DEPARTMENT OF PRIMARY INDUSTRIES

Recreational Fishery Management Controls of Commercially Important Species

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Recreational Fishery Management Controls of Commercially Important Species

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CONTENTS

1 NON-TECHNICAL SUMMARY **2**

2 ACKNOWLEDGEMENTS **5**

3 BACKGROUND **5**

4 NEED **9**

5 OBJECTIVES **9**

6 METHODS **10**

6.1 EVALUATION APPROACHES 10
6.2 LEGAL MINIMUM LENGTH PREDICTIVE MODEL 11
6.3 EVALUATING THE EFFECTS OF DAILY BAG LIMITS 17
6.4 MONITORING THE EFFECTS OF MANAGEMENT CONTROL CHANGES 21

7 RESULTS **23**

7.1 EVALUATION OF LEGAL MINIMUM LENGTH STRATEGIES FOR A BREAM FISHERIES. 23
7.2 EFFECTIVENESS OF BAG LIMIT STRATEGIES 36
7.3 DETECTING THE EFFECTS OF MANAGEMENT CONTROL CHANGES 41

8 DISCUSSION **47**

8.1 GENERAL 47
8.2 MODELLING THE EFFECTS OF LEGAL MINIMUM LENGTH CHANGES ON FISHING MORTALITY. 47
8.3 EVALUATING THE USE OF DAILY BAG LIMITS TO CONSTRAIN FISHING MORTALITY 51
8.4 MONITORING THE EFFECTS OF CHANGES TO MANAGEMENT CONTROLS. 53

9 BENEFITS **56**

10 FURTHER DEVELOPEMENTS **57**

11 PLANNED OUTCOMES **57**

12 CONCLUSION **58**

13 REFERENCES **60**

APPENDIX 1: INTELLECTUAL PROPERTY **65**

APPENDIX 2: STAFF **65**

APPENDIX 3: DATA SUMMARIES **66**

98/146 EVALUATION OF RECREATIONAL MANAGEMENT CONTROLS OF COMMERCIALLY IMPORTANT SCALEFISH SPECIES

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OBJECTIVES:

1. Develop methods to evaluate the impact of alternative management controls on recreational fisheries.
2. Compare the effectiveness of alternative management tools- seasonal and area closures, sizes limits and bag limits- in controlling recreational harvest of snapper, King George whiting and black bream stocks in Victoria.

1 NON-TECHNICAL SUMMARY

OUTCOMES ACHIEVED

This project provides approaches to forecast and evaluate the effects of changes to two commonly applied recreational fishing management controls on fishing. The assessment approaches were illustrated using data obtained from creel surveys, and angler diary records for case studies of the Victorian black bream, snapper and King George whiting fisheries. The effects of variability in angler catch rates on the ability to detect changes in key fishery indicators were explored.

There are increasing demands for Australian fisheries management agencies to demonstrate that fisheries under their jurisdiction are being managed in accordance with the principles of ecologically sustainable development (ESD). The decision-making processes of the ESD management framework requires, amongst other things, the establishment of specific and measurable objectives and performance indicators for the management of fisheries, both commercial and recreational. This study focused on the development of methods to assist in evaluating the effectiveness of alternative management controls in addressing these objectives. Methods were developed for conducting *a priori* and *a posteriori* evaluations of the effectiveness of alternative legal minimum length (LML) and daily bag limit (DBL) management options in controlling fishing mortality (F) in marine recreational scale fisheries. These methods were then illustrated using case studies involving three southern Australian scalefish species: black bream, snapper and King George whiting. A predictive age-structured model was developed to assess the likely impacts of LML changes using the Sydenham Inlet and Gippsland Lakes black bream fisheries as examples. A model for assessing the likely effects of alternative DBLs was illustrated using information from the snapper and King George whiting fisheries in Port Phillip Bay and Western Port bay, and the black bream recreational fishery in the Gippsland

Lakes. The effects of three LML changes previously applied to the black bream fishery in the Gippsland Lakes were also assessed.

A time series of catch and growth rate data were used to demonstrate how the abundance and survival rate of dominant year-classes in a fish population with variable cohort strength could be projected under various LML and fishing mortality combinations using an age-structured model. The model assumed constant natural mortality (M) of all fish sizes and constant fishing mortality (of fish above the LML), but treated the growth of year-classes separately. The model parameters were estimated using angler diary catch data and ageing samples collected from a black bream fishery in the Gippsland Lakes over a 3-year sampling period. At the time of sampling the bream stock consisted primarily of two dominant year-classes, a slow growing cohort which contained individuals both above and below the LML, and a faster growing cohort which was below the LML. The anglers providing diary information were asked to alter their choice of fishing gears and locations in order to provide representative samples of the size distribution of the entire fish stock above the selectivity threshold of the angling equipment. Estimates of natural mortality were made from the decline in catch rates over time for cohorts before they reached the LML. This then allowed fishing mortality to be estimated from the decline in catch rates of cohorts once they were above the LML. Projected catch rates for the separate year-classes showed the extent to which differing growth rates of the year-classes could influence the impact of a change to the LML. The combined year-class catch rates were used to predict the degree of protection in terms of catch rate (and survival rate) achieved by various LMLs under different levels of fishing mortality. This approach to fishery assessment would allow managers to set a new LML according to a desired change in fishing mortality. For instance, the model can be used to predict the period of protection afforded by an increased LML before the year-classes again become fully vulnerable to harvesting.

The potential effects of lowering DBLs in reducing average catch rate, and therefore fishing mortality, was evaluated using data on the distribution of daily angler catch rates. The assessment approach was illustrated using creel survey data previously collected from recreational black bream, King George whiting and snapper fisheries. The potential reduction in fishing mortality as a result of a change in DBL varied between fisheries and years. It was estimated that a 20% reduction in current fishing mortalities could be achieved by reducing DBLs to 2-4 fish/angler/day (black bream), 6-10 fish/angler/day (King George whiting) and 2-3 fish/angler/day (snapper). The evaluation approach used here assumed that once the anglers reach the DBL they did not have any further impact on the fish stock, and that a lower DBL did not change the total fishing effort applied to the target species. These assumptions may not always hold true where anglers choose to switch to catch and release fishing once they have reached their bag limit. For multi-species fisheries a low DBL on one species may result in the transfer of fishing effort to another species or high grading of previously caught fish.

The magnitude of the potential reduction in average catch rates as a result of a change in DBL is not always proportional to the magnitude of reduction in the DBL. This is because the distribution of individual catch rates between or within fisheries can vary substantially depending on the characteristics of the fish stock and/or the behaviour of the fishers. The selection of an appropriate DBL to achieve the desired reduction in fishing mortality for a given species is therefore dependent on forecasting the likely mean and distribution of daily angler catches for that species given the new DBL.

A posteriori assessment approaches were developed using daily angler catch and length frequency data collected from creel survey or angler diary programs to detect the impacts of LML or DBL changes on both recreational fishery outcomes and fish stocks. Changes over time in catch rates of particular size or age classes measured from creel survey samples were used as an indicator of a change in fishing mortality. Catch rates of size and age classes of fish by experienced anglers was investigated as an approach by which to detect the effects of a management change on fish stocks. These approaches were illustrated for the recreational bream fishery in the Gippsland Lakes that had undergone three LML and DBL changes between 1996 and 1997.

Creel surveys of shore-based (1995-2000) anglers provided the catch data required to assess the impact of the changes to management controls on the recreational fishery. Catch details recorded by experienced anglers as part of a fishing diary program (1997-2000) were used to illustrate the approach by which the impact of the management control changes on fish stocks could be monitored. Length frequency and daily catch rate data collected from the creel survey indicated that the anglers complied well with the regulation changes. The size composition of the black bream retained by anglers changed significantly as a result of the LML shifts, while the distribution of daily angler catches showed that the DBLs implemented were set too high to have any significant impact on retained bream catches. Changes in angler catch rates (both retained and discarded) from the creel survey could not be attributed to the shifts in the LML. The catch rate data collected by the experienced anglers were less variable than creel survey catch rate data, and provided a more complete assessment approach in terms of the size/age composition of the black bream stock. Nevertheless, the variability was still too high to give sufficient power to detect anything less than large changes in catch rates with current sample sizes.

Length frequency and daily retained catch from angler creels provided an excellent means of assessing the compliance and impact of LML and DBL changes to black bream, King George whiting and snapper fisheries. For fisheries which are characterised by large fluctuations in catch rates, however, that occur for reasons which may not be related to overall abundance, catch rate data collected via creel surveys are unlikely to detect the effects of management controls changes. Experienced anglers fishing with the appropriate sampling intensity provide a more accurate measure of catch rates as an indicator of abundance. Although not specifically assessed as part of this project, this approach also has a potential application in the evaluation of marine protected areas as a fisheries management tool, in addition to the demonstrated use in evaluating the effects of LMLs and DBLs.

KEYWORDS: Recreational fisheries, bag limits, legal minium length, snapper, black bream, King George whiting

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3 BACKGROUND

In 1990 the Commonwealth Government coordinated the development of a national strategy for the application of the principles of ecologically sustainable development (ESD) to fisheries (Anon. 1991). More recently the Standing Committee on Fisheries and Aquaculture has been coordinating the development of a national ESD reporting framework for the management of fisheries. Guiding principles by which the management of fisheries might be achieved within an ESD framework include decision-making processes that effectively integrate both long and short-term economic, biological and social equity considerations. The decision-making processes of the ESD management framework require, amongst other things, the establishment of specific and measurable objectives and performance indicators for the management of fisheries, both commercial and recreational. This study focuses on the development of methods to assist in identifying suitable biological sustainability objectives and performance indicators for recreational fisheries and in evaluating the effectiveness of alternative management controls in addressing these objectives. Development of such methods is particularly important for recreational fisheries based on fish resources that are also commercially fished, and where an ESD reporting framework is being developed or is in place for the commercial sector of the fishery.

Management controls commonly used in Australia for recreational fisheries include, LMLs, DBLs, closed areas, and gear restrictions. There are few published accounts of the specific fisheries management objectives or performance indicators these measures were intended to address (Jones *et al*. 1990; Hancock 1992; Fisheries Victoria 1998). Most Australian studies of recreational fisheries have focused principally on estimating catch and effort, with evaluations of management controls limited to the impact of the measures that were in place at the time of the study (Conron and Coutin 1995; Ferrell and Sumpton 1996; McGlennon and Jones 1997).

Some guidance in developing methods for evaluating the merits of alternative management measures in addressing specific recreational fishery objectives has come from work undertaken in the United States, South Africa and, more recently, New Zealand, where recreational fisheries information is routinely collected for these purposes. For example, the effectiveness of LML changes for some US inland recreational fisheries has been assessed by comparing retained catch rates, and length and/or weight distributions of catches, sampled before and after size limit changes were imposed (Gabelhouse 1984; Meador and Green 1986; Munger and Kraai 1997; Webb and Ott 1991). This approach can assist managers to make *a posteriori* evaluations of the impacts of management measures, but they do not provide a basis for making *a priori* evaluations of alternative management measures and selecting the most appropriate option.

Evaluations of alternative LMLs for some fisheries have been undertaken using age- and length-structured models to predict expected changes in retained catches and/or fishing mortality (Harley *et al*. 2000; Gilbert and Bradford 1999; Attwood and Bennett 1990; Lockwood 1987). These studies required parameter estimates for algorithms involving abundance, growth and mortality associated with the target fish stocks.

For recreational fisheries, the DBL can be used to constrain fish mortality by limiting retained catches. Assessments of the potential effect of future of alternative DBLs on retained catches, and fishing mortality have relied on censoring historical samples of angler daily catches (Jones *et al*.1990; Attwood and Bennet 1995; Gilbert and Bradford 1999). In these studies it is assumed that anglers with catches greater than the bag limit would have kept only the number allowed by the bag limit and then stopped fishing. The sample observations are organised into a frequency distribution of catch per trip and then censored to reflect the bag limit. These assessments are principally based on the assumption that the reduction that can be achieved in the average retained catch rate by the DBL is proportional to the reduction in fishing mortality. To forecast the impacts of DBLs adjustments in following years requires predictions of the effects of fishing mortality on both angler catches and stock abundance (Porch and Fox 1990; Porch and Fox 1991). As with most recreational fisheries assessment models there are a number of assumptions about the behaviour of recreational fishers in response to the introduction of a DBL. Also consideration must be given to the potential impact of any related commercial fisheries.

There have been a number of studies into the benefits of closed areas as part of management strategies for marine fisheries (Horwood *et al*. 1998; Bohnsack 1996; Attwood and Bennett 1991). Key factors in assessing the fisheries benefits of area closures include:- determining whether the closure enhances reproductive success or survival and subsequent recruitment of target fish stocks to areas still open to fishing; and determining whether fishing activities displaced by closed areas cease or are merely transferred to other areas where fishing is still permitted (Ward *et al*. 2001). In addition to parameter estimates of the abundance, growth and mortality of fish inside and outside the closed area, the evaluation of the impact of a closed area requires information on movement of adult fish and larva in and out of the closed area, and on the conduct and regulation of the fishery. Bennett and Attwood (1991) demonstrated that the exclusion of both recreational and commercial fishing from the de Hoop Nature Reserve in South Africa had resulted in an increase in the abundance of the recreationally important Coracinid species galjoen (*Coracinus capensis*) inside the reserve. A tagging study showed that some galjoen emigrated from the reserve and that the unharvested reserve population was restocking adjacent exploited areas with adult fish providing significant benefits to the fishery (Attwood and Bennett 1994). The de Hoop Nature Reserve covers some 50 km of coastline and demonstrates the benefits of scaling the reserve size in relation to the mobility of the species and the intensity of the fishery.

In this study we develop methods for conducting *a priori* and *a posteriori* evaluations of the effectiveness of alternative LML and DBL management options in controlling fishing pressure in marine recreational scale fisheries. These methods are developed and illustrated using case studies involving three southern Australian scalefish species which have different biology, distribution and movement characteristics. King George whiting (*Sillaginodes punctata*) is a coastal marine species with, in Victoria, a relatively short period of vulnerability to commercial and recreational fisheries in bays and inlets, and a subsequent movement of adult spawning stock into open coastal waters (Jenkins *et al*. 2000) where there is little fishing pressure. Snapper (*Pagrus auratus*) are vulnerable to fishing through some of their juvenile and all of their adult life as they migrate between coastal waters and the gulfs, bays and inlets of southern Australia (MacDonald 1982; McGlennon and Jones 1997). Black bream (*Acanthopagrus butcheri*) are residents of southern Australian estuaries, but seasonal movements within these estuaries alter their vulnerability to commercial and recreational fisheries (Butcher and Ling 1962; MacDonald 1997; Conron and Bills 2000).

At the time this study commenced planned marine protected areas that would be closed to fishing had not yet been established in southern Australian waters. In addition, the planned marine protected areas were not selected to address specific fishery management objectives in relation to snapper, King George whiting or black bream stocks. Consequently no information was available to assist in developing methods for evaluating closed areas as a recreational fishery management tool for these species. Furthermore, the mobile nature of these three species suggests that large areas would need to be closed to achieve any significant reduction in fishing pressure. This study was therefore confined to developing methods whereby the effectiveness of alternative DBLs and LMLs, the more commonly employed management tools, could be evaluated.

4 NEED

Because of the popularity of recreational fishing in Australia, and the social and economic benefits it provides, there is increasing recognition of the need to manage recreational fisheries - as well as commercial fisheries - according to an ESD-based framework. This includes identifying specific and measurable objectives and performance indicators for the biological, economic and social components of individual fisheries, and evaluating which management measures are likely to be most effective in achieving the stated objectives. This study contributes to the development of methods for identifying suitable biological sustainability objectives and performance indicators for recreational fisheries, and for conducting evaluations of the effectiveness of alternative LML and DBL management measures in achieving such objectives.

Recreational fishery surveys have been conducted in the bays and inlets of Victoria throughout the 1990s (Coutin *et al*. 1995; Conron and Bills 2000), with the data collected being used to estimate total catch and effort in some cases, and provide time series of catch rate and age/length data in other cases. Further analyses of these available data can assist in the development and testing of methods for evaluating the effectiveness of alternative LML and DBL management measures in achieving management objectives for recreational snapper, King George whiting and black bream fisheries.

5 OBJECTIVES

1. Develop methods to evaluate the impact of alternative management controls on recreational fisheries.
2. Compare the effectiveness of alternative management tools- seasonal and area closures, sizes limits and bag limits- in controlling recreational harvest of snapper, King George whiting and black bream stocks in Victoria.

All the original project objectives stated above have been achieved with the exception of evaluating the effectiveness of seasonal and area closures compared with other management tools. As outlined previously the required data sets necessary for this task were not available and collection a suitable new data set was beyond the scope of the study. The uses of recreational catch data as a tool for monitoring the impacts of seasonal and area closures has been discussed.

6 METHODS

6.1 Evaluation approaches

Of possible management tools and evaluation approaches, this study focuses on those which can be practically implemented and have achievable information requirements for small-scale inshore marine and estuarine scalefish fisheries. Recreational catch and effort data are commonly gathered by Australian fisheries agencies using creel surveys and therefore this type of information was identified as being the most available information source for assessment approaches. However, the high costs of creel surveys mean that in most cases they are only run intermittently for any particular fishery. Voluntary fishing diary programs have been identified as an appropriate alternative method to creel surveys in obtaining an extended time series of catch and effort data (Conron and Kirwin 2000).

The Victorian recreational fisheries for black bream, snapper and King George whiting were chosen as case studies because of the ready availability of catch and effort data. The range and extent of Victorian fisheries data available for these species were thought to be sufficient to allow evaluation of LML and DBL changes, and no additional information from other States was used. A predictive model was developed to assess the likely impacts of LML changes using two black bream fisheries as an example. The effects of two LML changes previously applied to the black bream fishery in the Gippsland Lakes were also assessed. The model for assessing likely effects of various alternative DBLs was illustrated using information from the snapper and King George whiting fisheries in Port Phillip Bay and Western Port bay, and the black bream recreational fishery in the Gippsland Lakes.

