New and innovative approaches to monitoring small-scale recreational fisheries

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Table of Contents

1. Non-technical summary

2008/005 New and innovative approaches to monitoring small-scale recreational fisheries

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Outcomes achieved to date

This study provides confidence in 'research-angler' diary (RAD) and 'general-angler' diary (GAD) programs as innovative approaches to monitoring small-scale recreational fisheries. Both programs were found to be cost-effective, scientifically robust if managed diligently, and supported by the angling community, fishery managers, and researchers as methods suitable for monitoring recreational fisheries. RAD and GAD programs can foster greater stewardship and engagement of stakeholders in the collection of information needed for fisheries management and sustainable use of key fisheries resources in recreational fisheries. Whilst such programs are reliable and most cost-effective for monitoring any-sized recreational fishery, they are particularly suited to providing data for assessment of small-scale, data-poor recreational fisheries in estuarine and inland waters.

Accepted by researchers across Australia, the findings from the present study resolved the debate about whether 'angler-diary' data provide for satisfactory scientific rigour in monitoring recreational fisheries. The RAD method provides for valid stock-performance indicators, whereas the GAD method provides for valid fishery-performance indicators. Furthermore, RAD and GAD programs can include routine tag release-recapture and sampling for age determinations, which enable application of spatially- and age-structured, stock-assessment models. These innovative monitoring methods provide a basis for a consistent national approach to monitoring and to enhanced management of recreational fisheries.

A guide ('tool kit') provides for the establishment of RAD and GAD programs to enhance the ability of government, industry, researchers and recreational fishers to apply 'angler-diary' programs. The tool kit is based on review of monitoring programs for fishery management, including review of the utility of the available monitoring methods, and the results of power analysis of available data from past and present RAD and GAD programs. The tool kit is also developed from the results and costing of field trials from the present project comparing catch rates and catch length-frequency composition among the RAD and fishery-independent survey (FIS) methods and on reported information from application of angler-diary programs as case studies addressing fishery-management questions in Victoria and Queensland. A Queensland case study demonstrates how 'angler-diary' programs could incorporate routine tag and release of fish for improved understanding of availability and movement of various size classes in a population among regions.

Victoria's ongoing 'angler-diary' programs won two prestigious awards as part of World Environment Day Awards 2011: the United Nations Association of Australia's Excellence in Marine and Coastal Management Award and the Victorian Coastal Council Awards for Excellence 2011 Community Action and Partnership. Media coverage resulting from the awards widely promoted the programs.

Objectives:

1. To refine, to validate and to enhance the utility of 'angler-diary' programs as a cost-effective tool for monitoring the status of key target fish stocks in small, data-poor recreational fisheries.
2. To ensure that the project findings on the utility and cost-effectiveness of 'angler-diary' programs are communicated to all relevant stakeholders, researchers and fisheries management agencies.

The two objectives of the project were met fully. Objective 1 was met through review of published information and the results and costing of field trials for comparison of 'research-angler' diary (RAD) and fishery-independent survey (FIS) methods undertaken as part of the present study. In addition, the study examined reported or published information on the application of RAD and 'general-angler diary' (GAD) programs designed to answer fishery management questions. Each of four programs examined (three in Victoria and one in Queensland) is treated as a case study. Objective 2 is being met through engagement of 'research-anglers' as part of the present study, stakeholder participation on the project Technical Steering Committee and its workshops, and distribution of the FRDC final report to all key stakeholders. Media coverage provided valuable publicity for RAD programs, particularly when Victoria's programs received two prestigious awards. Three appendices providing full details from the present study can stand-alone as separate reports or papers in internationally reviewed journals. A fourth appendix provides information on the two awards and other media coverage.

Various methods are deployed for monitoring diverse recreationally and commercially harvested species of fish in freshwater, estuarine and marine water bodies throughout Victoria. Several fishery-dependent methods involving creel census with interviews for monitoring catch rate and catch composition (species and length-frequency distribution) and involving aerial, boat-ramp or polling survey methods provide for periodic estimation of catch and fishing effort. Such methods are expensive and accumulate large volumes of data with the disadvantage of no control of spatial and temporal coverage.

The FIS method enables control over spatial and temporal sampling with fishing gear specifically designed to catch one or more species of wide size-range in a particular water body, but the high costs limit frequency of deployment of the gear and sampling replication. In addition to catch, fishing effort, and catch composition data, depending on the fishing gear, the length-selectivity parameters can be estimated for each species. Although the setting and hauling the gear associated with the FIS method requires highly trained operators, the method provides the opportunity for tag and release, collection of biological data (e.g. length-weight, length-maturity, and length-fecundity), and collection of biological samples (e.g. otoliths, scales or vertebrae for age-estimation, and stomach contents for diet analysis).

The GAD method is highly cost-effective, because it enables intense and wide-scale sampling across a fishery. However, the data tend to skew towards the high-density areas for targeted species with limited scope for control of spatial and temporal sampling, the fishing gear deployed, and collection of ancillary data and biological samples. Nevertheless, GAD programs provide the opportunity to tag and release fish.

The RAD method optimises the advantage of spatial and temporal control of sampling associated with the FIS method with the advantage of cost-effectiveness associated with the GAD method. The RAD method requires a group of dedicated 'research-anglers' spatially distributed over the fishery, who are prepared to operate according to agreed protocols prescribing the attributes of particular fishing gear (e.g. gap size of hooks) and the spatial and temporal distribution of sampling. 'Research-anglers' need to be prepared to undertake periodic training and to record full details of catch, fishing effort, and catch composition, to collect ancillary data and biological samples, and to tag and release fish.

Information from monitoring and research is applied routinely for updating stock status reports, which underpin legislative and licensing arrangements, including annual review of total allowable commercial catch for particular fisheries. This work is designed for ensuring that catches from harvested resources are sustainable and shared equitably. Within the international frameworks of 'ecosystem-based fisheries management' and 'ecologically sustainable development', Australian reporting requires specifying stock status against five classification categories relating to stock sustainability. This depends on understanding the interactions among stock biomass (or biomass proxy), recruitment and fishing intensity. For recreationally harvested stocks requiring only a biomass proxy, the RAD or FIS method is appropriate for provision of a stock-performance indicator through monitoring catch species composition, and, for each species, catch rate and catch length-frequency composition. Whether to apply the RAD or FIS method depends on the species and the water body, but initially it is likely that both methods need to be deployed together. This provides biological samples required for assessing 'biological productivity', which is related to maturity, fecundity, and longevity. It also provides ancillary information for assessing 'catchability', which is related to fishing-gear 'selectivity' for length of fish encountering the gear, 'encounterability' of the available fish population to the gear, and the 'availability' of a fish population within the water body. Where estimates of total catch are required, catch rate from the GAD method is suitable (provided the 'general-angler' diarists are representative of the angling community), coupled with a survey method for estimating total fishing effort. The GAD method provides a fishery-performance indicator, but because of targeting practices, it may be a biased stock-performance indicator. Limiting recreational fisheries monitoring to the RAD and GAD methods, with some use of FIS and survey methods, simplifies procedures for collection, management, analysis and reporting of data. The approach is scientifically rigorous and the RAD and GAD methods are cost effective and engage anglers.

The RAD and FIS methods were trialled as part of the present study according to a design for sampling recreational fish populations of estuary perch (*Macquaria colonorum*) in Anderson Inlet, black bream (*Acanthopagrus butcheri*) in Lake Tyers, and Murray cod (*Maccullochella peelii peelii*) in the Murray River. The catch rates and catch length-frequency distributions were compared among these methods for each of the three target species in their respective water bodies. These comparisons were interpreted using the concept of 'catchability' and its three components such that depending on length (or age) of fish, 'catchability' = 'availability' x 'encounterability' x 'selectivity'. The FIS methods consistently caught significantly more species of fish and much higher numbers of fish than did the RAD method. There was statistically better agreement among the RAD and FIS methods in the patterns of catch rate and catch length-frequency distribution for fish of length above legal minimum length (LML) than for fish <LML or for fish <LML and ≥LML pooled. All methods caught a wide length-range of fish of both <LML and ≥LML, but the FIS methods could catch smaller fish than the RAD method. The higher catch rates for the FIS methods than for the RAD method for fish ≥LML are explained by higher 'encounterability', whereas the much higher catch rates for fish <LML are explained by the combination of higher 'encounterability' and much higher 'selectivity' of the fishing gear. For each of the FIS (demersal trawl), FIS (beach seine), and FIS (electrofishing) methods, catch rate and catch length-frequency composition provide reasonably unbiased indices of relative abundance and population length-frequency distribution (or cohort-strength distribution derived via an age-length key). Conversely, apart from the smallest fish in the population (too small to catch during the trials), the RAD and FIS (gillnet) methods cannot be applied as indicators of the relative strengths of length classes or cohorts in the population without adjustment for the effects of species-specific length-selectivity.

Two of the four case studies demonstrate that time series of annual catch length-frequency distributions collected by the RAD method, adjusted for the effects of hook length-selectivity, can be converted by annual age-length keys to express number of fish per angler-hour for each age-class in a population. This enables tracking specific cohorts from one year to the next. Tracking cohort strength this way over several years provides a basis for estimating mortality rate in a population, which is a key component of stock assessment. One case study demonstrates how catch rates from the RAD method can be applied in ecological experiments to address fishery-management questions, such as assessing the effectiveness of artificial reefs for enhancing recreational fishing. Another case study shows how 'general-anglers' can serve as 'research-taggers' to tag and to release large numbers of fish for determining patterns of movement and mixing within a population.

Tag data collected as part of RAD (or FIS) and GAD programs together with catch rate data from the GAD method and fishing effort distribution over a population from independent survey could be used for estimating movement rates among separate regions of a fishery by applying an appropriate movement model. In addition, applying a stock-performance indicator derived from catch rate and catch length-frequency distributions corrected for the effects of 'length-selectivity' and weighted by age-length keys collected routinely by the RAD method allows the additional step of applying high-level stock-assessment models. Routine tag release–recapture data and routine age-composition of the catch collected together enable the application of stock-assessment models that are spatially structured and age structured for integrating the dynamics of the fish population and the dynamics of the harvest processes in the fishery.

Although the combination of RAD, GAD, and FIS methods together with a separate survey method for estimating total fishing effort (and hence total catch) is applicable to a wide range of species in diverse water bodies, there may be particular species in certain water bodies with specific requirements for monitoring, assessment and management. Nevertheless, it is concluded that RAD, GAD and FIS methods are highly effective for monitoring recreational fisheries.

Keywords: 'Research-angler' diary, fishery-independent survey, recreational-fishery monitoring.

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Members of the Technical Steering Committee providing guidance for the project included Victorian 'research-anglers' John Harrison, Peter Spehr, Ken Radley, and Ross Winstanley; Dr Doug Rotherham and Dr Charles Gray of New South Wales Department of Primary Industries; Dr Lynnath Beckley of Murdoch University; Dr Sean Tracey of Institute of Marine and Antarctic Studies (University of Tasmania); Dr Keith Jones of Primary Industries and Resources South Australia; Dr Jeremy Hindell and Andrew Pickworth of Arthur Rylah Institute for Environmental Research (DEPI); Simon Conron of Fisheries Victoria; and Dr Daniel Grixti (Chair) and Dr Murray MacDonald formerly of Fisheries Victoria. Other people contributing to the Steering Committee as observers or participating in workshops were William Sawynok of Infofish Australia; Dr James Andrews of Fisheries Victoria; and Lauren Brown, Thérèse Stokie, and Matt Ward formerly of Fisheries Victoria.

Dr Carolyn Stewardson of FRDC, Ross Winstanley, and an anonymous reviewer are acknowledged for their meticulous comments through the peer review process contributing to improvement of the standard of the report from Draft Final Report to Final Report.

3. Background

Australian fisheries management agencies need to demonstrate that fisheries under their jurisdiction are managed in accordance with the principles of Ecosystem-Based Fisheries Management (Pikitch *et al.* 2004) and Ecologically Sustainable Development (Fletcher *et al.* 2002). The decision-making process of these management frameworks requires specific and measurable objectives and performance indicators for the assessment and management of fisheries. Commercial fishers routinely provide mandatory catch and effort information used for fisheries assessment. In contrast, recreational fishers are generally not required to report similar information.

Increasing numbers of recreational fishing participants coordinated lobbying of government by stakeholders and appreciation by policy-makers of the social and economic benefits of recreational fishing have led to progressive resource reallocation to the recreational sector by creating exclusively recreational fisheries in several water bodies. The trend towards removing commercial fishing from estuaries, small inlets and inland waters across Australia has created a need for alternative sources of fisheries monitoring data. The reduction in commercial activities has not only removed a source of data, but has reduced the funds available for supporting fishery-independent methods of monitoring.

During the late 1990s, Fisheries Victoria recognised that the absence of commercial fishing would cause a decline in the quantity and quality of data available for fisheries assessment and impede fisheries management. Consequently, angler-based monitoring programs were developed and implemented, and have been operational since 1997. These programs include angler diarists providing time-series data on catch rate, catch length-frequency composition, and catch age-frequency composition for key target species in selected Victorian recreational fisheries (Conron and Bridge 2004).

'Research-angler' diarists (RAD) and 'general-angler' diarists (GAD) participating in the monitoring programs complete dairies where they can record the time spent fishing, bait and sizes of hooks used, and species and length of each fish caught. In addition, they collect otoliths (ear bones) from a sample of their catch for subsequent laboratory processing for age determination. The information provided by the 'research-anglers' and 'general-anglers' research is collected throughout the year and thereby includes information on intra-annual and inter-annual variation in catch rates and catch composition. RAD programs standardise fishing effort in a structured way (e.g. at prescribed times and locations with specified hook size and type) to provide time-series data on catch rate and catch composition for computing a stock-performance indicator. GAD programs, on the other hand, monitor normal fishing practices of anglers to provide time-series data on catch rate catch composition for computing a fishery-performance indicator (Conron 2004).

The Victorian experience with RAD and GAD programs indicates that the approach has been particularly effective in small, data-poor fisheries. For example, catch rates provided by a RAD program for black bream (*Acanthopagrus butcheri*) in the Gippsland Lakes since 1997 were comparable with catch rates from both fishery-independent survey of pre-recruit fish and commercial fishing. Given the success of these RAD programs, they have been adopted in fishery management plans as the principal method for monitoring the status of key target fish stocks in small estuaries where commercial fishing is excluded (Department of Primary Industries 2006a; Department of Primary Industries 2006b; Department of Primary Industries 2006c; Department of Primary Industries 2007a; Department of Primary Industries 2007b).

Despite the potential value of RAD programs, there has been uncertainty about whether the catch rate and catch composition data produced are representative of the overall abundance and size and age composition of the populations of the species monitored. The present study evaluates and validates the utility of RAD and GAD programs as cost-effective for provision of monitoring data for stock assessment of recreational fisheries in Victoria. In doing so, the present project will guide the development of recreational-based methods for the assessment of fisheries resources throughout Australia, and thereby address the FRDC Research Challenge to "Maintain and improve the management and use of aquatic natural resources to ensure their sustainability"

4. Need

Recreational fisheries in estuaries, inlets and inland waters are typically complex and target a variety of fish species using several fishing methods, and variation in the numbers of fish caught are not only affected by fishing intensity, but by fluctuations in habitat and environmental conditions. In response to limited resources available for monitoring, assessment and management of these fisheries, Victoria has developed and implemented GAD and RAD programs to provide time series of monitoring data for key target fish species in selected water bodies. The innovative and cost-effective 'angler-diary' programs are embraced by researchers, fishery managers and stakeholders in Victoria. Given the strong support in Victoria and the possible application of these methods to small, data-poor fisheries throughout Australia, this project addresses an urgent need to evaluate the suitability of the RAD and GAD methods for provision of data as input to quantitative stock assessment.

5. Objectives

The project has two objectives.

1. To refine, to validate and to enhance the utility of angler diary programs as a cost-effective tool for monitoring the status of key target fish stocks in small, data-poor recreational fisheries.
2. To ensure that project findings on the utility and cost-effectiveness of angler diary programs are communicated to all relevant stakeholders, researchers and fisheries management agencies.

6. Methods

The study set up the Technical Steering Committee comprising fishing representatives, fisheries managers, and leading scientists from around Australia. The Committee's role was to oversee, guide and advise the development and progress of the project to ensure the findings in Victoria can be expanded and taken-up around Australia. The Committee had members from Victoria, Tasmania, New South Wales, Queensland, South Australia, and Western Australia (see Acknowledgements section). The members held three meetings (24 October 2008, 02 July 2009, 15 July 2010) and engaged by correspondence before, between and after the meetings.

The study had seven components leading to a guide ('tool kit') to enable government, industry, researchers and recreational fishers to apply 'angler-diary' programs:

1. validate data from RAD programs by comparison with data from FIS methods;
2. evaluate from case studies the success of angler diary programs for providing robust data;
3. identify information required for management of recreational fisheries;
4. review the utility of available monitoring methods for provision of robust data;
5. determine required sampling intensity of 'angler-diary' programs by statistical power analysis using available data from past and present programs;

6. undertake a cost-benefit analysis; and
7. develop a 'tool kit' for implementation of 'angler-diary' programs.

Seven sub-headings addressing these seven components are adopted under each of the two sections of the present report headed Methods and headed Results and Discussion.

This report presents information at three levels of detail, where an account of the project at each level can stand-alone. The first account is the Non-technical Summary designed to provide an executive overview. The second is the main body of the report designed to provide a readable account of the project in the FRDC standard format to suit most stakeholders. The third account, presented in three appendices, prepared for submission for publication to scientific journals reviewed internationally, has a level of detail designed to gain the imprimatur of the scientific community through scientific peer review. Appendix 3 titled "Comparison of catch rates and catch composition among 'research-angler' diary and fishery-independent survey methods in Victoria, Australia" (pages 27–48) corresponds to component a. Appendix 4 titled "Four case studies applying 'research-angler' diary method for fishery monitoring" (pages 49–80) corresponds to component b. Appendix 5 titled "New directions for monitoring recreational fisheries in Victoria, Australia" (pages 81–110) corresponds to components c–g.

6.1 Comparison of RAD and FIS methods

Comparison and evaluation of the RAD and FIS methods were made in each of three Victorian recreational fisheries: the Anderson Inlet Estuary Perch Fishery, the Lake Tyers Black Bream Fishery, and the Murray River Murray Cod Fishery. The estuary perch (*Macquaria colonorum*), black bream (*Acanthopagrus butcheri*), and Murray cod (*Maccullochella peelii peelii*) are iconic angling species targeted by recreational fishers and, in these three fisheries, isolated from commercial fishing. The choices were based on advice from the Technical Steering Committee, a pilot study undertaken during February–May 2009, the high priority for management plans in those fisheries, and the already active participation of 'research-anglers' as part of ongoing RAD programs in those water bodies. It was proposed in the application to include golden perch, in addition to Murray cod, in the Murray River, but the Technical Steering Committee recommended excluding golden perch because of logistical difficulties associated with targeting two species.

The experimental design for comparison and evaluation of the RAD and FIS methods in the three fisheries involved careful construction of one or more units of fishing gear (i.e. one demersal trawl, five multifilament gillnets, and one beach seine) and use of readily available fishing gear (i.e. one or two rods and reels for each 'research-angler', and one electrofishing unit). The species and length were recorded for each fish caught in standard diaries adopted for the RAD and GAD methods or on data sheets adopted for the FIS method. Other data recorded included details of fishing gear used, location of fishing, duration of fishing, and bait when applicable. Otoliths collected from subsamples of the catches of estuary perch and black bream were used subsequently in the laboratory for age determination..

Several gears were used for fishery-independent survey.

- Multi-panel experimental gillnets (five 35-m long x 2-m deep gillnets each with seven 5-m long panels of 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 and 4.5-inch mesh-size) for estuary perch in Anderson Inlet.
- Otter trawl (a small demersal trawl with 3.5-m wide mouth of 15-mm mesh-size) for estuary perch in Anderson Inlet.
- Beach seine (20-m long x 2-m deep of 6-mm mesh-size with 30-m long hauling ropes each end) for black bream in Lack Tyers.
- Electrofishing (aluminium Smith-Root Model GPP 2.5 H/L boat with 7.5 kW generator) for Murray cod in the Murray River.

Five experienced anglers in each of Anderson Inlet and Lake Tyers and seven experienced anglers in the Murray River served as 'research-anglers' targeting the selected species using standardised fishing gears, methods and behaviours typical of the target fishery. The results of creel surveys and data from past angler diary programs provide a guide for these procedures. The 'research-anglers' used hooks or lures that are similar to and smaller than those normally used so as to target smaller fish sizes. Within each of the three water bodies, the 'research-anglers' selected several water sections four fishing areas (areas large enough to allow several fishing boats and the gear for the FIS methods to operate simultaneously. The 'research-anglers' commenced fishing 30 minutes before sunrise each morning and operated for four 52-minute sessions each angler day. While the 'research-anglers' operated in their water sections, the FIS gears provided estimates of abundance and diversity of fish (including fish lengths) in adjacent water sections. A breakdown of the total number of RAD 'angler-days' and FIS sampling days for each RAD and FIS method in each water body and the associated replication is provided in Table 1 on page 30 of Appendix 3. Maps of the three water bodies with their water sections appear in Figure 1 on page 31 of Appendix 3.

Catch rates (<LML, ≥LML and combined), length-frequency distributions, and age-frequency distributions among fishing trips and methods over the same spatial and temporal scales were compared among the RAD and FIS methods applying various statistical procedures in the statistical packages in GENSTAT and SAS. Designed to identify strengths and weaknesses of the RAD method, these tests provide a basis for validation of the RAD method for provision of scientifically defensible data. Preliminary trials and historical studies indicate that applying multiple fishery-independent methods provide the most robust indicators of population composition. A full scientific account of the methods of statistical testing for differences in catch rates (<LML, ≥LML and combined), length-frequency distributions, and age-frequency distributions among fishing trips and methods are provided in Appendix 3.

6.2 Case studies of angler diary programs

The present study identifies and describes four studies (referred to here as case studies) where the RAD method is applied in Australia to resolve several fishery management questions. Three of the four case studies are from Victoria and the fourth is from Queensland (Appendix 4). These studies were selected because they apply to key recreational species and because their designs for data collection ensure statistical rigor for data analysis. The three Victorian case studies were undertaken and reported independently of the present study; hence, the methods and results are only briefly summarised here. The results from the Queensland study, however, have not been reported previously and therefore are reported fully in Appendix 4. The three Victorian studies apply the RAD method with 'research-anglers' providing time series of catch rate and catch length-frequency composition used for making inferences on changes in abundance of particular age classes or size classes in a fish populations. The Queensland study applies the RAD method with 'research-taggers' providing extensive tag-release-recapture data used for making inferences on movement and mixing patterns of fish in a population.

In Case Study 1 for snapper (*Pagrus auratus*) in Port Phillip Bay, RAD annual catch length-frequency distribution for each of four years was converted to percentage age-frequency distribution using an annual age-length key. The percentage-age-frequency distributions produced were back-calculated to age 0+ years and then compared with relative abundances of the 0+-age class in a 12-year time-series (2000–11) from fishery-independent pre-recruit surveys by beam trawl.

In Case Study 2 for black bream (*Acanthopagrus butcheri*) in Mallacoota Inlet and Lake Tyers, RAD annual-catch-length-frequency distribution, adjusted for the effects of hook length-selectivity, for each of several years were converted into a percentage age-frequency distribution using an annual age-length key. The percentage-age-frequency distributions were then converted to number of fish per angler-hour for each age-class to identify several strong cohorts in the two populations. The strong cohorts were followed through several periods to estimate total mortality by linear regression analysis. Inferences were made about the effects of closing these areas to commercial fishing by comparing total mortality between a selected period before closure of these estuaries to commercial fisheries and a selected period after closure.

Case Study 3 demonstrates how the RAD method can be used to determine the effectiveness of artificial reefs for enhancement of recreational fishing. A trial with a BACI ('Before–After-Control–Impact') design was undertaken at three separate localities in eastern Port Phillip Bay, where each locality had three sites of different 'habitat-type': 'artificial reef', 'sandy substrate', and 'natural reef' (i.e. 3 localities x 3 'habitat-types' = 9 study sites). The BACI trial was undertaken over 3 years, each with two 2-month sampling-periods of RAD fishing, such that 'before-control–impact sampling' (before installation of the artificial reefs—hollowed concrete structures, each with several fish entrances) occurred during Year 1. The 'after-control–impact sampling' (after installation of the artificial reefs at the end of Year 1) occurred during Year 2 and Year 3. This case study demonstrates how the RAD method for monitoring fish stocks harvested by recreational fishers can contribute data to a broad-scale study required to address specific fishery-management questions

Case Study 4 introduces the concept of 'research-tagger'. 'Research-taggers' have elements of the GAD method because they report their catch, fishing effort and catch length-frequency composition, while operating according to their normal recreational fishing practices (i.e. not to a pre-determined sampling design as occurs for 'research-anglers'). 'Research-taggers' also have elements of the RAD method because they apply scientific methods for tagging fish. This case study demonstrates how tag release-recapture data generated by 'research-taggers' can be applied to determine valuable information about the movement and mixing patterns of barramundi (*Lates calcarifer*) among the inland water systems of eastern Queensland.

6.3 Information required for management of recreational fisheries

Management decisions for fisheries, to a greater or lesser extent, take account of the condition of the stocks (Gulland 1983) or are based on assumptions about the stock dynamics (Hilborn and Walters 1992). Understanding of stock dynamics ranges from intuition to explicit representation in fishery stock assessment models. Fisheries are not static systems easily reshaped through management; yet, without adequate management, the fisheries can progress rapidly from early development through stages of sustainability to severe stock depletion. For sustainable use of fish resources, there is recognition that stock assessment involves understanding and making predictions about the response of fishery systems to alternative management actions involving choices in the face of uncertainty.

Various types of model are available for fishery stock assessment, which vary considerably in complexity. Their application inevitably requires data and expertise, the availability of which usually depends on the value of the fishery and willingness to invest in tailoring models to the peculiarities of particular fisheries. Their application also requires collecting appropriate fishery monitoring data, and studying the population biology and habitats of key species.

Management of fisheries is increasingly required to account for fishing impacts on habitats; by-catch species; threatened, endangered and protected species; and associated ecological communities. This has led to the concept of Ecosystem-based Fisheries Management (EBFM) (Pikitch *et al.* 2004) and, in Australia, development of an ecological risk assessment framework termed Ecological Risk Assessment for the Effects of Fishing (ERAEF). The framework is hierarchical in that information required increases through the hierarchy, and allows for assessment of data-poor fisheries; uncertainty in information is treated as high risk in accordance with the precautionary approach (Hobday *et al.* 2011).

