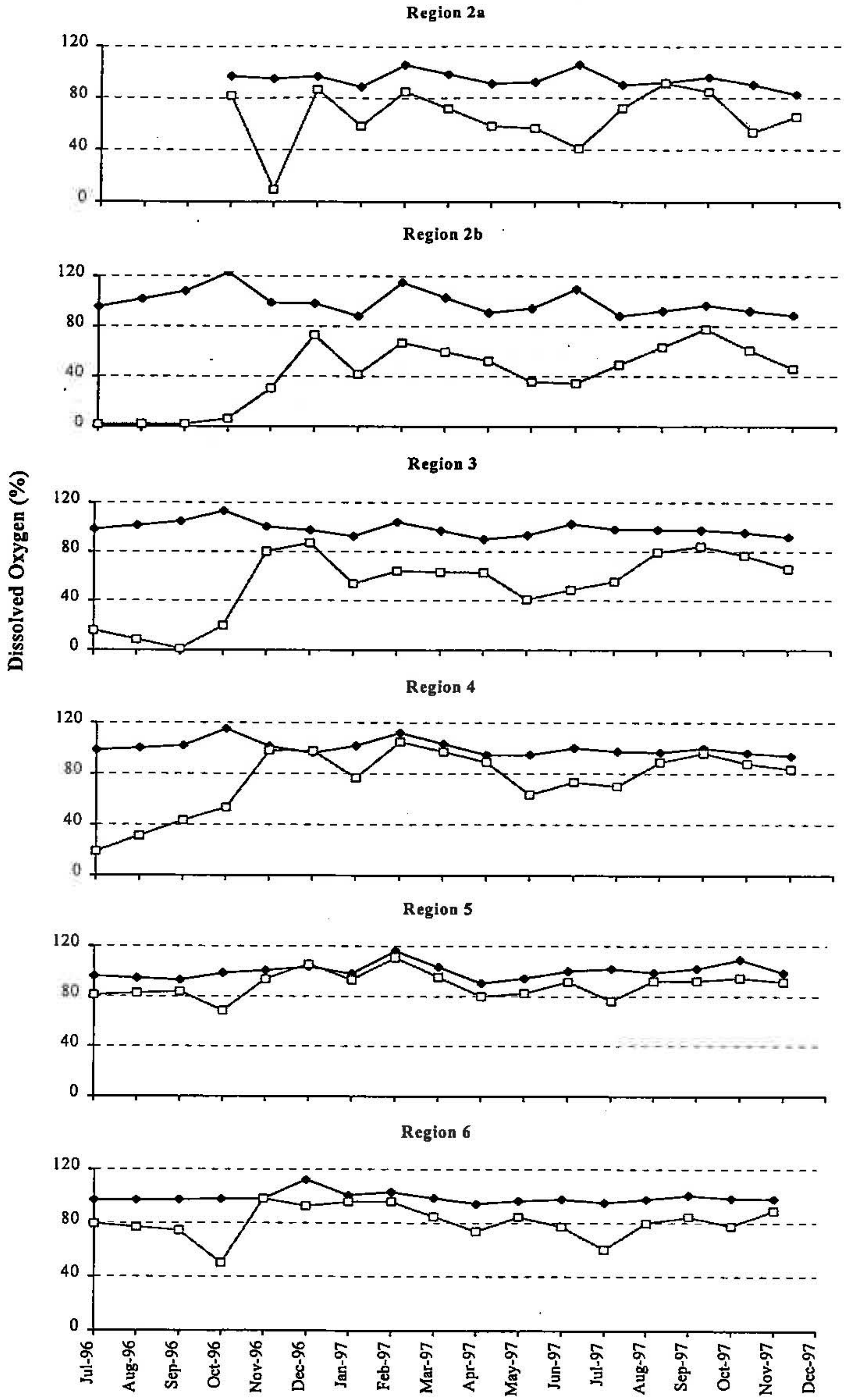


Figure 16. Mean monthly surface (◆) and bottom (□) percentage dissolved oxygen for each region of the Gippsland Lakes between July 1996 to November 1997. The lower limit by ANZECC water quality standards is 80% dissolved oxygen.