6.2 Legal Minimum Length predictive model

A LML predictive model was developed with the aim of exploring the effects of potential changes to regulations on fish stocks based on an index of abundance. The model was sufficiently parsimonious to not rely too heavily on the use of many parameters while still being a useful tool for management. This allowed the model to be implemented on a spreadsheet hence lending itself to portability and ease of use. Of particular interest was the projected effect on relative stock abundance after changes in LML to both the recreational and commercial fisheries. The model was constructed firstly for a case study of the black bream fishery in the Sydenham Inlet where a time series of data for the single cohort is available. The model is then presented as a case study for the black bream fishery in the Gippsland Lakes for which two cohorts are modelled. The model encompasses enough generality to be extended to other fisheries for which an index of abundance is available. A major feature of the model for two cohorts was to allow for different growth rates between cohorts. All model inputs were assumed to be known without error and the research anglers are assumed to have negligible impact on abundance.

The models used angler catch rate as an index of abundance. The angler catch rate data were provided through an angler fishing program specifically set up to monitor the abundance of the various size/year-classes of black bream populations in the Sydenham Inlet and the Gippsland Lakes. The participating anglers altered their fishing techniques in order to catch the full size range of black bream. A detailed catch diary was filled in recording the time spent fishing, fish lengths and bait and hook sizes used. In addition to filling in a catch diaries, anglers also removed the otoliths (or provided the frames of fish from which the otoliths were later removed) from a sample of their bream catch for the purposes of ageing. Age estimates were made by counting opaque increments from sectioned otoliths (Morison *et al*. 1998). A special permit was issued to each angler permitting collection of fish under the LML. In the following discussion anglers participating in the fishing sampling program will be known as research anglers, to avoid any confusion with the recreational anglers.

Abundance and recruitment

Underlying the model is the catch rate (It) of the research angler. The catch rates of the research anglers, as stated above in the data collection, was designed so as their catch rates reflected abundance of fish. From a modelling perspective this index of abundance is given by the simple relationship,

$$I_t = pN_t, \qquad \textbf{(1)}$$

where N_t is the number of fish at age t for a given year class and p is a proportionality constant. Two factors that need to be accounted for to relate research angler data to the abundance of fish are selectivity and recruitment. Recruitment to the research angler catch is the onset of vulnerability to being caught whereas selectivity is determined by fishing gear used. Using a selectivity function, s_t, and a recruitment function for the research angler catch, r_t at age t,

$$I_t = pN_t r_t s_t \qquad \textbf{(2)}$$

It was assumed that catch rate is not influenced by any other factors (eg. movement or catchability) other than overall stock abundance and that fishing and natural mortality remained constant.

Selectivity at length L (s_L) is,

$$s_L = 1/(1 + exp[-r(L-Lc)]) \qquad \textbf{(3)}$$

where r is a constant with a value which increases with the steepness of the selection curve, and Lc is the mean length at first capture at which a fish has a 50% chance of being captured (see King 1995). The selectivity of the research angler's fishing gear was estimated using the combined length frequency of bream caught in each estuary over the study period. A logistic function was then fitted to approximated r and Lc using probit analysis (SAS Institute 1989).

The dynamics of individual year-classes is modelled by the differential decay equation,

$$\frac{dN_t}{dt} = -(M + FR_t(LML))N_t \qquad \textbf{(4)}$$

where M is the natural mortality rate, F is the combined fishing mortality from all forms of fishing (recreational and/or commercial*)* and $R_t(LML)$ is recruitment of fish at age *t* into the fishery given a legal minimum length of *LML*.

Equation (3) may be solved by integration to arrive at an equation for numbers at age.

$$N_t = N_0 \exp(-Mt + F\int R_t(LML)dt) \qquad \textbf{(5)}$$

The integral term in equation (5) is solved by numerical integration. The abundance of a given year-class may be estimated for the years of research angler catch by equation (2). Projections for following years is then provided by equation (5), with exponential decline of the cohort population

Growth

Growth of an individual is modelled via the von Bertalanffy growth equation (von Bertalanffy 1938):

$$L_t = L_\infty(1 - \exp(-K(t - t_0)) \qquad \textbf{(6)}$$

where L_t is the total length of the fish at age *t*, K is the mean growth parameter and L_∞ is the estimated asymptotic fork length attained by the population. The parameter t_0 indicates the x-intercept of the growth curve. The mean growth rate, K, is estimated using linear regression of the inverse von Bertalanffy equation from the age-length key which is constructed from the ageing samples collect by the research anglers.

$$t = \frac{1}{K}\ln\left(\frac{L_\infty}{L_\infty - L_t}\right) + t_0 \qquad \textbf{(7)}$$

Stochasticity of estimated mean growth rate was introduced into the growth equation ***(7)*** by assuming that the growth parameter is a random variable with a gamma distribution and a mean of K (Troynikov 1998*)*.

$$f(K,\alpha,\beta) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} K^{(\alpha-1)}\, \mathrm{e}^{\frac{K}{\beta}} \qquad \textbf{\textit{(8)}}$$

where α, β are considered random variables in the population, and $\Gamma(x)$ is the standard gamma function. For further details on the use of the gamma distribution for growth see Troynikov (1998).

Mortality parameter estimates

Two approaches were used to estimate natural mortality. The first approach was to follow the procedure described by Alverson and Carney (1975) which uses life-history parameters; growth (K) and age (t*) at which an unfished cohort reaches its greatest biomass to estimate M **(9)**.

$$M = 3k / exp(t^* K)\text{-}1 \qquad \textbf{(9)}$$

Alverson and Carney determined empirically that $t^* \approx 0.38\, t_m$, where t_m is maximum observed age.

Natural mortality was also estimated by catch curve analysis (Quinn and Deriso 1999) which involved tracking the rate of decline in research angler's catch rate (C_a) of the cohort at age $_a$ over successive years while the cohort remained below the LML (see equation **(10)**). This is possible as below the LML we have catch rate data from the research angler who is assumed to have negligible affect on the fish population (ie. for fish less than the LML F=0)

$$M = \ln\left(\frac{I_t r_{t+1} s_{t+1}}{I_{t+1} r_t s_t}\right) \qquad \textbf{(10)}$$

Fishing mortality was estimated following the estimation of total mortality (Z) and natural mortality parameters, F=Z-M (Ricker 1947). Total mortality was estimated by catch curve analysis for the cohort above the LML and hence vulnerable to fishing mortality. (see equation **(11)**).

$$F = \ln\left(\frac{I_t R_{t+1}}{I_{t+1} R_t}\right) - M \qquad \textbf{(11)}$$

Total and natural mortality as well as catchability (*q*) was assumed to be constant over the study period. The cohorts were assumed to be closed to migration, so that changes in abundance are due only to fishing and natural mortality. Mortality associated with catch and release was not included. The model was used to project the relative abundance and survival rates (*S*) of the major year-classes for selected LMLs and values of fishing and natural mortality.

Age-structured LML model case study 1 – the Sydenham Inlet black bream fishery

Sydenham Inlet is an extensive shallow lagoon system in south-eastern Victoria, with a delta built out by a river. The estuary supports a significant black bream recreational fishery. There has been no commercial fishing in Sydenham Inlet since the early 1900s. The only information available on the size and abundance of black bream in Sydenham Inlet is a fishing diary kept by an angler who fishes regularly since the late 1960s. The numbers and length of bream caught by the angler over a period of about 30 years suggests that the bream population is characterised by cycles of high and low abundance. Tracking the proportion of the catch under the LML shows these cycles in catch rates are consistent with fluctuations in spawning success and therefore the abundance of fish under the LML. In the early 1990s the angler started to provide fish frames from a sample of the catch (for ageing purposes) and fished in a range of locations and used hook sizes and baits which sampled a wide size range of bream (pers. com. John Kirk 2001). Fishing effort was transcribed from the catch diary by trip rather than hours. The data used from the model consisted of catch data and otoliths samples taken by a single research angler in February from 1994 to 2000 and suggests that a single cohort of bream dominants the research anglers catches. Catch data for the first three years of sampling (1994-1996) was used to estimate the model parameters and forecast the abundance (after 1996) for the dominant year-class. These abundance forecasts were then compared to the reported angler catch rates (1997-2000). The impact of a LML change (from 26 to 30 cm TL) on abundance was also estimated. The survival rate of bream from the previous year was also estimated and compared to the forecasted survival rates for the year-class using the same LML , M, and F combinations.

Age-structured LML model case study 2 – the Gippsland Lakes black bream fishery

The Gippsland Lakes supports the largest commercial and recreational black bream fisheries in Victoria. There is very little migration of bream in or out of the Lakes system (MacDonald 1997). The black bream stock is characterised by substantial fluctuations in annual reproductive success, resulting in an age profile that is dominated by one or two strong year-classes (Morison *et al*. 1998). The growth and relative abundance of 1989 and 1995 bream year-classes have been documented by Cashmore *et al.* (2000). At the commencement of this study, two year-classes of black bream dominated the stock in the Gippsland Lakes, one that was both above and below the LML (1989), and one that was below the LML (1995). The 1989 year-class has been sustaining the fishery for a number of years due to it's high abundance, slow growth rate, and hence the long time period to be recruited into the recreational and commercial fisheries (in the sense of reaching the LML). By contrast to the 1989 year-class, the 1995 cohort was considered to be less abundant but exhibited a faster growth rate over the initial 2 years of growth. This cohort was expected to have recruited into the recreational fishery by 2001. In the case of Gippsland Lakes bream L_∞ was estimated to be 46 cm (TL) or 40 cm (FL).

Growth rates for the two cohorts were then be estimated separately by regressing the inverse von Bertalanffy equation on their respective age-length data.

$$t = \frac{1}{K_c} \ln\left(\frac{L_\infty}{L_\infty - L_t}\right) + t_0 \ , \qquad \textbf{\textit{(12)}}$$

Where K_c represents the growth rate for cohort *c*. To avoid the biologically improbable situation of a younger year-class growing past an older year-class a function was incorporated into the growth equation which would slow the growth of the younger cohort at a particular age. This was consistent with a slowing of the growth rate due to density/habitat dependent effects.

Density dependence was incorporated into a modified von Bertalanffy growth function

$$L_t = L_\infty(1 - \exp(-(K_c - d_t)(t - t_0))) \qquad \textbf{\textit{(13)}}$$

where given t_d is the age where the density dependent/habitat growth starts and d_c is the density/habitat dependent constant. The function d_t as defined below declines inversely with the age of the fish therefore gives a large initial growth when the younger cohort first start to compete with the older cohorts. The impact of density dependence then declines as the cohort becomes older.

$$d_t = \begin{cases} 0, t < t_d \\ d_c / t \geq t_d \end{cases}$$

The catch data were provided by a single angler fishing the Gippsland Lakes in November over the three years 1997, 1998 and 1999. Research angler catch rates were projected for the two dominant year-classes both individually and combined for three values of the LML (26, 28 and 30 cm) and three values of fishing mortality (equal to that estimated from the catch curve, twice the estimate of F and three times the estimate of F). The survival rate of bream from the previous year was also estimated and projected for the combined year-classes using the same LML and fishing mortality combinations.

6.3 Evaluating the effects of Daily Bag Limits

Two approaches were used to evaluate the effects of DBLs, each of these approaches are described below.

The first approach estimated the likely immediate effects on fishing mortality of various DBL changes in a number of different fisheries. By examining the immediate effects of the catch rates the assumption is that stock size and effort remain constants. This method was similar to that used, by Attwood and Bennett (1995) who described the relationship between the potential reduction in fishing mortality by a DBL and retained catch rate by anglers. It was assumed that the daily retained catch rate (C_t) is proportional to the product of catchability q, stock size (N) and fishing effort (E).

$$C_t = q_t EN \qquad \textbf{(14)}$$

Fishing mortality was assumed to be proportional to catchability when effort remains constant. In the case of restricting the catch the containment of fishing mortality (F_t^{DBL}) is achieved by limiting the catchability of the fish by the DBL

$$F = qE \quad \text{and} \quad F_t^{DBL} = q_{DBL}E \qquad \textbf{(15)}$$

Further, for a given level of abundance, if no change in recreational fishing effort occurs as a consequence of the DBL, then any reduction in C_t as a result of the enforcement of a catch restriction should cause an equivalent proportional reduction in fishing mortality. Therefore if C_t^{DBL} and F_t^{DBL} are the restricted daily catch and fishing mortality rates respectively, which would result from the enforcement of a DBL, then equation (14) and (15) imply that

$$\frac{C_t^{DBL}}{C_t} = \frac{F_t^{DBL}}{F} \qquad \textbf{(16)}$$

If the number of anglers who caught i fish of species j on day d is A_{ijd} then the proportion of catch that is above the DBL is

$$P_{jd}^{DBL} = \sum_{i>DBL} A_{ijd}(i - DBL) \Big/ \sum_i A_{ijd}\, i \qquad \textbf{(17)}$$

Following from equation (16) and (17) the relative reduction of fishing mortality on species *j*, as a result of the enforcement of a DBL fish per angler per day averaged over the sampling days

$$(F - F^{DBL)} \big/ F = P_j^{DBL} . \qquad \textbf{(18)}$$

This represents the potential reduction in fishing mortality caused by the introduction of a DBL per angler per day.

This method was illustrated for snapper and King George whiting recreational fisheries using completed trip creel survey data gathered between 1994 and 2001 from boat-based parties who had completed fishing trips in Port Phillip Bay and Western Port bay, and for the Gippsland Lakes boat-based bream fishery. To determine individual daily angler catch rates, fishing party catch data were evenly allocated among individual anglers in a party and any remaining fish were allocated individually to the anglers in order.

Catch rates were calculated using total effort data and not partitioned according to the species targeted. The frequency distribution of angler catch rates for each species, estuary and year were calculated and then censored to reflect the bag limit. Estimates of the relative reduction in average catch rate (fishing mortality) for a range of bag limits were calculated.

The second approach estimated the potential effectiveness of a two bream DBL in reducing F in a fishery where catch rates were declining. The principles of the method used are outlined by Porch and Fox (1990), and take into consideration the effects of the DBL on F, stock abundance and the average daily angler catch (C) of the fishery over successive years. The stock abundance on bream above the LML was approximated by the research angler catch rate of the 1989 bream year-class (*I*). It was assumed that the average catch rate of the fishery was linearly related to stock abundance above the LML (see equation 19). The proportion of reduction in fishing mortality, $\%F_t = F_t^{DBL} / F$, is linearly related to the proportional change in the corresponding catch rates.(see equation 20)

$$C_t = \alpha I_t + \beta \quad (19)$$

$$\%F = \sigma\left(\frac{C_t^{DBL}}{C_t}\right) + \lambda \quad (20)$$

Where $\alpha, \beta, \sigma, \lambda$ are constants.

The theoretical catch rate for a given bag limit was calculated by truncating catches above the bag limit to equal the bag limit quota. Therefor if x is the number of fish caught per day by angler i, then ,

$$C_d^{DBL} = \sum_{\substack{i \\ x_i \le DBL}} x_i + \sum_{\substack{i \\ x_i > DBL}} DBL \quad (21)$$

These relationships were estimated using a linear regression of three years of bream catch data from the Gippsland Lakes for 1997-1999. A stepwise calculation method was used to forecast the trends in stock abundance with and without a two fish DBL in a bream fishery. The calculation method started with the angler catch rate of the 1989 year-class (I_t) in 1997. The sequence of calculations used in our simulations is as follows:

Step1: The average daily angler catch of bream (C_t) for the boat fishing is estimated from equation (12).

Step2: The truncated C_t^{DBL} is calculated using equation (14)

Step3: The proportion reduction in F with a 2 bream DBL is calculated from equation (13) and F_t^{DBL} is then computed with an assumed constant F .

Step4: The population in the following year with the bag limit ($N_{t+1}^{DBL=2}$) is computed for the calculate bag limit fishing mortality ($F_t^{DBL=2}$) and the assumed natural mortality (M) values.

$$N_{t+1}^{DBL=2} = N_t^{DBL} \exp(-(F_t^{DBL=2} + M)) \qquad (22)$$

Steps 1 to 4 were repeated with $N_{t+1}^{DBL=2}$ and $I^{noDBL}{}_{t+1}$ as the starting point to give abundance estimates with and without the DBL for 1999. It is assumed throughout this document that the research angler catch rate is and index of abundance. Therefor we may compare the population with out a bag limit, I_t with the population with a bag limit, N_t^{DBL}

It was assumed that the 10 bream DBL in place at the time of sampling had little effect on constraining F and therefore approximated the effect of no DBL. It was also assumed that there was a similar reduction in total catch (terms of fishing mortality) by the commercial and recreational shoreline bream fisheries.

The effectiveness of the low DBL in reducing total mortality was predicted for two successive years, under three different levels fishing mortalities (0.3, 0.6 and 0.9 yr^{-1}) and assuming natural mortality equals 0.1 yr^{-1}. For the purposes of the demonstration, it was assumed that the 1989 year-class was fully recruited to the fishery and the fishery was closed to recruitment of other year-classes.

6.4 Monitoring the effects of management control changes

Detecting impacts to recreational fisheries

Methods were developed to monitor the impact of a LML and a DBL on both the fishery and the fish stocks. The compliance of the recreational anglers to the management controls applied was initially assessed from creel survey catch data. A length categorisation technique (Johnston and Anderson 1974) was applied to the length distribution of the retained catches to assess the compliance of the anglers the LML. Comparisons were made between the percentage of the retained catch in the size groupings using a one-way analysis of variance (ANOVA) following a Bartlett's test for homogeneity of variance. The compliance of the recreational fishery to the DBL was assessed by comparing the distribution of retained catches by anglers (this procedure has been previously detailed in section 6.2).

Catch data from a creel survey and angler diary programs were used to demonstrate ways in which the impacts of management controls on catch rates and fish mortality can be monitored. Changes in catch rates of year and/or size classes, before and after the management control changes, are assumed to reflect changes in fish stock abundance and therefore a change in fishing mortality. The ability of various sampling strategies to detect changes in catch rates of a given magnitude was also assessed.

These methods were illustrated using catch data from the Gippsland Lakes black bream recreational fishery. Three management control changes were applied to the recreational fishery between 1996 and 1997. In December 1996, a temporary DBL of 5 fish was applied, accompanied by a shift in the LML from 24 cm to 26 cm (TL). The temporary size limit of 26 cm TL and DBL were allowed to lapse in July 1997. In October 1997 the 26cm LML was reinstated accompanied by a more lenient DBL limit of 10 bream. The same LML changes were also applied to the commercial fishery. The compliance of the recreational fishery to the LML shifts was assessed by tracking the percentage of bream in the retained catches in five length categories (less than 24 cm, 24 to 25 cm, 26 to 29 cm, 30 to 35cm and longer than 36 cm). The length frequency data required were obtained from several recreational fishery creel surveys undertaken in the Gippsland Lakes between 1995 and 1997 (Conron and Coutin 1996, Conron and Bills 2000) and from additional fixed-point and roving creel surveys conducted between 1997 and 2000. The impact of the DBL changes was assessed using completed trip catch data from a survey of boat-based anglers. The survey commenced in January 1997, just after the first changes to the LML and DBL, and continued to December 2000.