Before designing monitoring programs for recreational fisheries, there is first a need to consider the information needed for fisheries management in Australia relating to the frameworks of EBFM and

ERAEF and requirements for reporting stock status. The requires considering the concepts of 'species, water body and stock identity'; 'species biological productivity'; 'stock performance indicators'; and species 'catchability', 'catch susceptibility', and their components.

6.4 Utility of available monitoring methods for provision of robust data

Based on the information requirements for management of recreational fisheries, the utility of available methods for monitoring recreational fisheries was reviewed by listing the advantages and disadvantages against the types of data produced by each type of method. Based on available literature and data provided or assessed by the present project, the broad types of methods considered by review were GAD, RAD, offsite survey, onsite survey and FIS.

6.5 Power analysis for sampling intensity of RAD, GAD & FIS programs

To ensure monitoring programs are cost-effective, statistical power analyses can be applied to determine the annual number of 'angler-days' required for the GAD or RAD methods and the annual number of 'sampling-days' required for the FIS method. For the present study, power analyses were performed with data angler diary data available for five key recreational fish species from Victorian water bodies monitored since 1997 and with data from the RAD and FIS trials undertaken for three species during 2010 (see under (a) above). The theory behind power analysis and procedures for determining the minimum sample size (i.e. minimum 'number of fishing-days') required to detect a specified change in mean catch rate in a future year from the past overall mean annual catch rate (100%, 80% and 50% change for the present study) are presented in Appendix 5 on page 99). The power analyses were performed using the procedure GLMPOWER with a contrast statement in the statistical and data management package SAS (version 9.3) (SAS Institute, Cary, North Carolina, USA).

Existing RAD and GAD programs can give a guide to sampling intensity when establishing new programs. However, as data are collected periodic power analyses can determine whether sampling intensity it adequate for detecting a specified change in catch rate used as a stock-performance indicator by a RAD of FIS program or as a fishery-performance indicator by a GAD program.

6.6 RAD, GAD and FIS cost-benefit analysis

A comparison of cost-effectiveness among the GAD, RAD and FIS methods was made from the 2010 trials sampling the fish populations of the recreational fisheries for estuary perch in Anderson Inlet, black bream in Lake Tyers, and Murray cod in the Murray River. Cost items were categorised as 'start-up costs', 'annual costs', and 'operational costs' for each of four sampling methods identified for the purpose of the cost comparison as GAD, RAD, FIS (one gear), and FIS (two gears). 'Angler diarists' targeting Murray cod in the Murray River were treated as 'research anglers' as part of the RAD method for the purpose of data analysis, but for the purpose of cost comparison, they were treated as 'general-anglers' as part of the GAD method. Because of the large distances involved in fishing the Murray River, choice of RAD angling days had to be flexible and left to the discretion of the 'research-angler' as occurred for 'general anglers' in all three water bodies. 'Angler diarists' targeting estuary perch in Anderson Inlet and those targeting black bream in Lake Tyers were treated as 'research-anglers' for both data analysis and cost comparison.

6.7 Tool kit for implementation of 'angler-diary' programs

Standard procedures for implementation of GAD, RAD and FIS monitoring programs for recreational fisheries are developed and described. These standard procedures for monitoring recreational fisheries are cost-effective, statistically rigorous, and engage recreational fishers. The procedures are designed to simplify not only the field operations, but data management, analysis and reporting. The data provided need to be comparable and compatible over time to allow for time-series analyses of both continuous (non-broken) and non-continuous (broken) data-series.

7. Results and Discussion

7.1 Comparison of RAD and FIS methods

During the FIS methods sampling period of February–July 2010, field teams set the fishing gear on 44 ‘sampling-days’, and during the RAD method sampling period of February–May 2010, 17 ‘research-anglers’ fished a total of 183 ‘angler-days’ across the three water bodies of Anderson Inlet, Lake Tyers and Murray River. A total catch of 19 797 fish (including 13 691 fish of the 3 target species) caught and measured from the FIS method exceeded the total catch of 1682 fish (including 1452 fish of the 3 target species) caught and measured from the RAD method. Similarly, total catches of the three target species in the three water bodies, respectively, were consistently more for the FIS methods than for the RAD method (2822: 108 estuary perch, 10 604: 1225 black bream, and 198: 116 Murray cod). Furthermore, the number of non-target species was higher for the FIS methods (35 species) than for the RAD method (11 species) (Appendix 3, Table 2 on page 34).

The number of species caught tested by one-way analysis-of-variance was significantly higher for the FIS methods than the RAD method in all three water bodies. The FIS (demersal trawl) method and FIS (gillnet) method caught 4.6 and 3.8 times, respectively, the number of species taken by the RAD method in Anderson Inlet. The FIS (beach seine) method in Lake Tyers and the FIS (electrofishing) method in the Murray River caught 2.1 and 2.6 times, respectively, the number of species taken by the RAD method in each of those water bodies. The different number of species caught by the FIS (demersal trawl) and FIS (gillnet) methods in Anderson Inlet was not significant.

The FIS methods applying four separate types of fishing gear—demersal trawl and gillnets in Anderson Inlet, beach seine in Lake Tyers, and electrofishing in the Murray River—consistently caught significantly more species of fish and much higher numbers of fish than did the RAD method. All methods caught a wide length-range of fish both <LML and ≥LML, but the FIS methods could catch smaller fish than the RAD method. Differences in catch rates among separate sampling trips for each RAD and FIS method were not detected for any of the three target species during the period of the fishing trials February–July 2010. For each of the three target species (estuary perch, black bream, and Murray cod), there was statistically better agreement among the RAD and FIS methods in the patterns of catch rate and catch length-frequency distribution for fish ≥LML than for fish of length <LML or for fish of all lengths pooled. These patterns are shown in Appendix 3, Figures 2–3 (pages 39–40) and 4 (page 43).

For Murray cod in the Murray River, only a small section of the river could be covered for the fishing trials, and the habitat types fished and the timing of the trips between the RAD and FIS (electrofishing) methods were different. Electrofishing was undertaken at sites of shallow snag piles, whereas ‘research-anglers’ fished in shallow and deep areas on the edge of snag piles.

The FIS (electrofishing) method has several limitations for sampling fish populations. The efficiency of electrofishing is affected by environmental and habitat factors, attributes of the fish species, and the adopted sampling strategy. Environmental and habitat factors include width and depth of a river, debris and vegetation cover, and conductivity of the water, which is affected by salinity, turbidity and temperature. Species attributes affecting efficiency, which are likely to be inter-dependent, include shape, size and conductivity of the fish species. Sampling strategy factors affecting efficiency include speed of boat, use of direct current or alternating current, voltage gradient and current density applied in the water, voltage between electrodes, and ability of the dip-netters to see the stunned fish and then to dip-net the fish before they recover and escape. In addition, the frequency of pulsed direct current (e.g. a low frequency of 15 Hz compared with a high frequency of 60 Hz) affects efficiency.

7.2 Case studies of angler diary programs

Case Study 1 demonstrates how data from RAD method, when combined with fishery-independent pre-recruit data, can provide essential information on the dynamics of relative cohort strength and recruitment.for snapper (*Pagrus auratus*) in Port Phillip Bay. RAD percentage-age-frequency distributions clearly identify differences in the strengths of separate cohorts progressing through a 4-year period. When back calculated to age 0+ years, the cohorts match well to the corresponding relative abundances of the 0+-age class in a 12-year time-series (2000–11) from fishery-independent pre-recruit surveys by beam trawl (Appendix 4, Figures 1–2 on pages 53–54).

Case Study 2 demonstrates how data from the RAD method can be applied to evaluate the effects of removing commercial fishing on total mortality for black bream (*Acanthopagrus butcheri*) in Mallacoota Inlet and Lake Tyers. There was a marked change in total mortality for several strong cohorts between a selected period before closure of these estuaries to commercial fisheries and a selected period after closure (Appendix 4, Table 1 on page 58). This indicates that the closure of these estuaries to commercial fisheries markedly reduced fishing mortality, assuming no change in natural mortality between the two periods.

Case Study 3 demonstrates how the RAD method can be used to determine the effectiveness of artificial reefs for enhancement of recreational fishing in eastern Port Phillip Bay using a BACI ('Before–After-Control–Impact') design. Statistical analysis of snapper RAD catch-rates (i.e. no. fish per angler-hour) from the nine study sites over the three years indicated that the artificial reefs installed on 'sandy-substrate' 'habitat-type' improved catch rates to a level similar to 'natural-reef' 'habitat-type' (Appendix 4, Table 2 and Figure 3 on pages 61 and 64, respectively).

Case Study 4 demonstrates how anglers can serve as 'research-taggers' to apply scientific methods to tag and release large numbers of barramundi for determining (1) patterns of mixing between wild-bred and hatchery-bred fish in the population and (2) patterns of movement among the inland water systems of eastern Queensland. This large data-set of tag release-recapture could be readily applied with the catch rate data provided by the 'research-taggers' and a survey to determine the distribution of fishing effort across the inland water-system to provide estimates of movement rates among separate regions. A similar approach was used for school shark (*Galeorhinus galeus*) across southern Australia (Walker *et al.* 2008). Applying the RAD method for collecting catch rate data to provide a stock-performance indicator and for collecting length-at-age data makes using a spatially-structured and age-structured stock assessment model feasible. A similar model has been used to integrate the dynamics of the fish population and dynamics of the harvest processes for school shark (Punt *et al.* 2000).

7.3 Information required for management of recreational fisheries

Fishery management inevitably requires reporting stock status, which depends on management needs and availability of data and information. Complexity of reporting may range from ERAEF, through reporting of species stock-performance indicators, to full quantitative integrated stock assessment. These assessments require specifying species, water body, and stock identity; species 'biological productivity'; species stock-performance-indicator trends; and species 'catchability', 'catch susceptibility', and their components ('availability', 'encounterability', 'selectivity', and 'post-capture mortality') (Walker 2005).

Assessment of one or more species in a water body depends on available information (e.g., genetics, restocking from hatcheries, or tag movement) or assumptions for each species about 'stock identity' in the water body and the connectivity of the population in that water body with the populations (or sub-populations) in other water bodies.

'Biological productivity' of a population, applied explicitly in ERAEF and implicitly in stock assessment, is a measure of population turnover. Low biological productivity is associated with low natural mortality rate (long lived) and low reproductive rate. High biological productivity is associated with high natural mortality rate (short lived) and high reproductive rate. As a general rule species of low 'biological productivity' are at higher risk from the effects of fishing and take longer to recover from depletion than species of high 'biological productivity'. Integrated fishery stock assessment, however, requires additional information for computing trends in biomass, stock numbers, and recruitment and for evaluating alternative harvest strategies.

The need for species stock-performance indicators provides the rationale for fishery monitoring programs. Stock assessment require time-series data that can indicate whether the trend in abundance of a harvested population (e.g. total biomass or total stock number), or a component of the population (e.g. mature biomass, available biomass, specific size-classes or specific age classes), is decreasing, stable or increasing. Potential indicators of relative abundance of the population include catch rate or of components of the population include *inter alia* length-frequency composition, age-frequency composition, or mean length, mean mass, or mean age of fish in the catch. A measure for any one of these indicators for one year alone is relatively uninformative because it cannot indicate a trend. Trends in time series for these indicators of only 3 or 4 years are uncertain because a time series of a longer period is required to distinguish a trend from natural inter-annual variability in the data. Nevertheless, catch length-frequency composition or, preferably age-frequency composition, for one or several years can indicate the presence or absence of various size classes or age classes in the catch. Relating catch rate applied as an index of relative stock abundance to a population or relating catch length-frequency distribution or catch age-frequency distribution to the population length-frequency distribution or population age-frequency distribution, however, requires invoking the concept of 'catchability' and its various components.

'Catchability' affects catch rates and catch length-frequency distributions through one or more of its three components: 'availability', 'encounterability', and 'selectivity'. 'Catchability' is the proportion of the harvested population taken by one unit of fishing effort and has a value in the range 0–1 for any length or age of fish. It is the product of three factors of which each also has a value in the range 0–1; i.e. 'catchability' = 'availability' x 'encounterability' x 'selectivity'. 'Availability' is the proportion of the fish population within the range of operations of a fishery, 'encounterability' is the proportion of that part of the population available to the fishery encountered by the fishing gear for one unit of fishing effort, and 'selectivity' is the proportion of the fish encountering the fishing gear captured by the gear. The concept of 'catchability' is essential for stock assessment of target and by-product species where most of the fish captured are retained, but the concept has been broadened from 'catchability' to 'catch susceptibility' for ERAEF in data-poor fisheries. 'Catch susceptibility' adds the additional factor of 'post-capture mortality' (proportion of fish caught in the fishing gear dying because of capture) to allow for mortality of that part of the catch released alive, which can be all of the catch for by-catch species. Each of the factors 'catch susceptibility' and 'post-capture mortality' also has a value in the range 0–1 and the two factors are related to each other and to 'catchability' by the equation 'catch susceptibility' = 'catchability' x 'post-capture mortality'.

Fishery status reports are prepared in Victoria applying the five nationally-adopted classification categories of stock status that relate biomass level (or biomass proxy), adequacy of recruitment, and fishing intensity: 'sustainable stock', 'transitional recovering stock', 'transitional depleting stock', 'overfished stock', and 'undefined stock' (Flood *et al.* 2012). Preparation of a stock status report for a recreational fishery or for the recreational component of a mixed fishery for one or a group of water bodies requires review of available information and data. Where there is a need for updating a stock performance indicator or undertaking a full stock assessment, there will also be a need to identify the required data, monitoring methods, and fishing gear for sampling the population. Crucial to the selection of an appropriate method and sampling gear for a particular stock is to ensure that planned data will be compatible with existing data. Other factors influencing the choice of method include the peculiarities of species in particular water bodies, level of sampling required, costs, priorities and time lines associated with fisheries management, and availability of suitable personnel and expertise. Consideration of the most appropriate method and sampling gear for a monitoring program requires examining the utility of a range of available methods for monitoring recreational fisheries, estimating the amount of sampling intensity required to detect a specified change in stock abundance, and estimating potential costs.

7.4 Utility of available monitoring methods for provision of robust data

Various methods of monitoring stocks provide data for trend analysis directly and provide biological samples for provision of data and information on population biology. Biological samples can be routinely processed in a laboratory for provision of data for estimating biological parameters required for stock assessment models (e.g. age and growth from otoliths, and fecundity and maturity from reproductive tissues) or can be used for validating model assumptions. Monitoring data used directly for stock assessment is summarised as catch species composition and, for any species, catch length-frequency composition, catch rate, catch rate change, and total catch from a fishery. Fishing gear 'selectivity' parameters can be estimated from monitoring data, but a better approach is to adopt an experimental approach through controlled fishing trials. In addition, these methods provide the benefit of improved fisher engagement in fishery monitoring, research and management processes.

Fishery-dependent survey-methods involving recreational anglers are categorised as off-site surveys or on-site surveys. Conducted away from the fishing location, off-site surveys include angler diary programs, logbooks and catch cards, mail surveys, telephone surveys, and door-to-door surveys. These surveys involve sampling anglers where the sample is a group of anglers considered representative of the angling community. These methods depend on self-reporting and therefore the recollection of anglers of fish encountered and their experience identifying fish species. Conducted at the fishing location, on-site surveys include aerial, roving creel, and access point surveys. These surveys involve sampling a fishing event during or soon after the event at selected fishing locations. Fishery-independent survey (FIS) avoids biases in fishery-dependent methods. The FIS method allows the monitoring fishing-effort to be standardised by either time or number of sets of the gear, or both, and by fishing location. The relative costs, advantages and disadvantages of the FIS method vary depending on scale and the fishing gears adopted for sampling fish populations. The types of data, advantages and disadvantages for each offsite and onsite method and for each of the four FIS fishing gears adopted for the experimental fishing trials comparing the RAD and FIS methods were assessed and summarised (Appendix 5, Tables 1─4 on pages 89─98).

For reporting stock status against five classification categories relating to stock sustainability under Australia's framework for stocks requiring only a biomass proxy, the RAD method or FIS method is appropriate for monitoring catch rate and fish-length composition of species in the catch. Whether to apply the RAD method or FIS method depends on the species and the water body. Initially it is likely that both methods need to be deployed together to provide ancillary biological samples and key information on 'length-selectivity' by the fishing gear, 'encounterability' of the fish to the gear, and 'availability' of the species in the water body. Once the key ancillary information is available, it is likely that the RAD method will be favoured over the FIS method because of lower costs and angler engagement.

Where estimates of total catch are required, the GAD method is appropriate, coupled with an independent survey method for estimating total fishing effort (or total number of fishers engaged in the fishery). The GAD method provides a fishery-performance indicator, but may provide biased stock-performance indicators, because of the targeting practices of 'general-angler' diarists.

7.5 Power analysis for sampling intensity of RAD, GAD & FIS programs

Two types of available data were used for determining sampling intensity by power analyses. One type of data were from past GAD and RAD monitoring programs for each of five species variously monitored in six Victorian water bodies; the other type of data were from the 2010 RAD and FIS fishing trials

(Appendix 5, Table 5 on page 100). For past GAD and RAD monitoring, the five species were snapper, King George whiting, black bream, dusky flathead (*Platycephalus fuscus*), and estuary perch and the six water bodies were Port Phillip Bay, Western Port, Anderson Inlet, Gippsland Lakes, Lake Tyers, and Mallacoota Inlet. For the 2010 RAD and FIS fishing trials, data were used for estuary perch in Anderson Inlet and black bream in Lake Tyers, but available data for Murray cod in the Murray River were excluded from the analysis. The periods of available data for the GAD or RAD methods range from 4 years for dusky flathead in Mallacoota Inlet to 13 years for three species in three water bodies, where the methods were first applied in 1997. Two separate power analyses were performed for snapper by selecting November–December data only to represent mature fish and January–April data to represent juvenile ('pinkie') fish. Similarly, January–April data only were selected for King George whiting because most fishing occurs during this period. For all other species, available data were pooled for each calendar year. No account was taken of hook size or the need to stratify sampling in large water bodies.

For the present study, the mean and distribution of daily catch rates expressed as number of fish per hour were computed for N 'fishing-days' (i.e. N 'angler-days for the GAD and RAD methods and N 'sampling-days' for the FIS method) from the available data for each species in each water body. Applying power analyses were then used to determine the minimum sample size (i.e. minimum 'number of fishing-days') required to detect a change in mean catch rate in a future year from the past overall mean annual catch rate for each of a 100%, 80% and 50% change (Appendix 5, Table 6 on page 102).

7.6 RAD, GAD and FIS cost-benefit analysis

Cost comparisons for monitoring recreational fisheries among RAD, GAD & FIS methods made from the 2010 trials sampling estuary perch in Anderson Inlet, black bream in Lake Tyers, and Murray cod in the Murray River indicated that the highest costs per 'fishing day' were for FIS depending on fishing gear used and water body, followed by RAD, and then GAD). The sum of the 'start-up costs' and 'annual costs' were similar among the four methods: GAD ($67,500), RAD ($67,500), FIS (one gear) ($67,500), and FIS (two gears) ($71,000). For all practical purposes, these differences are small enough to ignore. Most of the differences among the methods are attributable to operational costs. The highest costs were for FIS (two gears) targeting estuary perch in Anderson Inlet ($86,160) followed by FIS (one gear) targeting black bream in Lake Tyers ($43,080) and targeting Murray cod in the Murray River ($28, 720). Considerably cheaper was RAD in each of Anderson Inlet ($6300) and Lake Tyers ($6300) and GAD in the Murray River ($315) (Appendix 5, Table 7 on page 103). This cost analysis demonstrates cost savings with GAD and RAD methods over the FIS method.

There are other trade-offs considered above when selecting an appropriate method for monitoring fish populations. For example, the value of evaluating the utility and comparing cost-effectiveness among methods for sampling tropical and temperate fish assemblages on reefs as clearly demonstrated in Western Australia. That comparison indicated that in general the 'baited remote underwater stereo-video station method' is more cost-effective, can be deployed in greater depths of water, and produces less variable estimates in metrics of biomass and species richness than the 'diver-operated stereo-video transect method' (Langlois *et al.* 2010).

7.7 Tool kit for implementation of 'angler-diary' programs

Recreational fishery monitoring strategy

The RAD method is preferred for monitoring catch rate and catch length-frequency composition; the FIS method as an alternative or addition depending on the species, water body, and initial needs for provision of ancillary data. Important ancillary data relate to 'selectivity' for fish length by the fishing gear, 'encounterability' of the fish to the gear, and 'availability' of the fish population in the water body. The FIS method is preferred for collection of ancillary data from the catch or from biological samples. The GAD method is preferred for monitoring the performance of anglers and, if participating 'general-anglers' are considered representative of the angling community, for estimating total catch, determined from GAD catch rates combined with total fishing effort estimates by an onsite or offsite survey method. Other methods are used only where these methods are considered inadequate for a particular species or water body. The success of the Suntag tagging program in Queensland, particularly given the high numbers of both released and recaptured fish, suggests that the GAD and RAD programs could be readily expanded to encourage anglers to tag the fish they release. This would provide additional data that could be applied in spatially-structured and age-structured stock-assessment models.

Implementation of a new or renewed monitoring program for particular species in a water body inevitably requires review of available information and of how this information and any new information collected will be used for determining stock status or addressing some other fishery management needs. Important considerations include compatibility of the proposed data with existing data and how the data can be applied for short-term and long-term requirements. In addition to assessing the information needs for fishery management, the peculiarities of the species and the water body to be monitored and the various attributes of the fishing gear to be used for sampling need careful consideration. Other factors requiring consideration include potential environmental gradients that might be encountered, rare and threatened species, the level of sampling required as determined by power analysis, availability and location of 'general-anglers' and 'research-anglers', management of the monitoring program, methods for communication and extension of GAD and RAD programs, and costs.

Species and water body features and suitability of fishing method for sampling

Environmental conditions varying spatially and temporally within a water body can cause catch rates and catch length-frequency distributions of a species to change directly because of redistribution of the fish or appear to change because of changes in the effectiveness of the fishing gear. For example, heavy rains in the catchments of rivers flowing into Anderson Inlet, Lake Tyers and other estuaries, and the Gippsland Lakes, are likely to affect the distributions of species such as estuary perch and black bream following changes in salinity. In addition, most electrofishing equipment is ineffective in saline waters, and video methods are inappropriate for turbid conditions. Sheltered waters can typically be accessed by anglers for much of the year, but catchability of the fish might vary seasonally. Certain fishing gears for the FIS method might not suit particular species in a water body; e.g., electrofishing is ideal for Murray cod in the shallow-water sections of the Murray River, but is inefficient in slower-flowing, deep-water sections. Furthermore, gaining adequate sampling coverage in a large water body such as the Murray River poses special problems, and requires a stratified sampling design.

Rare or threatened species such as platypus (*Ornithorhynchus anatinus*) create special problems for sampling. If the aim is to avoid capture of such species, then the GAD and RAD methods are an advantage because they rarely encounter such species, although hooking and release can cause injury. On the other hand, if the aim is to catch a rare or threatened species for the purpose of assessing its abundance, then the FIS method increases the likelihood of catching such a species. Sampling to determine the risk of such encounters is problematic, because a large sampling effort is required to determine accurately the probability of rare events.

Managing a recreational fishery monitoring program

Recruiting and managing personnel, field operations, and data management associated with a GAD, RAD and FIS program require managerial, technical and administrative capability. Follow-up analysis of the data and its interpretation, and reporting and public presentation require science capability.

Initiation of a monitoring program requires an adequate period for general planning and for recruiting and training anglers for the roles 'general-angler' or 'research-angler'. Recruiting such personnel at a convenient location is difficult in some water bodies at short notice. 'General-anglers' for the GAD method are easier to recruit and train than 'research-anglers' for the RAD method. There are advantages starting anglers as ‘general-anglers’ and then progressing them to become ‘research-anglers’; this provides time to build the program and to improve reporting skills.

Cost of monitoring varies among the GAD, RAD and FIS methods. The GAD method, as the cheapest of all monitoring methods to implement, provides the greatest opportunity for ongoing monitoring. A GAD program requires little direction; ‘general-anglers’ simply record details of their normal fishing operations. The relatively low costs of GAD and RAD monitoring programs improve the likelihood of on-going monitoring and improve coverage across the numerous water bodies across Victoria.

Communication and extension are essential for maintaining the commitment of ‘general-anglers’ and ‘research-anglers’ in GAD and RAD programs. Keeping volunteer ‘general-anglers’ and ‘research-anglers’ well informed and providing recognition for their efforts is essential (Appendix 6 on pages 111─114).

Checklist of steps for implementation of GAD and RAD programs

1. Define the species and water body to be monitored. The GAD method is likely to provide less representative samples of species populations in a water body than the RAD or FIS method; ‘general-anglers tend to target specific species, whereas the RAD and FIS methods have fixed-site or stratified-random sampling-designs.
2. For the RAD method, define the attributes of the fishing gear for sampling the water body; i.e. specify hook or lure sizes and ensure all ‘research-anglers’ fish the same way. Seeking to provide wide coverage of a water body with carefully defined fishing locations (e.g. with marks from the global positioning system and sampling periods (e.g. set dates for fishing days) provide for good data quality, but rigid rules for fishing areas and fishing days can reduce interest by anglers in participation in the program.
3. Create a diary for the program to obtain standard data for inclusion in a standard database. This includes species, length, and, if practical, sex, tag release and recapture number(s), and biological sample number(s) of each fish, location (site or grid) and depth of fishing, specifications of hooks and other attributes of the fishing gear, and period of fishing (start and finish times). Additional information may be required and the diary might need tailoring to suit the species and water body. Facilitate ease-of-use by ‘general-anglers’ and ‘research-anglers’ by use of waterproof paper, simple columns and headings, and sufficient writing space.
4. Determine the number of ‘general-anglers’ or ‘research-anglers’ or both to be recruited for the water body; this is best undertaken by power analysis using existing data.
5. Develop a recruitment plan using posters for websites, local newspapers, magazines, forums, fishing clubs, and boat ramps for ‘general-anglers’ or ‘research-anglers’ or both.
6. Develop a selection plan for ‘general-anglers’, who pay attention to detail, motivated to participate, and operate similarly to most ‘general anglers’, or for ‘research-anglers’, who must be prepared to fish less effectively and have experience for the defined water body, or both.
7. Develop a training plan by one-to-one or one-to-group training and avoid distributing diaries and relying on instruction sheets for provision of complete and accurate recording of data, collection of biological samples, and tag and release. Consider periodically accompanying the ‘general-angler’ or ‘research angler’ or both to provide tips on how other anglers complete their diaries and aim to minimise compromising the quality of their fishing experience.
8. Maintain contact systems through newsletters and social media and feedback mechanism such as phone calls and meetings. To ensure good data quality, discuss errors detected in the data with ‘general-anglers’ and ‘research anglers’.
9. Develop a program awareness campaign. Data quality and angler satisfaction requires community awareness and credibility gained through publicising the program’s achievements such as results to date and provide awards to participants for excellence.