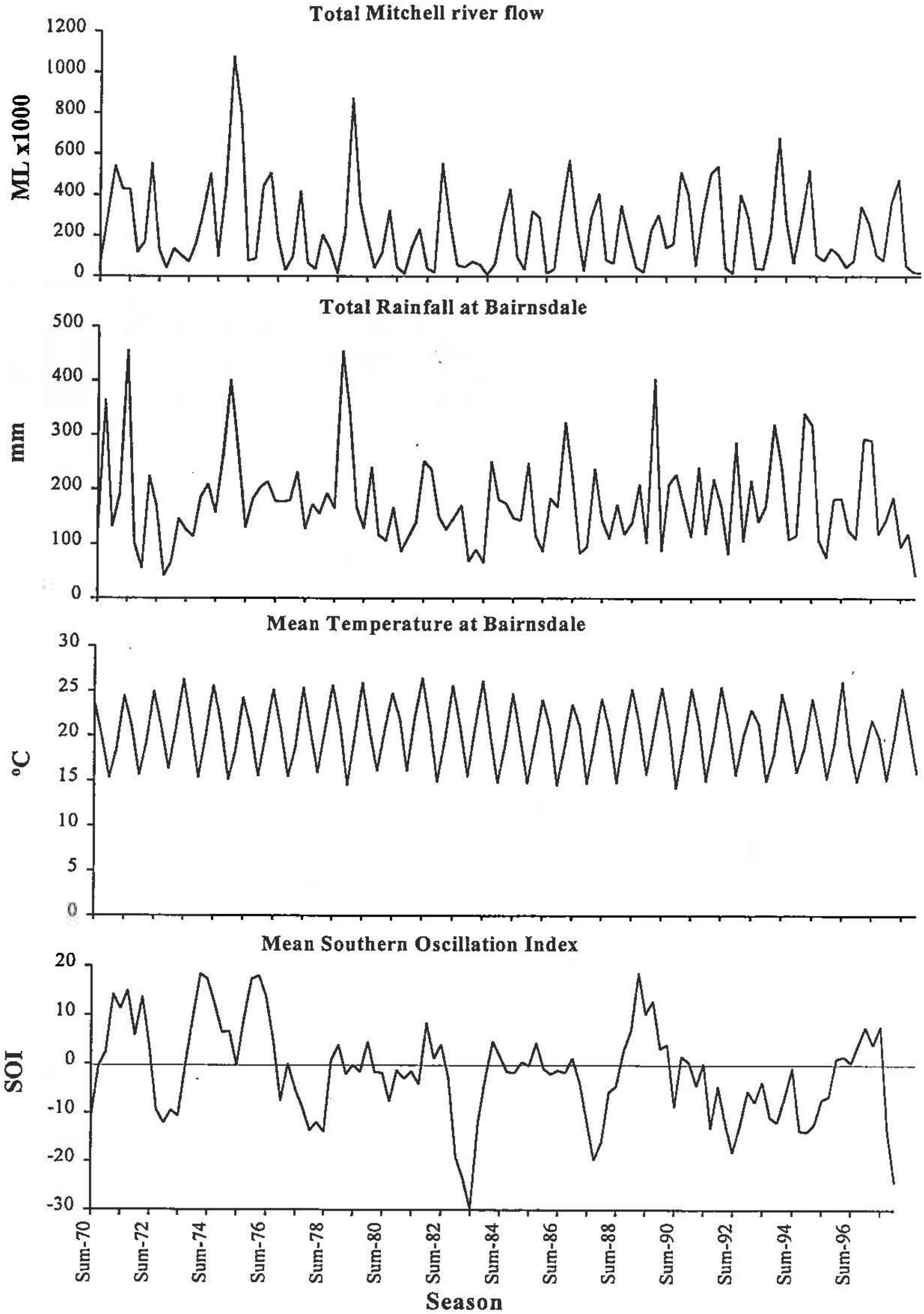


Figure 17 Quarterly environmental variables used in modelling including total Mitchell river flow (ML x1000), total rainfall at Bairnsdale (mm), mean air temperature at Bairnsdale (°C) and the mean Southern Oscillation Index (SOI).