Estimates of retained and discarded catch rates, obtained from a roving creel survey of shoreline anglers, were used as an index of stock abundance before and after the LML and DBL changes. For analysis, the catch rate data were grouped by seasons, since seasonal changes in catch rates of bream have been shown to occur in parts of the Gippsland Lakes (Conron and Bills 2000). The timing of the management control changes resulted in some non-seasonal grouping of catch rate estimates. Average catch rates were calculated using the mean-of-ratios estimator (Jones *et al*. 1995). The "bootstrap" method was used to estimate confidence limits (CL) for the catch rate estimates, using a resample size of *n*/2. (Efron and Tibshirani 1993). The power analysis was performed using SAS V8.2 (SAS Institute 1989) to estimate the detectable changes (α =5%) in catch rates for different sampling intensities. The retained catch rates were partitioned between the dominant year-classes using the length distributions of bream in the retained catch and applying an age-length key for that year. The age-length keys were produced from otolith samples collected as part the angler fishing diary program (1997-1999) and annual net surveys (1996-2000). The distribution of the retained catch between the year-classes was assumed to be without error.

Detecting impacts to fish stocks

Catch rates of size-groups above and below LML provided an indication of changes in abundance in response to the management controls implemented. The catch data were provided by the research angler program (as referred to in section 6.1). Estimates of average catch rates and confidence limits were calculated using the ratio-of-means estimator (Jones *et al*. 1995) and confidence intervals were calculated using bootstrap techniques as described above. Because of the smaller number of black bream sampled by the angler diary program compared to the creel survey, only three size-groupings were used: less than 24 cm, 24–25 cm and 26 cm and longer. Catch rates of the dominant year-classes that were vulnerable to the diary angler fishery, were estimated for input in the age-structured model (section 6.1). This method was assessed as a tool for monitoring changes in year-class abundance.

7 RESULTS

7.1 Evaluation of Legal Minimum Length strategies for a bream fisheries.

Angler catch data

Over seven sample periods (1994-2000), the research angler fishing Sydenham Inlet, fished on 120 days and measured 1,285 captured bream, from which 1,100 otolith samples were taken and aged. The length distribution of sampled bream suggests that the fish stock was characterised by fish over 20 cm until 1999 when a group of smaller bream were detected in the research angler's catches (**Figure 1**).

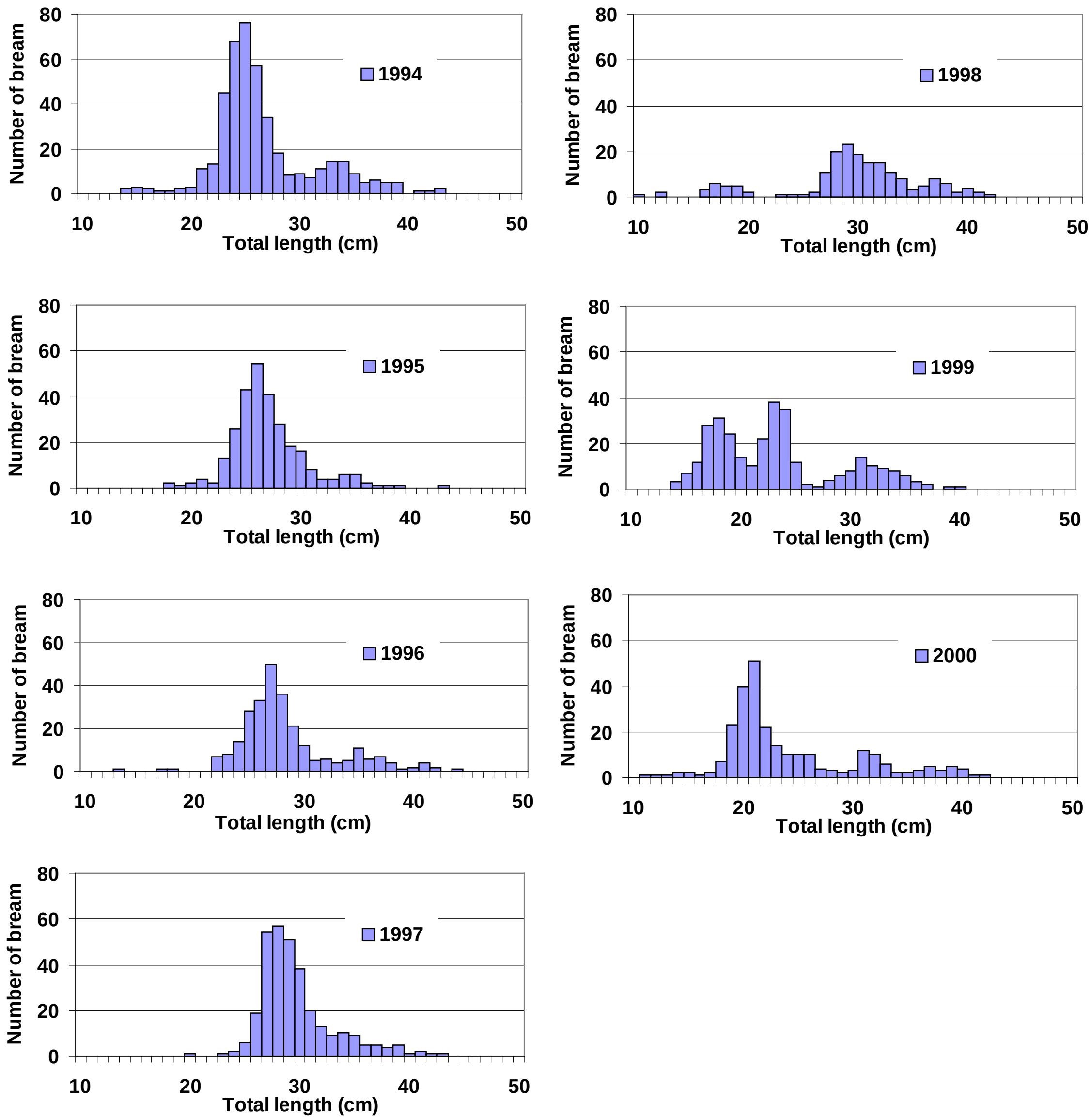

Figure 1 Frequency distribution of black bream caught by a research angler fishing Sydenham Inlet from 1994 to 2000 (n=1285).

The application of the annual age-length keys to the length distribution samples confirmed that from 1994 until 1999 the bream stock comprised of the single dominant cohort, the 1988 year-class. This dominant cohort was from the spring/summer spawning of 1987.

The research angler sampled the Gippsland Lakes on 41 separate days and measured

466 captured bream over three years (1997-1999). A wide size range of bream were recorded in the research anglers catches (Figure 2).

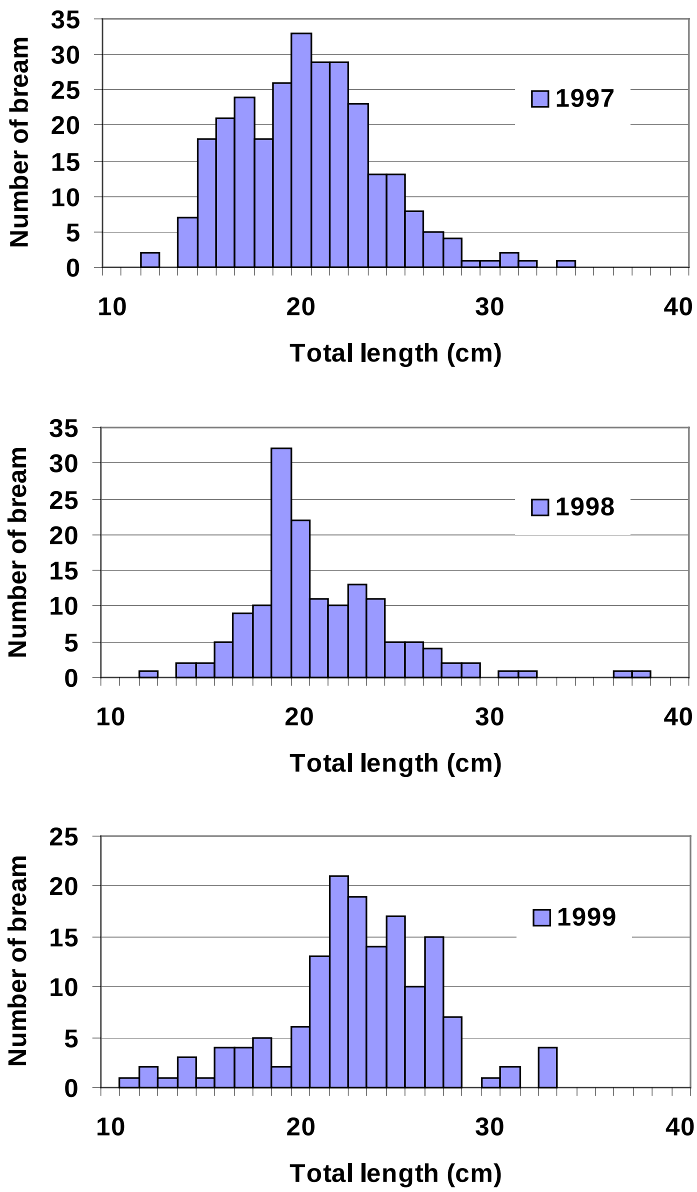

Figure 2 Frequency distribution of black bream caught by a research angler fishing the Gippsland Lakes from 1997 to 1999 (n=466).

The annual age-length key were constructed from the ageing of the 380 otoliths samples collected by the research angler and a net survey which confirmed that the stock was dominated by members of only two year-classes (1995 and 1989 year-class).

Selectivity

The mean length of bream at first capture (*Lc*) for by the angler fishing the Sydenham Inlet was estimated to be18 cm (TL) and fully selective for 22 cm bream. By comparison the fishing gear used by the angler fishing the Gippsland Lakes was estimated to be less selective with a mean length of bream at first capture of 16 cm (TL) and fully selective for 20 cm bream (**Figure 3**).

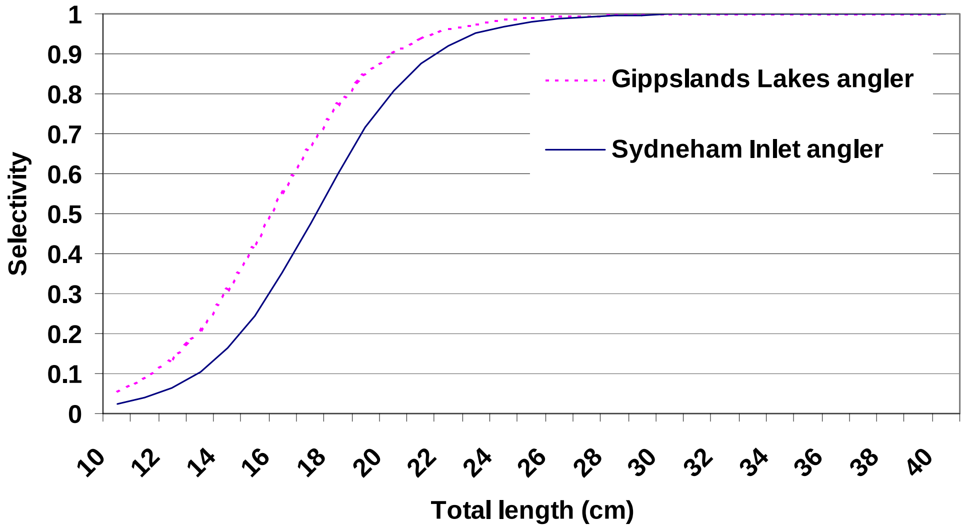

Figure 3. A comparison on the estimated selectively of the fishing gears used to catch black bream in the Gippsland Lakes and Sydenham Inlet.

Abundance estimates

The mean catch rates of the dominant year-classes (adjusted for fishing gear selectively) in the Sydenham Inlet and Gippsland Lakes suggest a decline in abundance in the study periods (Figure 4 & Figure 5).

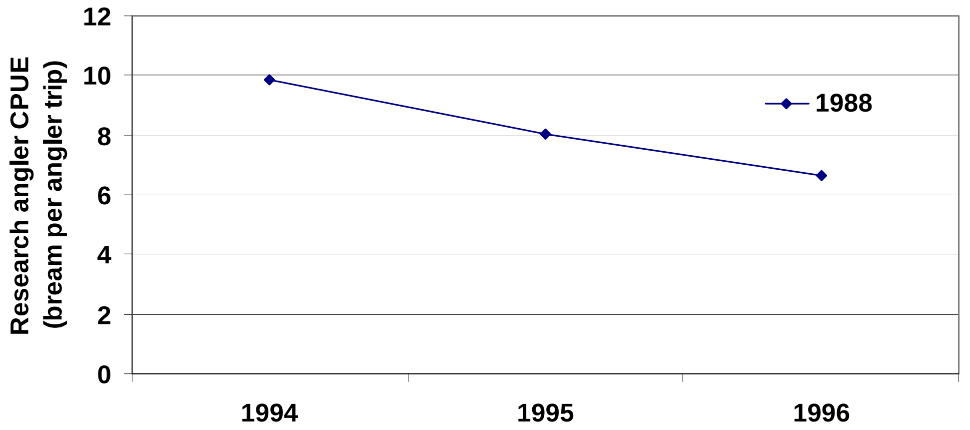

Figure 4. Research angler mean catch rates for the 1998 year-class of black bream in Sydenham Inlet 1994-1996.

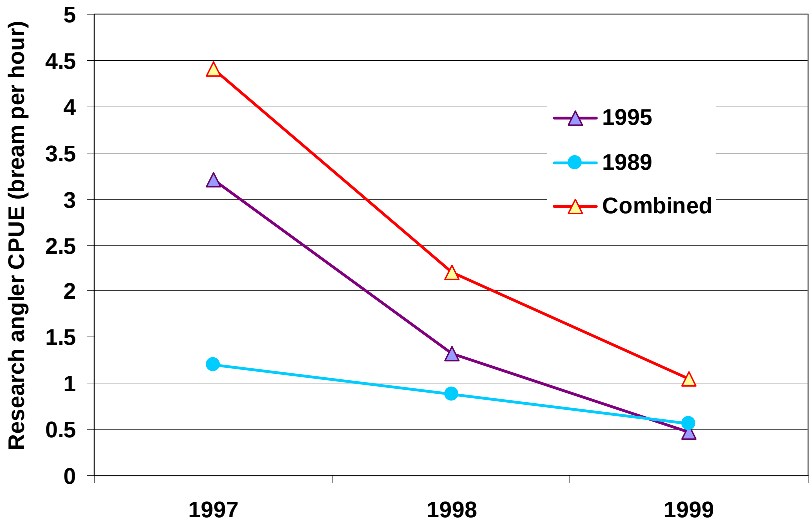

Figure 5. Research angler mean catch rates for the major year-classes of black bream in the Gippsland Lakes 1997-1999.

Growth and Mortality

The 1995 Gippsland Lakes cohort was estimated to be growing at a faster rate than both the 1989 Gippsland Lakes and 1988 Sydenham Inlet cohorts (Table 1). The cohort growth estimates provided a means of estimating natural mortality using the life-history analysis approach. The maximum observed bream age was 37 years (MAFRI unpublished data). Natural mortality estimates ranged from 0.07 to 0.11 (Table 1).

Total mortality estimates for the three year-classes using the catch curve analysis are also shown the table 1. Surprisingly, the 1995 year-class in Gippsland Lakes, which was below the LML through-out the sampling period, had a higher estimated total mortality than the older year-classes which were mainly above the LML. Possible reasons for this high natural mortality estimated for the 1995 year-class are investigated later in this report. For the purposes of providing parameter estimates for the age-structured model, a natural mortality estimate of 0.1 (based on the life-history analysis) was used. The estimate of fishing mortality for the 1988 year-class in Sydenham Inlet was similar to the 1989 year-class in the Gippsland Lakes.

Table 1. Parameter estimates for the major year-classes of black bream caught by research anglers fishing Sydenham Inlet (1994-1996) and the Gippsland Lakes (1997-1999).

Parameter	Sydenham Inlet 1988 year-class	Gippsland Lakes 1989 year-class	Gippsland Lakes 1995 year-class
Mean length of first capture (*Lc*)	18 cm	16cm	16cm
Growth (*K*)	0.098	0.061	0.125*
Natural mortality[l] (*M*)	0.09	0.11	0.07
Total mortality[c] (*Z*)	0.37	0.37	0.7
Natural mortality[c] (*M*)			≈0.95
Fishing Mortality (*F*)	0.28	0.26	
Start age of density dependent/habitat growth (t_d)			3
Density/habitat dependent constant (d_c)			0.02

[c] Estimated using catch curve analysis.

[l] Estimated using life-history analysis, t_m=37 years.

Recruitment to the fishery

The recruitment curve to the Sydenham Inlet fishery estimated that, for the 1988 cohort, 50% recruitment at 8 years old (by 1996) and 95% of this cohort is recruited at 14 years old (by 2002)(Figure 6). This was a similar recruitment pattern to the 1995 cohort in the Gippsland Lakes which was estimated to be 50 % recruited to the fishery (recreational and commercial) at 7 years old (by 2002) and 95% recruited at 15 years old (by 2010). By comparison the 1989 cohort in the Gippsland Lakes was recruited to the fishery (recreational and commercial) over a longer time period with estimated 50% recruitment at 12 years old (2001) and 95% recruitment at 20 years old (2009).