10. Strive to maintain stakeholder support and recognition of the program, which may help secure funding for the program.

8. Benefits & Adoption

The present study together with past angler-diary programs fostered greater stewardship and engagement of stakeholders in the collection of data needed for fisheries management. Fisheries management agencies throughout Australia can have confidence that GAD and RAD programs provide appropriate fishery-performance and stock-performance indicators and other information required for stock and fishery assessment. Data from GAD programs can be readily integrated with independent survey estimates of total fishing effort to provide estimates of total catch.

The present study dispels concerns about the uncertainty about data quality from GAD and RAD programs, provided such programs are managed diligently. In addition, the study demonstrates that a RAD program is an effective fishery-independent survey method, provided catch length-frequency composition is adjusted for the effects of hook species-specific length-selectivity. Hook 'length-selectivity' correction factors can be determined as part of a RAD program by ensuring a range of hook sizes are used by the 'research-anglers'.

In Victoria, budget constraints and associated rationalisation of more traditional on-site and off-site methods of monitoring, research and assessment capability require simplifying and streamlining the collection, management, summary and analysis of data to provide standard outputs accessible to all stakeholders. Adoption of RAD and GAD programs in Victoria has led to a network of 'research anglers' operating throughout the state. Furthermore, evaluation of data provided by RAD and GAD programs provides for high confidence in Victoria for the quality of its recreational fisheries monitoring data, which in turn will provide confidence in the management fishery decisions made on the basis of available data.

Existing databases in Victoria can accommodate extensions to time series of data from existing GAD and RAD programs and could be expanded to cover recreational fisheries in other water bodies. The methods used for data collection and data processing in Victoria can serve as a model for developing a national approach to monitoring and assessment of recreational fisheries. Furthermore, consistent with national policy for science capability consolidation, Fisheries Victoria could serve as a national repository for such data or provide a national service implementing and managing GAD and RAD programs.

9. Further Development

In Victoria, it is essential that RAD and GAD programs be designed to provide the appropriate data for determining hook 'length-selectivity' as a function of length of fish and size of the hook gap (measurement from the shank to barb tip). This requires 'research-anglers' to record in addition to the species and length of each fish caught, the gap of the hook used to catch the fish. In addition, each 'research-angler' needs to use a range of hook sizes together in a common locality and to record the fishing time for each hook-gap size. Once a species-specific equation relating hook 'length-selectivity' to length of fish and to hook gap is determined, it will be possible to use catch length-frequency distribution for determining the population length-frequency distribution. This could be applied to each species for all monitoring data where hook sizes are known.

Determining the length-frequency composition of the fish population together with using other types of fishing gear can provide insights into the 'availability' of a population and its various size and age components within a water body. This can also provide insights into the 'encounterability' of the available population to the fishing gear and the 'selectivity' of the gear to that part of the fish population encountering the gear.

The Victorian GAD and RAD programs could be expanded to encourage the anglers to tag the fish they release. This would provide additional data that could be applied in spatially-structured and age-structured stock-assessment models.

Having reviewed, improved and documented procedures for monitoring recreational fisheries in Victoria, the present project demonstrates that RAD and GAD programs would be suitable as a national approach to cost-effective monitoring for provision of scientifically robust data. Information has already been shared through the Technical Steering Committee, which had wide representation from around Australia, and the information will be further disseminated nationally with distribution the final report. To ensure the credibility of the approach, three papers scientific papers have been prepared (see as Appendices 3–5 of present report), which will be submitted for publication to internationally refereed journals, once FRDC approves the final report.

10. Planned Outcomes

General outcomes planned before the beginning of the present project were guided by the extension service developed by Recfishing Research as part of FRDC Project 2007/227 "Recfishing Research: National Strategy for Recreational Fisheries Research, Development and Extension" (Sawynok *et al*. 2010). Recfishing Research is a national body established by FRDC and Recfish Australia to improve investment and the return on investment in research, development and extension at a national scale. Recfishing Research has taken a multi-pronged approach to assist extension of project results through a series of initiatives:

- establishment of the Recfishing Research Network comprising peak recreational fishing bodies, fishing organisations, fishing media, research agencies, fisheries agencies and recreational fishers;
- using the Network to further distribute information of interest to the participants' networks;
- provision of information on current research and activities of interest to the Network;
- distribution of scientific papers and technical reports through the Network;
- development of a rapid response information service for emerging issues, especially those receiving media or internet attention;
- upgrade the Recfishing Research Website to extend access to technical reports and fact sheets;
- provision of funding to projects to increase the funding available for the distribution of the results from research; and
- assist in development of information products from research suitable for their target audiences.

Hence, in developing an extension plan consistent with these initiatives, the present project identified its target audiences as recreational fishers, fisheries managers, associated researchers, and key state industry bodies responsible for fisheries. The project initially had two key messages.

1. Limited resources available for investment in management of small-scale fisheries require innovative, cost-effective assessment methods.
2. RAD programs are a cost-effective way for fisheries management agencies to assess key target fish species in small, data poor inland and estuarine recreational fisheries.

However, from the conclusions of the present project, it is appropriate to broaden Key Message 2:

> "RAD and GAD programs complement each other and are cost-effective for fisheries management agencies to assess key target fish species in recreational fisheries of all sizes, and stock assessment can be improved by expanding these programs to include tag release-recapture and sampling for age determinations".

Prior to starting the present project, means identified for conveying Key Message 1 to the target audiences included:

- updated and new fact sheets for species listed on the Recfishing Research Website, with links to a project webpage on the Fisheries Victoria Website;
- updating results from the present project through the Recfishing Research email news bulletin;
- presentations and reports to key recreational group meetings; i.e. Victorian Recreational Fishing Peak-Body (VRFish), Victorian Ministerial Fisheries Advisory Council, Seafood Industry Victoria (SIV); South Australian Recreational Fishing Advisory Council (SARFAC); Tasmanian Association for Recreational Fishing Incorporated (TARFish), NSW Advisory Council on Recreational Fisheries (ACoRF), NSW Recreational Fish Saltwater Trust, Sunfish Queensland Incorporated, Queensland Charter Vessel Association (QCVA), and the peak recreational fishing body in Western Australia (Recfishwest);
- progressive articles in FRDC News, State Fisheries agencies publications and newsletters to commercial fishers, State Peak Recreational Fishing bodies newsletters, SIV newsletter, South Australian Fishing Industry Council (SAFIC) magazine, Profish NSW magazine, Queensland Fisherman magazine, Western Australia's professional fishing industry magazine ProWest; and
- general media releases.

Means for conveying Key Message 2 to the target audiences include:

- publication of results in relevant refereed scientific and non-refereed industry journals;
- presentations and reports to stock assessment groups and management advisory committees responsible for the relevant species; and
- presentations and reports to key recreational (as above) and commercial group meetings.

Four planned outcomes were identified before beginning the present project.

1. Foster greater stewardship and engagement of stakeholders in the collection of information needed for fisheries management and sustainable use of key fisheries resources in small recreational fisheries.
2. Provide more cost-effective and reliable monitoring and assessment of small-scale, data poor recreational fisheries in estuarine and inland waters.
3. Enhance management of such waters based on routine integrated application of more innovative monitoring methods.
4. Enable a more consistent national approach to monitoring and assessment of small-scale recreational fisheries, with potential to apply to larger fisheries as required.

These four planned outcomes expected from the present project were achieved for Victorian fisheries. The program's participants deploying the innovative RAD and GAD monitoring methods as part of the Victorian Angler Diary Program received excellence awards at both the state (Victorian Coastal Council Awards for Excellence 2011) and national level (World Environment Day Awards 2011, Recreational Fishing Awards 2012). In Victoria, the program has been funded to provide a cost-effective reliable monitoring tool for small-scale fisheries for more than 10 years and to provide important data for assessment of the fish stocks in larger fisheries such as snapper, King George whiting and sand flathead. The data outputs from the program are currently being assessed and reported according to the five nationally-adopted classification categories for stock status in Australia (Flood *et al.* 2012). The key findings from the present report will be communicated to national stakeholders once the report has been published and the following three scientific papers have been accepted for publication in internationally-refereed journals.

Conron, S. D., Giri, K., Hindell, J. S., Grixti, D., and Walker, T. I.. (in prep.) Comparison of catch rates and catch composition among 'research-angler' diary and fishery-independent survey methods in Victoria, Australia (see Appendix 3).

Conron, S. D., Grixti, D., and Walker, T. I.. (in prep.) Four case studies applying 'research-angler' diary method for fishery monitoring (see Appendix 4).

Walker, T. I.. Conron, S. D., Grixti, D., and Giri, K. (in prep.) New directions for monitoring recreational fisheries in Victoria, Australia (see Appendix 5).

Three key outputs were identified before beginning the project.

1. The development of the integrated, validated monitoring 'tool kit', based on the research angler diary (RAD) program and incorporating complementary methods for the assessment of fish stocks in small-scale recreational fisheries.
2. Provision of recommendations on the types of fisheries where the RAD program would be an appropriate method with which to assess fisheries questions.
3. Detailed evaluation of the approach and value of RAD programs in providing information required for fish stock assessment and management advice in inland and estuarine fisheries.

These three outputs were achieved by the present project. The only departure is that the emphasis of applying to only the RAD method was extended to applying equally to both the RAD method and the GAD method. On the one hand, the RAD method, after appropriate correction of catch length-frequency composition for the effects of hook 'length-selectivity', can be used to produce the population length-frequency composition (or the population age-frequency composition derived from the population length-frequency composition using an age-length key). Expressed as number of fish per angler-hour for selected length classes (or selected age classes), this can provide a stock-performance indicator. On the other hand, the GAD method, uncorrected for effects of hook length-selectivity, provides a fishery-performance indicator that can be combined with estimates of total fishing effort (determined by independent survey) to provide estimates of total catch (if required).

Following an initial media release on 10 November 2009 and establishment of a webpage with links to established sites (*http://www.depi.vic.gov.au/fishing-and-hunting/science-in-fisheries/angler-diary-program*), extensive extension of the results occurred within Victoria during the conduct of the project directly with stakeholders and through the Fisheries Victoria Website. Given the high confidence in the RAD and GAD methods gained from completion of the present project, it is now appropriate to adopt a strategic approach to disseminating the information nationally. Arrangements are now in place for RecFishing Research to disseminate the present report, the three scientific papers, various fact sheets, and a three-part video program about the Victorian GAD program, to all recreational fishing bodies in Australia through the Recfishing Research Network. Once these arrangements are in place, success of this extension will be evaluated from the number of downloads of the relevant material from the Recfishing Research Website and frequency of access to the project webpage on the Fisheries Victoria Website. Eventually, an electronic questionnaire will be distributed through an email bulletin list for the final stage of extension evaluation for the project.

11. Conclusions

Conclusions 1–11 and 12–13 are from addressing Objectives 1 and 2, respectively.

1. Data from the RAD method for monitoring recreational fisheries were validated by comparison with data from the FIS method by applying a design for sampling recreational fish populations of estuary perch (*Macquaria colonorum*) in Anderson Inlet, black bream (*Acanthopagrus butcheri*) in Lake Tyers, and Murray cod (*Maccullochella peelii*) in the Murray River. However, before use, length-frequency composition needs to be adjusted for the effects of selection for fish length ('length-selectivity') by the fishing gear.
2. Differences in catch rates and catch length-frequency distributions among the RAD and FIS methods for each of the three target species in their respective water bodies could be interpreted using the concept of 'catchability' and its three components; i.e. 'catchability' = 'availability' x 'encounterability' x 'selectivity', depending on length of fish, where each term has a value range of 0–1.
3. For reporting stock status against five classification categories relating to stock sustainability under Australia's framework for stocks requiring only a biomass proxy, the RAD method or FIS method is appropriate for monitoring catch rate and fish-length composition of species in the catch. Whether to apply the RAD method or FIS method depends on the species and the water body. Initially it is likely that both methods need to be deployed together to provide ancillary biological samples and key information on 'length-selectivity' by the fishing gear, 'encounterability' of the fish to the gear, and 'availability' of the species in the water body. Once the key ancillary information is available, it is likely that the RAD method will be favoured over the FIS method because of lower costs and angler engagement.
4. Where estimates of total catch are required, the GAD method is appropriate, coupled with an independent survey method for estimating total fishing effort (or total number of fishers engaged in the fishery). The GAD method provides a fishery-performance indicator, but may provide biased stock-performance indicators, because of the targeting practices of 'general-angler' diarists.
5. The GAD method is cheapest followed by the RAD method, and then by the FIS method. Reducing recreational fisheries monitoring to these three methods combined with a survey method for estimating total fishing effort, when estimates of total catch are required, allows for implementation of focussed and thereby simpler cost-effective procedures for collection, management, analysis and reporting of the data. This can be achieved whilst ensuring scientific rigor and angler engagement with the monitoring, research, management and compliance of recreational fisheries.
6. The FIS method applying four separate types of fishing gear (demersal trawl and gillnets in Anderson Inlet, beach seine in Lake Tyers, and electrofishing in the Murray River) consistently caught significantly more species of fish and much higher numbers of fish than did the RAD method. For all three target species, there was statistically better agreement among the RAD and FIS methods in the patterns of catch rate and catch length-frequency distribution for fish of length above legal minimum length (LML) than for fish <LML or both <LML and ≥LML pooled.
7. Both the RAD and FIS methods caught a wide length-range of fish both <LML and ≥LML, but the FIS methods could catch smaller fish than the RAD method.
8. Differences in catch rates among separate sampling trips for the RAD and each FIS method were not significant, suggesting no change in 'availability' of the fish <LML or ≥LML for any of the three target species during the period of the fishing trials (February–July 2010).
9. The higher catch rates by the FIS methods than by the RAD method for fish ≥LML are explained by higher 'encounterability', whereas the much higher catch rates by the FIS methods than by the

RAD method for fish <LML are explained by the combination of higher 'encounterability' and higher 'length-selectivity' to the fishing gear.

10. For the FIS (demersal trawl), FIS (beach seine), and FIS (electrofishing) methods, it is likely that catch rate and catch length-frequency composition provide reasonably unbiased indices of relative abundance and length-frequency distribution (or cohort-strength distribution derived from catch length-frequency distribution using an age-length key) for the three sampled populations. Conversely, apart from the smallest fish in the population (too small to catch during the trials), the RAD and FIS (gillnet) methods cannot be applied as indicators of the relative strengths of length classes or cohorts in the population without adjustment for the effects of species-specific 'length-selectivity'.
11. There is scope to expand the Victorian GAD and RAD programs to encourage the 'general-anglers' and research-anglers' to tag the fish they release. This would provide additional data that could be applied in spatially-structured and age-structured stock-assessment models.
12. Recreational fishers, researchers and fisheries management agencies were actively engaged at every stage of the project through a technical committee serving as a steering committee to provide guidance for the project. The committee had members from Victoria, Western Australia, Tasmania, New South Wales, and South Australia. Anglers participating as part of the GAD and RAD methods received information directly from the project. These anglers in turn passed on information by word-of-month to the general angling community.
13. The present report will enhance the ability of government, industry and recreational fishers to confidently implement and use angler-diary programs as the primary source of data for monitoring recreational fisheries. The flow of benefits from this project will be measured not only by the amount of new or improved angler-diary programs, but by the number of anglers engaged in these programs.

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Appendix 1: Intellectual Property

No intellectual property has arisen from the research that is likely to lead to significant commercial benefits, patents or licences. Intellectual property associated with information produced from the project will be shared equally by the Fisheries Research and Development Corporation and by the Victorian Department of Environment and Primary Industries.

Appendix 2: Staff

The project was undertaken by the Department of Environment and Primary Industries with staff from Fisheries Victoria and the Arthur Rylah Institute for Environmental Research.

Dr James S. Andrews	Principal Investigator	Fisheries Victoria
Simon D. Conron	Project Scientist	Fisheries Victoria
Dr Terence I. Walker	Project Scientist	Fisheries Victoria
Dr Khageswor Giri	Statistician	Fisheries Victoria
Dr Daniel Grixti	Project Scientist	Fisheries Victoria (formerly)
Therese K. Bruce	Project Scientist	Fisheries Victoria (formerly)
Natalie F. Bridge	Project Scientist	Fisheries Victoria (formerly)
Dr Jeremy S. Hindell	Co-investigator	Arthur Rylah Institute for Environmental Research

Comparison of catch rates and catch composition among 'research-angler' diary and fishery-independent survey methods in Victoria, Australia

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Abstract

'Research-angler diary' (RAD) and fishery-independent survey (FIS) methods were trialled according to a design for sampling recreational fish populations of estuary perch (*Macquaria colonorum*) in Anderson Inlet, black bream (*Acanthopagrus butcheri*) in Lake Tyers, and Murray cod (*Maccullochella peelii*) in the Murray River. The catch rates and catch length-frequency distributions were compared among these methods for each of the three target species in their respective water bodies. These comparisons were interpreted using the concept of 'catchability' and its three components such that, at any length of fish, 'catchability' = 'availability' x 'encounterability' x 'selectivity'. The FIS methods consistently caught significantly more species of fish and much higher numbers of fish than did the RAD method. However, there was statistically better agreement among the RAD and FIS methods in the patterns of catch rate and catch length-frequency distribution for fish of length above legal minimum length (LML) than for fish of length <LML or for fish of all lengths pooled. All methods caught a wide length-range of fish of length of both <LML and ≥LML, but the FIS methods could catch smaller fish than the RAD method. The higher catch rates for the FIS methods than for the RAD method for fish of length ≥LML are explained by higher 'encounterability', whereas the much higher catch rates for fish of length <LML are explained by the combination of higher 'encounterability' and much higher 'selectivity' of the fishing gear. The FIS (demersal trawl), FIS (beach seine), and FIS (electrofishing) methods catch rate and catch length-frequency composition provide reasonably unbiased indices of relative abundance and length-frequency distribution (or cohort-strength distribution derived via an age-length key). Conversely, apart from the smallest fish in the population (too small to catch during the trials), the RAD and FIS (gillnet) methods cannot be applied as indicators of the relative strengths of length classes or cohorts in the population without adjustment for the effects of species-specific length-selectivity.

Introduction

Victoria has a history of applying several fishery-dependent methods for monitoring catch rates, catch length-frequency composition, and catch age-frequency composition for various species in recreational fisheries. These methods include creel census with interviews and, for periodic estimation of total catch and total fishing effort, are combined with aerial, boat-ramp or polling survey. Such methods are expensive and accumulate large volumes of data with the disadvantage of limited control over the spatial and temporal distribution of the data collected. Furthermore, without ancillary information on length-selectivity and the attributes and deployment of the fishing gear, interpretation of the indices of relative abundance of the fish populations monitored can be uncertain.

Victoria, in recent times, has sought to reduce costs and to provide statistically rigorous indices of relative abundance through attention to appropriate spatial and temporal coverage by greater use of fishery-independent survey and by distributing angling diaries to recreational anglers. The present study compares and evaluates two methods referred to as 'fishery-independent survey' (FIS) and 'research anger diary' (RAD), and makes reference to a third method referred to as 'general-angler diary' (GAD).

The FIS method enables control over spatial and temporal sampling with fishing gear specifically designed to sample the populations of one or more species over a wide length-range, but the relatively high operating-costs limit the frequency of deployment of the fishing gear and, hence, the extent of sampling coverage and replication. In addition to obtaining catch, fishing effort, and catch-composition data, the FIS method can be designed to provide data that can be used for determining length-selectivity parameters for each species caught by the fishing gear. Furthermore, although setting and hauling the gear associated with the FIS method requires highly trained operators, the method provides the opportunity for tag and release, collection of biological data (e.g. length-mass), and collection of biological tissues (e.g. otoliths, scales or vertebrae for age-estimation, stomach contents for diet analysis, and reproductive tissues for determination of maturity and fecundity). Catch rates from the FIS method provide unbiased indices of relative abundance that can be used as a stock performance indicator.

The GAD method requires fishers to record data during their normal recreational fishing activities and is cost-effective as it enables intense and wide-scale sampling across the recreational fisheries. However, the GAD method provides limited scope for control over the spatial and temporal coverage in sampling, the specifications of fishing gear deployed, and the collection of ancillary data and biological material. Data from the GAD method tend to be skewed towards the high-density areas for targeted species. Catch rates from the GAD method can be used as a 'fisher performance indicator', but is potentially biased as a stock performance indicator. These catch rates can be combined with estimates of total fishing effort determined from separate surveys to provide estimates of total catch.

The RAD method was developed in Victoria with the aim of optimising the advantages of sampling control associated with the FIS method and the advantages of cost-effectiveness and recreational-fisher engagement associated with the GAD method. The RAD method requires a group of dedicated recreational fishers to serve as 'research-anglers' spatially distributed over the fishery. 'Research-anglers' are required to operate according to agreed protocols prescribing the attributes of particular fishing gear and the spatial and temporal distribution of fishing operations and to record full details of catch, fishing effort, and catch composition (species and length of each fish). In addition, the 'research-angler' training programs can include procedures for collection of ancillary data and biological material. Catch rates from the RAD method provide unbiased indices of relative abundance that can be used as a stock performance indicator.

The present study compares and evaluates the RAD and FIS methods for the purpose of providing procedures for designing and implementing future angler diary programs (Appendix 5). This includes a checklist of the steps of implementation, but requires a common-sense approach to evaluating the suitability and feasibility of an angler diary program for monitoring recreational fisheries in a particular location and to deciding whether the RAD method or the GAD method, or both, should be adopted.

Methods

Experimental design

Comparison and evaluation of the RAD and FIS methods were made in each of three recreational fisheries: the Anderson Inlet Estuary Perch Fishery, the Lake Tyers Black Bream Fishery, and the Murray River Murray Cod Fishery. The estuary perch (*Macquaria colonorum*), black bream (*Acanthopagrus butcheri*), and Murray cod (*Maccullochella peelii*) (Table 1) are ionic angling species targeted by recreational fishers and, in these three fisheries, isolated from commercial fishing. The choices were based on advice from a technical steering committee (see Acknowledgements), a pilot study undertaken during February–May 2009, the high priority for management plans in those fisheries, and the already active participation of 'research-anglers' as part of ongoing RAD programs in those water bodies.

The experimental design for comparison and evaluation of the RAD and FIS methods in the three fisheries involved careful construction of one or more units of fishing gear (i.e. one demersal trawl, five multifilament gillnets, and one beach seine) and use of readily available fishing gear (i.e. one or two rods and reels for each 'research-angler', and one electrofishing unit). For each of the RAD and

FIS methods separately within each fishery, the initial design was to set the various 'units of fishing gear' during each of three consecutive 'fishing-days' at one or more sites within one of three separate 'water sections' in the 'water body' of the fishery (Figure 1). Two separate 'water sections' (one for the RAD method and one for the FIS method) were to be fished during each of the three separate consecutive 'fishing-days' (i.e. 2 methods x 3 fishing-days = 6 'water sections'). The initial experimental design had operations during each of the three 'fishing-days' repeated during each of four separate 'trips'; i.e. a total of 72 'fishing-days' (i.e. 2 methods x 3 fishery water-bodies x 4 trips x 3 'fishing-days' = 72 'fishing-days').

Construction and setting of the FIS fishing gear involved one demersal trawl and five gillnets each 35-m long constructed with seven panels each of different mesh-size, in Anderson Inlet; one 20-m long beach seine in Lake Tyers; and 60–70-minute pass of electrofishing in the Murray River (Table 1). There were 17 'research-anglers' participating for the RAD method; i.e. 5 in Anderson Inlet, 5 in Lake Tyers, and 7 in the Murray River (Table 1). The pilot study indicated that for the RAD method, 'research-angler' activity had to be carefully coordinated and that each water body needed to be divided into 6 separate water sections to ensure that the RAD and FIS methods were independent from each other and not competing for the same fish. For similar reasons, each of these two methods was in a separate water section on each of three separate 'fishing days' (Figure 1). All 6 separate water sections of each water body were to be fished during each of the 4 separate trips. Hence, the initial design of fishing in 3 water bodies x 3 water sections x 2 methods provided a total 18 water sections (Figure 1) fished 4 times, i.e. once per 'trip' such that the full complement of fishing gear was to be deployed over 72 'fishing-days'.

In practice, there were several departures from this experimental design, but this did not compromise the integrity of the data for statistical analysis. In Anderson Inlet, two 'gear-types' (demersal trawl and multifilament gillnet) were deployed for the FIS method, where both the FIS (demersal trawl) method and FIS (gillnet) method could be compared with the RAD method and with each other. In the Murray River, although the water body was divided into 4 'water sections' for the FIS (electrofishing) method, it was not divided for the RAD method. Furthermore, in the Murray River, the number of trips was reduced from 4 to 3 for the RAD method and from 4 to 2 for the FIS (electrofishing) method. In addition, the number of 'fishing-days' per trip was increased from 3 to 4, although during Trip 2, the fishing-days were not consecutive and 2 of the 4 fishing-days were each undertaken over 2 days (Table 1). Hence the number of 'fishing-days' was reduced from 12 (i.e. 4 trips x 3 fishing-days) to 9 (i.e. 3 trips x 3 fishing-days) for the RAD method and from 12 to 8 (i.e. 2 trips x 4 fishing-days) for the FIS method. Another departure from the initial experimental design was that instead of all 5 'research-anglers' fishing together in one water-section on each 'sampling-day' as occurred in Anderson Inlet and Lake Tyers, 7 'research-anglers' independently determined their own 'fishing-days' for the Murray River. Although the separate trips and fishing-days could be identified for each 'research-angler' fishing in the Murray River, there was no synchronisation of the trips and fishing-days among the 7 research-anglers. Departures from the experimental design in the Murray River were caused by the large distances involved in fishing the Murray River and by spatial and temporal variations in salinity affecting the effectiveness and safety in use of electrofishing equipment.

For the RAD method in each of the three water bodies separately, the research-anglers selected to participate were skilled at targeting the key species in the respective water body regularly for more than 10 years. As 'research-anglers', these anglers were required to adjust their fishing practices to ensure the catch of a wide length-range of the target species and to standardise the fishing gear (i.e. number of rods and reels used, hook or lure size, and baits, fishing locations, and times of fishing). For the FIS method in each water body separately, the fishing gear adopted had to be suitable to the local conditions and habitats and was designed to catch a wide length range of the target species. Anglers targeting Murray cod in the Murray River were given greater flexibility on when and where they

Table 1. Sampling design for comparison of catch rate and catch length-frequency composition of fish among RAD and FIS methods in each water body during 2010

RAD, 'research-angler' diary; FIS, fishery-independent survey; OAL, overall length; na, not applicable; for each trip, a separate water-section was sampled each 'fishing day' (RAD 'angler-day' or FIS 'sampling-day', except in the Murray River, which was not divided for the RAD method, see footnotes).