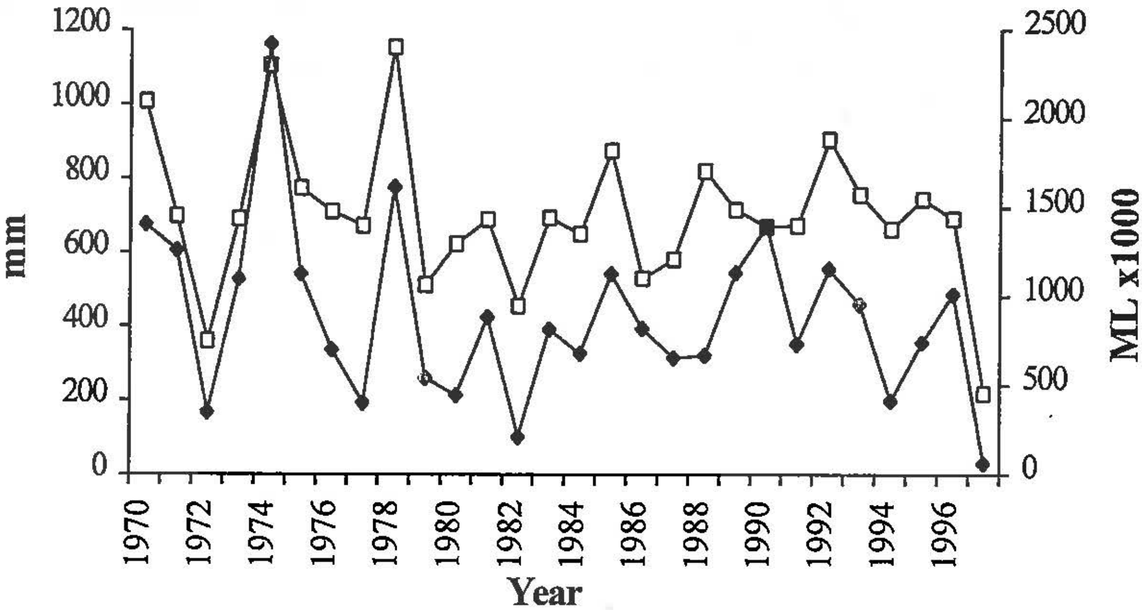


Figure 18. Annual total river flow from the Mitchell river (◆) (ML x1000), and rainfall at Bairnsdale (□) (mm) between 1970 and 1997.