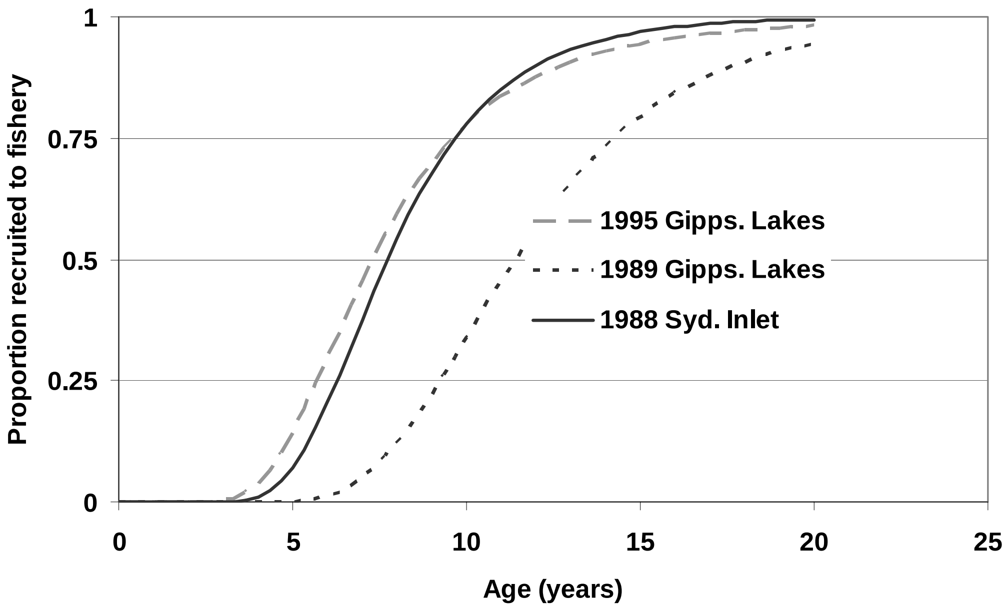

Figure 6. A comparison of the projected recruitment to the fishery (LML=26 cm) for black bream year-classes in the Gippsland Lakes and Sydenham Inlet.

Abundance Projections

Sydenham Inlet

Figure 7 shows a comparison between observed catch rates reported by the research angler under the 24 and 26 cm LMLs (1994-2000) and predicted catch rates (F=0.3 and M=0.1) that would have followed if a 30 cm LML had been introduced after 1996.

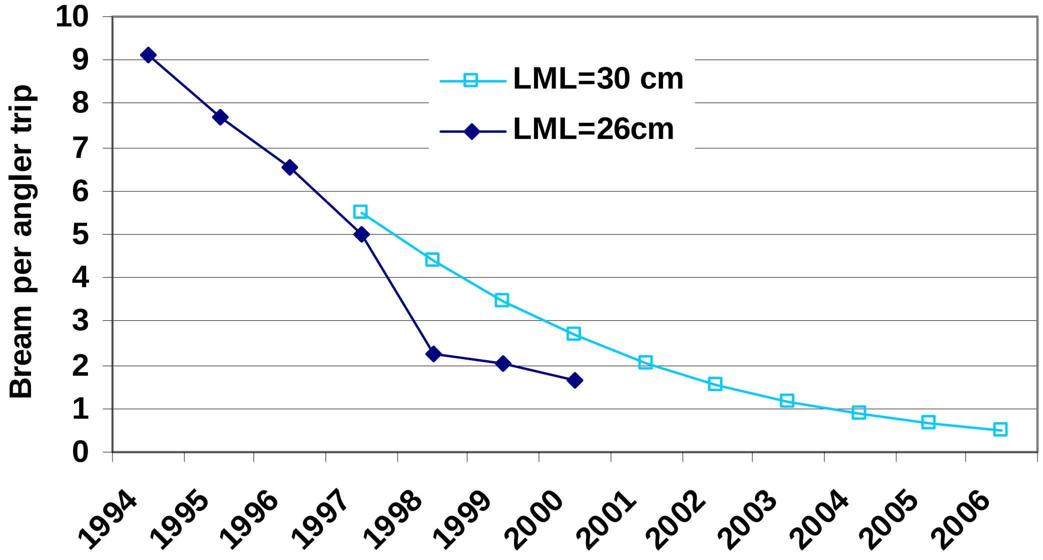

Figure 7. A comparison between projected (1997-2006) mean catch rates of the 1998 year-class under 30 cm LML regulations and estimated mean catch rates (1994-2000) for the reported research angler catches from Sydenham Inlet.

Under a 30 cm LML the estimated survival rate of the 1988 cohort once recruited to the fishery was 78% (F=0.3, M=0.1). By contrast the survival rate calculated from the research anglers reported catches fluctuated between 40 and 90 % (Figure 8).

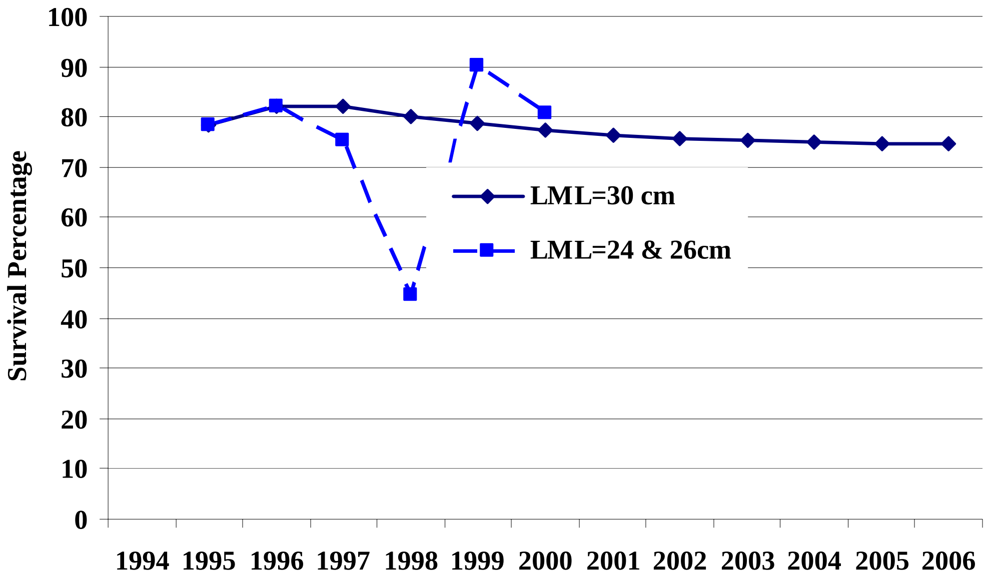

Figure 8. A comparison between projected (1997-2006) mean survival rates of the 1998 year-class under 30 cm LML regulations and reported mean survival rates (1995-2000) estimated from the reported research angler catches from Sydenham Inlet.

Gippsland Lakes

For the 1995 and 1989 year-classes the predicted research angler catch rates were affected more by the level of fishing mortality than the LML applied (Figure 9 and Figure 10). The projections predict that the angler catch rate for the combined year-classes will be approaching zero from 2003 to 2005 depending on the LML and fishing mortality rate applied (Figure 11). Plots of the predicted percentage survival from the previous year indicate that the protection from the impacts of fishing is greatest in the first year that a higher LML is applied, then declines over the successive years as the cohorts grow past the LML (Figure 12). The protection offered by the LMLs also decreased with higher levels of fishing mortality. However, the difference between catch rates for the different LML values was greatest and lasted longest at the higher level of fishing mortality.

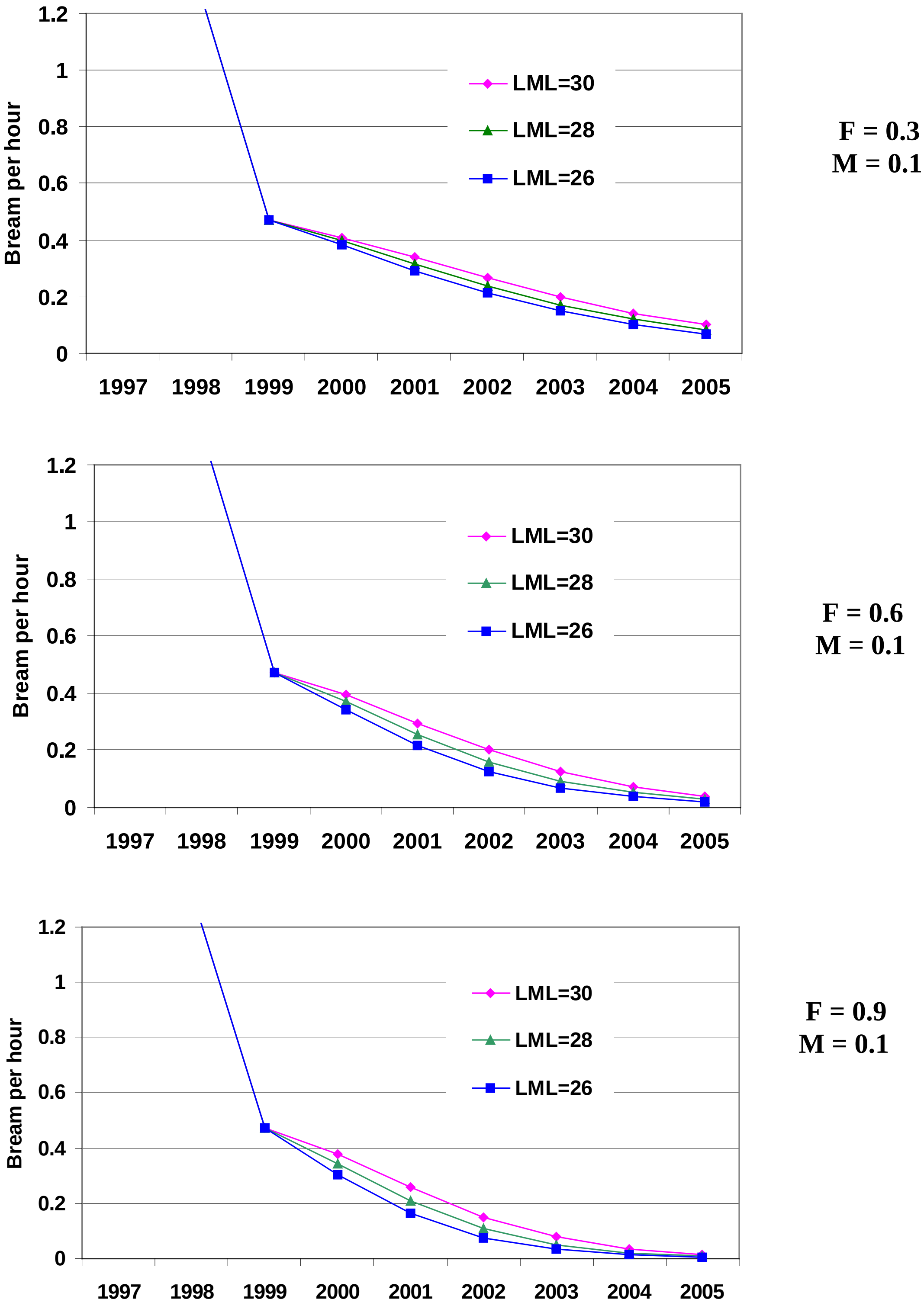

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Figure 9. Comparisons of predicted (2000-5) diary angler catch rates of the 1995 year-class under three different black bream LML regulations and fishing mortalities in the Gippsland Lakes

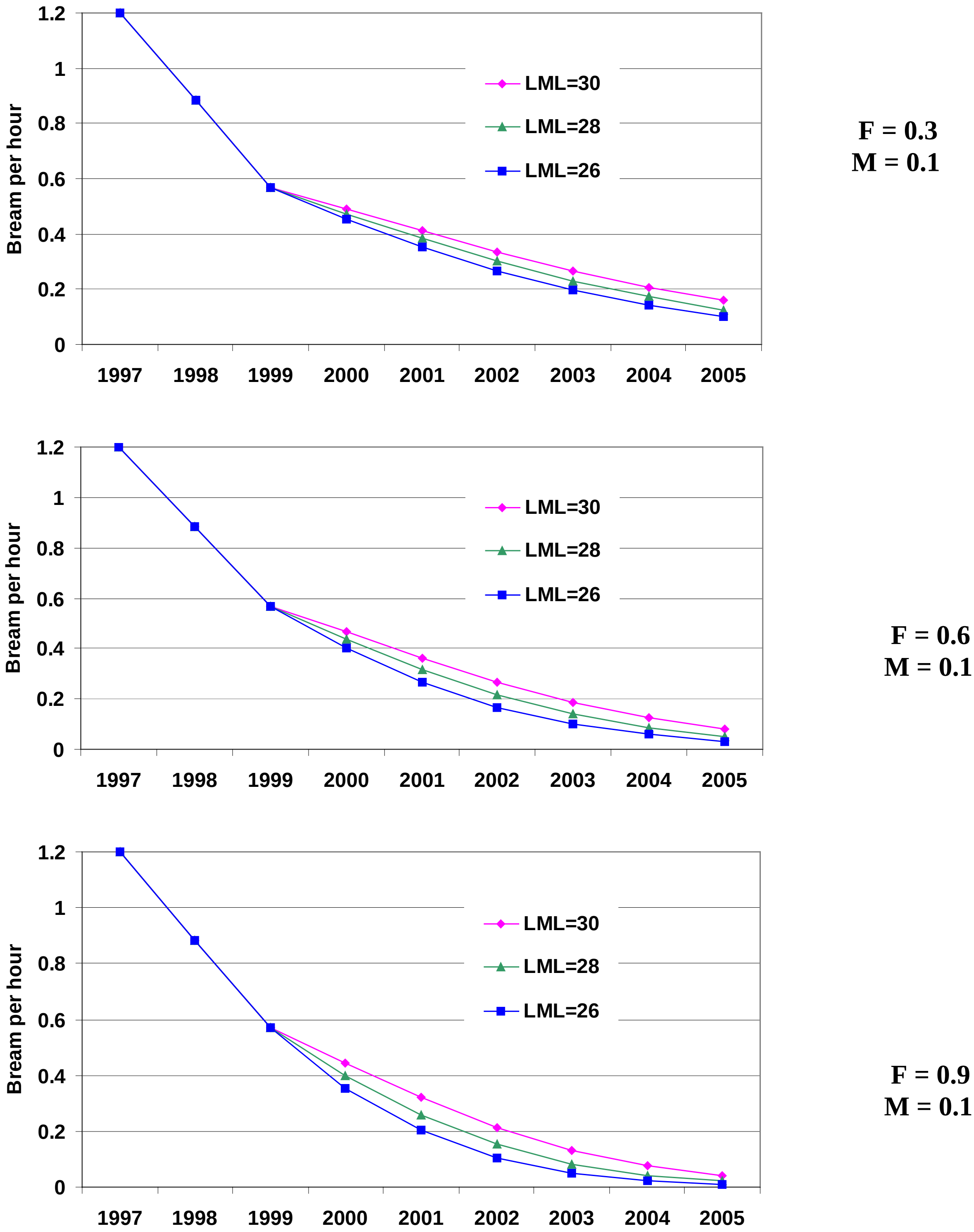

Figure 10. A comparison of predicted (2000-5) diary angler catch rates of the 1989 year-class under three different black bream LML regulations and fishing mortalities in the Gippsland Lakes**.**

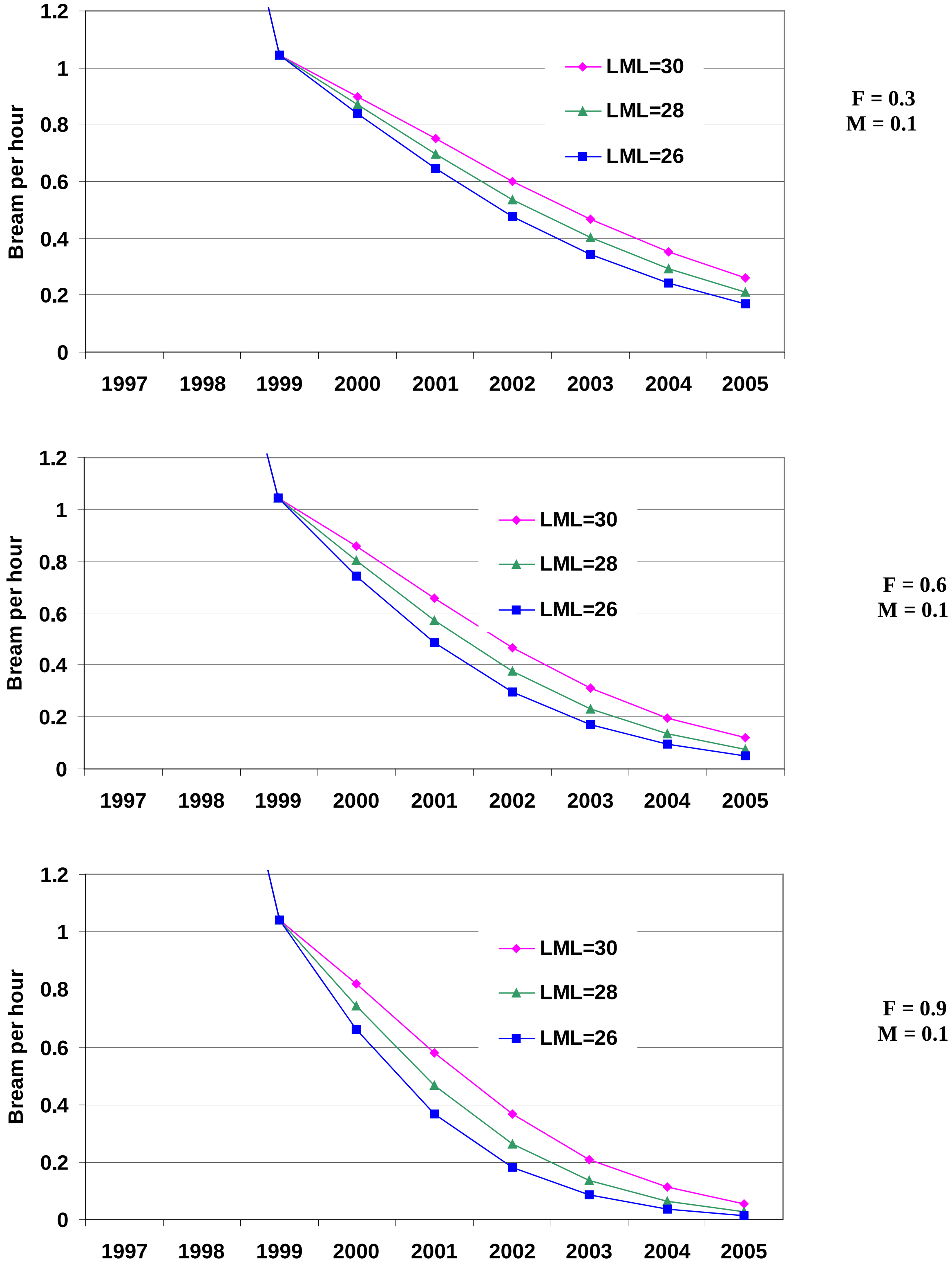

Figure 11. A comparison of predicted (2000-5) diary angler catch rates of the 1995 and 1989 year-classes under three different black bream LML regulations and fishing mortalities in the Gippsland Lakes.