Water body	RAD or FIS method	Unit of fishing gear	Fishing gear construction	No. units of fishing gear	No. of trips[A]	No. of days per trip[A]	Total no. of fishing-days	Total no. of RAD 'angler-days' or FIS 'sampling-days'	Operation each 'fishing-day'	Trip 1	Trip 2	Trip 3	Trip 4
Anderson Inlet	RAD	Single 'research-angler' in a boat <4.3 m OAL	1 x rod and reel with a small or large lure (used alternatively between sessions)	5	4	3	12	60	4 sessions each of 52 mins (start 30 min before sunrise; bait: sandworm, sardine, shrimp)	16–18 Feb	10–12 Mar	23–25 Mar	28–30 Apr
	FIS (trawl)	Single demeral trawl towed by a 5-m boat	3.5 m wide mouth & 15-mm mesh size	1	4	3[B]	12	12	5 tows of 5 mins at 2 knots (operated by 3 people)	16–18 Feb	10–12 Mar	23–25 Mar	28–30 Apr
	FIS (gillnet)	Five gillnets 35-m long x 2-m deep	5 multifilament gillnets each of 7 panels, each 5-m long x 2-m deep & of separate mesh-size (1.5, 2.0, 2,5, 3.0, 3.5, 4.0, & 4.5 inches)	1	4	3[B]	12	12	5 gillnets with 2-hour soak-time (set perpendicular to shore, & weighted each end with chains)	16–18 Feb	10–12 Mar	23–25 Mar	28–30 Apr
Lake Tyers	RAD	Single 'research-angler' in a boat <4.5 m OAL	1 x rod and reel with a small or large lure (used alternatively between sessions)	5	4	3	12	60	4 sessions each of 52 mins (start 30 min before sunrise; bait: sandworm, sardine, shrimp)	9–11 Feb	2–4 Mar	30 Mar–1 Apr	20–22 Apr
	FIS (beach seine)	Single beach seine 20-m long x 2-m deep	6-mm round mesh-size and 30-m long haul-ropes	1	4	3	12	12	4 hauls	9–11 Feb	2–4 Mar	30 Mar–1 Apr	20–22 Apr
Murray River	RAD	Single 'research-angler' in a boat <4.3 m OAL	2 x rod and reel (6/0 hook and 1/0 hook)	7	3	3[C]	9	63	4 sessions each of 52 mins (start 30 min before sunrise; bait: bardi grub,worm, cheese)	Optional for each angler during Feb–May			na
	FIS (electo-fishing)	Single large Smith–Root electofishing boat with 7.5 KVA generator	Pair of electrodes	1	2	4	8	8	5–8 sites per water-section for 60–70 mins (5 on Day 1, 8 on Day 2, 6 on Day 3, & 5 on Day 4) (1 boat driver plus 2 dip-netters)	15–18 Mar	3 & 7 May 26May&8Jul 3 Jun 6 Jun	na	na

[A]Distinct trips were not adopted for the RAD method in the Murray River: 7 'research-anglers' each undertook 3 trips of 3 days (i.e. 7 'research-anglers' x 3 trips x 3 days = 63 'angler-days');

[A]Trips planned for FIS (electrofishing) in the Murray River were 4 sequential sampling-days,

which were adopted for Trip 1 (15–18 Mar), but not for Trip 2 (the water-sections were not sampled on sequential days and two of the days were split such that Day 1 was 3 & 7 May and Day 2 was 26 May & 8 Jul);

[B]FIS (demersal trawl) and FIS (gillnet) methods were undertaken in separate parts of the same water-section on each 'sampling day'; and

[C]the Murray River (Bundalong–Howlong) was not divided into separate water-sections for the RAD method'.

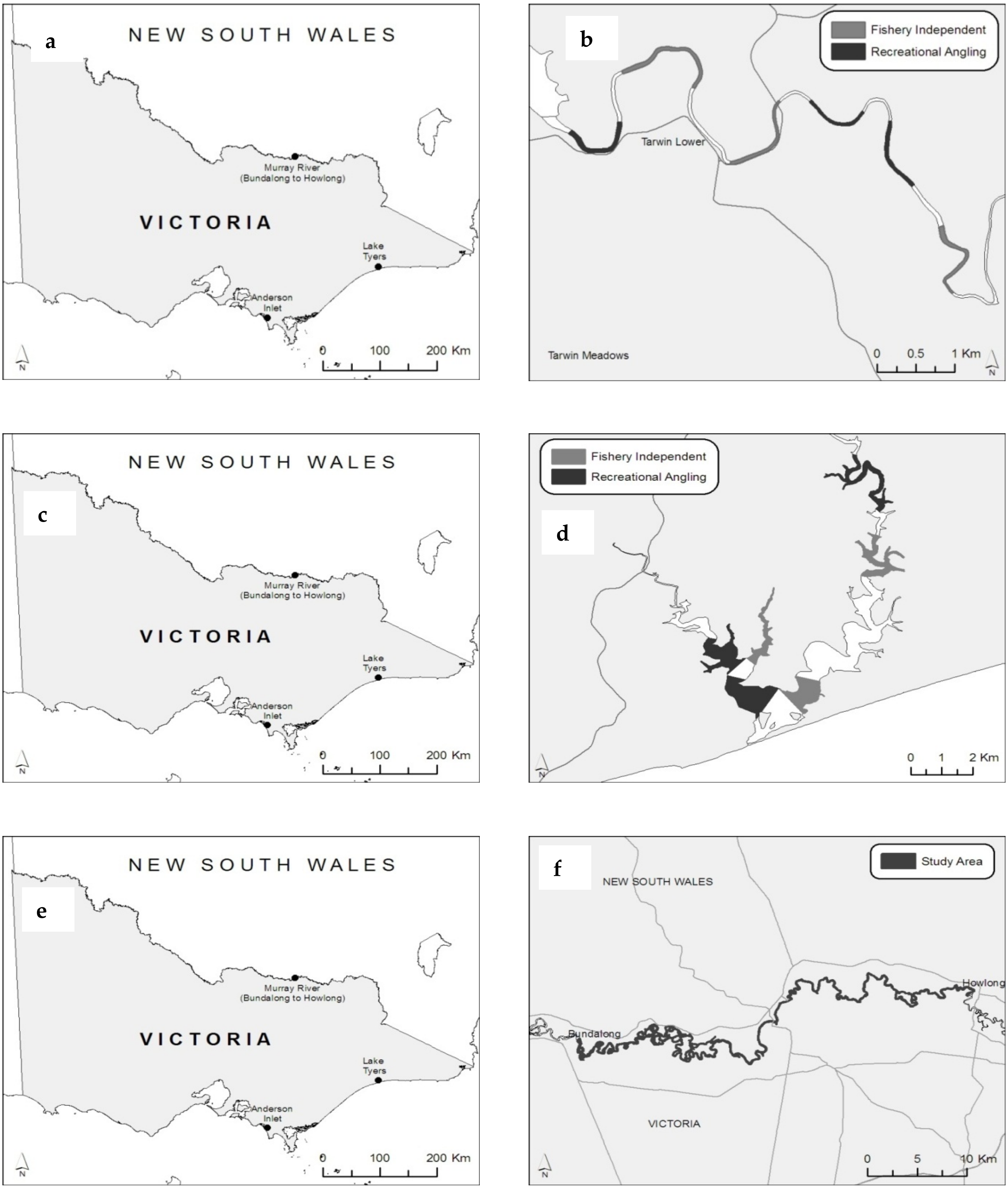

Figure 1. Map of Victoria showing the water bodies and water sections fished

Anderson Inlet (a) and water sections (b); Lake Tyers (c) and water sections (d); and Murray River (e) and river section studied (f).

could fish due to the different nature of the freshwater fishery and although in practice the RAD method resembled the GAD method in the Murray River, the data were treated as the RAD method for data analysis.

The species and length were recorded for each fish of all sizes in standard diaries adopted for the RAD and GAD methods or on data sheets adopted for the FIS method. Fork length (FL) was recorded for species with forked caudal fins (e.g. estuary perch and black bream) and total length (TL) for species where the caudal fins are not forked (e.g. Murray cod and dusky flathead). Other data recorded included details of fishing gear used, location of fishing, duration of fishing, and bait when applicable. Otoliths collected from subsamples of the catches of estuary perch and black bream were used subsequently in the laboratory for age determination.

For age determination, otoliths from about five fish were selected randomly from each 1-cm length-classes (i.e. ~5 otoliths x ~20 length-classes = ~100 otoliths) to provide an age-length key for each of estuary perch in Anderson Inlet and black bream in Lake Tyers, but not for Murray cod in the Murray River. The otoliths were extracted from fish caught mainly on hooks to avoid sampling bias caused by highly length-selective fishing gear such as gillnets. The age of a fish was determined by counting pairs of alternating translucent and opaque bands, which were assumed to be annual, in a transverse section of one of its paired otoliths (Morison *et al.* 1998). The age-frequency distribution of the catch of each of estuary perch and black bream for each of the RAD and FIS methods was determined by applying the general age-length key to the catch length-frequency distribution specific to the RAD or FIS method.

Data analysis

In preparation for data analysis, FL was converted to TL using several linear equations: TL=1.0402FL+0.7783 for estuary perch (DPI unpublished data) and TL=1.0533FL+1.2012 for black bream (DPI unpublished data), where FL and TL were expressed in centimetres. The data were then categorised by TL of fish as above or below the legal minimum length (LML) where LML was 27 cm TL for estuary perch, 28 cm TL for black bream, and 60 cm TL for Murray cod, which also has a legal maximum length of 100 cm TL. In addition, the data were grouped as 'fishing-day' (i.e. 'angler-day' for the RAD method and 'sampling-day' for the FIS method). Overall, there were 183 'angler-days' for the RAD method [i.e. 5 'research-anglers' x 4 trips x 3 fishing-days = 60 'angler-days' in each of Anderson Inlet and Lake Tyers, and 7 'research-anglers' x 3 trips x 3 fishing-days = 63 'angler-days' in the Murray River]. Similarly, there were 44 'sampling-days' [4 trips x 3 fishing-days = 12 'sampling-days' for each of FIS (demersal trawl) and FIS (gillnet) in Anderson Inlet and FIS (beach seine) in Lake Tyers, and 2 trips x 4 fishing-days = 8 'sampling-days' for FIS (electrofishing) in the Murray River] (Table 1).

The first of several statistical tests performed to compare the performance of the RAD and FIS methods tested for differences in the number of species caught by one-way analysis-of-variance for each of the three water bodies using the statistical package GenStat (Payne *et al.* 2009). The other tests performed related to catch rates and catch length-frequency compositions of the three target species in their respective water bodies. They were all performed for fish in three length-range categories: fish of TL <LML, fish of TL ≥LML, and for fish of all lengths pooled.

Testing for statistically significant differences in daily catch rates among trips for the RAD and each FIS method was undertaken by linear regression analysis for each target species in its respective water body. This required transforming catch rate by the natural logarithm to ensure the assumption that the residuals were normally distributed. A separate linear regression analysis was undertaken for fish within each of the three length-range categories for each RAD and FIS method, separately. The assumption of equality of variances among the trips was tested using Levene's test and, where necessary, the Bonferroni adjustment was made to the statistical significance level (Bland and Altman 1995) when making multiple comparisons of mean catch rate to identify significant differences among trips.

Testing for statistically significant similarity in daily catch rates among pairs of RAD and FIS methods within each of the three length-range categories was undertaken by correlation analysis for each target species in its respective water body. Similarity was based of the correlation coefficient r.

Testing for statistically significant differences in catch length-frequency composition among pairs of or groups of three RAD and FIS methods was undertaken within each of the three length-range categories. Unlike the other tests, the length-range for the category of fish of TL <LML was narrowed by a minimum cut-off TL to exclude some of the smallest-sized fish from the analysis (see Results). Because these length-frequency distributions were not normally distributed, two non-parametric tests were applied to compare the two or three length-frequency distributions among the RAD and FIS methods for each target species in its respective water body.

The Kolmogorov–Smirnov (K–S) test is used to detect differences in both location and shape of the empirical cumulative distribution functions of two samples, such that it quantifies the distance between their empirical cumulative distribution functions. If the two samples come from populations with the same distribution, then their cumulative distribution functions are expected to be close to each other. Conversely, if the cumulative distribution functions are not close, it suggests that the samples do not come from populations with the same distribution. The procedure NPAR1WAY of the statistical package SAS (version 9.3) (SAS Institute, Cary, North Carolina, USA) was used to perform this test and to provide the K–S statistic KS, which was used to calculate the asymptotic K–S statistic KSa computed as

$$KSa = KS\sqrt{n}\ ,$$

where n is the total number of observations. The K–S test cannot be applied to more than two samples.

The length-frequency distributions for the three fishing methods used for estuary perch in Anderson Inlet were compared by applying the Kruskal–Wallis (K–W) test that can test for differences in the distributions of more than two samples. The SAS procedure NPAR1WAY was used also to perform this test and to provide the K–W test statistic H, which has chi-square distribution with $k-1$ degrees of freedom where k is the number of samples.

Results

Catch and effort

During the FIS methods sampling period of February–July 2010, field teams set the fishing gear on 44 ‘sampling-days’, and during the RAD method sampling period of February–May 2010, 17 ‘research-anglers’ fished a total of 183 ‘angler-days’ across the three water bodies of Anderson Inlet, Lake Tyers and Murray River (Table 1). A total catch of 19 797 fish (including 13 691 fish of the 3 target species) caught and measured from the FIS method exceeded the total catch of 1682 fish (including 1452 fish of the 3 target species) caught and measured from the RAD method (Table 2). Similarly, total catches of the three target species in the three water bodies, respectively, were consistently more for the FIS methods than for the RAD method (2822: 108 estuary perch, 10 604: 1225 black bream, and 198: 116 Murray cod). Furthermore, the number of non-target species was higher for the FIS methods (35 species) than for the RAD method (11 species) (Table 2).

Catch species composition

The number of species caught tested by one-way analysis-of-variance was significantly higher for the FIS methods than the RAD method in all three water bodies. The FIS (demersal trawl) method and FIS (gillnet) method caught 4.6 and 3.8 times, respectively, the number of species taken by the RAD method in Anderson Inlet. However, the FIS (beach seine) method in Lake Tyers and the FIS (electrofishing) method in the Murray River caught 2.1 and 2.6 times, respectively, the number of species taken by the RAD method in each of those water bodies. The different number of species

Table 2. Summary of number of fish of each species caught by the RAD and FIS methods in each water body

RAD, research angler diary; FIS, fishery-independent survey; Gillnet, FIS (gillnet); Trawl, FIS (demersal trawl); Seine, FIS (beach seine); EF, electrofishing.

Species		Number of fish caught by each RAD and FIS method in each water body												
		Anderson Inlet				Lake Tyers			Murray River			Total		
Common name	Scientific name	RAD	Gillnet	Trawl	Total	RAD	Seine	Total	RAD	EF	Total	RAD	FIS	Total
Anchovy	*Engraulis australis*			5	5								5	5
Australian salmon	*Salmo salar*	5	10	4	19		1	1				5	15	20
Australian, smelt	*Retropinna semoni*									4382	4382		4382	4382
Blackfish, northern river	*Gadopsis marmoratus*									18	18		18	18
Bream, black	*Acanthopagrus butcheri*	3	40	27	70	1225	10604	11829				1228	10671	11899
Carp, European	*Cyprinus carpio*								26	374	400	26	374	400
Cod, Murray	*Maccullochella peelii peelii*								116	198	314	116	198	314
Cod, southern rock	*Pseudophycis sp*			1	1								1	1
Cod, trout	*Maccullochella macquariensis*								3	4	7	3	4	7
Cray, Murray	*Euastacus armatus*									7	7		7	7
Eel, freshwater	*Anguilla sp*		1		1								1	1
Flathead, dusky	*Playcephalus fuscus*					100	100	200				100	100	200
Flathead, southern bluespotted	*Playcephalus speculator*		2		2								2	2
Flounder	*Rhombosoleidae*		2	157	159		7	7					166	166
Garfish, southern	*Hyporhamphus melanochir*						9	9					9	9
Goby	*Gobiidae*			1	1								1	1
Goldfish (common carp)	*Carassius auratus*									29	29		29	29
Gudgeon	*Eleotridae*			14	14								14	14
Hardyhead	*Atherinidae*									156	156		156	156
Leatherjacket	*Monacanthidae*					6	4	10				6	4	10
Luderick	*Girella tricuspidata*		5	1	6	4	28	32				4	34	38
Mullet, sea	*Mugil cephalus*		9		9		6	6					15	15
Mullet, yellow-eye	*Aldrichetta forsteri*		113	33	146		17	17					163	163
Perch, English	*Perca fluviatilis*									12	12		12	12
Perch, estuary	*Macquaria colonorum*	108	1596	1226	2930							108	2822	2930
Perch, golden	*Macquaria ambigua ambigua*								15	109	124	15	109	124
Perch, silver	*Bidyanus bidyanus*								1	31	32	1	31	32
Sprat, sandy	*Hyperlophus vittatus*			5	5								5	5
Snapper	*Pagrus auratus*			1	1	46	2	48				46	3	49
Tailor	*Pomatomus saltatrix*	1	12	16	29	17	107	124				18	135	153
Toadfish	*Tetraodontidae*		1	30	31		3	3					34	34
Trevally, silver	*Pseudocaranx dentex*	1	88	50	139	5	99	104				6	237	243
Tupong	*Pseudaphritis urvillii*		6	34	40								40	40
Total		118	1885	1605	3608	1403	10987	12390	161	5320	5481	1682	19797	21479

caught by the FIS (demersal trawl) and FIS (gillnet) methods in Anderson Inlet was not significant (Tables 2 and 3).

Catch rate of target species

Testing for significant differences in mean daily catch rates among trips for each RAD and FIS method by linear regression for each target species in its respective water body indicates that in general trip was not an important factor and for all practical purposes can be ignored. Trip was significant for only the length category of fish of TL ≥LML for black bream; trip was not significant for any other category for all three target species (Table 4; Figure 2). It is likely that the significant result for black bream was not valid because the assumption of equality of variances required by the regression model was not met (Levene's test $P<0.05$)

Daily mean catch rates for fish of all lengths of estuary perch in Anderson Inlet ranged 0.42–0.67 fish per angler-hour for RAD, 15.57–26.27 fish per haul for FIS (demersal trawl), and 14.13–32.87 fish per set for FIS (gillnet). The catch rates were higher for fish of TL <LML (0.31, 20.48, and 16.65) than for fish of TL ≥LML (0.20, 0.66, and 9.95) for the three methods, respectively. Daily mean catch rates of black bream in Lake Tyers ranged 5.10–6.97 fish per angler-hour for RAD and 92.75–346.00 fish per haul for FIS (beach seine); they too were higher for fish of TL <LML (5.32 and 238.77) than for fish of TL ≥LML (0.51 and 2.23) for the two methods, respectively. Daily mean catch rates of Murray cod in the Murray River ranged 0.41–0.63 fish per hour for RAD and 12.03–13.71 fish per pass for FIS (electrofishing); they also were higher for fish of TL <LML (0.50 and 7.04) than for fish of TL ≥LML (0.03 and 1.54) for the two methods, respectively (Table 5).

Testing for significant similarity in daily mean catch rates among pairs of RAD and FIS methods by correlation analysis indicated that the highest correlation occurred for the category of fish of TL ≥LML (Table 5). The correlations were significant for most comparisons or, as occurred for the estuary perch RAD–FIS (demersal trawl) comparison, close to significant (i.e. $P=0.088$), and, although the Murray cod RAD–FIS (electrofishing) comparison was not significant, the correlation was high (i.e. $r=0.69$). The correlations of daily mean catch rates among pairs of RAD and FIS methods for fish of TL <LML and for all lengths pooled were not significant, except for the estuary perch RAD–FIS (trawl) comparisons, which were significant. Taken together, these results indicate that trends in catch rates from monitoring with the RAD method would generally agree with trends in catch rates from monitoring with FIS methods, for fish of TL ≥LML. However, the RAD method would under-estimate the abundance of fish in the population of TL <LML relative to the abundance of fish in the population of TL ≥LML.

Catch length-frequency composition of target species

Length-frequency composition of the catch for each of the three target species varied markedly among the RAD and three FIS methods deployed (Figure 3). The smallest estuary perch in Anderson Inlet were taken by FIS (demersal trawl) (4 cm TL), followed by FIS (gillnet) (10 cm) and RAD (15 cm), whereas the smallest black bream caught in Lake Tyers were similar for FIS (beach seine) (5 cm) and RAD (3 cm), and the smallest Murray cod caught in the Murray River were much smaller for FIS (electrofishing) (8 cm) than for RAD (23 cm). The largest Murray cod was also taken by FIS (electrofishing) (107 cm).

Proportions of targeted species caught of length <LML varied markedly between the RAD and FIS methods: RAD (45%) was similar to FIS (gillnets) (52%), but much less than FIS (demersal trawl) (96%) for estuary perch in Anderson Inlet; RAD (83%) was less than FIS (beach seine) (98%) for black bream in Lake Tyers; and RAD (95%) was higher than FIS (electrofishing) (83%) for Murray cod in the Murray River.

Four length-classes of estuary perch identified by the modes were caught in Anderson Inlet by the three sampling methods: 7 cm TL by only FIS (demersal trawl), 13 cm by FIS (gillnet) and FIS (demersal trawl), 19–20 cm by all three survey-methods of RAD, FIS (gillnet) and FIS (demersal trawl), and 27 cm by GAD and FIS (gillnet). Three length-classes of black bream were caught in Lake Tyers by

Table 3. Testing by analysis of variance for significant differences in the number of species in the catch among the RAD and FIS methods in each water body

RAD, research angler diary; FIS, fishery-independent survey; trawl, demersal trawl; seine, beach seine; df, degrees of freedom; MS, mean square; se, standard error; * p<0.05; ** p<0.01; *** p<0.001.

Water body	RAD and FIS methods	$df_{(Method)}$	$MS_{(Method)}$	$df_{(Residual)}$	$MS_{(Residual)}$	F-value	P-value	Mean no. species per angler-day for RAD or per sampling-day for FIS					
								RAD	FIS (trawl)	FIS (gillnet)	FIS (seine)	FIS (electro-fishing)	SE of means differences
Anderson Inlet	RAD, FIS (trawl), & FIS (gillnet)	2	89.333	9	2.778	32.16	p<0.001 ***	2.50	11.50	9.50			1.18
Lake Tyers	RAD & FIS (seine)	1	98.000	6	2.778	35.28	p<0.001 ***	6.50			13.50		0.71
Murray River	RAD & FIS (electrofishing)	1	40.833	6	1.722	23.71	p=0.017 *	3.67				9.50	1.20

Table 4. Testing by linear regression for significant differences in catch rate of the target species by RAD and FIS methods among trips in each water body

RAD, research angler diary; FIS, fishery-independent survey; TL, total length; LML, legal minimum length; df, degrees of freedom; r^2, proportion of variance explained by linear regression model; ns, not significant; * P<0.05; ** P<0.01; *** P<0.001.

Water body	Target species	RAD or FIS method	TL range[A]	No. of fish caught[B]	df	F-value	P-value[C]	Error df	r^2
Anderson Inlet	Estuary perch	RAD	<LML	49	3	2.75	0.09 ns	13	0.39
			≥LML	59	3	0.48	0.70 ns	12	0.11
			All sizes	108	3	0.63	0.61 ns	16	0.10
		FIS (demersal trawl)	<LML	1176	3	0.30	0.83 ns	8	0.10
			≥LML	50	3	0.89	0.52 ns	4	0.40
			All sizes	1226	3	0.30	0.83 ns	8	0.10
		FIS (gillnet)	<LML	836	3	1.93	0.20 ns	8	0.42
			≥LML	760	3	0.82	0.52 ns	8	0.23
			All sizes	1596	3	0.68	0.59 ns	8	0.20
Lake Tyers	Black bream	RAD	<LML	1021	3	2.12	0.14 ns	16	0.28
			≥LML	204	3	1.78	0.19 ns	16	0.25
			All sizes	1225	3	1.44	0.27 ns	16	0.21
		FIS (beach seine)	<LML	10443	3	3.38	0.08 ns	7	0.59
			≥LML	161	3	5.94	0.04 *	5	0.78
			All sizes	10604	3	3.57	0.08 ns	7	0.60
Murray River	Murray cod	RAD	<LML	110	2	0.62	0.55 ns	16	0.07
			≥LML	6	1	1.53	0.30 ns	3	0.34
			All sizes	116	2	0.90	0.43 ns	16	0.10
		FIS (electrofishing)	<LML	118	1	0.09	0.77 ns	34	0.00
			≥LML	24	1	3.77	0.07 ns	13	0.22
			All sizes	142	1	0.31	0.58 ns	24	0.01

[A]LML for estuary perch 27 cm TL, black bream 28 cm TL, and Murray cod 60 cm TL (with legal maximum length of 100 cm TL);
[B]an additional 56 Murray cod were stunned by electrofishing and counted, but escaped before they could be measured; and
[C]Bonferroni adjusted for multiple comparisons.

Table 5. Testing by correlation analysis for significant similarity in catch rate of the target species among pairs of RAD and FIS methods in each water body

RAD, 'research-angler' diary; FIS, fishery-independent survey; TL, total length; LML, legal minimum length; EF, electrofishing; df, degrees of freedom; r, correlation coefficient; ns, not significant; * P<0.05; ** P<0.01; *** P<0.001.

Water body	Target species	Methods compared	TL range[A]	Mean catch rate for each method over all fishing-days				Statistical quantities for catch rate correlation analysis		
				RAD (no. per angler-hour)	FIS (trawl or seine) (no. per haul)	FIS (gillnet) (no. per set)	FIS (EF) (no. per pass)	df[B]	r	P-value
Anderson Inlet	Estuary perch	RAD–FIS (trawl)	<LML	0.31	20.48			10	0.65	0.023 *
			≥LML	0.20	0.66			10	0.51	0.088 ns
			All sizes	0.51	21.14			10	0.73	0.007 **
		RAD–FIS (gillnet)	<LML	0.31		16.65		10	0.36	0.260 ns
			≥LML	0.20		9.95		10	0.63	0.029 *
			All sizes	0.51		26.60		10	0.34	0.290 ns
		FIS (trawl)–FIS (gillnet)	<LML		20.48	16.65		10	0.36	0.280 ns
			≥LML		0.66	9.95		10	0.80	0.002 **
			All sizes		21.14	26.60		10	0.15	0.640 ns
Lake Tyers	Black bream	RAD–FIS (beach seine)	<LML	5.32	238.77			10	0.41	0.180 ns
			≥LML	0.51	2.23			10	0.63	0.011 *
			All sizes	5.83	241.00			10	0.39	0.210 ns
Murray River	Murray cod	RAD–FIS (electrofishing)	<LML	0.50			7.04	4	0.11	0.830 ns
			≥LML	0.03			1.54	4	0.69	0.130 ns
			All sizes	0.53			8.58	4	0.47	0.350 ns

[A]LML for estuary perch 27 cm TL, black bream 28 cm TL, and Murray cod 60 cm TL (with legal maximum length of 100 cm TL); and

[B]df=12–2=10 for Anderson Inlet and Lake Tyers (i.e. 4 trips x 3 days = 12 mean daily catch rates), and df=6–2=4 for the Murray River (i.e. 2 trips x 3 days = 6 mean daily catch rates).