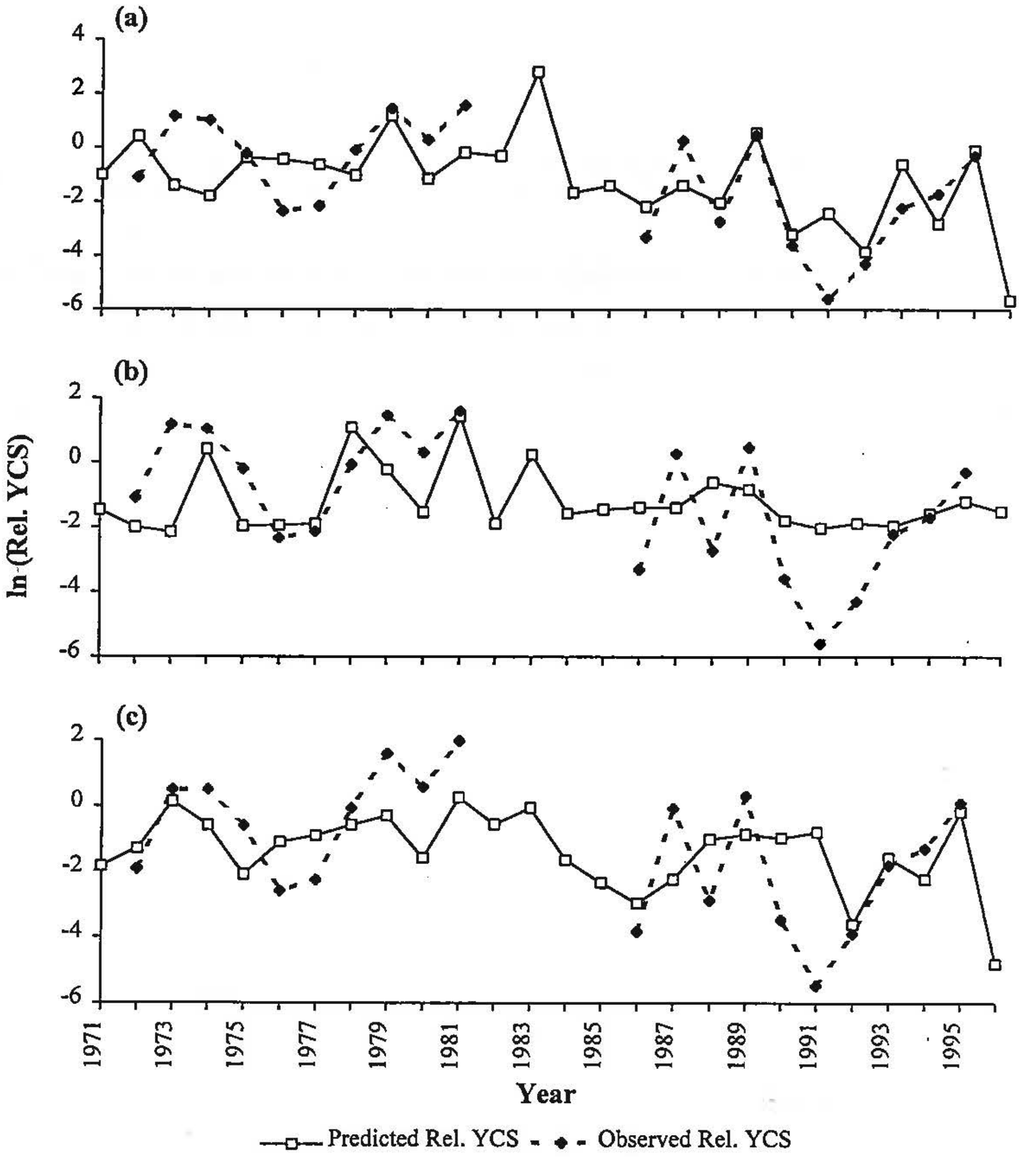


Figure 19. Observed and predicted values of relative year class strength (YCS) of black bream in the Gippsland Lakes (1971 to 1995) using the continuous model The predicted values are calculated from the relationships (a) Rel. YCS (Scenario 2) and temperature during the February in year of spawning, (b) Rel. YCS (Scenario 2) and rainfall in May in year of spawning and (c) Rel. YCS (Scenario 3) and temperature in the summer spawning period.

APPENDIX A

Mortality estimates

Two estimates of natural mortality (M) were used: a.1. From Pauly (1980) which includes growth parameters and water temperature and a.2. Gulland (1983) which incorporates maximum age.

$$Ln(M) = -0.0066 - 0.279 * ln(L_\infty) + 0.6543 * ln(K) + 0.463 * ln(T) \qquad a.1$$

Where M is natural morality, is the L_∞ is the asymptotic length of the von Bertalanffy growth equation, K is the average growth rate and T is the average water temperature of the Gippsland Lakes.

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

Where M is natural mortality and t_{max} is the theoretical maximum age of black bream.

Total mortality was calculated from the decline in numbers of the 1987 year class based on three years of aging data from 1994 to 1996. The length-frequency distributions for both mesh nets and estuary beach seines used in the commercial fishery were adjusted to represent total numbers in catches for each year. The length-frequency distributions were then adjusted by the age-length key of each respective year to determine the number in each age class greater than LML. These numbers were then adjusted by the proportion greater than LML within each year class to determine the total number of fish with the year class. To make the three years comparable, values were then adjusted to by dividing by the relative effort (Table A.1).

Total mortality (Z) calculated from a plot of the natural log of total numbers against year (Fig. A.1) was high with values ranging from 1.1 to 1.2. The two estimates used for calculating initial numbers were Z = 0.9, and Z = 1.1.

Table A.1 Data and calculations for estimating total mortality from the 1987 year class for data from the (a) estuary beach seine catches, (b) mesh net catches and (c) combined for total fishery.

a	Effort	> LML	p > LML	Rel Effort	Total	ln(total)
1994	992	133189.2	0.25	1	532756.8	13.186
1995	828	84852.8	0.59	0.835	172303.9	12.057
1996	637	29308.8	0.91	0.642	50156.72	10.823
b	**Effort**	**> LML**	**p > LML**	**Rel. Effort**	**Total**	**ln(total)**
1994	2275	261177.8	0.25	1	1044711	13.859
1995	2695	494323.8	0.59	1.185	707264.9	13.469
1996	2460	113145.0	0.91	1.081	114986.8	11.653
c		**> LML**	**p > LML**		**Total**	**ln(total)**
1994		394367	0.25		1577468	14.271
1995		579176.5	0.59		879568.8	13.687
1996		142455.8	0.91		165143.5	12.015