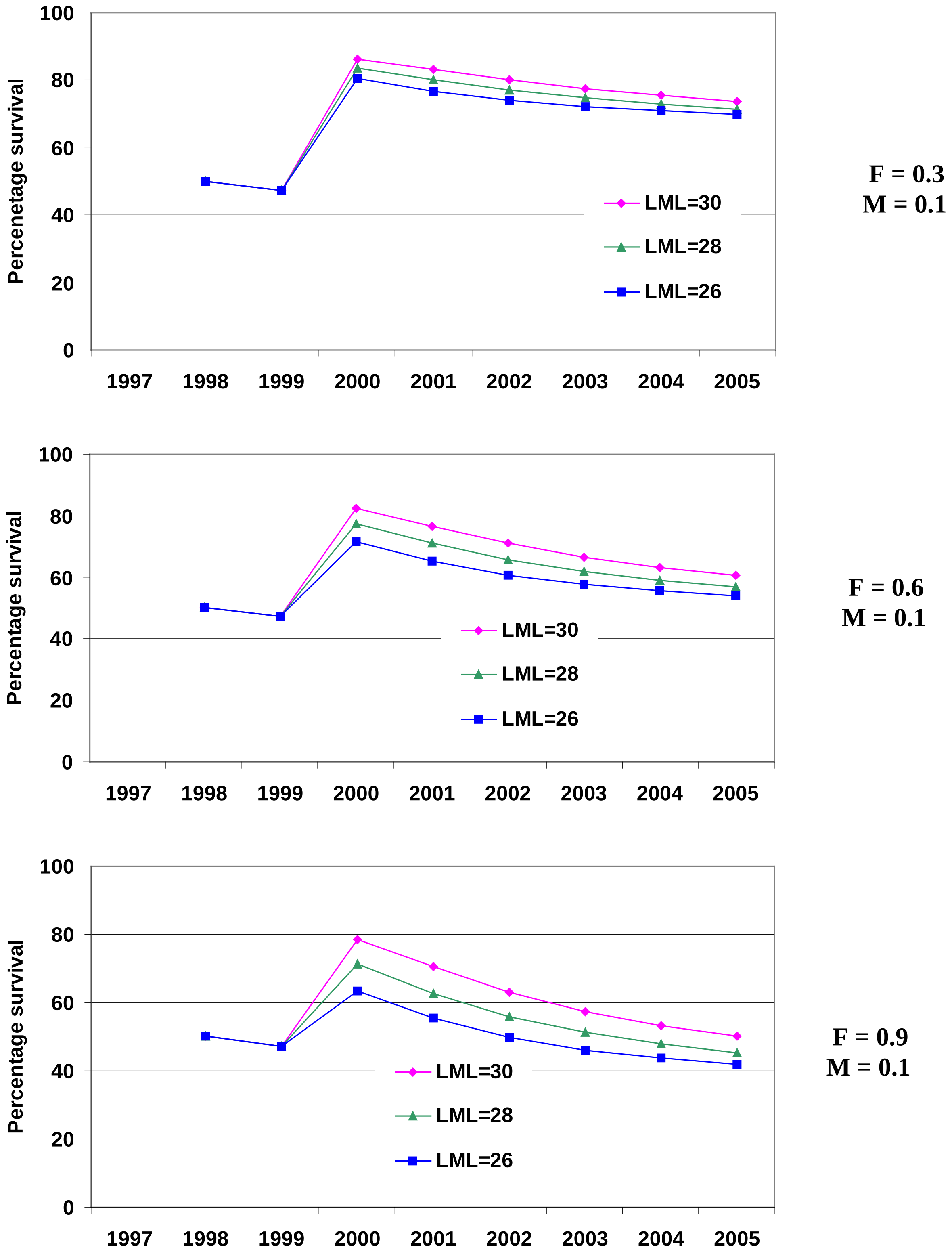

Figure 12. Predicted (2000-5) percentage survival for black bream (combined year-classes) in the Gippsland Lakes for three different LMLs and fishing mortalities.

7.2 Effectiveness of bag limit strategies

Short term

For most anglers surveyed each year, catching and retaining fish was a relatively rare event (Appendix 1) resulting in daily catch rate distributions which were highly skewed and had large positive kurtosis values (Appendix 2). The potential reduction in fishing mortality (F) as a result of a change in DBL varied between fisheries and years depending of the mean and distribution of daily catch rates (Appendix 3). A 20% reduction in fishing mortality would be achieved by DBLs of 2-4 fish/angler/day, 6-10 fish/angler/day and 2-3 fish/angler/day for black bream, King George whiting and snapper respectively. The potential reduction in fishing mortality, as a result of a DBL, declined with increasing DBL (Figure 13 to Figure 15). Within each fishery, the potential reduction in F for a specific DBL was generally higher in years with a higher average daily angler catch (C_t) although there were a few exceptions.

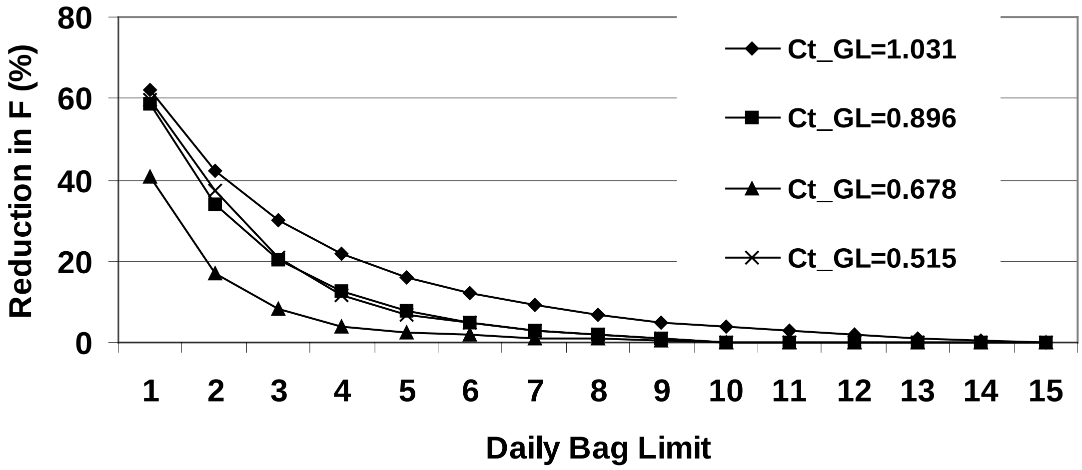

Figure 13. Relationships between the potential reduction of fishing mortality (F) resulting from the enforcement of various DBLs for black bream caught by anglers fishing in the Gippsland Lakes (GL). Each line represents a year of catch data with an average daily angler catch ($\boldsymbol{C_t}$).

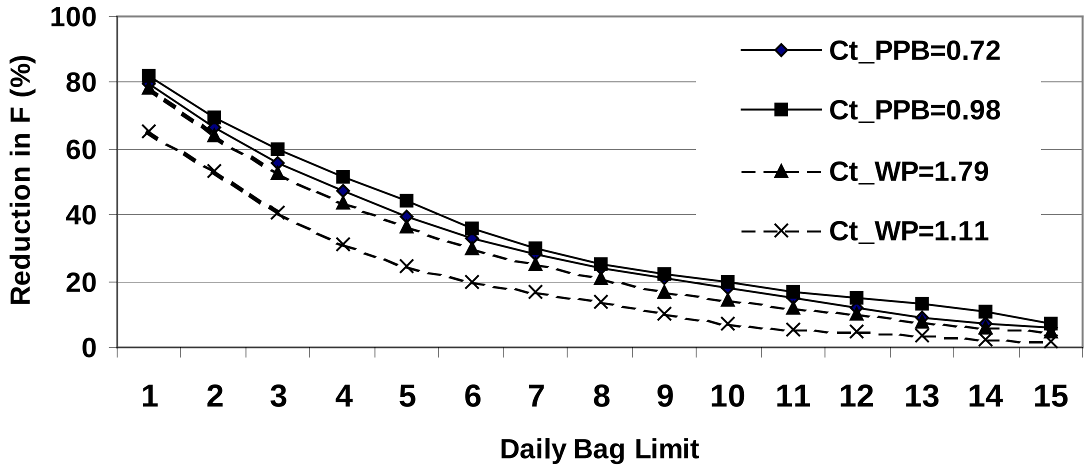

Figure 14. Relationships between the potential reduction of fishing mortality (F) resulting from the enforcement of various DBLs for King George whiting caught by anglers fishing in Port Phillip Bay (PPB) and Western Port bay (WP). Each line represents a year of catch data with an average daily angler catch ($\boldsymbol{C_t}$).

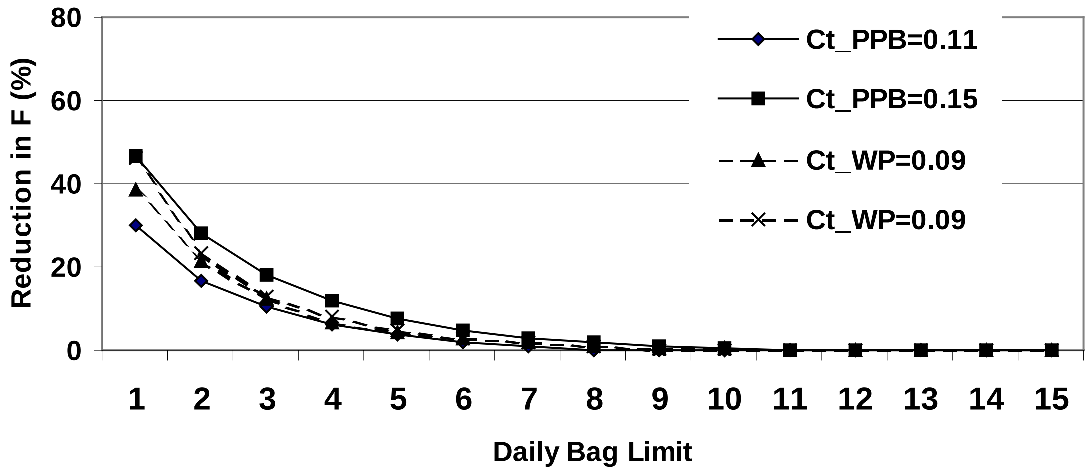

Figure 15. Relationships between the potential reduction of fishing mortality (F) resulting from the enforcement of various DBLs for Snapper caught by anglers fishing in Port Phillip Bay (PPB) and Western Port bay (WP). Each line represents a year of catch data with an average daily angler catch ($\boldsymbol{C_t}$).

Forecasting the impacts of a bag limit changes

The average daily angler catch (***C_t***) of bream boat fishery in Gippsland Lakes over 3 years (1997-1999) was highly correlated with the research angler average catch rate (Figure 16).

The percentage reduction in fishing mortality as a result of 2 bream DBL decline with average daily angler catch rate from 1997 to 1999 and was linearly related according to the equation shown in Figure 17.

The projected research angler catch rate of the 1989 year-class were more affected by the level of fishing mortality than the application of the 2 bream DBL (Figure 18).

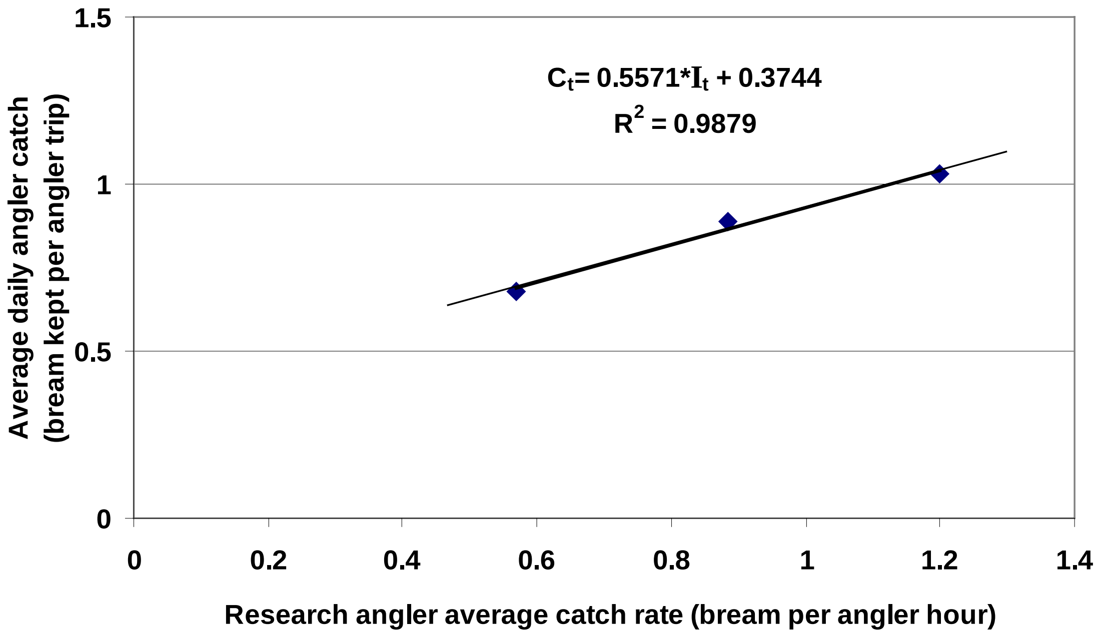

Figure 16. A comparison between the estimated average catch rate (I_t) for the 1989 black bream year-class by the research angler and the average daily angler catch (C_t) for the boat fishery in the Gippsland Lakes (1997-1999).

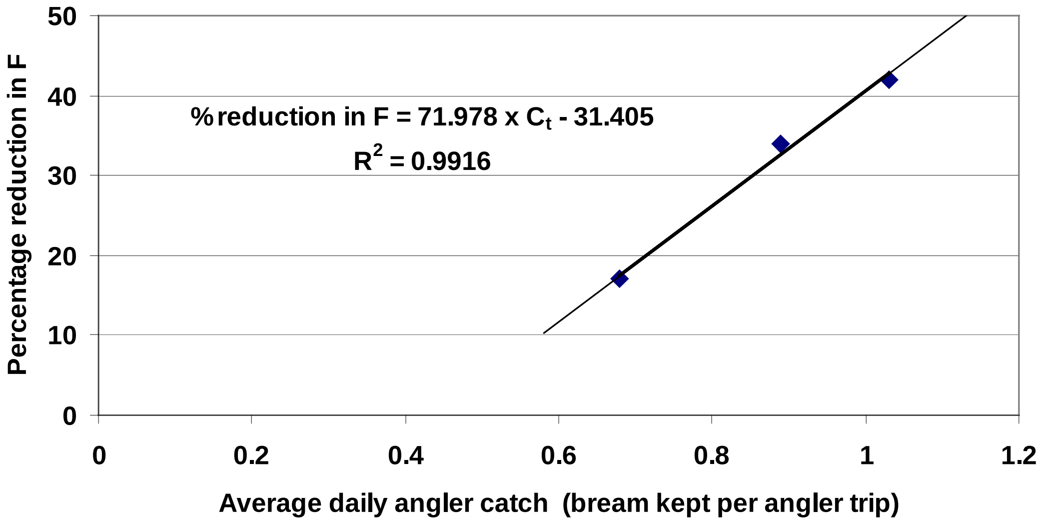

Figure 17. A comparison between the estimated percentage reduction in F from the introduction or a 2 bream DBL and the average daily angler catch (C_t) for the recreational boat fishery in the Gippsland Lakes (1997-1999)

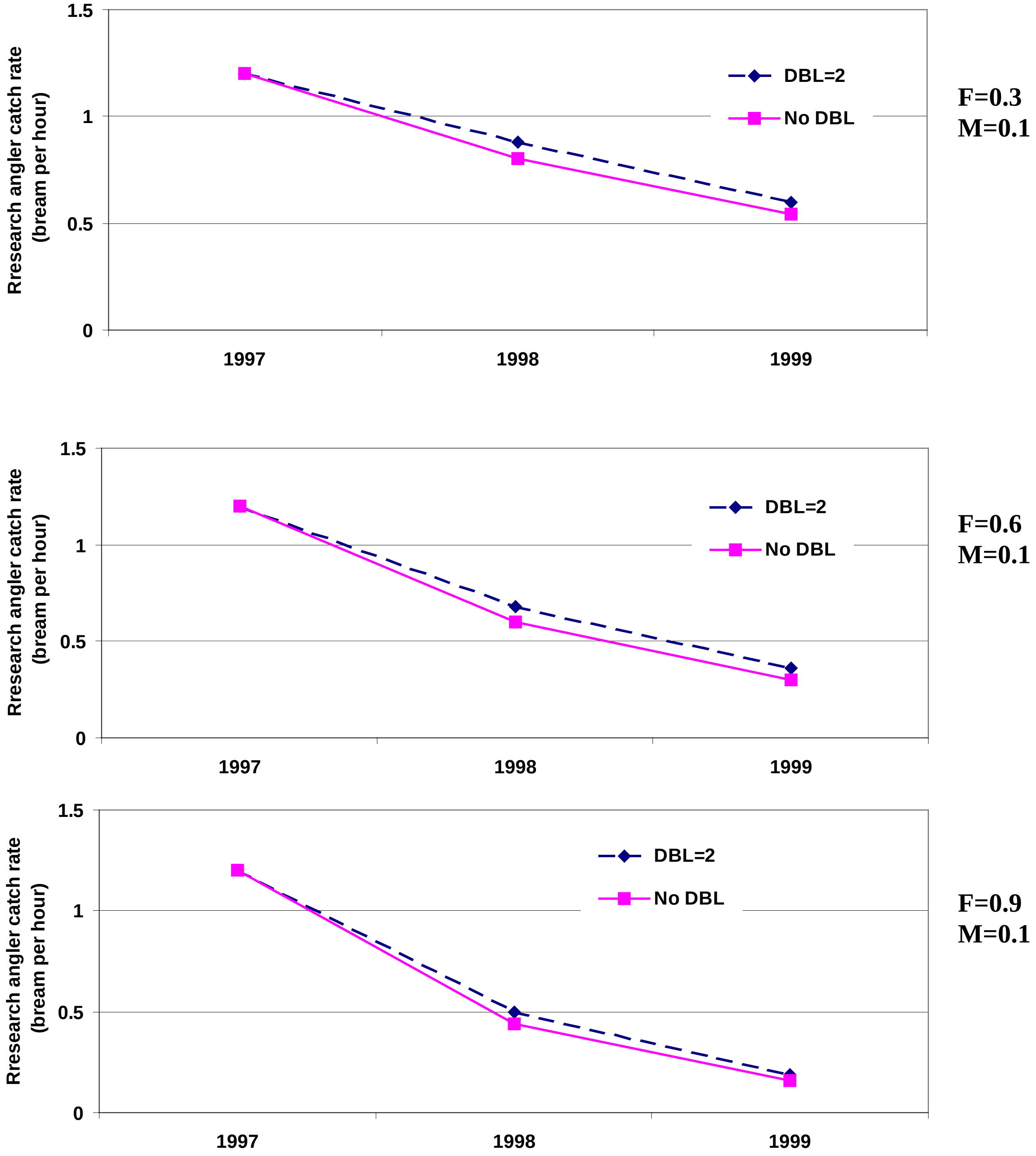

Figure 18 . A comparison of forecasted indexes of abundance (research angler catch rate of the 1989 year-class) with DBL=2 and no DBL under three different fishing mortalities for the Gippsland Lakes bream fishery 1997-1999.