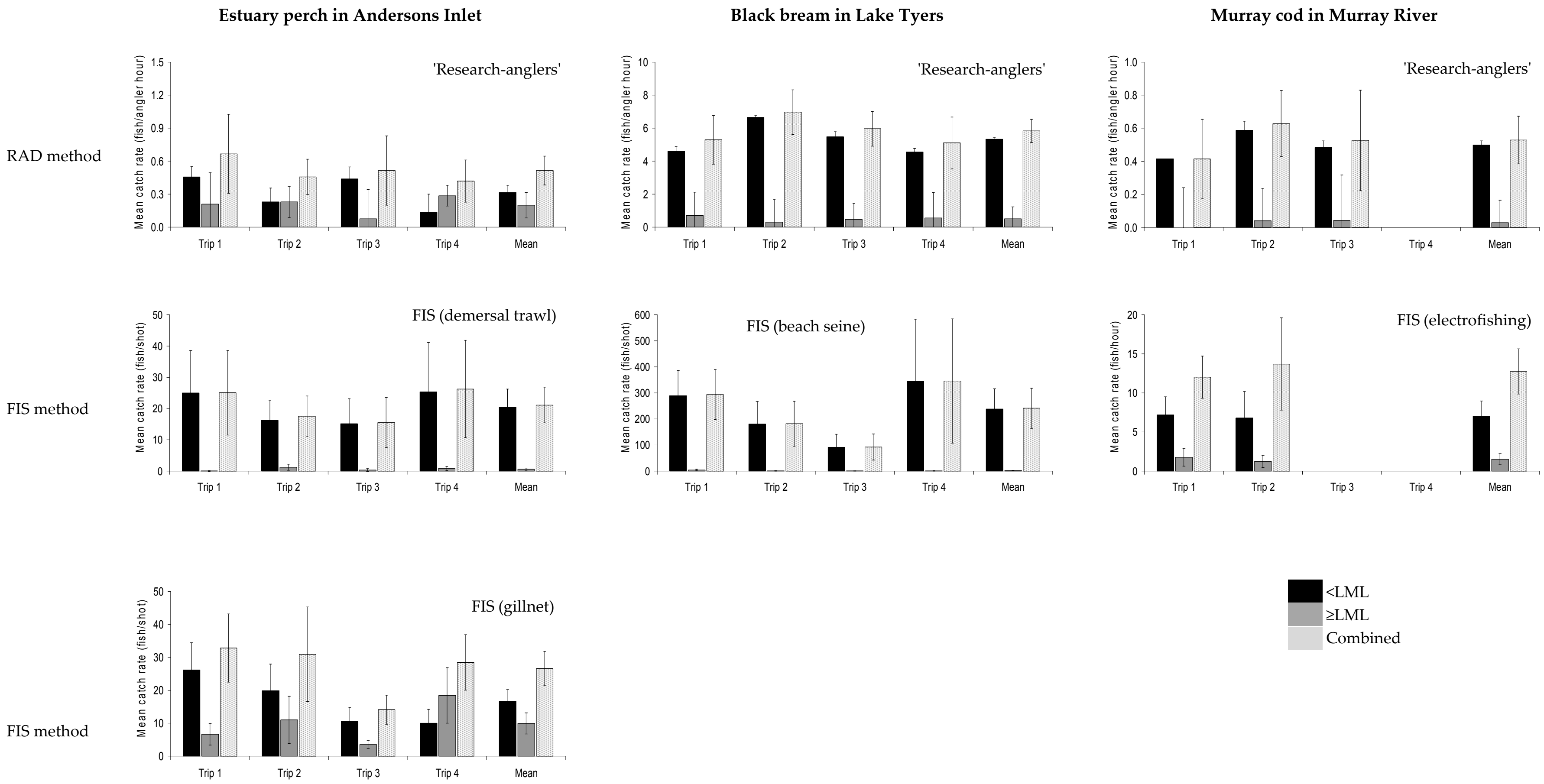

Figure 2. Mean catch rates for fish of TL ≥LML, TL <LML, and all lengths for RAD–FIS methods comparisons

RAD, research angler diary; FIS, fishery independent survey; LML, legal minimum length; TL, total length; FL, fork length; conversions of FL to TL are given by TL=1.0402FL + 0.7783 for estuary perch and TL=1.0533FL + 1.2012 for black bream; lengths are 14–24 cm FL for estuary perch, 15–25 cm FL for black bream, and 20–60 cm FL for Murray cod; bars, standard error on mean catch rate.

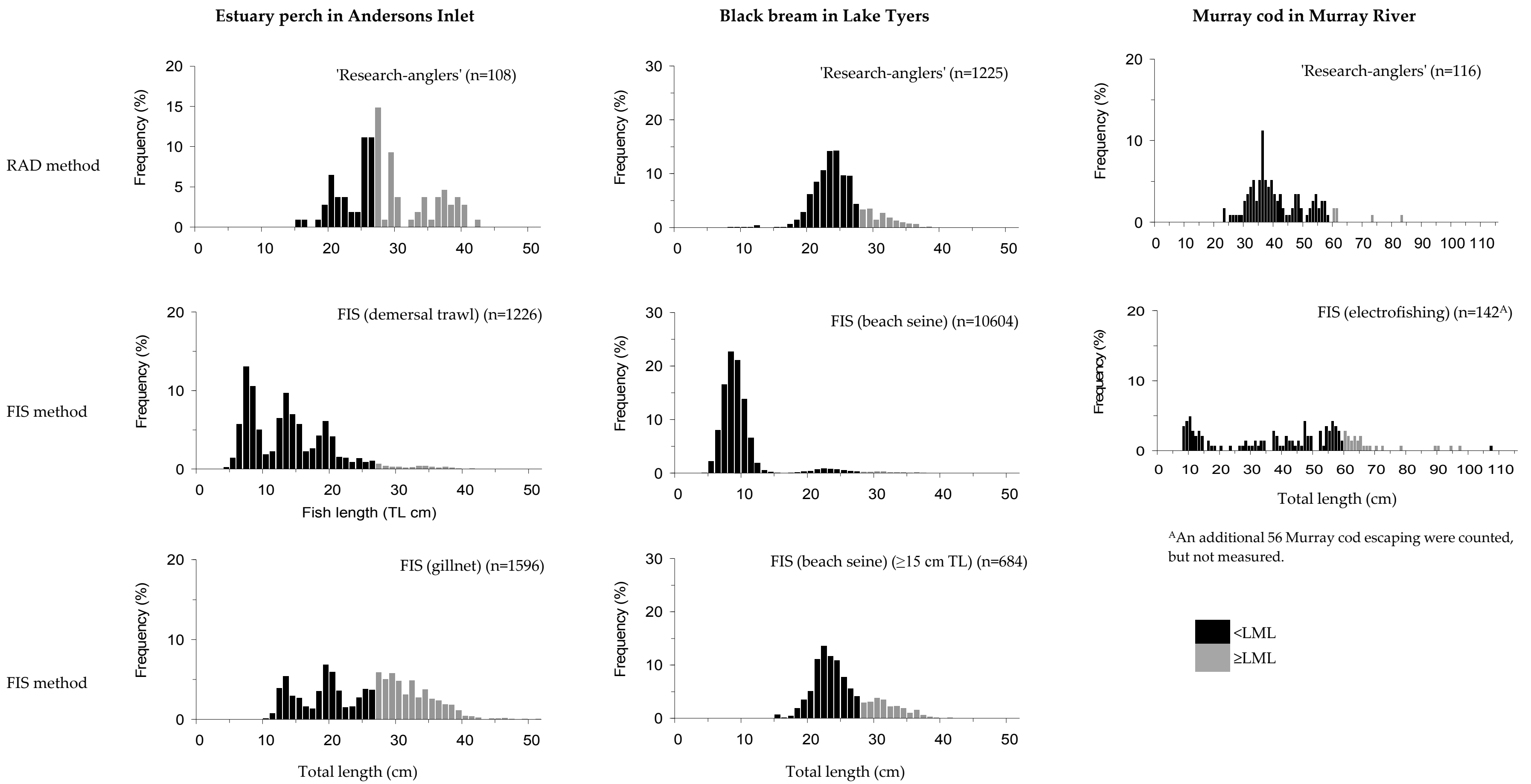

Figure 3. Catch length-frequency distributions RAD–FIS methods comparisons

RAD, research angler diary; FIS, fishery independent survey; LML, legal minimum length; n, number of fish measured; TL, total length; FL, fork length; conversions of FL to TL are given by TL=1.0402FL + 0.7783 for estuary perch and TL=1.0533FL + 1.2012 for black bream; length ranges chose for comparisons are 14–26 cm TL for estuary perch, 15–27 cm TL for black bream, and 22–60 cm TL for Murray cod.

the two sampling methods: 8 cm by only FIS (beach seine), and 22–24 and ~30 cm by both RAD and FIS (beach seine). Four length-classes of Murray cod were caught in the Murray River by the two sampling methods: 10 cm TL by only FIS (electrofishing), 36 cm by only RAD, and 47–48 and 54 cm by both RAD and FIS (electrofishing).

Testing for significant differences in catch length-frequency composition among pairs of or groups of three RAD and FIS methods undertaken by the K–W and K–S non-parametric tests provided results consistent with, but more definite than, the results from testing for similarity in catch rates by correlation analysis. All methods compared for fish of TL <LML and for fish of all lengths were significantly different (i.e. P <0.001), whereas none of the methods compared for fish of TL ≥LML were significant (Table 6). Consistent with the results from the correlation analyses of catch rates, these results indicate that trends in catch rates from monitoring with the RAD method generally agree with trends in catch rates from monitoring with FIS methods, for fish of TL ≥LML. However, the RAD method would under-estimate the abundance of fish in the population of TL <LML relative to the abundance of fish in the population of TL ≥LML.

Catch age-frequency composition of target species

The age-length keys determined for each of estuary perch in Anderson Inlet (n=106) and black bream in Lake Tyers (n=106) enabled conversion of the catch length-frequency distribution (Figure 3) into a catch age-frequency composition (Figure 4) for each RAD and FIS method adopted for these two species. The catch age-frequency distribution of estuary perch in Anderson Inlet ranged 1–20 years for RAD and FIS (gillnets) and 0–15 years for FIS (demersal trawl) method. The distribution for FIS (demersal trawl) was dominated by the 0+ (38%) and 1+ (~28%) year-classes, with the 13+ and 14+ age-classes missing, whereas 60% of the catches for the RAD and FIS (gillnet) methods included the 2+, 3+ and 4+ age-classes (with 0+, 13+, 14+, 17+, and 19+ missing) and the 1+, 2+, 3+, and 4+ age-classes (with 13+, 14+, 17+, and 19+ missing), respectively. The catch age-frequency distribution of black bream in Lake Tyers ranged 1–15 years for RAD and 1–21 years for FIS (beach seine). The distributions for the RAD and the FIS (beach seine) methods for fish ≥15 cm TL were dominated by the 3+ and 4+ age-classes (70%) (with 2+, 13+, and 14+ missing for RAD, and 1+, 2+, 14+, 16–20+ missing for FIS (beach seine), whereas for FIS (beach seine) black bream over all lengths was dominated by the 0+ age-class (40%).

Discussion

Broad summary of results

1. The FIS methods applying four separate types of fishing gear—demersal trawl and gillnets in Anderson Inlet, beach seine in Lake Tyers, and electrofishing in the Murray River—consistently caught significantly more species of fish and much higher numbers of fish than did the RAD method.
2. All methods caught a wide length-range of fish of length of both <LML and ≥LML, but the FIS methods could catch smaller fish than the RAD method.
3. Differences in catch rates among separate sampling trips for each RAD and FIS method were not detected for any of the three target species during the period of the fishing trials February–July 2010.
4. For each of the three target species estuary perch, black bream, and Murray cod, there was statistically better agreement among the RAD and FIS methods in the patterns of catch rate and catch length-frequency distribution for fish of length ≥LML than for fish of length <LML or for fish of all lengths pooled.

Framework for comparing performance of RAD and FIS methods for stock monitoring

A harvested fish population of a species consists of one or more cohorts, where the magnitude of each cohort at any time depends on the strength of its initial recruitment, and the subsequent levels of

Table 6. Testing non-parametrically for significant differences in catch length-frequency composition of the target species among RAD and FIS methods in each water body

RAD, research angler diary; FIS, fishery-independent survey; TL, total length; LML, legal minimum length; df, degrees of freedom; K–S; Kolmogorov–Smirnov two-sample non-parametric-test; K–W, Kruskal–Wallis more than two-sample non-parametric-test; ***KSa***, K–S statistic; ***H***, K–W statistic; ns, not significant; * P<0.05; ** P<0.01; *** P<0.001.

Water body	Target species	Methods compared	TL class[A]	No. of fish for methods compared[BC]	df	Non-parametric test	***KSa*** or ***H*** statistic	P-value
Anderson Inlet	Estuary perch	RAD–FIS (trawl)–FIS (gillnet)	<LML (14–26 cm)	45: 357: 583	2	K–W	79.470	<0.001 ***
			≥LML	63: 51: 783	2	K–W	0.352	0.837 ns
			All sizes	108: 1226: 1596	2	K–W	1188.24	<0.001 ***
		FIS (trawl)–FIS (gillnet)	<LML (14–26 cm)	357: 583	1	K–S	3.143	<0.001 ***
			≥LML	51: 783	1	K–S	0.738	0.648 ns
			All sizes	1226, 1596	1	K–S	14.855	<0.001 ***
		RAD–FIS (trawl)	<LML (14–26 cm)	45: 357	1	K–S	3.057	<0.001 ***
			≥LML	63: 51	1	K–S	0.763	0.605 ns
			All sizes	108: 1226	1	K–S	7.784	<0.001 ***
		RAD–FIS (gillnet)	<LML (14–26 cm)	45: 583	1	K–S	2.202	<0.001 ***
			≥LML	63: 783	1	K–S	1.078	0.195 ns
			All sizes	108: 1596	1	K–S	2.540	<0.001 ***
Lake Tyers	Black bream	RAD–FIS (beach seine)	<LML (15–27 cm)	1081: 551	1	K–S	2.007	<0.001 ***
			≥LML	182: 152	1	K–S	1.042	0.228 ns
			All sizes	1225: 10604	1	K–S	30.754	<0.001 ***
Murray River	Murray cod	RAD–FIS (electrofishing)	<LML (22–60 cm)	110: 77	1	K–S	2.150	<0.001 ***
			≥LML	6: 27	1	K–S	0.903	0.389 ns
			All sizes	116: 142	1	K–S	2.082	<0.001 ***

[A]LML for estuary perch 27 cm TL, black bream 28 cm TL, and Murray cod 60 cm TL (with legal maximum length of 100 cm TL),
[B]an additional 56 Murray cod were caught but not measured; and
[C]the order of the number of fish compared for each RAD and FIS method is given in the column headed 'methods compared'.

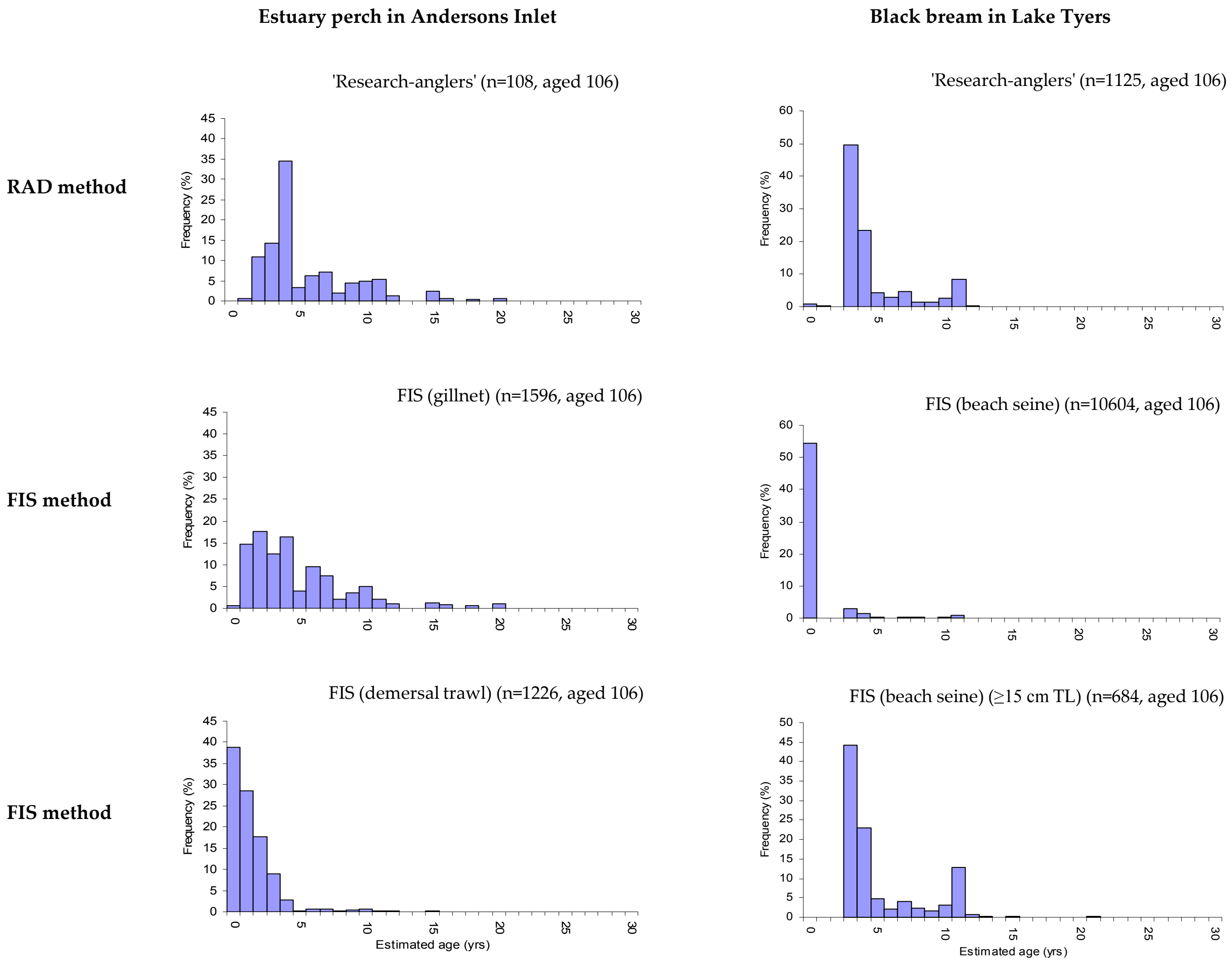

Figure 4. Age composition of catch for RAD–FIS methods comparisons

RAD, research-angler diary; FIS, fishery-independent; n, number of fish measured; samples of Murray cod from the Murray River were not aged.

mortality. The mortality includes natural mortality related to variation in environmental conditions and intra- and inter-species factors, and levels of fishing mortality related to fishing intensity, attributes of the fishing gear, and the biological attributes of the species. RAD and FIS methods used for monitoring catch rate and catch length-frequency composition can be combined with an age-length key for determining catch age-frequency composition. Relating this monitoring catch information to the relative strengths of length-classes or cohorts of fish in the population requires invoking the concept of 'catchability', specific to a particular type of fishing gear and a species.

'Catchability' is the proportion of the harvested population taken by one unit of fishing effort and is the product of three factors: 'catchability' = 'availability' x 'encounterability' x 'selectivity'. The concept of 'catchability' arose for stock assessment of target and by-product species where most of the fish captured are retained, but the concept has been broadened from 'catchability' to 'catch susceptibility' for rapid assessment and ecological risk assessment in data-poor fisheries. 'Catch susceptibility' adds the additional factor of 'post-capture mortality' to allow for mortality for that part of the catch released alive (Stobutzki *et al.* 2002). Each of the factors 'catch susceptibility' and 'post-capture mortality' also has a value 0–1 and they are related to each other and to 'catchability' by the equation 'catch susceptibility' = 'catchability' x 'post-capture mortality', which can be expanded as 'catch susceptibility' = 'availability' x 'encounterability' x 'selectivity' x 'post-capture mortality' (Walker 2005). 'Availability' is the proportion of the habitat area of a population fished, 'encounterability' is the proportion of that part of the population available to the fishery encountered by the fishing gear of one unit of fishing effort, and 'selectivity' is the proportion of the fish encountering the fishing gear captured by the gear. 'Post-capture mortality' is the proportion of the fish that die because of being caught in the fishing gear. Target and by-product species that are mostly retained have a 'post-capture mortality' value approaching 1. This can be less if some are discarded because of their length or breeding condition. 'Post-capture mortality' for discarded species can vary markedly. In addition to handling by fishers, the fishing gear and biological attributes can contribute to various kinds of mortality referred to as 'unaccounted fishing mortality' or as 'collateral mortality' (Hall 1996). Post-capture mortality from normal handling by anglers is mostly low for 'jaw-hooked' fish, but high for 'gut-hooked' fish. See Appendix 5 for more extensive definitions of terms.

Evaluation of RAD and FIS Methods

Time series of monitoring data collected from recreational, artisanal, and industrial fisheries by RAD, GAD, FIS and other methods have been applied with the concept of 'catchability' for fishery stock assessment in Victoria (Kemp *et al.* 2013) and with the concept of 'catch susceptibility' for ecological risk assessment for the effects of fishing in Australia (Hobday *et al.* 2011).

Catch rates for Murray cod, estuary perch and black bream were consistent among trips for both the RAD and FIS methods, suggesting no change in the 'availability' of these species among the different times of the trips. Depending on the RAD and FIS method, the very small fish were probably absent from the catches because of the effects of 'selectivity'. However, given the trips were undertaken during only part of the year, seasonal growth probably affected 'availability' of very small fish for parts the year, suggesting it would have been better to spread the trips over a full year.

For Murray cod in the Murray River, only a small section of the river could be covered for the fishing trials, and the habitat types fished and the timing of the trips between the RAD and FIS (electrofishing) methods were different. Murray cod are dependent on in-channel woody habitat as evidenced by increasing catch rates by 'research anglers' during 2007–12 following "re-snagging" the Murray River as part of a habitat restoration program (Lyon *et al.* 2012). Electrofishing was undertaken at sites of shallow snag piles, whereas 'research-anglers' fished in shallow and deep areas on the edge of snag piles.

The FIS (electrofishing) method has several limitations for sampling fish populations. Various studies show that the efficiency of electrofishing is affected by environmental and habitat factors, attributes of the fish species, and the adopted sampling strategy. Environmental and habitat factors include width and depth of a river, debris and vegetation cover, and conductivity of the water as affected by salinity, turbidity and temperature. Species attributes affecting efficiency, which are likely to be inter-dependent, include shape, size and conductivity of the fish species. Sampling strategy factors affecting efficiency include speed of boat, use of direct current or alternating current, voltage gradient and current density applied in the water, voltage between electrodes, and ability of the dip-netters to see the stunned fish and then to dip-net the fish before they recover and escape (Bayley and Austen 2002). In addition, the frequency of pulsed direct current (e.g. a low frequency of 15 Hz compared with a high frequency of 60 Hz) affects efficiency (Pugh and Schramm Jr 1998).

For the present study, the efficiency of the FIS (electrofishing) method depended on water flow, which can vary daily in the Murray River to the extent of restricting application of the method to only certain sites and times of the year, varying from year to year. Cognisant of the need to standardise electrofishing among the sampling sites where, in the Murray River, conditions vary (generally turbid water with large woody debris), electrofishing controls were usually set with a pulse frequency of 60 Hz and pulse widths 6.7–10.0 ms (reduced to 2 ms for higher pulse frequencies). These settings were chosen after determining the effective electrical conductivity of Murray cod (46–80 $\mu S\ cm^{-1}$) following trials under experimental conditions in tanks. The settings were varied to elicit a response of mild 'immobilisation' (impeded swimming with temporary loss of equilibrium), whilst avoiding the more extreme responses of 'narcosis' and 'tetany', and the milder behavioural responses 'escape' and 'forced swimming' (irregular and jerky) (Bearlin *et al.* 2008).

On occasions when large numbers of fish were stunned, not every fish could be dip netted and measured before the fish recovered and escaped. Although every stunned fish seen was counted there was a bias towards dip netting the large fish and hence the escape of 56 Murray cod (i.e., 28% of 198 counted) created a slight bias towards the larger fish represented in the catch length-frequency distribution. The dominant length-classes of Murray cod for FIS (electrofishing) (10 cm TL mode) and RAD (36 cm TL mode) were very different. This raises uncertainty about whether the observed difference in the dominant length-classes might be attributed to differences in 'encounterability' of Murray cod between the habitat types at the sites of shallow snag piles fished by the FIS (electrofishing) method and open waters at the sites on the edge of snag piles fished by the RAD method. This is consistent with age 0+ year-olds (<15 cm) selecting habitats shallower, closer to the bank, and with greater amounts of structural woody debris than the habitats selected by the adult fish (Koehn 2009). Another explanation is to attribute the differences to length-selectivity whereby a large fish is more likely than a small fish to move from a snag pile to open water to take a baited hook. Among Murray cod, small fish are cryptic to avoid predation through cannibalism from larger fish (Paul Brown, Fisheries Victoria, personal communication).

For Murray cod of length ≥LML caught by the RAD and FIS (electrofishing) methods, low numbers caught made it difficult to detect a significant correlation in catch rates between these methods. However, this was consistent with the lack of significance for fish of length ≥LML and highly significant differences in catch length-frequency distributions for fish of length <LML. The results are consistent with the RAD method providing an adequate indicator of abundance of fish of length ≥LML, but providing a poor indicator of pre-recruitment strength. The FIS (electrofishing) method provides a better indicator of abundance over the length-range of fish.