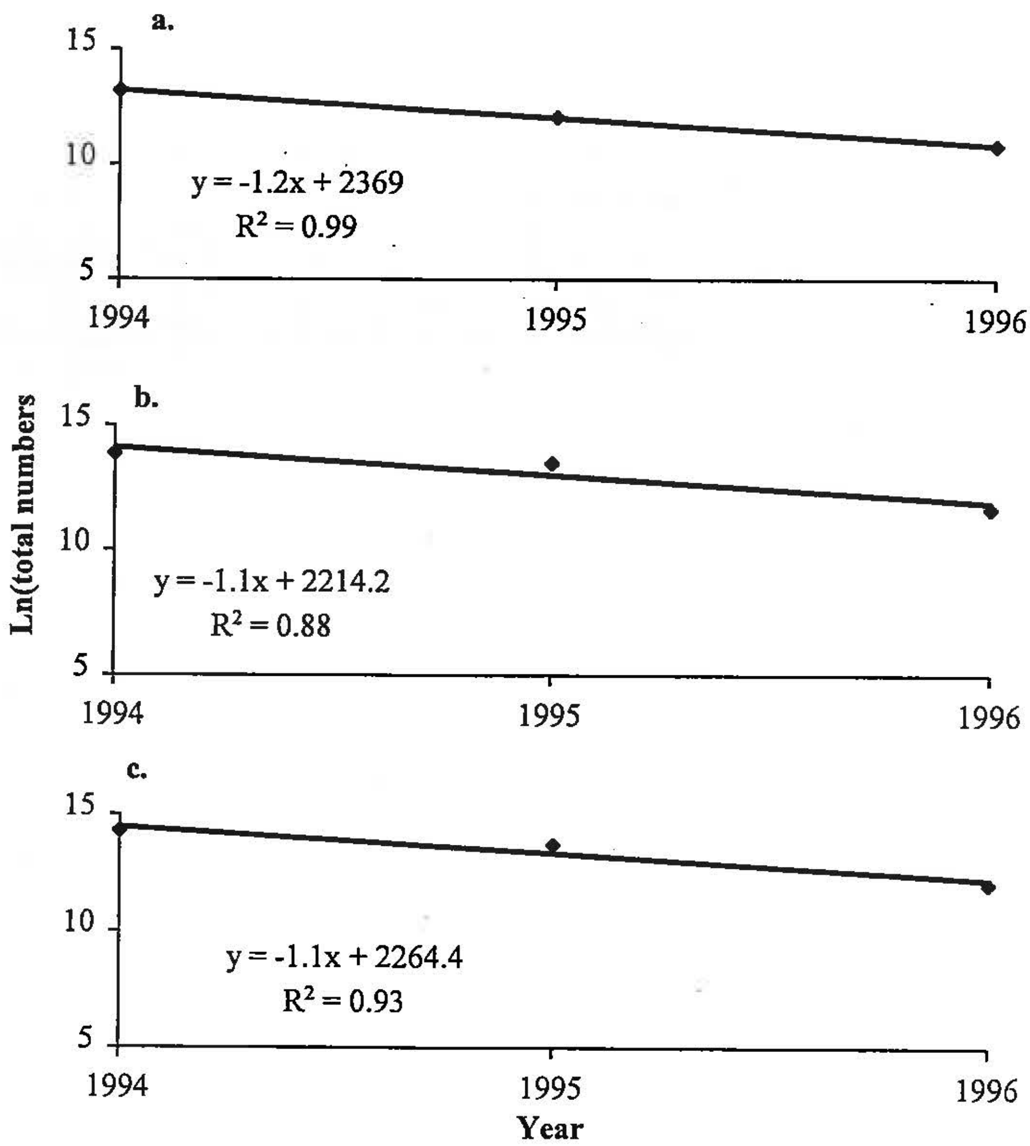


Figure A1. Total mortality estimated from the decline total numbers (log transformed) of black bream in the 1987 year class (a) estuary beach seine catches, Z=1.2, (b) mesh net catches, Z=1.1 and (c) combined catches, Z=1.1.

APPENDIX B

Discrete Fishery model

The data set between 1985 to 1995 was back calculated using the discrete method (Hilborn and Walters, 1992) and four scenarios for natural and total mortality (Table 3). No statistically adequate dynamic regression models were found between relative year class strength (log transformed) and quarterly environmental data for each of the four scenarios. The results indicate that parameter estimates and the overall significance of the model are sensitive to changes in values of M and Z.

However, a significant positive relationship was found between relative year class strength and May rainfall both during the same and previous time periods, for each of the scenarios. However, the presence of residual autocorrelation could not be completely accounted for. Also a significant positive relationship was found between relative year class strength and the October SOI during both the same and previous time periods but the model was not statistically adequate since the residuals could not be reduced to white noise (Table B1). A statistically significant ($\alpha = 0.05$) model describes the relationship between the September temperature following spawning and the relative year class strength (log transformed, $R^2 = 0.55$). The parameters of this model are outlined in Table B2. This model closely predicts the relative strength of the 1989 year class but underestimates the strength of the 1987 year class (Fig B1).

The combined data set between 1971 to 1995 was also back calculated using the discrete method and four scenarios of M and F, as previously described. Temperature during September were found to be positively correlated with the relative year class strength (log transformed) consistent with the results for the 1985-95 data (Table B1). No statistically adequate models were found between relative year class strength and quarterly environmental data for all four scenarios (Table B3). The parameters for the statistically significant model describing the relationship between the November rainfall prior to the birthdate (January 1st) and relative year class strength are set out in Table B4. This model is only significant when data is calculated with low natural mortality (M=0.14), eg. scenario 3 and 4.