7.3 Detecting the effects of management control changes

Changes in the length profile of catches resulting from shifts in a LML.

The evaluation approach was illustrated using creel survey length frequency data collected from the shore- and boat-based black bream fisheries in the Gippsland Lakes. For the periods before and after the changes to the bream LML there were clear differences in length profile of bream in the retained angler catches (Figure 19). One-way analysis of variance confirmed that anglers kept a higher proportion of bream in the 24 and 25cm size-group for the 24cm LML than for the 26cm LML (P<.0001). There were no significant differences in the proportion of the retained catch under 24 cm reported for the two LMLs.

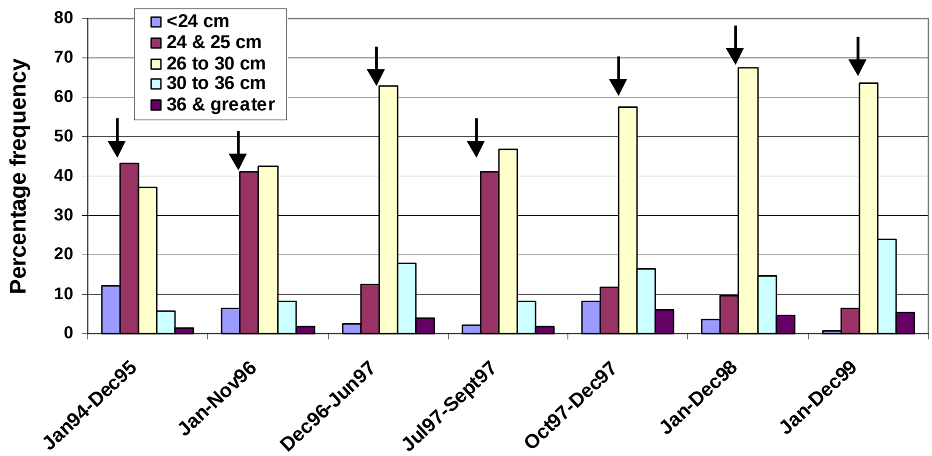

Figure 19 Distribution of lengths (TL) of black bream retained by shore and boat-based anglers fishing in the Gippsland Lakes between 1994 and 1999 (n=9231).

Changes in catches resulting from shifts in a DBL.

The evaluation approach illustrated retained catch data collected from creel surveys of the boat-based black bream fishery in the Gippsland Lakes. Distributions of daily catches indicated that the anglers complied well with the bream DBL changes. Between July and September 1997, 10 % of boat-based anglers interviewed had exceeded the retained catch limit of 5 bream per angler, however this was during the period when the DBL had been removed from the fishery.

Table 2. The relative frequency of the boat-based catches per angler per day (bag size by number.) for bream in the Gippsland Lakes regions 1997-2000.

Survey period	No. of angler trips	DBL	Mean catch per day	Relative frequency of bag size							
				0	1	2	3	4	5	>5	>10
Sum96/97-Jun97	454	5	0.7	0.652	0.194	0.066	0.024	0.035	0.020	0.008	
Jul-Sept97	347	none	1.81	0.447	0.219	0.115	0.072	0.023	0.020	0.104	0.024
Oct-Dec97	140	10	0.49	0.743	0.157	0.043	0.014	0.021	0.014	0.007	
Sum97/98-Spr98	372	10	0.9	0.629	0.151	0.099	0.054	0.022	0.022	0.014	
Sum98/99-Spr99	397	10	0.68	0.599	0.237	0,106	0.030	0,015	0.008	0.006	
Sum99/00-Spr00	334	10	0.52	0.790	0.093	0.033	0.036	0.024	0.009	0.015	

Changes in the catch rates of bream by angler catches

Catch and effort information collected from the creel survey of shore-based anglers in the Gippsland Lakes indicated that changes in catch rates could not be attributed to the shifts in the LML (Figure 20 and Figure 21). Seasonal estimates of the mean retained and discarded bream catch rates were calculated from 4029 interviews with fishing parties between the summer of 1995 and the winter of 2000 (Appendix 4). Retained and discarded catch rates fluctuated throughout the study period, which also included the three LML shifts. An increase in the LML would be expected to lead to a decrease in the retained catch rate, and an increase in the discarded catch rate, as a higher proportion of the population becomes protected. Conversely, a decrease in the LML would be expected to lead to an increase in the retained catch rates, and a decrease in the discarded catch rates. However, changes in the mean retained and discarded rates for the period before and after the LML shifts did not consistently follow these patterns.

Power analysis (80% power, α =5%) suggested that between 100-200 interviews per seasonal period would be needed to detect a 100% change in the estimated retained mean catch rates (Appendix 5 and 6). The detection of a 50% change in either retained or discarded catch rate would require about 500 interviews per season.

The application of the age-length key to the length distribution of bream in retained catches rates indicated that the 1989 year-class was the most dominant in the catches, while the 1987 year-class was a significant component of the retained catch in 1996 and 1997 (Figure 22).

The distribution of retained catch among the more abundant year-classes is shown in Table 3. The confidence limits around the catch rates of the 1989 year-class before and after the LML changes over-lapped suggesting that the differences that occurred could not be detected.

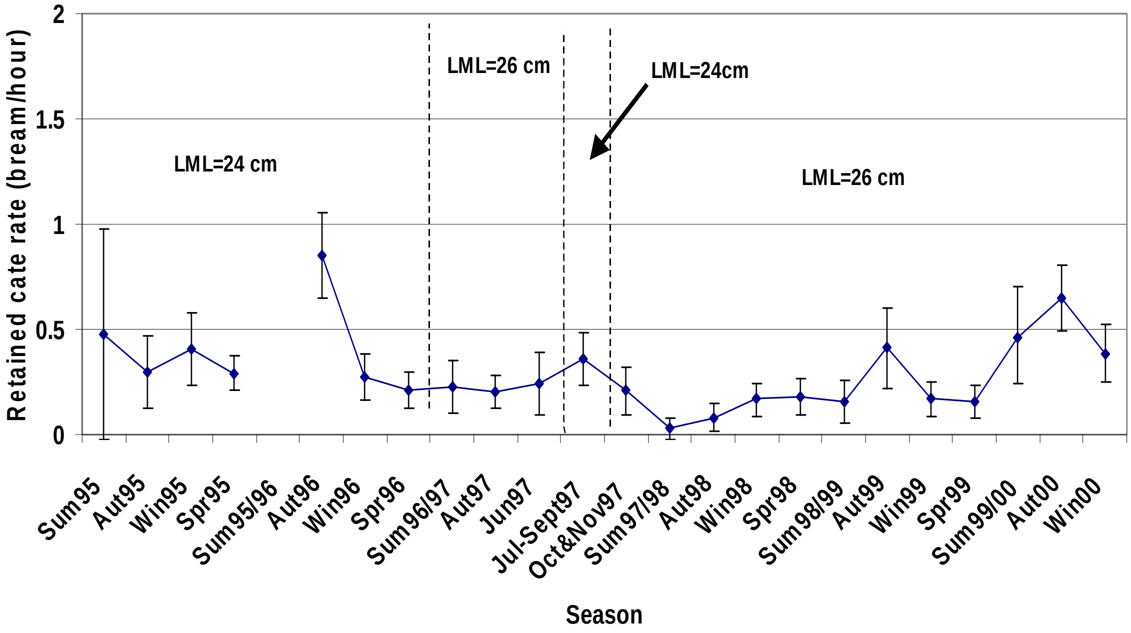

Figure 20. Estimated mean retained catch rates (± 2 s.e.) for shore-based anglers targeting black bream in the Mitchell and Tambo rivers.

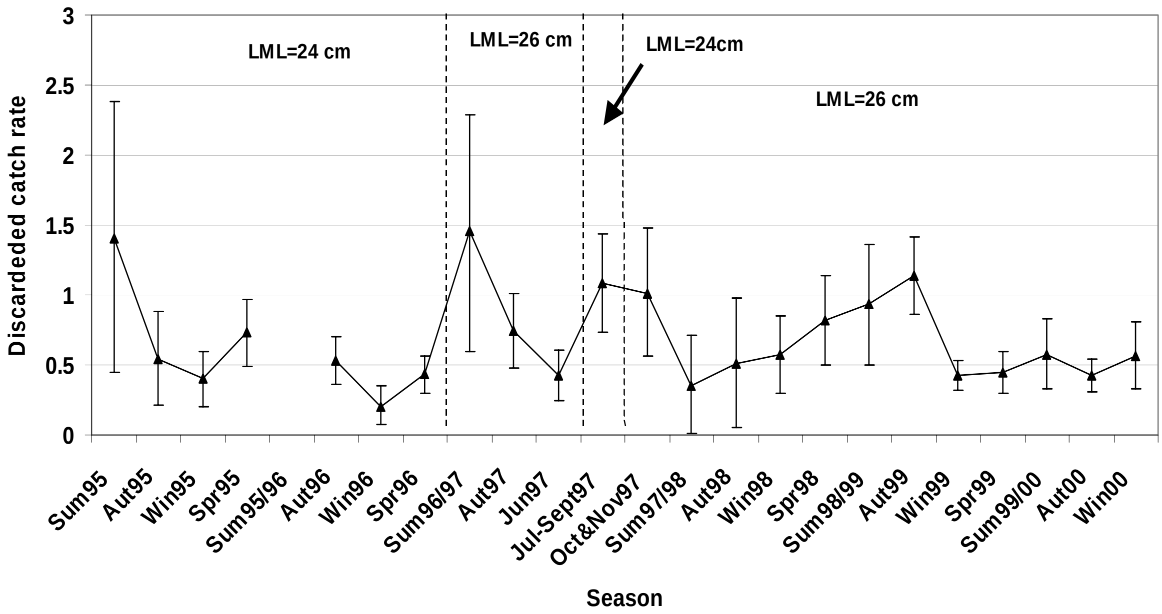

Figure 21. Estimated mean discarded catch rates (± 2 s.e.) for shore-based anglers targeting black bream in the Mitchell and Tambo rivers.

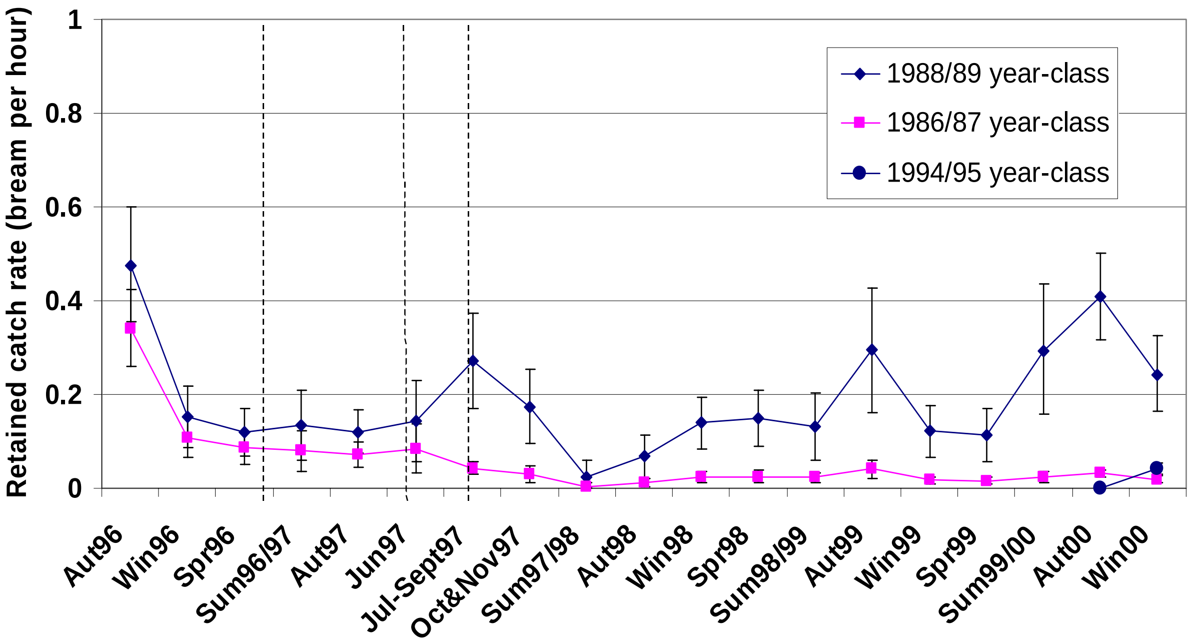

Figure 22. Estimated mean retained year-class catch rates (± 2 s.e.) for shore-based anglers targeting black bream in the Mitchell and Tambo rivers.

Table 3. Estimated percentage composition of the dominant year-classes in retained bream catches by anglers fishing the Gippsland Lakes between 1996-2000.

Period	Estimated year-class proportion (%) in the retained bream catch		
	1986/87	1988/89	1994/95
Aut96-Spr96*	40	55	
Sum96/97-Jun97*	35	60	
Jul-Sept97	10	80	
Oct97 & Nov97	15	70	
Sum97-Spr98*	10	70	
Sum98/99-Spr99*	10	70	
Sum99/00-Win00*	5	60	5

***** Note sampling periods have been combined because of limited ageing data.

Assessment of changes in the length/age profile to a bream stock

This assessment approach was illustrated using catch rate, length frequency and age data collected by diary anglers fishing for bream in the Gippsland Lakes. The research angler provided catch and effort data from 41 fishing trips between 1997-99 (Appendix 7). This represented 70 hours of fishing effort for the three sampling periods. The confidence limits around the mean catch rates for the length categories over the sampling period indicates that a change could not be detected (Figure 23). The research angler catch rate generally showed less variation than creel survey catch data. Consequently, power analysis (80% power, α =5%) indicated that about 50 trips per sampling period would be sufficient to detect a 100% change in the estimated catch rates for each length categories. Increasing the sample size to 100 trips per season would allow detection of a 60% change in catch rate (Appendix 8).

The catch information collected by the diary anglers was also used to illustrate how catch rates of the major year-classes in the Gippsland Lakes bream stock could be monitored. Angler catch rates of year-classes from the Gippsland Lakes indicated a similar decline in abundance of the two bream year-classes in the fish stock despite the 1988/89 year-class being above and below the LML and the 1994/95 year-class being entirely below the LML (Figure 3).

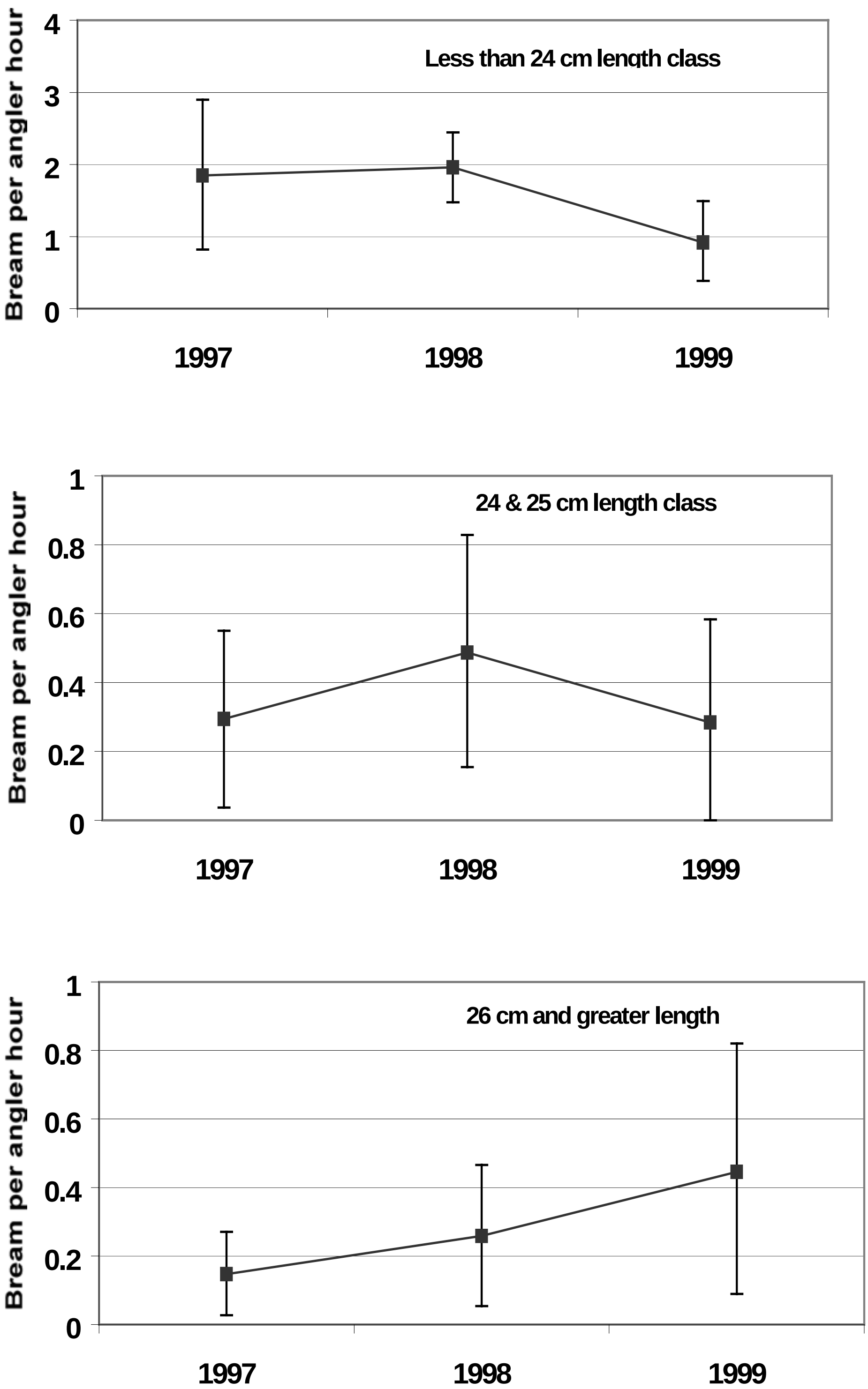

Figure 23. Estimates of the mean black bream catch rates (± 2 s.e.) for three length categories (less than 24 cm, 24 & 25 cm and 26 cm and greater, total length) for diary angler catches in the Gippsland Lakes 1997-99.