A similar pattern in the differences of catch length-frequency distribution between recreational anglers and electrofishing was found for largemouth bass (*Micropterus salmoides*) in Kentucky (Buynak and Mitchell 1993), which is likely to be similar to Murray cod in its response to electrofishing. For both Murray cod and largemouth bass, catch rates were most highly correlated for mid-sized fish, but less correlated for the smallest and largest length classes with these length classes less well represented in the angler catches.

As for Murray cod in the Murray River, the FIS methods provide indices of abundance for a wider length range of estuary perch in Anderson Inlet and black bream in Lake Tyers, than did the RAD method. The RAD method provided an indicator of abundance for fish of length ≥LML, but was a less effective indicator of pre-recruitment strength. Differences in catch length-frequency distributions of estuary perch and black bream among the RAD method, FIS (demersal trawl), FIS (gillnets), and FIS (beach seine) can be attributed to differences in 'encounterability' and 'selectivity', with 'selectivity' having the dominant effect for the estuary perch catch by the FIS (gillnets) methods. Although the gillnets were constructed with a range of different mesh sizes, this does not eliminate dome-shaped length-selectivity, instead it broadens the length range of the dome (Kirkwood and Walker 1986).

Consistent with 'selectivity' affecting the catch length-frequency distribution of estuary perch were the lower proportions taken by a method of fish of TL <LML for the RAD (45%) and FIS (gillnet) (52%) methods than for the FIS (trawl) method (96%). Similarly, the catch length-frequency distribution of black bream had a lower proportion of fish of TL <LML for the RAD method (83%) than for the FIS (beach seine) method (98%). This is consistent with the effects 'selectivity', but the effects appear to be weaker for black bream than for estuary perch, except the black bream of TL <15 cm TL (0+ year-olds) were caught by the FIS (beach seine) method, but not the RAD method.

Black bream recruit to the fishery at 28 cm TL, when they are 3–4 years old. The RAD method sampled pre-recruits about two years prior to them entering the fishery. Whilst the RAD method could detect the strong pre-recruit 19–20 cm TL length class of estuary perch and pre-recruit 22–24 cm TL length class of black bream, better estimates of abundance for these pre-recruit length classes could be provided from catch length-frequency distributions, if the selectivity functions and their parameters were available data. Although the comparison for fish of TL <LML was significantly different, the difference was a 1 cm difference in the median, the RAD method was effective at catching under-sized fish of TL >15cm for black bream.

Conclusions

The higher catch rates for the FIS methods than for the RAD method for fish of length ≥LML are explained by higher 'encounterability', whereas the much higher catch rates for fish of length <LML are explained by the combination of higher 'encounterability' with the fishing gear and much higher 'selectivity' by the gear. It is likely that the FIS (demersal trawl), FIS (beach seine), and FIS (electrofishing) provide reasonably unbiased indices of relative abundance and length-frequency distribution (or cohort-strength distribution derived via an age-length key) for the entire 'available' and 'encountered' population. Conversely, apart from the smallest fish in the population (not caught during the trials), the RAD and FIS (gillnet) methods can be used for monitoring catch rate and catch length-frequency composition. However, they cannot be applied as indicators of the relative strengths of length classes or cohorts in the population without adjustment for the effects of species-specific length-selectivity for each of these two types of sampling method.

For stock assessment applying monitoring data collected by the RAD and FIS methods, 'catchability' and 'selectivity' vary with length, whereas 'availability' and 'encounterability' can be assumed constant for all lengths of fish (and implicitly all ages of fish) and their product (i.e. 'availability' x 'encounterability') can be given by q'. Hence, catchability q_l at length l can be calculated from the equation $q_l = q's_l$, where 'selectivity' at length l (i.e. length-selectivity) is given by the variable s_l.

The parameter q' can be estimated by an integrated stock assessment model, but calculation of length-selectivity requires equating the variable s_l to length of fish l and, for some types of fishing gear, a measurable variable attribute of the gear. Commonly used attributes include mesh size of gillnets (Kirkwood and Walker 1986), mesh size in the cod-end of a demersal trawl net (Millar 1994), and hook size of rod and line (Conron *et al.* 2010; Millar 1995; Wolla *et al.* 2001). This requires determining an appropriate mathematical function linking the relationships among the variables length-selectivity, length of fish, and the variable gear attribute, and then undertaking a controlled selectivity experiment. The experiment involves deploying several sets of identical fishing gear (except for the variable gear attribute such as hook size) in close proximity for similar duration and recording the length of each fish caught in each gear. The variable gear attribute should be represented with a range of values (i.e. several hook sizes). An alternative experiment is to compare a 'length-selective' gear (e.g. a single hook size) with a non-length-selective gear. Provided there are sufficient catch data for several sets of gear, parameters of the mathematical function can be estimated by simultaneously fitting the function to data on the number of fish caught in each of several length-classes across the several sets of gear.

Preliminary length-selectivity parameters (and hence curves) can be obtained from the data collected as part of the present study. As a first step it is reasonable to assume that $s_l = 1$ over an appropriate TL range for estuary perch taken by FIS (demersal trawl), black bream taken by FIS (beach seine), and Murray cod taken by FIS (electrofishing). The RAD length-selectivity parameters can then be estimated by fitting catch numbers within selected length-classes from each of the RAD and FIS methods to an appropriate selectivity model for each of the three target species in its respective water body. If the data are inadequate for providing parameters usable for stock assessment, then the results of the analyses should at least provide a basis for designing further experiments. Results for Murray cod need to be treated with caution because it is likely that length-selectivity is dome shaped for both the RAD and FIS (electrofishing) methods and hence potentially having complex confounding effects on estimated parameters. It is not feasible to determine length-selectivity for estuary perch caught taken by FIS (gillnets) because mesh size was not recorded with length of each fish caught.

As part of ecological risk assessment, the results from the present study provide adequate data for determining risk associated with 'catch susceptibility' for the fish species in each of the three water bodies investigated.

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Four case studies applying 'research-angler' diary method for fishery monitoring

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Abstract

Two of four case studies together demonstrate that time series of annual catch length-frequency distributions collected by the 'research-angler' diary (RAD) method, adjusted for the effects of hook length-selectivity, can be converted by annual age-length keys to express number of fish angler-hour^{-1} for each age-class in a population to enable tracking specific cohorts from one year to the next. Tracking cohort strength over several years provides a basis for estimating mortality rate in a population, which is a key component of stock assessment. One case study shows how catch rates from the RAD method can be applied in ecological experiments to address fishery-management questions, such as assessing the effectiveness of artificial reefs for enhancing recreational fishing. Another case study shows how 'general-anglers' can serve as 'research-taggers' to tag and release large numbers of fish for determining patterns of movement and mixing within a population. This type of tag data could be readily applied with the catch rate data from the 'general-angler' diary (GAD) method (as provided by the 'research-taggers') with a survey of the distribution of fishing effort across the population to provide estimates of movement rates among separate regions. Then taking the additional step of routinely collecting catch rate for provision of a stock-performance indicator and collecting length-at-age data for provision of annual age-length keys by the RAD method, a spatially-structured and age-structured stock-assessment model integrating the dynamics of the fish population and dynamics of the harvest processes could be applied to the fishery.

Overview

Following review of management-information requirements from fisheries monitoring and research and review of monitoring methods for recreational fisheries, it is concluded from the present study that the 'research-angler diary' (RAD) method and 'fishery-independent survey' (FIS) method are effective for monitoring catch rate and catch length-frequency composition. However, trials of the RAD and FIS methods by the present study indicate that adjustment for the effects of length-selectivity of hooks for the RAD method and of other gears for the FIS method is usually necessary to relate length-frequency composition of the catch to length-frequency composition of the fish population (see Appendix 3). Estimates of total catch, if required, can be determined from catch rate by the 'general-angler diary' (GAD) method coupled with a method for estimating total fishing effort. The GAD method, on its own, provides valuable information on fishing performances by the angler community, but because of targeting practices may provide biased stock-performance indicators. Power analysis, for determining required sampling intensity, and review of costs by the present study indicate that the RAD and GAD methods provide for simple cost-effective procedures for data collection, management, analysis and reporting. If closely managed, RAD and GAD programs provide for scientific rigor and angler engagement with fishery monitoring, research, management and compliance (Appendix 5).

Furthermore, several conclusions were drawn from the trials comparing the RAD and FIS methods from sampling three important recreational fish populations in Victoria. Higher catch rates for the FIS methods than for the RAD method for fish of length greater than the legal minimum length (LML) are explained by higher 'encounterability'. The much higher catch rates for fish of length <LML are explained by the combination of higher 'encounterability' and much higher 'length-selectivity' of the fishing gear (see Appendix 5 for definitions). Catch rate and catch length-frequency composition provided by the FIS (demersal trawl), FIS (beach seine), and FIS (electrofishing) methods appear to provide unbiased indices of relative abundance and length-frequency distribution (or cohort-strength

distribution derived via an age-length key), because of the weak effects of length-selectivity by the gear for these methods. The RAD and FIS (gillnet) methods, on the other hand cannot be applied as indicators of the relative strengths of length classes or cohorts in the population without adjustment for the effects of species-specific length-selectivity to each of these two types of sampling method. However, it is not feasible to adjust the relative strengths of the length-classes for the smallest fish in the population, because they were two small to catch during the trials (Appendix 3).

In addition, the present study identifies and describes four studies (referred to here as case studies) where the RAD method applies in Australia to resolve several fishery management questions (Appendix 5). Three of the four case studies are from Victoria and the fourth is from Queensland. These studies were selected because they apply to key recreational species and because their designs for data collection ensure statistical rigor for data analysis. The three Victorian case studies were undertaken and reported independently of the present study; hence, the methods and results are only briefly summarised here. The results from the Queensland study, not reported previously, are therefore reported here more fully. The three Victorian studies apply the RAD method with 'research-anglers' providing time series of catch rate and catch length-frequency composition used for making inferences on changes in abundance of particular age classes or size classes in a fish populations. The Queensland study applies the RAD method with 'research-taggers' providing extensive tag-release-recapture data used for making inferences on movement and mixing patterns of fish in a population.

Case Study 1 for snapper (*Pagrus auratus*) in Port Phillip Bay converts the 'research-angler' diary (RAD) annual catch length-frequency distribution for each of four years into a percentage age-frequency distribution from an annual age-length key. The percentage-age-frequency distributions produced clearly identify differences in the strengths of separate cohorts progressing through the 4-year period, which when back calculated to age 0+ years match well to the corresponding relative abundances of the 0+-age class in a 12-year time-series (2000–11) from fishery-independent pre-recruit surveys by beam trawl.

Case Study 2 for black bream (*Acanthopagrus butcheri*) in Mallacoota Inlet and Lake Tyers converts the RAD annual-catch-length-frequency distribution, adjusted for the effects of hook length-selectivity, for each of several years into a percentage age-frequency distribution from an annual age-length key. The percentage-age-frequency distributions are then converted to number of fish angler-hour^{-1} for each age-class to identify several strong cohorts in the two populations. Following the strong cohorts through several periods provide a basis for measuring a change in total mortality, and by inference a change in fishing mortality (assuming constant natural mortality), between a selected period before closure of these estuaries to commercial fisheries and a selected period after closure.

Case Study 3 demonstrates how the RAD method can contribute data to a broad-scale trial required to address the effectiveness of artificial reefs for enhancement of recreational fishing. A trial with a BACI ('Before–After-Control–Impact') design was undertaken at three separate localities in eastern Port Phillip Bay, where each locality had three sites of different 'habitat-type': 'artificial reef', 'sandy substrate', and 'natural reef' (i.e. 3 localities x 3 'habitat-types' = 9 study sites). The BACI trial was undertaken over 3 years, each with two 2-month sampling-periods of RAD fishing, such that 'before-control–impact sampling' (before installation of the artificial reefs—hollowed concrete structures, each with several fish entrances) occurred during Year 1. The 'after-control–impact sampling' (after installation of the artificial reefs at the end of Year 1) occurred during Year 2 and Year 3. Statistical analysis of snapper RAD catch-rates (i.e. no. fish angler-hour^{-1}) from the nine study sites over the three years indicated that the artificial reefs installed on 'sandy-substrate' 'habitat-type' improved catch rates to a level similar to 'natural-reef' 'habitat-type'.

Case Study 4 introduces the concept of 'research-tagger'. 'Research-taggers' have elements of the 'general-angler' diary (GAD) method because they report their catch, fishing effort and catch length-frequency composition, while operating according to their normal recreational fishing practices (i.e. not to a pre-determined sampling design as occurs for 'research-anglers'). 'Research-taggers' also have elements of the RAD method because they apply scientific methods for tagging fish. This case study demonstrates how tag release-recapture data generated by 'research-taggers' can be applied to determine valuable information about the movement and mixing patterns of barramundi (*Lates calcarifer*) among the inland water systems of eastern Queensland.

The four case studies together demonstrate how a time series of annual catch length-frequency distributions collected by the 'research-angler' diary (RAD) method, adjusted for the effects of hook length-selectivity, can be converted by annual age-length keys to express the number of fish per angler-hour for each age-class in a population for the purpose of tracking specific cohorts over time. Tracking cohort strength over several years provides a basis for estimating mortality rate in a population, which is a key component of stock assessment. In addition to supporting stock assessment, the case studies show how the RAD method can be applied in broad-scale ecological experiments to address fishery-management questions such as the effectiveness of artificial reefs as suitable habitat for recreational fish. One of the case studies shows how 'general-anglers' can serve as 'research-taggers' to apply scientific methods to tag and release large numbers of barramundi (*Lates calcarifer*) for determining patterns of mixing between wild-bred and hatchery-bred fish in the population and patterns of movement among the inland water systems of eastern Queensland. This large data-set of tag release-recapture could be readily applied with the catch rate data provided the 'research-taggers' with a survey of the distribution of fishing effort across the inland water-system to provide estimates of movement rates among separate regions as applied to school shark (*Galeorhinus galeus*) across southern Australia (Walker *et al.* 2008). Applying the RAD method for collecting catch rate to provide a stock-performance indicator and for collecting length-at-age data for provision of annual age-length keys would make it feasible to take the additional step of using a spatially-structured and age-structured stock assessment model integrating the dynamics of the fish population and dynamics of the harvest processes as adopted for school shark (Punt *et al.* 2000).

Case Study 1: RAD method identifying snapper cohorts in Port Port Phillip Bay

Introduction

Case Study 1 demonstrates how data from the 'research-angler' diary (RAD) method, when combined with fishery-independent pre-recruit data, can provide essential information on the dynamics of relative cohort strength and recruitment in the Victorian western stock of snapper (*Pagrus auratus*). Recent data available for this type of analysis were collected as part of two of several monitoring sub-programs known collectively as the Channel Deepening Baywide Monitoring Program in Port Phillip Bay. The Program was designed to detect whether changes in several biological and environmental variables were outside expected natural variability in response to large-scale dredging operations in shipping lanes. The two sub-programs providing the monitoring data on snapper were the Baywide Recreational Fishery Surveys Sub-Program and the Baywide Egg and Larval Surveys Sub-Program. The recreational-fishery surveys were designed to monitor changes in the distribution, catch rate and catch length-frequency composition of key recreational-fishing species in the Bay. The egg and larvae surveys were designed to monitor changes in the relative abundance of eggs and larvae of snapper and Australian anchovy (*Engraulis australis*) in the Bay. The Baywide Recreational Fishery Surveys Sub-Program provided a 4-year time-series for each of the older age-classes by combining catch composition data with age-length keys (Bruce *et al.* 2012). The Baywide Egg and Larval Surveys Sub-Program provided data for only two years (summers of 2009–10 and 2010–11) (Jenkins and Kent 2011), but these data supplemented egg and larvae data from the five previous summers (Hamer *et al.* 2011a). Two other fishery-independent pre-recruit surveys include a multi-species otter-board trawl survey (1994–11) and a small beam trawl survey designed specifically for sampling snapper in the 0+-year age-class (2000–11) (Hamer and Jenkins 2004; Kemp *et al.* 2012). Whilst there is high consistency among the trends in relative abundance of snapper for the three separate pre-recruit surveys, for Case

Study 1, trends in cohort strength in the catches of 'research-anglers' from the RAD method were compared with the 12-year trend in the 0+-year age-class from the beam trawl survey.

Methods

The RAD method sampling design, determined by power analysis (see Appendix 5), required a minimum of three 'research-anglers' to fish targeting snapper, King George whiting (*Sillaginodes punctata*), or black bream (*Acanthopagrus butcheri*) within each of seven specified regions of Port Phillip Bay (Bruce *et al.* 2012). The 'research-anglers' fished at depths of 3–18 m each 3-month period (January–March, April–June, July–September, and October–December) over the 4 years 2008, 2009, 2010, and 2011. For data analysis of snapper, the seven regions were grouped into three zones (Bellarine, Melbourne and Mornington) (Figure 1, map) and data only for the months January–May were included to cover the period when most of the recreational fishing occurs. Annual catch rate (with standard error) was calculated for each of three size-classes based on total length (TL) of snapper demarcated by the legal minimum length (LML) (i.e. TL <LML, TL ≥LML, and all TLs combined) for each zone and for all three zones combined. For each year separately, the annual-catch percentage-age-frequency distribution was derived from the annual-catch percentage-length-frequency distribution using an annual age-length key (Bruce *et al.* 2012).

A time series of indices of relative abundance of 0+-year-old pre-recruits from the beam-trawl survey in the Bay were computed from data at seven small areas (~4.5 km^2) sampled continuously for the 12 calendar years from 2000 to 2011; additional areas sampled for less than the entire 12-year period were excluded. The seven areas were sampled during March (Kemp *et al.* 2012), which is immediately after the expected end of the larval settlement period (Jenkins 1986). Sampling involved a small plumb-staff beam trawl towed during the night when catch rates are highest at a speed of 1.5–2.0 knots for 7 min with a warp-to-depth ratio of 5 : 1 to ensure contact with the sediments under all conditions. The number of 0+-year-old snapper (40–100 mm TL) collected for each tow was standardised to number per 1000 m^2 calculated from the operational width of the trawl (2.8 m) and measured distance of the tow (Hamer and Jenkins 2004).

As a final step for Case Study 1, the pattern of inter-annual strength of each cohort present in the 4 years of annual-catch percentage-age-frequency distributions was extrapolated back to age 0+ and compared with the 12-year time-series of indices of relative abundance of the 0+-year-old pre-recruits.

Results

During January–May for each of the four years 2008, 2009, 2010 and 2011, 'research-anglers' caught a total of 4269 snapper of which more than half were of length <LML (Figure 1). Target catch rates of snapper varied among the three zones and four years (Figure 1), but the differences were not statistically significant. The ages of the snapper sampled ranged 1–17 years of age, but the numbers were negligible above 10 years of age (Figure 2).

The relative strengths of the various cohorts present in the 'research-angler' catches are remarkably consistent from year to year over the four years with the relative abundances of the 0+-year-olds during the 12 years of pre-recruit sampling (Figure 2). For example, the relative strengths of the three strong cohorts of 1+, 2+, and 3+ years old in the 2011 catch agree well with the close to average relative-abundances of 0+-year-olds for 2008, 2009 and 2010, respectively. Similarly, the 2001 pulse of 0+-year-olds (~x2 average relative-abundance) persisted as the 10+-year-old cohort in 2011, and the particularly strong pulse of 0+-year-olds in 2004 (~x4 average) and weaker pulse in 2005 (~x1½ average) persisted as strong 6+- and 7+-year-old cohorts in the 2011. Conversely, the low abundances of 0+-year-olds in the intervening years correspond with cohorts of weak strength in 2011.

Discussion

The results provided as part of Case Study 1 indicate that sampling for catch length-frequency composition, an age-length key, and pre-recruit abundance had sufficient statistical power and that

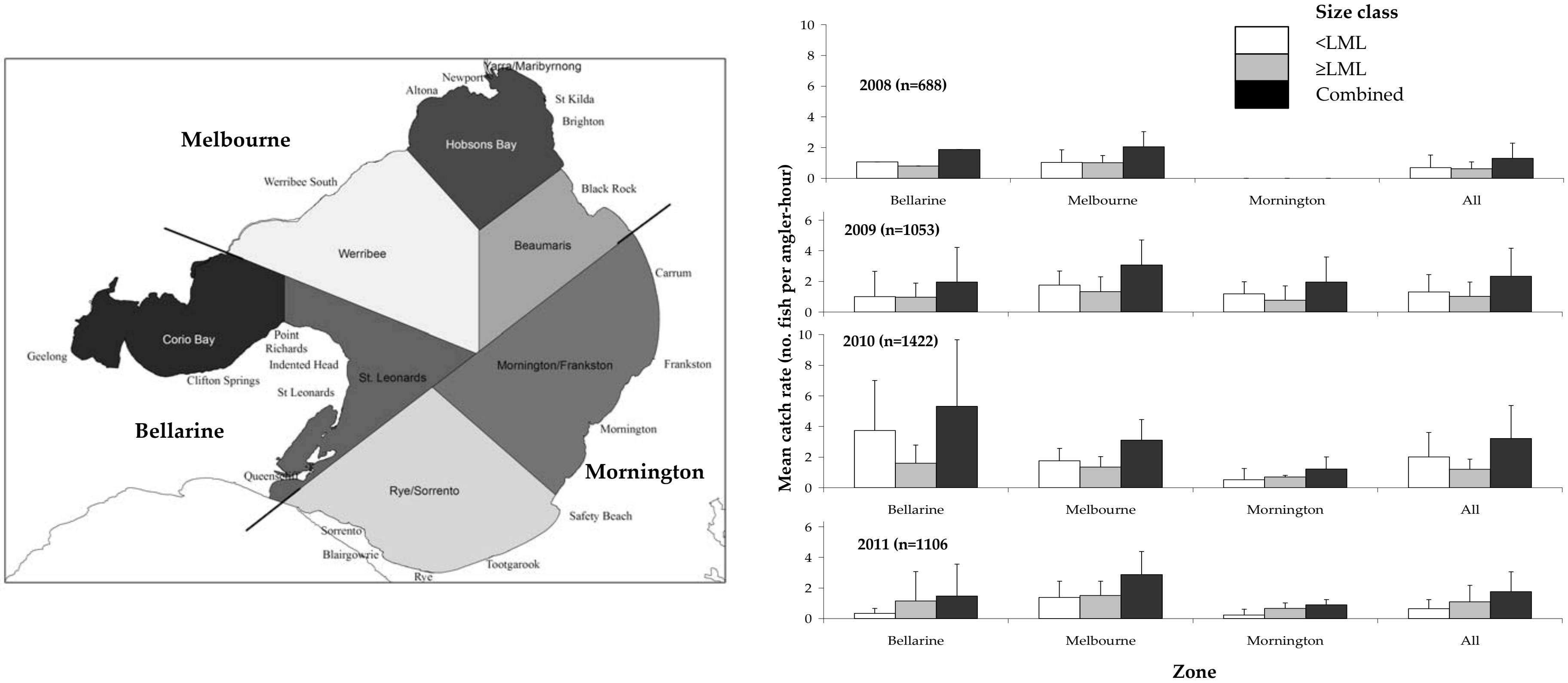

Figure 1. Mean catch rates of snapper by size class for the RAD method (histograms right) in each of three zones (map left) in Port Phillip Bay during January–May from 2008 to 2011

LML, legal minimum length; RAD, 'research-angler' diary; seven regions each with three research-anglers for each 3-month period were grouped into three zones (Bellarine, Melbourne and Mornington) (from Bruce *et al*. 2012)

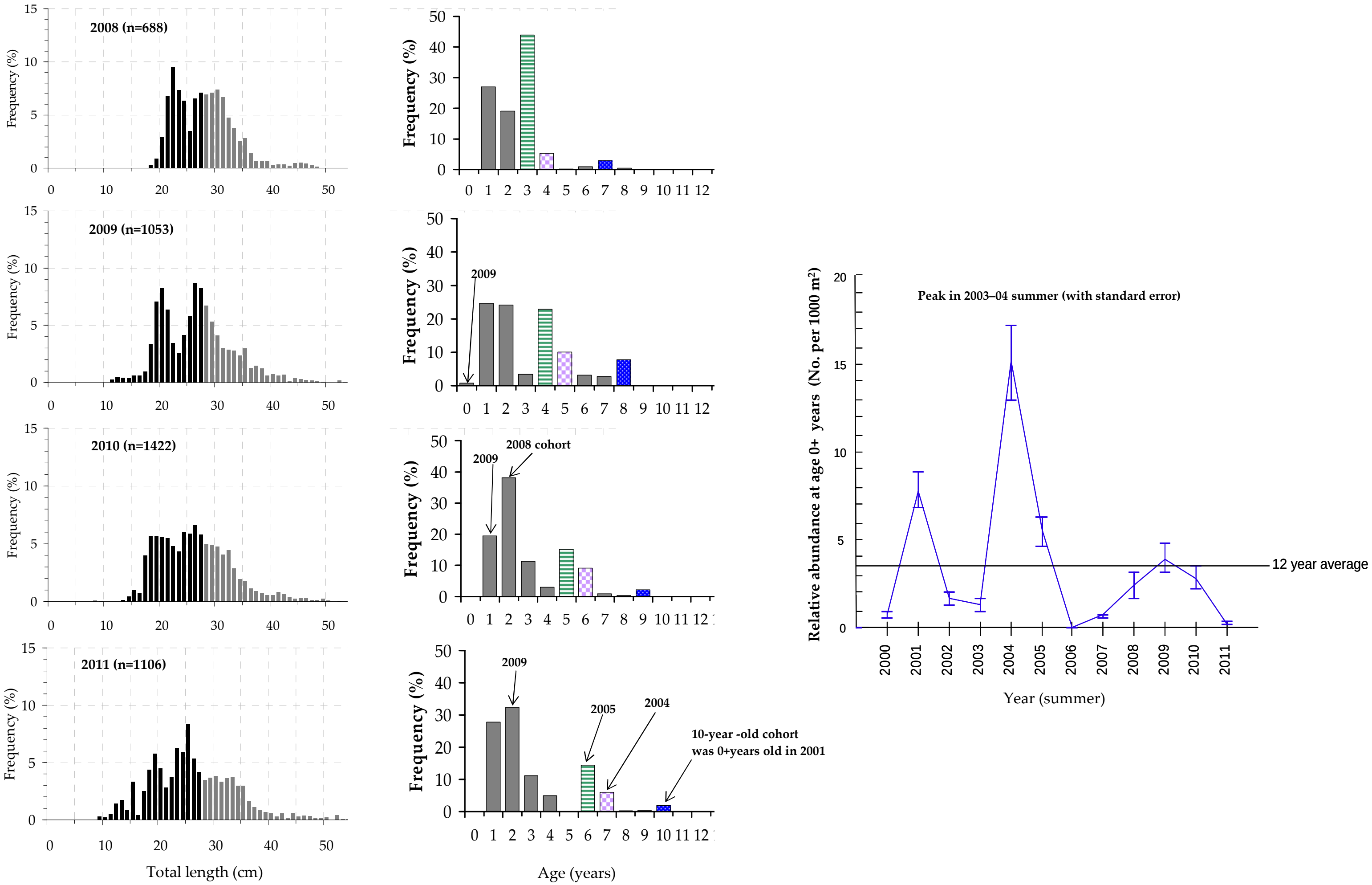

Figure 2. Comparison of RAD percentage-length-frequency (left) and percentage-age-frequency (centre) distributions and 0+ age-class (right) trend for snapper caught in Port Phillip Bay

n, number of fish measured; RAD, 'research-angler diary'; fish of total length (TL) longer than legal minimum length (LML) are indicated by grey bars and those of TL <LML are indicated by black bars; length-frequency distributions are for January–May (2008–11) (from Bruce *et al*. 2012) and age-frequency distribution are for January–April (2008–2011) (from Bruce et al. 2012); the percentage-age-frequency distribution (centre) is derived from the percentage-length-frequency distribution for each year separately from an annual age-length key. Trend in relative abundance of 0+ years age-class was determined form the 0+-year-old beam trawl survey for snapper during 2000–11 summers (from Kemp *et al*. 2012).

age determination of the snapper had sufficient accuracy to detect distinct cohorts of varying strength progressing consistently in the 'research-angler' catches for four successive years. The consistency of this pattern with the trend in relative abundance of the 0+ year-old pre-recruits provides for high confidence in the data collected and demonstrates that in-principle the RAD method is a suitable for monitoring catch rates, catch length-frequency distribution, and catch-age-frequency composition.