The model (Fig. B2) may be represented as:

$$y_t = -8.2198 + 0.0259X_{t-1} - 1.3824\varepsilon_{t-1} + 0.7468\varepsilon_{t-2} + \varepsilon_t,$$

where y_t refers to relative year class strength (log transformed) at year *t*

X_t refers to mean rainfall for November at year *t*.

ε_t refers to the error at time *t*.

This model is developed using scenario 4, and the 1987 relative year class was omitted due to it's outlying value. The model accounts for serial autocorrelation at $\alpha = 0.05$ and has a regression coefficient of $R^2 = 0.89$. This model underestimates two strong year classes 1973 and 1987 and over predicts the 1989 year class, however, it very closely predicts weaker year classes (Fig B2).

Table B1. Discrete fishery model during 1985 to 1995. Summary of results using dynamic regression models between relative year class strength (log transformed) and environmental variables temperature, rainfall and southern oscillation index (SOI), for the different scenarios of M and Z. Italics and bold print represent statistically adequate models at $\alpha = 0.05$. (+) month refers to positive coefficient for that month.

Scenario	Variable		
	Temperature	Rainfall	SOI
1) M=0.27, Z=1.1			
no lag	***(+) Sep***, (+) Nov	(+) May	-
previous lag	-	(+) May,(+) Nov	(+) Oct
2) M=0.27, Z=0.9			
no lag	***(+) Sep***	(+) May	(+) Oct
previous lag	-	(+) May	(+) Sep
3) M=0.14, Z=1.1			
no lag	***(+) Sep***	(+) May	(+) Oct
previous lag	-	(+) May	(+) Oct
4) M=0.14, Z=0.9			
no lag	***(+) Sep***	(+) May	(+) Oct
previous lag	-	(+) May	(+) Oct

Table B2. Parameter estimates of the regression model (1985 to 1996 data) scenario 4 for temperature model during September of the same year.

Parameter	Estimate	Standard Error of estimate	t-ratio	*P*-value
intercept	-73.466	21.323	-3.445	0.009
temperature	3.919	1.240	3.160	0.013

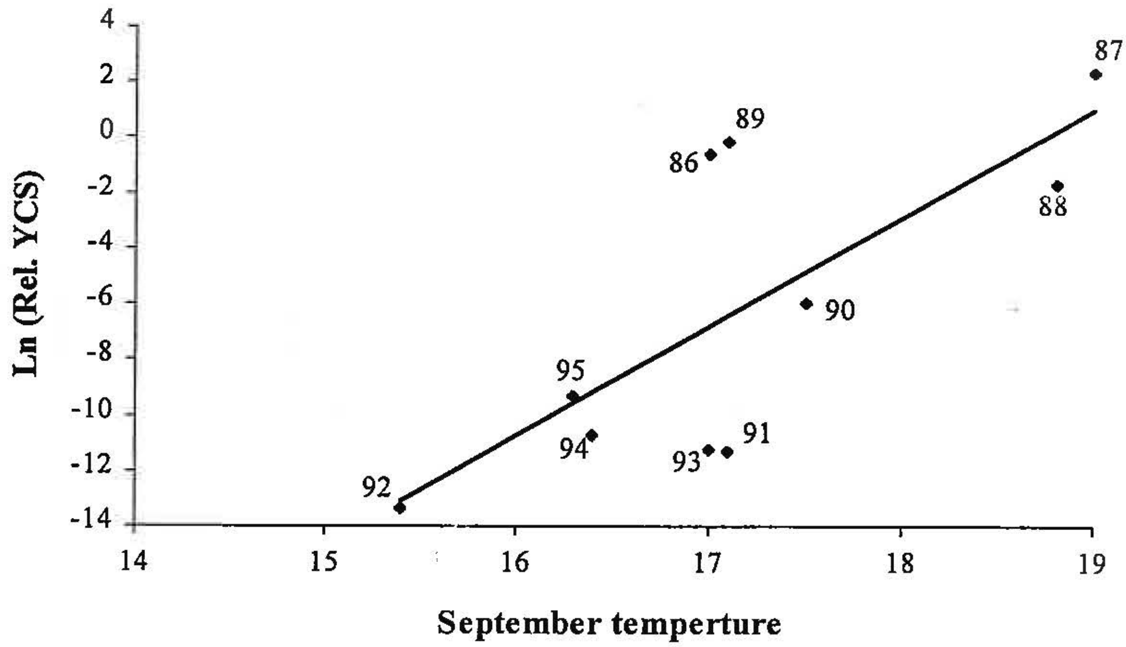
Table B3. Discrete fishery model during 1971 to 1995. Summary of results using dynamic regression models between relative year class strength (log transformed), and environmental variables temperature, rainfall and southern oscillation index (SOI), for the different scenarios of M and Z. Italics and bold print represent statistically adequate models at $\alpha = 0.05$. (+) Sep refers to positive coefficient for September.