8 DISCUSSION

8.1 General

Fisheries management agencies as natural resource managers, are required to identify suitable biological sustainability objectives, performance indicators, and management controls that can be applied to enable management objectives to be met. The effectiveness of current management controls such as LMLs and DBLs can be improved if assessments use recreational fishing data to assess their performance.

Recreational fishers, unlike commercial fishers, do not routinely provide fishing catch and effort returns on which can be assessments can be based. Survey programs that could provide annual estimates of total catch and effort are expensive. Assessments of recreational fisheries are therefore usually undertaken without the benefits provided by a time series of catch and effort information. Assessment approaches which use a time series of angler catch rates as an indicator abundance or total catch could provide a cost effective alternative and the opportunity to improve the management of recreational fisheries. The success of this strategy depends in part on the extent to which factors other than abundance which influence angler catch rates can be taken into consideration. Understanding the assumptions behind this assessment approach is also important.

8.2 Modelling the effects of Legal Minimum Length changes on fishing mortality.

The accuracy of predictions made using the age-structured model, like other fishery models, depend on the accuracy of parameter estimates, and the validity of the underlying assumptions. The growth, mortality and relative stock abundance parameters used in the age-structured model demonstrated in this study, were estimated separately for each of the year-classes in the black bream population using a time series of catch rate and ageing data from a fishing diary program. This approach requires that the catch rate data are a reliable index of fish abundance over the entire population of interest. For this assumption to be met, either the anglers must take representative samples of the fish population, or the selectivity of their fishing practices must be known. Experienced anglers however generally fish in periods and locations, and use bait and hook combinations, that are biased towards the capture of larger individuals in the fish stock. This potential source of bias was avoided in this study by the control of fishing gear, sampling times and fishing practices. In this study, gear selectivity was quantified by fitting a logistic regression to the pooled catch data from all hook sizes. Using catch data separated by hook size may be a more accurate method to estimate gear selectivity where there are sufficient catch data available.

The model used also assumes that catch rates are not affected by migration of fish. The black bream fisheries in the estuaries of southern Australia are well suited to this assessment approach because there is little migration. Additional sampling resources may be required for fisheries such as snapper and King George whiting, where components of the fish stock migrate in and out of the bays becoming, at times, less accessible to anglers. However, the uncertainties that arise from such movements are a problem for almost all assessment methods.

Another assumption of the model is that raising the LML does not result in an increase in fishing effort by either the recreational or the commercial sectors. This is likely to be the case in most recreational fisheries that are managed under a variety of input controls. It may not be a valid assumption, however, in fisheries under output controls. For example, it has been shown that an increase in the LML can result in increased fishing effort for the commercial snapper fisheries in New Zealand in order to attain the total allowable catch (TAC) (Harley *et al*. 2000). In this instance the increase in discard mortality on the proportion of the stock that is below the new LML was estimated to be greater than the reduction in fishing mortality afforded by the higher LML. This may be a similar situation for recreational fisheries where the DBL is achieved by anglers on the majority of fishing trips and high-grading occurs. In Australia the commercial fisheries for snapper, King George whiting and black bream are not principally managed by a TAC, and, as reported in this study, a low proportion of Victorian anglers achieve the current DBLs for any of these species.

The catch rate projections from the age-structured model for black bream were useful for indicating the effectiveness of LML increases as a means of reducing fishing mortality. They showed that the expected effect would be dependent both on the proportion of the fish stock under the new LML, and the time period of protection before the year-classes again become fully vulnerable to harvesting. This time period is determined by the growth rate and the size difference between old and new LMLs.

Other outputs of this modelling were additional estimates of total mortality and survival rate. The catch data from the research angler fishing in Sydenham Inlet demonstrated the potential annual fluctuations in these estimates that can be expected from this assessment method. The estimate of Z (0.4 yr^{-1}) for the Sydenham Inlet fisheries was based on the first 3 of 5 years of annual sampling of a cohort following recruitment to the fishery. The number of consecutive years over which a cohort catch rates can be potentially sampled by research anglers will determine the accuracy and precision of the estimate of Z and, among other things, will be strongly influenced by the degree of fishing mortality.

The total mortality estimate for bream recruited to the Gippsland Lakes fishery (Z=0.4 yr^{-1}) from the research angler catch rate data was lower than previous estimates (0.9-1.1 yr^{-1}) calculated from commercial seine and mesh net catch data (Walker *et al*. 1998). The three year sampling period included a drought year which may have affected bream catchability in the river regions of Gippsland Lakes where most research angler's fishing occurred (pers. com. Gordon Ahchow, research angler). The accuracy of estimate of mortality will be improved by extending the sampling years. The lower estimates of Z from the angler data is, however, consistent with reports of a greater proportion of larger bream in the angler catches compared to commercial catches (Cashmore *et al*. 2000). The size composition of the recreational King George whiting catches from Western Port bay also showed a greater proportion of larger sizes of whiting compared with the commercial catches (MAFRI unpublished data). Which sector provides the more representative sample of the total population is difficult to assess. Sampling recreational catches in some cases may provide a more accurate indication of mortality where recreational fishers can successfully target a broader size range in the fish population.

The age-structured modelling approach illustrated in this study projected angler catch rates assuming constant natural mortality and constant fishing mortality on the stock that was above the LML. Cohort analysis estimated the natural mortality to be 0.9 yr^{-1} for the proportion of the 1995 year-classes under the LML. This estimate was based on just three data points with the catch rate of the 1995 cohort in the first year having the greatest expansion from the size-selectivity curve. A high level of natural mortality for small bream may have been caused by an usually large number of Great Cormorants (*Phalacrocorax carbo carboides*) that were feeding on black bream in the Gippsland Lakes at time of this study (Reside and Coutin 2001). The number of black bream consumed by the cormorants was estimated to be greater than the combined commercial and recreational catches. The size range of these bream in the cormorant's diet was biased towards bream under the LML, suggesting that they were subject to higher natural mortality than larger size classes. The majority of the cormorants had migrated away from the Gippsland Lakes by 2000 therefore the natural mortality value used in the predictive model was reduced. The much lower estimate of M for the Gippsland Lakes of 0.1 yr^{-1} made using a life-history analysis technique suggests that M, like F, may not be constant across year-classes nor over time. Investigating the variation in natural mortality may also be required when applying this type assessment approach to snapper and King George whiting and other black bream fisheries.

For recreational fisheries where there is significant discarding of under-size fish, there may also be an indirect fishery effect on the under-size component of the stock through catch and release mortality. For the black bream fishery investigated in this study, comparisons between retained and discarded catch rates from the creel survey indicated that the majority (seasonal average of 70%) of bream caught by anglers were under-size and subsequently discarded. The actual level of mortality from the catch and release of undersized bream is unknown. Experiments undertaken to investigate mortality in snapper (<34 cm FL) after catch and release from recreational line fisheries indicate low mortality (5-10%) amongst lip hooked snapper and relatively high mortality (75-90%) amongst oesophageal hooked fish (McKenzie and Holdsworth 1997). Any mortality resulting from catch and release would have add a fishing mortality effect to the component of the stock which is under the LML but vulnerable to recreational fishing gear. Further work is required to identify the source and significance of natural and hooking mortality for black bream and incorporate these effects into the model. Similar data would also be required for models for fisheries for other species such as snapper and King George whiting.

The age-structured model used in this study assumes that any proposed LML changes would also apply to the commercial fishery, and that any associated catch and release mortality impacts are negligible. The main commercial gear types used to in Victorian bay and inlet fisheries are mesh (black bream) and seine nets (black bream and King George whiting), and longlines (snapper). The survival percentage of discarded fishing is likely to vary between fishing methods and among species. For haul seines used in Victorian waters the survival percentage for King George whiting was estimated to be 81% (Knuckey *et al*. 2001) and 100% for snapper (MAFRI unpub. data). No estimates are available for black bream seined in Victorian estuaries however a recent study of the survival of fish discarded in New South Wales haul seine fisheries reported and 80-100 % survival of yellow-fin bream (*Acanthopagrus australis*) and close to 100% survival for snapper (Gray and Kennelly 2001). Longlines generally catch snapper well above the current LML in Victoria (Coutin 1998) and therefore a change in the LML is unlikely to effect the rates of discard mortality for snapper. The selectively of mesh nets may vary according to the mesh size and the net design. Further studies may be required to ascertain the likely impacts of an increased LML for mesh net fisheries.

8.3 Evaluating the use of Daily Bag Limits to constrain fishing mortality

The distributions of daily angler catches from the creel survey data shows that, at the time of this study, the DBLs for Victorian black bream, snapper and King George whiting fisheries were not reached by the majority of anglers. The current DBLs for Victorian marine recreational fisheries have been set on social objectives (ie an acceptable number of fish to catch in one day for the purposes of consumption within the household) and not for reasons of fish stock conservation (Fisheries Victoria 1998). Consequently these DBLs did little to constrain fishing mortality and would have to have been set much lower (2-5 fish) to have any measurable effect on fishing mortality.

Censoring of the historical catch data showed that the immediate effect of a DBL in constraining F was generally greater in years with a higher average catch rate. The potential effect of a change to a DBL in reducing fishing mortality was dependent on the shape of the distribution of daily catches as well as the average daily catch. In this study the skewness and kurtosis of the distributions of daily catch rates fluctuated between fisheries and years. The method used to calculate angler daily catch distributions included all angler trips irrespective of target species. This may explain why catch distribution from a multi-species target fishery such as Port Phillip Bay (snapper and King George whiting) fishery is more skewed than a predominantly single target fishery such as the Gippsland Lakes bream fishery. Fluctuations in the distribution of angler catches between years are similar to those of Attwood and Bennett (1995) who reported that the distribution of daily catches sampled from a multi-species recreational shore-fishery on the Western Cape of South Africa did not conform to a particular type of distribution for any of the four species investigated. They suggested that the reason for this might be that fish capture events are not independent of one other, because of the effects either of the schooling behaviour of fish or of environmentally induced variation in catchability. The DBL operates best by preventing large daily catches during periods of higher catchability such as bream and snapper spawning aggregations in Victorian bays and Inlets. This highlights the utility of a time series of catch data for the fishery of interest in understanding the range of the potential reduction in F resulting of a DBL change.

The projections of bream stock abundance with and without a two bream DBL suggests that a low DBL would do little to constrain fishing mortality in a fishery where the abundance of the stock is declining. An important assumption of the model is that the average catch rate of the fishery decreases with stock abundance and the impact of the DBL in constraining fishing mortality. Attwood and Bennett (1995) showed from 36 years of fishing club competition catch records that the potential reduction in fishing mortality was correlated with catch rate for three of four species most often caught. The authors conceded that the assumption that competition records were no different to ordinary anglers may not be correct. In this study the average angler daily catch of bream in Gippsland Lakes over 3 years (1997-1999) was highly correlated with both the potential reduction in fishing mortality of a two bream DBL and the index of bream abundance. However an extended time period of catch and abundance data for bream, King George whiting, and snapper fisheries is required to confirm the validity of these assumptions.

Porch and Fox (1990) argued that censoring historical catch data will under-estimate the catch with the DBL because it fails to consider the relative increase in stock abundance if the DBL had been in place when the sample was taken. Porch and Fox (1991) also showed that the fishing mortality with a DBL was over-estimated for the same reasons. The modelling approach used in this study assumes the two effects cancel each other out.

Other important assumptions in the use of DBLs are that once the anglers reach the DBL they do not impact further on the fish stock, and that a reduction in a DBL does not change the total fishing effort. Whether these assumptions are valid will depend on the nature of each fishery. There are some situations where, even with perfect compliance with a reduced DBL, this assumption may not hold true. Anglers may choose to continue fishing once their bag limit was reached but release any additional fish caught or high-grade. Practices such as catch and release fishing may result in further fishing mortality, as outlined previously, and thus may reduce the effectiveness of the DBL. There may also be interactions between fisheries where a reduced DBL for one species may cause a switch in effort to another. This may not be a major issue for most black bream recreational fisheries because anglers have few options to target other species. King George whiting and snapper recreational fisheries, however, do occur within the same estuary or embayment, allowing the option of switching target species once a DBL is obtained. The effects of fishing effort changes and catch and release mortality could be incorporated into the assessment approach using targeting and catch details from fishing trips where anglers have reached the DBL, but these are yet to be quantified.

8.4 Monitoring the effects of changes to management controls.

The creel survey data proved very useful for describing the impact of changes to current LMLs and DBLs on the catch of recreational fishers. As expected, the DBL changes had little influence on the catch rates of bream, as few fishers reached the bag limit. By contrast, the LML changes had a clear impact on the observed length distributions of black bream in retained catches. The rapid response to the changed LMLs suggests a high level of compliance with the regulations. This in turn suggests that the anglers surveyed were both well informed and accepting of the LML alterations. Compliance was probably assisted by the existence of an active angler education program in the area (FishCare), the regular contact between anglers and survey staff over several years, and the day to day enforcement activities undertaken by fisheries officers. When the legislation lapsed the immediate shift in the length distribution of retained bream catches, back to one which was consistent with the 24 cm LML, suggests that black bream anglers may support and adhere to a higher size limit but will not voluntarily adopt one.

The creel survey data, however, were unable to detect changes in angler catch rates that resulted from the LML and DBL shifts. Unlike the size composition data, the catch rates of retained and discarded bream did not show changes that were consistent with the LML shifts. When the LML was 24 cm, about 40% (by number) of the retained bream catch was between 24 and 26 cm and when LML was 26 cm the proportion dropped to 10%. The difference between these values suggests that the retained catch rate should have dropped by about 30% immediately after the 2 cm LML increase, however no such change was observed in the mean retained catch rate. Similarly, an expected increase in the discarded catch rates was not evident in the data. Power analysis confirmed that the sampling intensity of the current creel survey (250-300 interviews per season) was unlikely to be able to detect catch rate changes of less than 50% in retained or discarded catch rate. Increasing the sampling intensity of the creel survey to 500 interviews per season only improved the power to detect a catch rate change by 10% and therefore provides poor value for the increased costs that would be involved.

The failure of catch rates among general anglers to reflect the size of available stocks was not expected. Estimates of fish population densities have been shown to be a good predictor of average angler catch rates of walleyes (*Stizostedion vitreum)* in the northern Wisconsin lakes of the United States (Beard *et al.* 1997). Similarly, estimates of population densities of King George whiting pre-recruits in Port Phillip Bay have correlated well with future catch rates of the commercial net fishery (Jenkins *et al.* 2000). However, the magnitude of the seasonal fluctuations in retained black bream catch rates by the shore-based anglers in the Gippsland Lakes suggests that, for this fishery, catch rates are not likely to be strongly related to overall stock density. Further work is required to assess the extent to which average catch rates in snapper, King George whiting and other black bream fisheries can be predicted.

The assessment approaches illustrated for a black bream fishery is this study showed that the use of experienced diary anglers, combined with a strategic sampling strategy, resulted in more precise catch rate estimates than those produced by the creel surveys. The results from these diary anglers, however, were still unable to detect a change in catch rates of black bream. The power analysis indicated that the sample sizes (11-16 fishing trips) used in the trial were well below that needed to detect a 100% change in catch rates (50 fishing trips). Implementing a diary angler program aimed at detecting the impacts of management control changes would require the involvement of enough experienced anglers to achieve the appropriate sampling power.

The low power for detecting changes in catch rates is a function of the high variability in angler catch rates. The shore-based black bream fishery in the Gippsland Lakes was originally selected to demonstrate this assessment approach because the time series of catch rate data covered several shifts in the black bream LML. The angler catch rates, however, proved to be highly variable. This may be attributable to both the wide range of angler fishing skills and the seasonal variability in availability and catchability of fish. One approach to reducing the variability in catch rates is to use only catches from skilled anglers as the sampling frame. Information on the fishing experience of anglers could be obtained when interviewed in the creel survey and the results from the less experienced anglers excluded from the sample prior to analysis (Bradford 2000). Greater power may also be achieved for fisheries that exhibit naturally lower fluctuations in catch rates. For example, anglers in boat-based fisheries are generally considered to be more experienced than their shore-based colleagues. Creel surveys based on such anglers may provide greater power to detect changes in catch rates.

Like most sampling strategies, there are advantages and disadvantages to using experienced anglers as a monitoring tool. An advantage of the diary program over a creel survey is that the diary anglers can (if given the necessary permits) sample size and/or year classes above and below the LML providing a broader range of data. The success of this approach, however, is still dependent on recruiting sufficient anglers to provide the required sampling intensity each year, and these are necessarily drawn from the smaller total pool of experienced anglers. Results from experienced anglers must also be interpreted with care; they are not representative of the whole angling population and extrapolations may produce biased estimates of some parameters. To determine the appropriate sampling intensity for a monitoring program it is important that any preliminary data are representative of the population to be sampled. Creel survey data would be more representative of the fishery as a whole, but experienced anglers may give more representative samples of the targeted fish population. The appropriate assessment approach to take will depend on the objectives of the study.

9 BENEFITS

Fisheries managers have accepted the angler diary program as a cost-effective approach to monitoring small-scale bream fisheries in Victoria. The program has been expanded to include three other black bream fisheries and is being trialed for snapper and King George whiting fisheries in Port Phillip Bay and Western Port bay. The relationship between researchers and anglers has greater enhanced the knowledge in terms of appropriate sampling strategies for black bream fisheries.