'Length-selectivity' of hooks, nevertheless, appears to affect the catch percentage-length-frequency distributions, which in turn affects the catch percentage-age-frequency distributions. As expected from the combined effects of natural mortality and fishing mortality, the relative strength of each cohort declines as it ages after the age of 2+ years from year to year. However, the increasing relative strength from age 0+ to 1+ years and from age 1+ to 2+ years is contrary to the effects of mortality and consistent with increasing 'catchability' for these year classes.

Given 'catchability' = 'availability' x 'encounterability' x 'selectivity' (see Appendix 5 for definitions), the clear under-representation of the 0+- and 1+-year-olds in the catch indicates that either 'availability', 'encounterability', or 'selectivity' or a mix of these factors is lower for these small fish than for the larger fish. Independent studies indicate that the Bay is an important site for snapper spawning and pre-recruits (Hamer *et al.* 2011a; Hamer and Jenkins 2004; Jenkins and Kent 2011; Jenkins 1986), which indicates that the absence of small snapper in the catch is not caused by low 'availability'. Low 'encounterability' cannot be ruled out, but 'length selectivity' of hooks is the most likely cause of under-representation of small snapper in the RAD catch. As found for estuary perch (*Macquaria colonorum*) in Anderson Inlet, black bream (*Acanthopagrus butcheri*) in Lake Tyers, and Murray cod (*Maccullochella peelii*) in the Murray River (see Appendices 3 and 4), there is a need to undertake experimental fishing trials using a range of hook sizes to determine hook 'selectivity' in relation to length of fish and to size of hook. If only one size of hook is used in the fishery, then the hook 'selectivity' for that hook size could be determined by experimental fishing trials with hooks and a fishing gear that is non-length-selective. Correction of the RAD catch percentage-length-frequency distributions for the effects of length 'selectivity' is likely to modify markedly these distributions and the catch percentage-age-frequency distributions beyond just the 0+ and 1+ age-classes. The catch percentage-age-frequency distributions after adjustment for the effects 'length selectivity' could be combined with estimates of total fishing effort, and hence total catch through appropriately weighting total fishing effort by RAD catch rates, for determining mortality rates (including natural mortality and 'catchability') (Paloheimo 1980).

Case Study 2: RAD method estimating mortality of black bream in Mallacoota Inlet & Lake Tyers

Introduction

Case Study 2 demonstrates how data from the 'research-angler' diary (RAD) method were applied to evaluate the effects of removing commercial fishing on total mortality of black bream (*Acanthopagrus butcheri*) stocks in each of the eastern Victorian estuaries of Mallacoota Inlet and Lake Tyers. The full evaluation is given in a report titled "Detecting the impacts of recent changes in fishing pressure on key recreational fish stocks in Mallacoota Inlet and Lake Tyers" (Conron *et al.* 2010a).

On 22 January 2004, Mallacoota Inlet and Lake Tyers were declared Fisheries Reserves for the primary purpose of maintaining or enhancing recreational fishing opportunities. This followed a long history of commercial fishing in Mallacoota Inlet and Lake Tyers from the late-1880s until April 2003 when the last remaining fishing licences were cancelled. Only commercial fishing for eel and bait fish are authorised in these Reserves, where bait fish are mainly prawn and bass yabby in Mallacoota Inlet and prawn, shrimp and sandworm in Lake Tyers (Department of Primary Industries 2006; Department of Primary Industries 2007).

Earlier studies of recreational fisheries indicate that black bream and dusky flathead (*Platycephalus fuscus*) were the most commonly caught species in Mallacoota Inlet and Lakes Tyers (Hall and

MacDonald 1985; Hall *et al.* 1985; Kent *et al.* 2010a; Kent *et al.* 2010b; Stokie *et al.* 2010), whereas black bream and luderick (*Girella tricuspidata*) were the main species in the Mallacoota Inlet commercial fishery (MacDonald *et al.* 1997) and black bream was the main species in the Lake Tyers commercial fishery (MacDonald 1997). During 1978–2003, black bream contributed significant proportions of the total commercial catch mass in each of Mallacoota Inlet (19%) and Lake Tyers (38%); in contrast, commercial catches of dusky flathead were incidental in both Mallacoota Inlet (2%) and Lake Tyers (3%). Hence, reduced fishing mortality from exclusion of commercial fishing from these estuaries was expected to improve catch rates and the average length of black bream for recreational anglers.

Methods

Catch rate and catch length-frequency composition data were collected by a RAD program on black bream and other key recreational species in the small estuaries of eastern Victoria (Bridge and Conron 2010; Conron and Bridge 2004; Conron *et al.* 2012). Participating 'research-anglers' altered their fishing techniques to catch a wide length-range of black bream by using a mixture of small- and large-sized hooks, and recorded start and finish fishing times, bait and hook sizes used, and species and length of each fish caught, in specially-designed diaries. They also removed the otoliths (ear bones) from a sample of their catch for subsequent age determination in a laboratory by counting growth-increment bands in transverse sections of the otoliths. Standard procedures were applied where one year of age is represented by a translucent and a subsequent opaque zone (Morison *et al.* 1998). 'Research-anglers' began recording their fishing trips (and collecting otoliths one year later) in Mallacoota Inlet during 1997 and in Lake Tyers during 2001. The resulting length-at-age data were used to construct annual age-length keys.

Annual catch length-frequency composition expressed as the number of fish per angler-hour in each 1-centimetre length-interval was first adjusted for the effects of hook length-selectivity (Conron *et al.* 2010b) and then weighted by the annual age-length key to provide annual catch age-frequency composition expressed as the number of fish per angler-hour in each 1-year age-class. The time-series of the annual catch age-frequency distributions arranged by fishing year (equivalent to fiscal year for black bream) were initially inspected to identify strong cohorts that could be tracked progressively from one year to the next as they declined from the effects of total mortality (sum of natural mortality and fishing mortality). Assuming constant natural mortality and catchability of the recruited black bream (i.e. length ≥LML of 26 cm total length), any change in total mortality is a measure of a change in fishing mortality. Total instantaneous mortality (Z) was determined as the gradient from linear regression of the natural logarithm of catch rate of the selected cohorts against year using the statistical package GenStat (Payne *et al.* 2009).

Results

'Research-anglers' in Mallacoota Inlet (MI) and Lake Tyers (LT) caught 3938 black bream (2000 in MI and 1938 in LT). Of these 2455 were aged (1912 in MI and 543 in LT) from 471 fishing trips (181 in MI and 290 in LT) by 3 'research anglers' (2 in MI and 1 in LT) during the periods September 1997–December 2009 in MI and October 2004–March 2009 in LT. Inspection of the catch-rate-at-age data identified that the most abundant cohorts exhibiting depletion over successive years were those aged 0+ years in 1992/93, 1993/94, 1994/95, 1997/98 and 1998/99 in MI and 1997/98, 1998/99 and 1999/00 in LT. Estimates of instantaneous total mortality (Z) were made for these cohorts once they were large enough to be fully recruited to the fishery (i.e. their length ≥LML) and then for selected years to represent periods immediately before and immediately after closure to commercial fishing.

In MI, Z was estimated for the selected three cohorts at age 0+ years during 1992/93, 1993/94 and 1994/95 for two periods in their life span. The first period was during the 3-year period from 2000/01 to 2002/03 (when the three cohorts spanned the ages 8–10, 7–9, and 6–8 years, respectively) to represent a commercial-fishing pre-closure period. The second period was during the 6-year period from 2003/04 to 2008/09 (when the three cohorts spanned the ages 11–16, 10–15, and 9–14 years, respectively) to represent a commercial-fishing post-closure period. The estimated reduction in Z was from 0.84 pre-closure to 0.37 post-closure, which can be expressed as a marked reduction in annual total mortality from 57% to 31% (Table 1).

In both MI and LT, the selected two younger cohorts at age 0+ years during 1997/98 and 1998/99 were too young to be fully recruited by the 3-year period from 2000/01 to 2002/03 (when the two cohorts spanned the ages 3–5 and 2–4 years old, respectively) to represent a commercial-fishing pre-closure period. However, both cohorts were fully recruited during the 2-year period from 2007/08 to 2008/09 (when the two cohorts spanned the ages 10–11 and 9–10 years old, respectively) to represent a commercial-fishing post-closure period. These two cohorts indicate that Z in MI was 0.45 $year^{-1}$ (equivalent to an annual total mortality of 36%) and in LT was 0.27 $year^{-1}$ (equivalent to an annual total mortality of 24%) (Table 1).

Discussion

The marked reduction in total mortality in Mallacoota Inlet and in similar total mortality in Lake Tyers after commercial fishing was phased out found by the present case study are consistent with the results from opinion surveys of recreational fishers in the two estuaries. Anglers surveyed in Mallacoota Inlet (n=357) and Lake Tyers (n=157) after the removal of commercial fishing were generally more satisfied with both black bream and dusky flathead fishing in these estuaries compared with anglers surveyed in the Gippsland Lakes (n=558), where commercial fishing continues. The majority of anglers fishing in Mallacoota Inlet and Lake Tyers (about two-thirds), believed that there were more or about the same number of black bream and dusky flathead and that the black bream were of similar size between mid-2003–2007 and 1999–mid-2003 or were larger during mid-2003–2007 than 1999–mid-2003. In contrast, anglers surveyed in the Gippsland Lakes felt there were less black bream and that they were smaller after mid-2003 than before mid-2003. Significantly more Gippsland Lake anglers believed there were less black bream after mid-2003 (61%) compared with anglers in Mallacoota Inlet (7%, p=0.003) and Lake Tyers (24%, p<0.001) (Conron *et al.* 2010a). This consistency between the findings from the RAD method and the recreational fishing opinion survey provides some validation of the RAD method in its application for estimating mortality rates.

Case Study 3: RAD method evaluating artificial reefs for recreational fishing in Port Phillip Bay

Introduction

Case Study 3 demonstrates how the 'research-angler' diary (RAD) method for monitoring fish stocks harvested by recreational fishers can contribute data to a broad-scale study required to address specific fishery-management questions. The broad-scale study associated with the present case study was part of an artificial-reef trial initiated by the Government of Victoria in 2006 (Hamer *et al.* 2011b), designed to evaluate the effectiveness of artificial reefs for enhancement of recreational fishing in Port Phillip Bay. The purpose of the trial was to understand how recreational catches of key species respond to installation of artificial reefs on sandy substrates. Recreational catch rates, such as those by the RAD method, provide data on the catchable component of the population of a species using the reefs, but do not necessarily provide data on the other life-history stages of the species or on its potential prey and predators. There was a need to know whether artificial reefs extend the suitable habitat of a species to allow for population growth or the reefs simply aggregate a population and thereby improve catch rates in the short-term by increasing 'catchability', but potentially causing stock reduction in the longer-term. Furthermore, there was also a need to understand the behavioral responses of anglers to the artificial reefs and to determine whether artificial reefs improve their fishing satisfaction. There was also a need to assess the resilience of the artificial-reef structures to impacts from recreational fishing activities, including anchoring, and environmental impacts related to sedimentation, slumping, burial, snagged fishing tackle, and accumulation of refuse, with potential effects on biodiversity and exotic species.

Table 1. Estimates of total mortality before and after the closures of Mallacoota Inlet and Lake Tyers to commercial fishing on 22 January 2004

Z, instantaneous total mortality estimated from depletion of selected cohorts after their full recruitment; se, standard error (insuffcient data for calculating se on Z from only 2 years of data for 2007/08 and 2008/09).

Estuary	Commercial fishing	No. cohorts & years included for Z estimate	Years when selected cohorts were aged 0+ years	Years when selected cohorts were included for Z estimate	Ages of selected cohorts for Z estimate (years)	Z estimate Mean±se	Annual total mortality
Mallacoota Inlet	Allowed	3, 3	1992/93, 1993/94, 1994/95	2000/01, 2001/02, & 2002/03	8–10, 7–9, & 6–8	0.84±0.17	57%
	Disallowed	3, 6	1992/93, 1993/94, 1994/95	2003/04, 2004/05, 2005/06, 2006/07, 2007/08 & 2008/09	11–16, 10–15, & 9–14	0.37±0.19	31%
	Disallowed	2, 2	1997/98, 1998/99	2007/08, & 2008/09	10–11, & 9–10	0.45	36%
Lake Tyers	Disallowed	2, 2	1997/98, 1998/99	2007/08, & 2008/09	10–11, & 9–10	0.27	24%

Methods

The trial had a BACI ('Before–After-Control–Impact') design (Green 1979; Quinn and Keough 2002) undertaken at three separate localities in eastern Port Phillip Bay, where each locality had three sites of different 'habitat-type': 'artificial reef' (10–12 m depth), 'sandy substrate' (10–12 m depth), and 'natural reef' (6–9 m depth). The artificial reef installed at each of three sites consisted of 96 hollowed concrete Reef Balls with several fish entrances. Three types of Reef Balls (16 Pallet Balls each weighing ~750 kg, 56 Bay Balls each weighing ~200 kg, and 24 Mini-Bay Balls each weighing ~120 kg) were arranged in a grid pattern on sandy substrate in a 50 m x 50 m square. Four methods were used for sampling the fish, macro-invertebrate and algal communities for patterns in abundance at each 'habitat-type': the RAD method by experienced 'research-anglers', baited underwater video (BUV), underwater visual census (UVC) by SCUBA divers, and photo-quadrat 25 cm x 25 cm (PQ) for monitoring fouling communities on the artificial reefs (Murphy and Jenkins 2010). In addition, on-site surveys of anglers at 20 boat ramps around the Bay were undertaken to contribute to creel census and to ask questions related to measuring anglers' awareness of, usage of, satisfaction with, and attitudes towards the artificial reefs. The trial period occurred during November 2008–April 2011, but for the purpose of statistical analysis of data from the BACI experiment treated as consisting of 3 years with each year specified as the period from 1 July to 30 June, where Year 1 was designated as 2008/09 (truncated at start of year), Year 2 as 2009/10, and Year 3 as 2010/11 (truncated at end of year). The 'before-control–impact sampling' (before installation of the artificial reefs) occurred during November 2008–April 2009 (i.e. Year 1) once for the RAD method and twice for the BUV and UVC; the 'control–impact' (installation of the artificial reefs) occurred May 2009 (i.e. near end of Year 1); and the 'after-control–impact sampling' occurred during May 2009–April 2011 (Year 1 and Year 2) twice for the RAD and angler-survey methods, six times for each of the BUV and UVC methods, and four times for the PQ method (Hamer *et al.* 2011b).

The RAD method targeted snapper, but data were recorded for all species caught. To sample the full length-range of the snapper population, research-anglers deployed the typical recreational snapper fishing method of a baited hook on a rod and reel with one of three alternative hook-sizes and baits: large suicide-hook (4/0) with Australian sardine (*Sardinops sagax*) as bait, medium suicide-hook (1/0) with Australian sardine as bait, and small long-shank hook (6/0) with pipi (*Donax deltoides*) as bait. RAD fishing was stratified into two sampling periods: November–December (spring–summer) when large-mature fish are normally caught and February–March (summer–autumn) when small- to medium-sized fish ('pinky' snapper) are caught; no sampling was undertaken during winter. During each 2-month sampling-period, each 'research-angler' used two hook-sizes (1/0 and 4/0 during November–December, and 1/0 and 6/0 during February–March) at each of nine study sites (i.e. 3 study localities x 3 'habitat-types' = 9 study sites). The three February–March sampling-periods (over three years) were fished for the 'before-control–impact sampling' during one period in Year 1 (2008/09) and for the 'after-control–impact sampling' during two periods in Year 2 (2009/10) and Year 3 (2010/11). Only the two 'after-control–impact sampling' November–December monitoring-periods were fished in Year 2 (2009/10) and Year 3 (2010/11); the absence of the proposed 'before-control–impact sampling' November–December monitoring-period in Year 1 (2008/09) was unavoidable due to timelines imposed on the study (Hamer *et al.* 2011b). The 'natural-reef' sites inshore were sampled only during the February–March period when 'pinky' snapper are normally targeted by anglers, whereas for the November–December sampling-period most fishing for large-mature snapper occurs on deeper sediment habitats.

Six 'research-anglers' undertaking the fishing all had >20 years fishing experience and had targeted snapper in the Bay for the last 10 years. For each 2-month sampling-period, the six 'research-anglers' were randomised over the 6 study sites fished during the November–December sampling-period and over the 9 study sites fished during the February–March sampling-period, such that each of 3 'research-anglers' fished each site for 2 hours on each of 4 fishing days. The total fishing time at a site during each 2-month sampling-period was 24 h, with the exception of one site ('sediment-substrate habitat-type') during the 2008/09 February–March sampling-period, which received 22 h. The 'research-angler' sampling protocol was as follows.

1. Arrive at the pre-allocated study site half an hour prior to sunrise.
2. Record conditions and site details and fishing start time in the 'research-angler' diary provided and begin fishing.
3. Use two rods per 'research-angler', one for each of two hook types, without using berley.
4. Fish for two hours with the two rod and record the species and total length (fork length for those species with a forked tail) of each fish caught in the diary supplied and release those fish of length less than legal minimum length (LML) (28 cm total length, 26 cm fork length for snapper).
5. When fishing is complete (after 2 hours), note the time of completion in the diary and tick the fishing event as completed in the sampling schedule.

The 'research-anglers' were also required to record all interactions with marine mammals and seabirds during their fishing trips. An interaction was defined as any incident where a seal, dolphin or water bird came into physical contact with the fishing equipment, boat or boating equipment, and pursued or removed a fish or bait being retrieved by an angler.

The numbers of fish caught for each species were compared among the habitat-types for each 2-month sampling-period and statistical analyses of RAD data from the BACI experiment. Although the original study (Hamer *et al.* 2011b) reported detailed results on flathead and snapper, only the snapper results are reproduced here. Catch-rate (i.e. no. fish angler-hour^{-1}) applied in an ANOVA at a site for a 2-month sampling-period was the mean catch rate for an individual 'research-angler' over four separate fishing days. The three separate 'research anglers' were treated as replicates. Snapper RAD catch-rate variation among the three habitat-types and three years was investigated using ANOVA separately for each of the two size classes <LML and ≥LML for each of the two sampling-periods (November–December and February–March). The assumption of equality of variances among the fishing days was tested using Levene's test, and the assumption of normality was checked by inspection of the catch-rate-frequency distributions. The catch rate data were subsequently log transformed to meet these assumptions.

Length-frequency distributions were compared statistically for snapper of length <LML and ≥LML among years, sites and year x site interactions (α= <0.05) using a Kolmogorov-Smirnov (K–S) two sample asymptotic test (see Appendix 3 for a more extensive description of test).

Results

The RAD method caught 1115 fish from 13 taxa (or taxon groups) for the two years 2009/10 and 2010/11 during the November–December sampling-periods and 5792 fish from 24 taxa (or taxon groups) for the three years 2008/09, 2009/10 and 2010/11 during the February–March sampling-periods (Table 2). For the two November–December sampling-periods, 10 and 9 taxa were caught on the 'artificial-reef impact' and 'sandy-substrate control' habitat-types, respectively (the 'natural-reef control' habitat-type was not fished during the November–December sampling-periods). The taxa caught in the highest numbers on both habitat-types were flathead (44%) and snapper (42%), where the flathead was a mixture of sand flathead (*Platycephalus bassensis*) and yank flathead (*P. speculator*) (Table 2) and counted here as two taxa. Most taxa were caught on both habitat-types, except leatherjacket (Monacanthidae), silver trevally (*Pseudocaranx georgianus*), cod (*Pseudophycis* spp), and gurnard (Triglidae), which were caught only on the 'artificial-reef impact' habitat-type. For the February–March sampling-periods, 17 taxa were caught on the 'artificial-reef impact' habitat-type, and of these, 4 taxa were caught only after installation of the artificial reefs; i.e. cod, southern goat fish (*Upenichthys vlamingii*), and barracouta (*Thyrsites atun*). A total of 16 taxa were caught on the 'sandy-substrate control' habitat-type, excluding leatherjacket and southern goatfish. A total of 19 taxa were

Table 2. Number of fish caught by the RAD method during each 2-month sampling period for each habitat type during the BACI trial

RAD, 'research-angler' diary; BACI, before–after-control–impact.

Species		Number of fish caught during each 2-month sampling-period for each habitat type																				
		Recreational fishing reef						Sediment control						Natural reef control						Total		
Common name	Scientific name	Before impact 2008/09		After inpact 2009/10		After impact 2010/11		Before impact 2008/09		After impact 2009/10		After impact 2010/11		Before impact 2008/09		After impact 2009/10		After impact 2010/11				
		Nov–Dec[A]	Feb–Mar	Nov–Dec	Feb–Mar	Nov–Dec	Feb–Mar	Nov–Dec[A]	Feb–Mar	Nov–Dec	Feb–Mar	Nov–Dec	Feb–Mar	Nov–Dec[A]	Feb–Mar	Nov–Dec	Feb–Mar	Nov–Dec	Feb–Mar	Nov–Dec	Feb–Mar	Total
Snapper	*Chrysophrys auratus*		91	112	823	218	772		30	48	98	87	199		609		749		767	465	4138	4603
Flathead, sand & yank	*Platycephalus bassensis & P. speculator*		354	135	80	82	67		327	148	301	128	115		17		12		4	493	1277	1770
Southern fiddler ray	*Trygonorrhina fasciata*		21	18	11	17	4		32	20	14	38	4		1					93	87	180
Leatherjacket	Monacanthidae		57		6	2			2		2		1							2	68	70
King George whiting	*Sillaginodes punctatus*		3								2						23		13	0	41	41
Yellowtail scad	*Trachurus novaezelandiae*		2				13		6				2		12		1		3	0	39	39
Southern eagle ray	*Myliobatis australis*		2	12		3				8		10			2					33	4	37
Australian salmon	*Arripis* spp		14						15		1		1		2					0	33	33
Silver trevally	*Pseudocaranx georgianus*					6			1						12		8		7	6	28	34
Stingray	Myliobatiformes		3				1		10		1	3					1		1	3	17	20
Cod	*Pseudophycis* spp			11			3		2											11	5	16
Southern goatfish	*Upenichthys vlamingii*				4		3								2		4		1	0	14	14
Toadfish	Tetraodontidea		1		1		2		2		1	1					1			1	8	9
Gurnard	Triglidae			1		3									3		1			4	4	8
Port Jackson shark	*Heterodontus portusjacksoni*		1			1	1			1		1			2					3	4	7
Snook	*Sphyraena novaehollandiae*								1				4				1			0	6	6
Gummy shark	*Mustelus antarcticus*		1		1						1		2							0	5	5
Mackerel	Scombridae										1				2		1			0	4	4
Tommy ruff	*Arripis georgianus*														2		2			0	4	4
Barracouta	*Thyrsites atun*						1					1							1	1	2	3
Southern sea garfish	*Hyporhampuhus melanochir*		2																	0	2	2
Longfin pike	*Dinolestes lewini*														1					0	1	1
Australian sardine	*Sardinops sagax*								1											0	1	1
Total			552	289	926	332	867		429	225	422	269	328		667		804		797	1115	5792	6907

[A]Sampling period not sampled

caught on the 'natural-reef control' habitat-type, including leatherjacket and southern goat fish. The taxa caught in the highest numbers were snapper followed by flathead on the 'artificial-reef impact' habitat-type; flathead followed by snapper on the 'sandy-substrate control' habitat-type; and snapper followed by King George whiting (*Sillaginodes punctatus*), flathead, silver trevally, and yellowtail scad (*Trachurus novaezelandiae*) on the 'natural-reef control' habitat-type (Table 2).

The November–December mean catch rates of snapper of length <LML were significantly higher on the 'artificial-reef impact' habitat-type than the 'sandy-sediment control' habitat-type, and significantly higher in 2010/11 than 2009/10, whereas the habitat-type x year interaction was not significant (Table 3.2). Mean catch rates for snapper of length ≥LML were not significant for habitat-type, year or habitat-type x year interaction. The length-frequency composition of the RAD catch on the 'artificial-reef impact' and 'sandy-substrate control' habitat-types ranged 15–90 cm FL (Figure 3).

The February–March catch rates of snapper of length <LML were highly significant for the effects of habitat-type, year, and habitat-type x year interaction (Table 3). The interaction term was significant because the catch rates on the 'artificial-reef impact' habitat-type before artificial-reef installation was not significantly different from the 'sandy-substrate control' habitat-type during 2008/09, but was significantly higher than the 'sandy-substrate control' habitat-type after artificial-reef installation during 2009/10 and 2010/11. Furthermore, the mean catch rates of snapper of length <LML were significantly higher on the 'natural-reef control' habitat-type than on both the 'sandy-substrate control' and 'artificial-reef impact' habitat-types before artificial-reef installation, but after artificial-reef installation, the catch rates for the 'artificial-reef impact' and 'natural-reef control' habitat-types were similar. The significant effect of year was due to significantly higher catch rates in 2010/11 than in 2008/09 (Figure 3; Table 3). Mean catch rates of snapper of length ≥LML differed significantly with habitat-type, but the effects of year and habitat-type x year interaction were not significant. The significant effect of habitat-type was due to the higher catch rates of snapper of length ≥LML on the 'natural-reef control' habitat-type than on both the 'artificial-reef impact' and 'sandy-substrate control' habitat-types (Table 3). The length-frequency composition was dominated by snapper of length <30 cm FL for all habitat-types, both before and after artificial-reef installation (Figure 3).