	Variable			
	Temperature	**Rainfall**	**Temp. (season)**	**SOI**
Scenario				
1) M=0.27, Z=1.1				
no lag	(+) Sep	-	(+) Spring	(+) Oct
previous lag	-	(+) Nov	-	-
2) M=0.27, Z=0.9				
no lag	(+) Sep	-	-	-
previous lag	-	(+) Nov	-	-
3) M=0.14, Z=1.1				
no lag	(+) Sep	-	(+) Spring	(+) Oct
previous lag	-	***(+) Nov***	-	-
4) M=0.14, Z=0.9				
no lag	(+) Sep	-	-	(+) Oct
previous lag	-	***(+) Nov***	-	-

Table B4. Parameter estimates of the regression model (1971 to 1995 data set) scenario 4 for rainfall model during November of the previous year.

Parameter	Estimate	Standard Error of estimate	t-ratio	*P*-value
intercept	-8.2198	1.2334	-6.664	0.0001
rainfall	0.02590	0.00729	3.554	0.0029
ϕ_1	-1.3824	0.1564	-8.838	0.0001
ϕ_2	0.7468	0.1524	4.900	0.0002

(a)



(b)

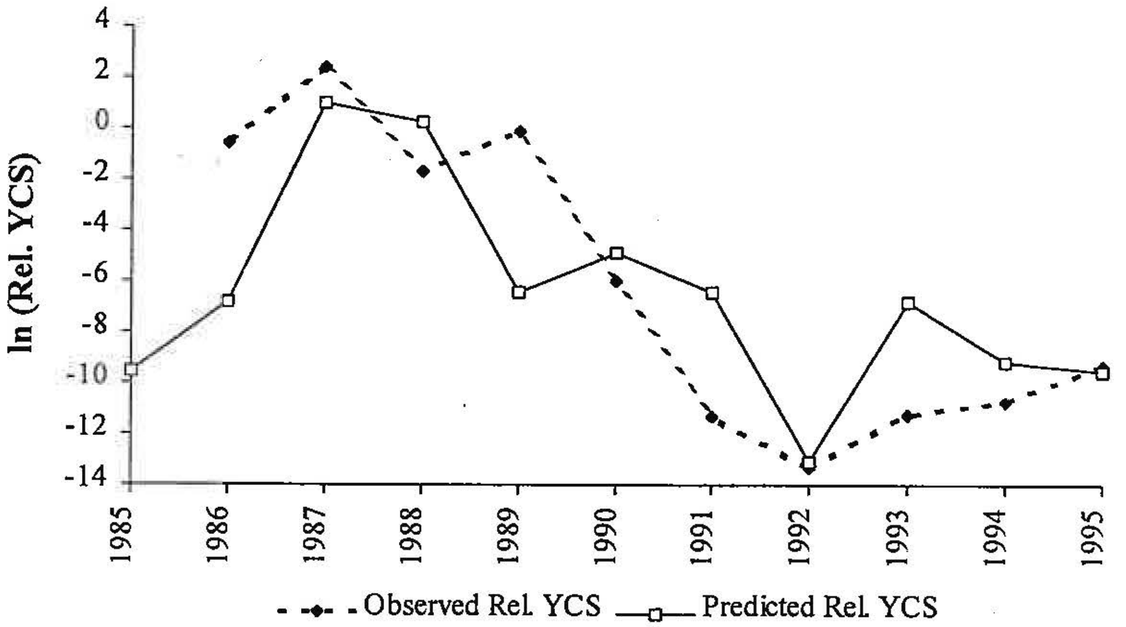
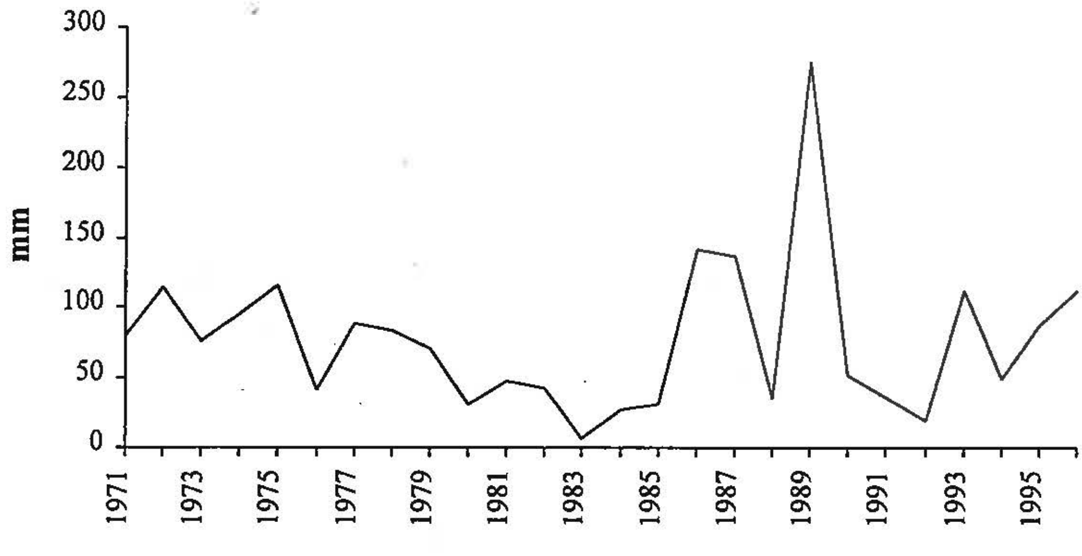