Sampling strategies for creel surveys of black bream shore and boat based fisheries in the Gippsland Lakes has been adjusted in accordance with objectives to monitor the size and age distribution of the retained catch and the distribution of daily angler catches rather than to detect small changes in abundance. The collection of ageing samples has been included as part of the objects of creel surveys undertaken for snapper and King George whiting fisheries in order to monitor the year-class profile in retained angler catches.

10 FURTHER DEVELOPEMENTS

The accuracy of predicted effects of LML and DBL increase would be further improved by incorporating the effects of catch and release mortality into the models. An application to measure the effects of catch and releases mortality in the black bream and snapper recreational fisheries has been submitted to FRDC. In this study separate models were used to describe the effects of LML and DBL changes. The next step would be to combine the two models into a single assessment package.

11 PLANNED OUTCOMES

The assessment methods developed and demonstrated in this study provide strategies by which managers of recreational fisheries can put in place cost effective data collection programs from which the impacts LML and DBL limit changes can be predicted and monitored in relations to stock abundance and fishing mortality management objectives. The information derived from this study has been incorporated into recent fishery assessments for the black bream fishery in the Gippsland Lakes and snapper Victorian fishery. The assessment approaches developed have been recently used to provide advice on the likely impacts of LML and DBLs changes to the Gippsland Lakes bream fishery which is currently experiencing declining trend in catches.

12 CONCLUSION

This study has shown how cost-effective data collection programs can be used to provide advice on the effectiveness of size limits and bags limits in constraining fishing mortality in recreational fisheries. The impact of LML changes to bream fisheries was predicted using an age-structured model, a time series of catch rate data, and data on size and age composition. The data were successfully collected through a voluntary fishing diary program designed to provide catch data that reflected the abundance and size/age composition of the fish stock. The model indicated that the effect of a LML change depended both on the proportion of the fish stock under the new LML, and the time period of protection before fish become fully vulnerable to harvesting again. This time period was determined by the growth rate and the size difference between old and new LMLs. The applicability of this assessment approach to existing Victorian snapper and King George whiting fisheries is hindered by the effects of stock migration to areas beyond those that are mainly targeted by the bay and inlet fisheries.

The impact of a series of three 2 cm shifts in the LML for black bream was monitored using a time series of size composition and catch rate data. The size composition data collected from creel surveys clearly showed the impact of LML shifts on the length distribution of black bream in the retained catches. The size composition data also provided a means of forecasting changes in catch rates that resulted from LML increases. Changes in retained and discarded bream catch rates collected from creel survey were not consistent with the LML shifts. The variability of, and magnitude of the seasonal fluctuations in, black bream catch rates by anglers in the Gippsland Lakes suggests that effect on catch rates of a small change in the LML is not likely to be easily detectable. Further work is required to assess the extent to which the effect of changes in the LML on average catch rates in snapper, King George whiting and other black bream fisheries can be predicted.

The use of experienced diary anglers, combined with a strategic sampling strategy, resulted in more precise catch rate estimates than those produced by the creel surveys. The results from these diary anglers, however, also did not detect a change in catch rates of black bream. The power analysis indicated that sample sizes used in the trial were well below that needed to detect even a 100% change in catch rate. Implementing a diary angler program to detect the impacts of management control changes would require participation of larger numbers of experienced anglers to achieve the required sampling power.

Censoring of historical creel survey catch rate data indicated the immediate effects of a DBL in constraining F is likely to be greater in years with a higher average retained catch rate. Analysis of retained catch rate data from bream, snapper and King George whiting fisheries showed that DBLs in place during the study did little to reduce fishing mortality. The potential effect of a lower DBL in reducing fishing mortality depended on the shape of the distribution of daily catches and the average daily retained catch.

The projections of bream stock abundance with and without a low DBL suggested that a two bream DBL would do little to constrain fishing mortality in a fishery where the abundance of the fish stock was declining. An important factor in determining this finding was the high proportion of recreational catches by anglers in the Gippsland Lakes that comprised of one or two bream per day. Similarly, daily catch distribution observed for King George whiting and snapper fisheries suggest that a low DBL would also have little affect in constraining fishing mortality where the catch rates for the fishery are declining.

The project successfully demonstrated the application and use of data acquired by cost effective means to evaluate and predict the use of management controls on recreational fisheries. The scope of the project was reduced by the fact that a component of one of the original objectives, to demonstrate the evaluation of the impact of area closures, was not addressed due to lack of a suitable data source.

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APPENDIX 1: Intellectual Property

The intellectual property derived from this project is shared equally between Fisheries Research and Development Corporation and Fisheries Victoria .

APPENDIX 2: Staff

Marine and Freshwater Resources Institute

Simon Conron - Principal Investigator
Natalie Bridge - Scientist

APPENDIX 3: Data summaries

Appendix 3.1. The relative frequency of the catches per angler per day (bag size by No.) for key recreational species and regions between 1997-2000.

Common name	Region	Survey period	No. of angler trips	Mean catch per day	Relative frequency of bag size										
					0	1	2	3	4	5	6	7	8	9	>9
Black bream	Gippsland Lakes	1997	992	1.031	0.609	0.189	0.077	0.038	0.027	0.018	0.012	0.006	0.009	0.005	0.01
		1998	365	0.896	0.627	0.151	0.101	0.055	0.022	0.022	0.008			0.005	0.009
		1999	397	0.678	0.599	0.237	0.106	0.030	0.015	0.008	0.003				0.002
		2000	336	0.515	0.792	0.092	0.033	0.036	0.024	0.009	0.009			0.003	0.002
KG whiting	Port Phillip Bay	1995/96	1734	0.720	0.854	0.052	0.018	0.013	0.010	0.011	0.005	0.008	0.003	0.002	0.024
		1996/97	5519	0.980	0.827	0.049	0.027	0.016	0.010	0.007	0.013	0.005	0.007	0.003	0.036
	Western Port Bay	1998/99	3787	1.790	0.617	0.122	0.060	0.039	0.030	0.028	0.014	0.011	0.014	0.011	0.054
		1999/00	3350	1.106	0.674	0.134	0.055	0.035	0.027	0.016	0.013	0.007	0.009	0.009	0.021
Snapper	Port Phillip Bay	1995/96	1732	0.110	0.923	0.062	0.008	0.002	0.002	0.002		0.001			
		1996/97	5521	0.149	0.920	0.053	0.012	0.006	0.002	0.003	0.002		0.001	0.001	
	Western Port Bay	1998/99	3787	0.085	0.948	0.037	0.007	0.003	0.002	0.001					0.002
		1999/00	3357	0.101	0.946	0.031	0.013	0.006	0.001	0.001	0.001		0.001		

Appendix 3.2. The mean, skewness and kurtosis of the daily catch data collect for key recreational species and regions between 1997-2000.

Common name	Region	Survey period	No. of angler trips	Mean retained catch per angler per day	Skewness of the distribution of retained catches per angler per day	Kurtosis of the distribution of retained catches per angler per day
Black bream	Gippsland Lakes	1997	992	1.031	4.239	27.415
		1998	365	0.896	2.836	10.197
		1999	397	0.678	2.908	14.491
		2000	336	0.515	3.578	15.767
KG whiting	Port Phillip Bay	1995/96	1734	0.720	5.113	28.783
		1996/97	5519	0.980	4.271	19.277
	Western Port Bay	1998/99	3787	1.790	3.426	18.197
		1999/00	3350	1.106	3.744	17.523
Snapper	Port Phillip Bay	1995/96	1732	0.110	9.165	125.032
		1996/97	5521	0.149	8.175	88.575
	Western Port Bay	1998/99	3787	0.085	10.039	143.960
		1999/00	3357	0.101	8.477	96.290

Appendix 3.3. The predicted percentage reduction of fishing mortality (F) resulting from the enforcement of various DBLs for three species commonly caught by anglers fishing in Victorian bays and inlets.

Species	Region	Period	DBL (fish/angler/day)						
			1	2	3	4	5	10	15
Black bream	Gippsland Lakes	1997	62.1	42.4	30.2	21.7	15.8	4.0	0.03
		1998	58.5	33.7	20.2	12.8	8.0	0.0	0.02
		1999	40.9	16.8	8.3	4.1	2.3	0.1	
		2000	59.6	37.1	20.8	11.7	7.0	0.0	
King George whiting	Port Phillip Bay	1995/96	79.7	66.5	55.9	47.2	39.8	18.0	6.0
		1996/97	82.3	69.6	59.7	51.4	44.1	19.8	7.4
	Western Port	1998/99	78.6	64.0	52.8	43.7	36.3	14.5	4.6
		1999/00	65.1	53.1	40.6	31.3	24.5	6.9	2.0
Snapper	Port Phillip Bay	1995/96	30	16.8	10.5	6.3	3.7	0	
		1996/97	46.6	28.2	18	12.1	7.6	0.5	
	Western Port	1998/99	38.4	21.3	12.2	6.9	4.1	0	
		1999/00	46.3	23.3	13	8.3	4.7	0	

Appendix 3.4. Mean catch rates (bream hour^{-1}) for anglers targeting black bream in the Tambo and Mitchell River regions of the Gippsland Lakes from 1995 to 2000

Sampling Period	No. of interviews	Mean retained catch rate (bream hour^{-1})	Skewness of the retained catch rate distribution	Kurtosis of the retained catch rate distribution	Mean discarded catch rate (bream hour^{-1})	Skewness of the discarded catch rate distribution	Kurtosis of the discarded catch rate distribution
Summer 1995	36	0.480	4.009	18.904	1.401	2.151	4.724
Autumn 1995	80	0.297	2.291	5.040	0.540	3.292	12.300
Winter 1995	292	0.403	6.137	47.937	0.404	7.523	81.075
Spring 1995	326	0.293	3.752	22.380	0.730	4.342	23.639
Summer 1995/96	not sampled						
Autumn 1996	331	0.848	2.774	10.466	0.529	4.427	27.943
Winter 1996	394	0.271	6.671	60.77	0.207	8.620	86.157
Spring 1996	338	0.213	4.281	22.168	0.435	4.103	24.832
Summer 1996/97	88	0.226	2.453	6.659	1.459	4.195	23.888
Autumn 1997	177	0.204	2.203	4.826	0.743	3.247	12.900
June 1997	118	0.241	4.036	20.371	0.422	1.905	2.833
Jul-Sept 1997	299	0.357	3.582	16.819	1.087	5.433	43.562
Oct & Nov 1997	136	0.209	4.732	32.990	1.006	3.535	14.414
Summer 1997/98	31	0.029	3.931	15.199	0.353	2.433	5.475
Autumn 1998	64	0.081	2.574	6.174	0.510	5.944	41.506
Winter 1998	233	0.169	3.436	12.452	0.573	4.757	27.145
Spring 1998	246	0.180	4.488	25.596	0.821	7.172	65.693
Summer 1998/99	82	0.160	2.364	5.906	0.934	3.693	20.521
Autumn 1999	196	0.410	4.837	29.531	1.136	2.056	5.340
Winter 1999	248	0.169	4.548	28.364	0.426	2.633	11.260
Spring 1999	236	0.159	5.638	46.405	0.443	3.682	18.974
Summer 1999/00	134	0.464	3.142	11.108	0.579	2.368	5.556
Autumn 2000	392	0.651	2.779	10.591	0.422	3.234	14.649
Winter 2000	286	0.386	4.430	31.085	0.568	3.801	16.681

Appendix 3.5. Estimates of the reliable detectable percentage change in the mean retained catch rate (bream per angler per hour) for sample sizes ranging from 100 to 500 interviews [1] (80% power, α =5%).

Sampling Period	Retained catch rate (bream $hour^{-1}$)		Estimated detectable % change by sample size				
	Mean	Standard deviation[2]	100	200	300	400	500
Summer 1995	1.881	0.480	130	90	80	70	60
Autumn 1995	0.837	0.297	100	70	60	50	50
Winter 1995	0.807	0.403	150	110	90	80	70
Spring 1995	1.023	0.293	110	80	70	60	50
Summer 1995/96	Not sampled						
Autumn 1996	1.377	0.848	90	70	50	50	40
Winter 1996	0.478	0.271	160	120	100	80	80
Spring 1996	0.647	0.213	140	100	80	70	70
Summer 1996/97	1.685	0.226	100	70	60	50	50
Autumn 1997	0.948	0.204	100	80	60	50	50
June 1997	0.663	0.241	140	100	80	70	60
Jul-Sept 1997	1.444	0.357	130	90	70	70	60
Oct & Nov 1997	1.215	0.209	130	90	80	70	60
Summer 1997/98	0.382	0.029	220	160	130	110	100
Autumn 1998	0.591	0.081	100	70	60	50	50
Winter 1998	0.742	0.169	130	90	70	60	60
Spring 1998	1.001	0.180	150	110	90	80	70
Summer 1998/99	1.094	0.160	110	80	70	60	50
Autumn 1999	1.547	0.410	130	90	80	70	60
Winter 1999	0.596	0.169	160	110	90	80	70
Spring 1999	0.601	0.159	170	120	100	90	80
Summer 1999/00	1.043	0.464	120	80	70	60	50
Autumn 2000	1.073	0.651	100	70	60	50	50
Winter 2000	0.954	0.386	130	90	80	70	60

[1] Data were provided from a shore-based survey of anglers targeting black bream in the Tambo and Mitchell River regions of the Gippsland Lakes from 1995 to 2000.

[2] Standard deviation of the bootstrapped mean (n=1000).

Appendix 3.6. Estimates of the reliable detectable percentage change in the mean discarded catch rate (bream per angler per hour) for sample sizes ranging from 100 to 500 interviews [1] (80% power, α =5%).

Sampling Period	Retained catch rate (bream hour^{-1})		Estimated detectable % change by sample size				
	Mean	Standard deviation[2]	100	200	300	400	500
Summer 1995	1.881	0.480	90	60	50	50	40
Autumn 1995	0.837	0.297	110	80	70	60	50
Winter 1995	0.807	0.403	170	120	100	90	80
Spring 1995	1.023	0.293	120	90	70	60	60
Summer 1995/96	Not sampled						
Autumn 1996	1.377	0.848	120	90	70	140	120
Winter 1996	0.478	0.271	270	190	160	60	50
Spring 1996	0.647	0.213	120	80	70	60	50
Summer 1996/97	1.685	0.226	110	80	70	50	50
Autumn 1997	0.948	0.204	100	70	60	50	50
June 1997	0.663	0.241	100	70	60	60	50
Jul-Sept 1997	1.444	0.357	120	80	70	60	50
Oct & Nov 1997	1.215	0.209	110	80	70	60	50
Summer 1997/98	0.382	0.029	110	80	70	80	70
Autumn 1998	0.591	0.081	150	110	90	80	70
Winter 1998	0.742	0.169	150	110	90	70	60
Spring 1998	1.001	0.180	130	90	80	50	40
Summer 1998/99	1.094	0.160	90	60	50	40	40
Autumn 1999	1.547	0.410	70	50	40	50	40
Winter 1999	0.596	0.169	90	60	50	60	50
Spring 1999	0.601	0.159	110	80	60	50	50
Summer 1999/00	1.043	0.464	100	70	60	60	50
Autumn 2000	1.073	0.651	110	80	70	60	60
Winter 2000	0.954	0.386	150	100	90	80	70

[1]Data were provided from a shore-based survey of anglers targeting black bream in the Tambo and Mitchell River regions of the Gippsland Lakes from 1995 to 2000.

[2] Standard deviation of the bootstrapped mean (n=1000)

Appendix 3.7. A summary of the catch and effort data collected by diary anglers fishing in the Gippsland Lakes in November1997-1999.

Sample month	Trip No.	Effort (angler hours)	No. fish measured < 24cm (total length)	24-26cm (total length)	26cm and greater (total length)
Nov-97	1	7	2		2
Nov-97	2	4.25	6	1	1
Nov-97	3	6.25	6	3	1
Nov-97	4	5	18	2	
Nov-97	5	4.5	9	3	
Nov-97	6	6.5	7		
Nov-97	7	5.5	2	1	1
Nov-97	8	5	1	2	2
Nov-97	9	5.5	4		
Nov-97	10	3.5	11		2
Nov-97	11	5.25	8		
Nov-97	12	4	13	1	1
Nov-97	13	2	13		
Nov-97	14	1	9	1	1
Nov-97	15	5	12	7	
Nov-97	16	4.5	17	1	
Nov-98	1	6	7	6	4
Nov-98	2	8	17	6	2
Nov-98	3	3	8	5	3
Nov-98	4	5	10	1	1
Nov-98	5	6.5	9	1	3
Nov-98	6	2.5	5	1	2
Nov-98	7	3.5	11	4	
Nov-98	8	5	5	3	1
Nov-98	9	4.5	8	2	
Nov-98	10	4	5	3	
Nov-98	11	3.25	5		
Nov-98	12	5	15		
Nov-98	13	4	7		1
Nov-98	14	5.5	12		
Nov-99	1	5.5	13	5	2
Nov-99	2	6.75	11	1	4
Nov-99	3	8.75	4	1	4
Nov-99	4	5.75	9	7	8
Nov-99	5	6.5	3	2	2
Nov-99	6	8	4		4
Nov-99	7	8	4	1	1
Nov-99	8	5	2	1	7
Nov-99	9	8	3	1	
Nov-99	10	7.25	8	1	
Nov-99	11	4.5	7	1	1
Totals	41	214.5	330	75	61

Appendix 3.8. Estimates of the detectable percentage change in the catch rate (sample sizes of 50 and 100 fishing trips, 80% power, α =5%) for anglers targeting black bream in the Tambo and Mitchell River regions of the Gippsland Lakes from 1997 to 2000.

Length Class (cm)	Sampling Period	Mean catch rate (bream $hour^{-1}$)	Standard deviation* of mean combined catch rate (bream $hour^{-1}$)	Detectable % change (50 trips)	Detectable % change (100 trips)
<24	November 1997	1.84	2.07	70	50
	November 1998	1.95	0.87	30	20
	November 1999	0.91	0.91	60	50
24 to 25	November 1997	0.29	0.51	100	80
	November 1998	0.48	0.60	80	50
	November 1999	0.28	0.48	100	70
26 and above	November 1997	0.14	0.24	100	70
	November 1998	0.25	0.37	90	60
	November 1999	0.45	0.61	80	60

* Standard deviation of the bootstrapped mean (n=1000)