Figure B1. (a) Relationship between temperature at Bairnsdale in the September in the same year and the relative year class strength from 1985 to 1995 (log transformed) for the discrete model, scenario 4. (b) Observed and predicted values of relative year class strength (log transformed) for black bream in the Gippsland Lakes during 1985 to 1995. Predicted values are based on the September temperature relationship in (a).

(a)



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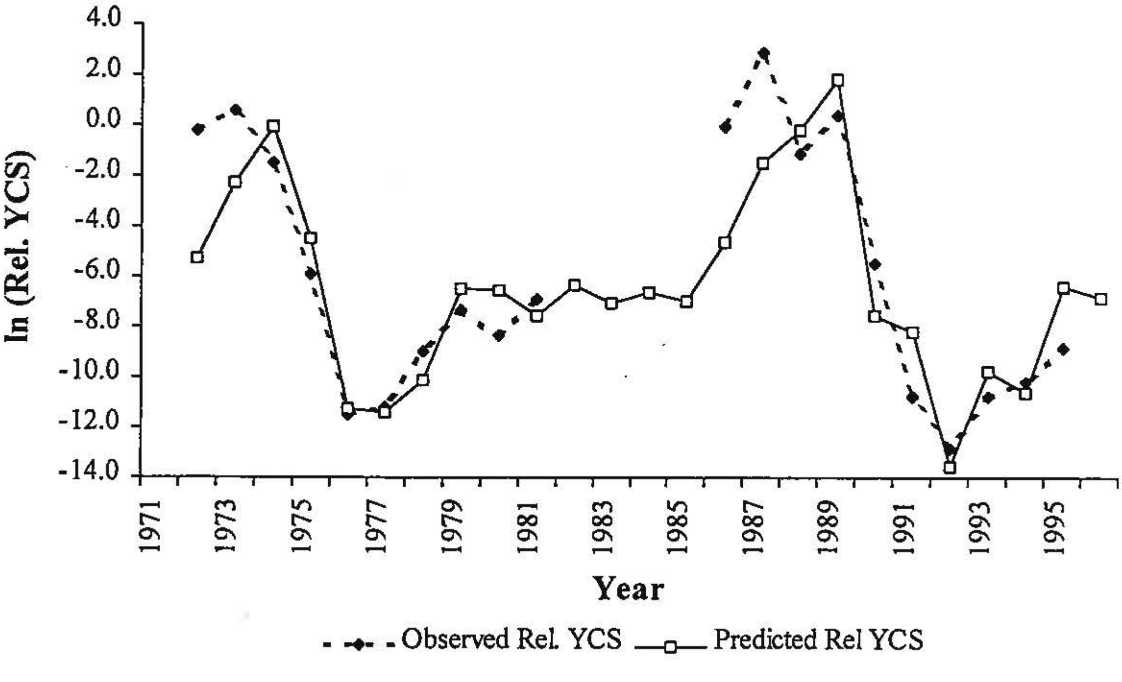

Figure B2. (a) Rainfall in November at the beginning of the spawning season. (b) Observed and predicted values for relative YCS (log transformed) of black bream in the Gippsland Lakes from 1971 to 1996. The predicted values are based on the relationship between the relative YCS (scenario 4) and rainfall in the November at the start of the spawning season.