Interactions of 'research-anglers' were rare with seals and birds and never with dolphins on all three habitat-types. During 144 hours of RAD fishing on each habitat-type in 2008/09 before artificial-reef installation, the only interactions to occur were with 1 seal on the 'natural-reef control' habitat-type and 1 bird on the 'sandy-substrate control' habitat-type. During the 576 hours of RAD fishing on each habitat-type in 2009/10 and 2010/11 after artificial-reef installation; 1, 6 and 3 interactions with seals and 1, 3 and 1 interactions with birds occurred the 'natural-reef control', 'artificial-reef impact', and 'sandy-sediment control' habitat-types, respectively.

Discussion

The artificial-reef trial in Port Phillip Bay demonstrated a strong response to the presence of artificial reefs by key recreational fish species within 2 years of their installation. Despite the diverse range of fish taxa observed on the artificial reefs by the BUV and UVC methods (56 taxa) (Hamer *et al.* 2011b), the RAD catches were dominated by snapper and flathead, which might be explained by snapper being focus species for the recreational fishing component of the trial and targeting practices of the 'research-anglers' fishing the artificial reefs.

Snapper were attracted in large numbers to the artificial reefs by the first spring–summer period after their installation and catch rates increased rapidly and remained high compared with those on the 'sandy-substrate control' habitat-type. Catches of adult snapper occurred on both the 'artificial-reef impact' and 'sandy-substrate control' sediment-types during November–December, but a difference in catch rates between the habitat-types could not be detected statistically. On the other hand, by the end of the 3-year monitoring-period, catch rates and size compositions of small 'pinky' snapper during February–March were similar between the 'artificial-reef impact' and 'natural-reef control' habitat-types. Both the BUV (Hamer *et al.* 2011b) and RAD methods demonstrated rapid and progressive

Table 3. Testing for the effects habitat-type, year and location and interactions on snapper catch rates for each 2-month sampling-period and size group

ANOVA analyses are on log-transformed catch rates (no. fish angler $hour^{-1}$); LML, legal minimum length (28 cm total length); df, degrees of freedom; MS, mean square; * p <0.05; ** p <0.01, *** p <0.001; ω^2, semipartial omega-square (proportion of variance attributable to each effect); LCL, conservative lower 90% confidence limit for ω^2; UCL, conservative upper 90% confidence limit for ω^2; pairwise comparisons are among habitat-types and years for each sampling period and size group; ns, not significant; habitat, habitat-type; ARI, 'artificial reef' impact; SSC, 'sandy-substrate' control; NRC, 'natural-reef' control.

Size group	Source	df	MS	F-value	P-value	ω²	LCL	UCL	Planned pairwise comparisons
November–December sampling-period									
<LML	Habitat	1	3.73	37.81	<0.0001 ***	0.4869	0.2922	0.6340	2009/10: ARI > SSC significant
<LML	Year	1	0.84	8.53	0.0075 **	0.0995	0.0017	0.2837	2010/11: ARI > SSC signficant
<LML	Habitat x Year	1	0.21	2.13	0.1577	0.0149	<0.0001	0.1629	
<LML	Location (Habitat)	4	0.04	0.42	0.7941	0.0308	<0.0001	0.0022	
<LML	Year x Location (Habitat)	4	0.01	0.12	0.9750	0.0467	<0.0001	<0.0001	
≥LML	Habitat	1	0.00	0.02	0.8775	0.0212	<0.0001	0.0407	2009/10: ARI – SSC ns
≥LML	Year	1	0.40	3.86	0.0612	0.0620	<0.0001	0.2488	2010/11: ARI – SSC ns
≥LML	Habitat x Year	1	0.00	0.00	0.9938	0.0217	<0.0001	<0.0001	
≥LML	Location (Habitat)	4	0.32	3.11	0.0338 *	0.1833	0.0116	0.3951	
≥LML	Year x Location (Habitat)	4	0.12	1.20	0.3383	0.0170	<0.0001	0.1957	
February–March sampling-period									
<LML	Habitat	2	16.93	165.68	<0.0001 ***	0.4985	0.3611	0.5909	2008/09: ARI < NRC significant
<LML	Year	2	7.67	75.04	<0.0001 ***	0.2241	0.0928	0.3394	2009/10: ARI > SSC significant
<LML	Habitat x Year	4	2.29	22.42	<0.0001 ***	0.1297	0.0103	0.2207	2010/11: ARI > SSC signficant
<LML	Location (Habitat)	6	0.17	1.71	0.1359	0.0065	<0.0001	<0.0001	
≥LML	Habitat	2	1.14	21.67	<0.0001 ***	0.3629	0.2344	0.4872	2008/09: ARI – NRC ns
≥LML	Year	2	0.09	1.74	0.1844	0.0131	<0.0001	0.0997	2009/10: ARI – SSC ns
≥LML	Habitat x Year	4	0.05	0.98	0.4251	0.0006	<0.0001	0.0748	2010/11: ARI – SSC ns
≥LML	Location (Habitat)	6	0.02	0.43	0.8532	0.0298	<0.0001	0.0060	
≥LML	Year x Location (Habitat)	12	0.02	0.46	0.9277	0.0566	<0.0001	<0.0001	

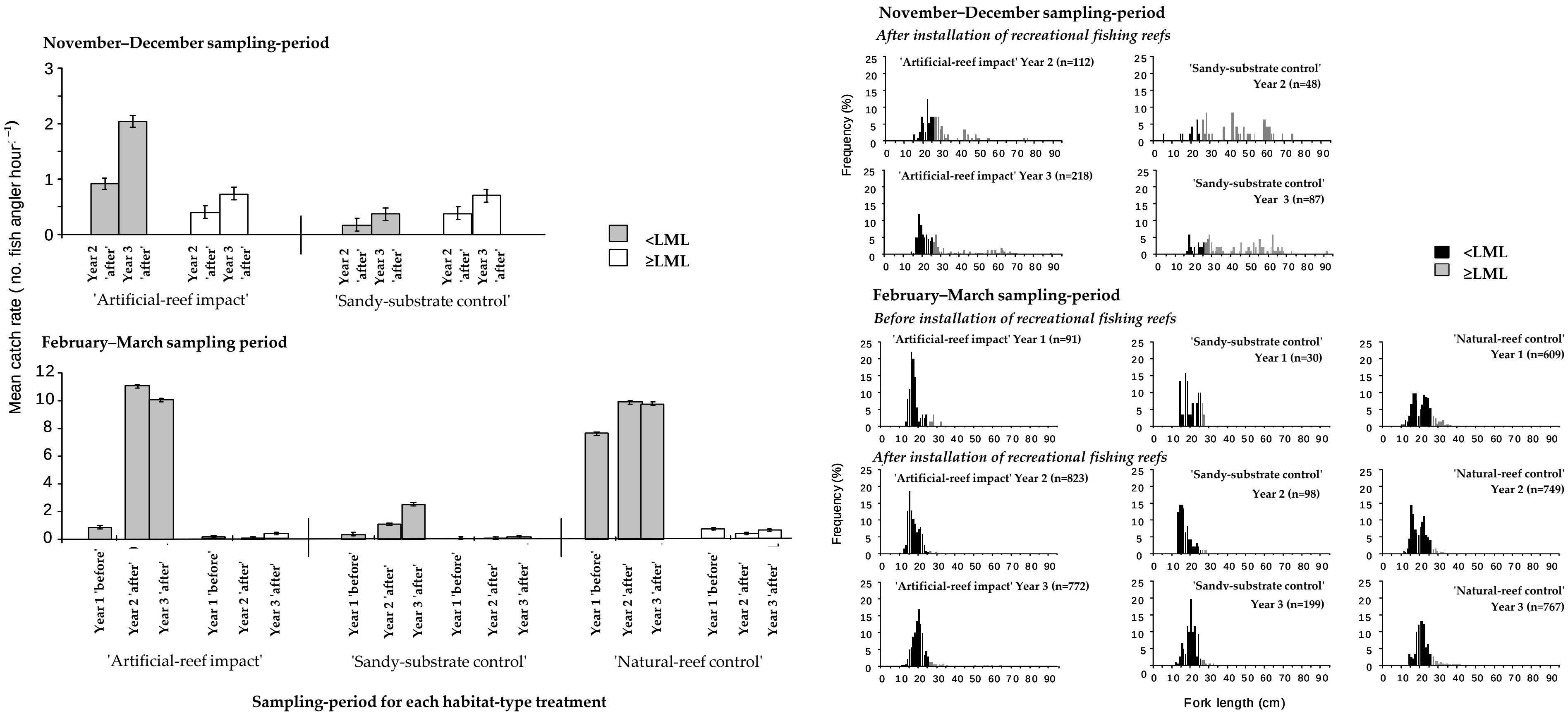

Figure 3. RAD method mean catch rates (left) and catch percentage-length-frequency distributions (right) of snapper for each fishing periods from BACI experimental fishing trials

bars, ±standard error; LML, legal minimum length (28 cm total length); n, sample size; BACI, before–after-control–impact; the fishing periods were November–December and February–March for 'before-control–impact sampling' and 'after-control–impact sampling'; 'recreational fishing reefs' are 'artificial reefs'; note that the sampling period for November–December did not occur for 'before installation of artificial reefs'; Year 1, 2008/09; Year 2, 2009/10; Year 3, 2010/11 (from Hamer *et al*. 2011b).

increases in the presence of large 'pinky' snapper on the artificial reefs after their installation. This may have been related to the initial development and succession of the biological communities and food sources supported by the artificial reefs making them increasingly attractive to larger snapper.

The rising abundance of small 'pinky' snapper during the three years 2008/09, 2009/10, and 2010/11 observed on all three habitat-types is also consistent with increased abundance of pre-recruits throughout the Port Phillip Bay as indicated by rising abundance of 0+-year-old snapper during the three years 2007, 2008 and 2009 from the results of pre-recruit beam-trawl surveys (Case Study 1, Figure 2). The recruitment and growth of these recent cohorts of young snapper on the artificial reefs was clearly indicated by the temporal changes in abundance and size composition of snapper measured by BUV (Hamer *et al.* 2011b). Furthermore, the increase in both the detection by BUV and catch rates of snapper of length ≥LML on the artificial reefs would have been at least partly related to the growth of pre-recruits in 2007/08 to the LML by the 2010/11 summer.

The rapid colonisation of the artificial reefs by young snapper does indicate that the new reefs provided a highly attractive habitat for these early life-history stages. While small (<10 cm length) 0+ age snapper are commonly associated with sediment habitats (Hamer and Jenkins 2004; Saunders 2009), larger juveniles are commonly associated with structured habitats such as natural-reef and rubble-bed habitat-types (Kingett and Choat 1981; Thrush *et al.* 2002). The high attraction of juvenile snapper to the new structures is consistent with their naturally observed patterns of habitat use, and may relate to a combination of increased food availability and refuge from predation provided by the reef structures (Francis 1995; Thrush *et al.* 2002).

The results from the RAD method indicate that large adult snapper periodically utilise the artificial reefs, although they were less likely to be consistently present. Adult snapper are likely to be more sporadically attracted to the new reefs in search of food, and their occurrence on the reefs may vary in relation to feeding patterns. The largest individual snapper caught by a 'research-angler' was on an artificial reef during November–December 2009/10 and it is possible that the attractiveness of the structures to larger snapper may increase over time as the biological communities and food availability develop. The catch rates of large snapper by the 'research-anglers' on the artificial reefs may have biased downwards the higher occurrence of larger fish lost due to line breakage from abrasion against the reef structures, as reported by the 'research-anglers'. Interestingly, the BUV method detected only one large adult snapper (>80 cm) on an artificial reef. Furthermore, despite the consistently high catch rates of 'pinky' snapper on the new structures, the BUV and UVC data indicated a decline in overall numbers of 'pinky' snapper on the reefs at the end of the trial. These differences may be related to increased behavioural aversion to the BUV method and to divers with increasing size, or the difference in time of day when the two sampling methods were applied.

Rapid colonisation of the artificial reefs by snapper is consistent with the observations on similar artificial reefs installed in NSW estuaries, where snapper were detected on the structures within 2 months of installation (Lowry *et al.* 2006).

Several important conclusions about the RAD method can be drawn from this case study.

- The RAD method provides the best data for measuring recreational fishing enhancement.
- The RAD method demonstrated the presence of larger snapper, whereas BUV and UVC did not; it is suggested that large snapper avoid divers and cameras.
- Length-frequency composition for snapper of length <LML from the RAD and BUV methods was similar for each 2-month sampling-period and study site.
- The RAD method is not effective for understanding underwater fish communities with a large number of observed taxa. RAD catches are dominated by target species and other catchable species, whereas many species present on the reefs are never captured.
- The RAD method was much cheaper to implement than the BUV and UVC methods.

Case Study 4: RAD method determing tag movements of barramundi on Queensland east coast

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Introduction

Details of fish tagged and released, catch and effort data and other data such as gear used, and hooking location are collected by Suntag anglers for each fishing trip. These anglers can be viewed as operating with elements of both the 'general-angler' diary (GAD) and the 'research-angler' diary (RAD) methods according to the definitions adopted the present study. On the one hand, because these anglers operate according to their normal fishing practices (not to a pre-determined sampling design) and submit details of their catch and effort, they are applying the GAD method. On the other hand, because they tag and release fish, they are applying elements of the RAD method. For the purposes of the Suntag program and Case Study 4, they are termed 'research-taggers'.

Whilst data have been collected since the mid-1980s, data from the period 2000–11 have been used to provide a decadal view of barramundi movements. Tag release-recapture data are analysed with other fish capture and environmental data to determine movement patterns, interactions between wild and stocked fish, and the impact of environmental factors.

The Suntag tagging program in Queensland is a joint program between the Australian National Sportfishing Association Qld Inc (ANSAQ) and Fisheries Queensland, Department of Agriculture, Fisheries and Forestry, and is managed by Infofish Australia. Commencing in its current form in 1986/87, the program has continued through to the present time. Tagging is undertaken voluntarily by members of ANSAQ and at the end of 2011 more than 655,000 fish had been tagged and released of which more than 52,000 had been recaptured, reported and entered into a database.

Barramundi (*Lates calcarifer*) are an important commercial and recreational species with an east coast commercial harvest of ~254t in 2010 (Fisheries Queensland 2011). Barramundi are highly targeted by recreational fishers and are widely stocked in impoundments and open systems, primarily to enhance the recreational fishery. Barramundi is a key species tagged in the Suntag program with 216,815 fish tagged and 17,950 recaptures (Suntag database 2011). This includes tagging both wild and stocked fish. These data were used to assess movement of barramundi to address three objectives.

1. Determine intra-river and inter-river tag release-recapture movement patterns of barramundi on the east coast of Queensland and relative significance of the various river systems to the overall stocks.
2. Assess the interaction of wild and stocked barramundi using tag release-recapture data for potential genetic mixing.
3. Assess the relationship between barramundi movement and local climatic conditions (rainfall and river flow) in the various river systems using tag release-recapture data.

Methods

Data collection

Tagging, catch and effort data and other data such as gear used and hooking location are collected by Suntag 'research-taggers' for each fishing trip. The minimum information collected on tagged fish includes tag number, species, date, length, location and angler. 'Research-taggers' are encouraged to voluntarily provide additional data on catch and effort, which includes number of persons fishing, start and finish times for the fishing trip, species and numbers of all fish kept or released and other data on gear used, hooking location, and injury to fish.

'Research-taggers' submit their data electronically using a standard EXCEL spreadsheet (Infofish 2006 e-trip form) or as a paper record to the tagging coordinator. Each trip form is allocated a unique trip code that allowed it to be identified. The form has been designed to allow upload of tag release, tag recapture, catch, fishing effort, and other data to the database. Data received from 'research-taggers' are validated prior to uploading to the database. Data are corrected where required and any unresolved discrepancies referred back to the 'research-tagger'. Once trip details have been validated, the data are uploaded to the Infofish 2012 (current version) database. Data on catch, fishing effort and released and recaptured tagged fish are automatically uploaded into their respective tables. Subsets of the data can then be extracted in a variety of formats and analysed using a variety of analytical tools.

Recaptures of tagged fish can be reported on the tag through an 1800 toll free number or through the Infofish website www.info-fish.net/suntag. Feedback on the history of the fish is provided to the person who recaptured the fish and the person who tagged the fish; certificates with the details are provided by email or mail.

Fish stocking groups have also used tagging as a method of monitoring the fish they stock. In the case of barramundi, a number of stocking groups have released batches of fish of ~200 mm length where all fish have been tagged. 'Research-taggers' also tag stocked fish over the length range above 200 mm. This provides a simple mechanism for monitoring these fish through time. Stocking groups collect the data in the same way as 'research-taggers'. Data have been collected since the mid-1980s, but only data for 2000–11 were used to provide a decadal view of barramundi movements.

Determining movement from tagging data

Locations are recorded as a text description of the site where the fish was caught on a map and grid reference, Global Positioning System (GPS) coordinates, or latitude and longitude where available. Map and grid references are derived from grid maps that have been constructed covering river systems and fishing locations along the coast. Grids are mostly 1 km^2, but in some areas grids are 2 km^2. This provides fine scale information on where a fish was tagged without compromising the specifics of the angler's fishing spot.

Most tag records have a map and grid reference and sufficient details are sought from recaptures to identify the map and grid where caught. This allows the distance from the tag release location to the recapture location to be calculated. The distance is calculated as the shortest distance following the watercourse between the locations. Tag and recapture locations can be displayed using MapInfo GIS or Google Earth.

Determining movement patterns for barramundi

Data were used for a number of systems where sufficient data were available. Rivers that were selected were Mary River, Fitzroy River, Pioneer River, Burdekin River, Johnstone River, Mulgrave–Russell Rivers, and Barron River (Figure 4, map). The Mary River is in the sub-tropics and at the southern limit of the barramundi's range, whereas the Fitzroy, Pioneer and Burdekin are in the dry tropics and the Johnstone, Mulgrave–Russell and Barron in the wet tropics. Data for the Johnstone River mostly comes from Fisheries Queensland monitoring, data from the Mulgrave–Russell comes mostly from the Cairns Area Fish Stocking Group, and the remaining data come from 'research-taggers'.

Movement of fish is categorised as 'intra-river movement' defined as movement within a river system and tributaries and as 'inter-river movement' defined as movement outside the system from where they were tagged. The first four rivers have weirs or barrages on them that create an artificial barrier between the saltwater estuary and freshwater and are a barrier to upstream movement by barramundi. Data on tagged fish were limited to fish tagged in the estuary and movement was further categorised as within the estuary or upstream to the freshwater past the barrier. Inter-system movement was further categorised as being to the north or to the south.

Determining interaction of stocked and wild barramundi

Barramundi have been widely stocked in Queensland impoundments and river systems since the 1980s. Stocked impoundments do not have a natural population of wild fish; however, stocked barramundi leave these impoundments when flow conditions allow and mix with the wild

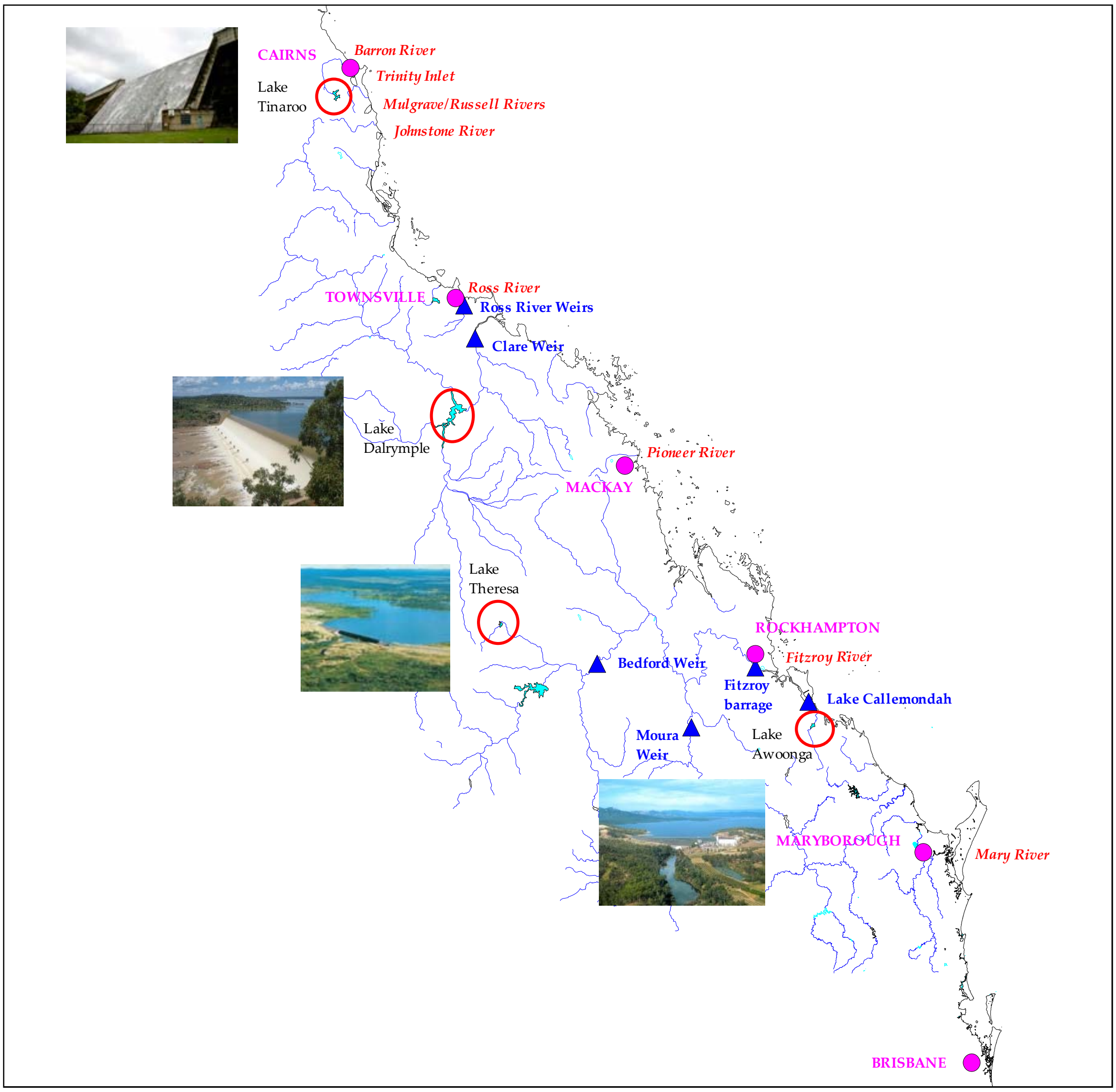


Figure 4. Queensland east coast rivers showing locations for assessment of barramundi movement

population. Since the early 2000s fish stocking groups have released batches of barramundi larger than ~200 mm length, which have been tagged or fish have been tagged by 'research-taggers' when fishing in these impoundments. Tagged barramundi have also been stocked into open river systems where they can interact with the wild population. This has allowed movements of these fish to be monitored over time providing information on the interaction of stocked and wild fish.

At the same time wild fish have been tagged in some river systems where stocking has occurred, allowing the interaction of stocked and wild fish to be further examined. A previous report examined the movement of stocked barramundi from 1987–07; however, since then there has been a significant wet period, which included large floods during 2011 in many of the rivers where barramundi were stocked, allowing many fish to leave the impoundment in which they were stocked.

Three large impoundments that have been stocked with barramundi and overflowed during the period were examined. These were Lake Awoonga on the Boyne River near Gladstone, Lake Dalrymple on the Burdekin River near Ravenshoe, and Lake Tinaroo on the Atherton Tableland. One small impoundment, Lake Theresa on Theresa Creek at Clermont was also examined (Figure 4, map).

Several weirs on rivers have also been stocked with barramundi and were examined for movement. These were Moura Weir at Moura, Bedford Weir at Blackwater, and the Barrage on the Fitzroy River at Rockhampton. All these weirs are on rivers that form part of the Fitzroy River system. Also examined was Lake Callemondah at Gladstone, which was formed by a weir on Police Creek at Gladstone and separates the freshwater from the tidal reaches of Auckland Creek. Clare Weir on the Burdekin River at Clare was also examined. There are three weirs on the Ross River at Townsville: Black Weir, Gleeson Weir, and Aplin Weir. Because these weirs are within close proximity (within 5 km of each other), data for these weirs were combined. Movement of fish in lakes and weirs was categorised as being within the impoundment, above the impoundment, to the freshwater below the impoundment, or to the estuary and beyond.

Several open river systems that were stocked were also examined. These were Mulgrave River, Trinity Inlet, and Barron River in the Cairns area. Movement of fish in these rivers was categorised as within or outside the system.

Examining the relationship between barramundi movement and local climatic conditions

Barramundi stocks are strongly related to river flow and rainfall during the wet season (Halliday *et al.* 2010). River flows allow juvenile fish to move upstream and access off-stream lagoons and freshwater reaches of river systems and allow adults to move downstream for spawning. Using tagging data from the Fitzroy River, it was found that, where barramundi have the opportunity to move either upstream or downstream, 71.6% of juvenile fish (below the legal minimum length of 580 mm) moved upstream on river flows, whereas 84.5% of adult fish (above legal minimum length) moved downstream.

Data on river flows were obtained for four river systems: Fitzroy River, Burdekin River, Johnstone River and Barron River. The first two rivers are classified as being in the dry tropics, whereas the last two are in the wet tropics. Only fish tagged in the Fitzroy and Burdekin estuaries were included in the analysis; stocked fish that moved long distances to the estuary were not included.

Flow data for each river were obtained from watermonitoring.derm.qld.gov.au. Monthly flows were aggregated into wet season flows for December–March and dry season flows for April–November. Median and average monthly flows were also aggregated to dry and wet season for each recording station over the timeframe data were available.

Movement of fish that were at liberty for more than 30 days and moved more than 10 km were compared with flow conditions between tag release and recapture. Flows between tag release and recapture were categorised as low (below median wet season flows), medium (between median and average wet season flows), and high (above average wet season flows).

Results

Determining movement patterns of barramundi

During 2000–11, a total of 33,816 barramundi were tagged and released of which 5,239 (15.5%) were recaptured in the estuarine sections of the Mary River, Fitzroy River, Pioneer River, Burdekin River, Johnstone River, Mulgrave–Russell Rivers and Barron River. Table 4 provides the number of fish tagged and recaptured in each river system over that period, whereas Figure 5 provides a breakdown of the percentage of fish that moved over a range of distances and the distance moved within and outside each river.

Overall 91.5% of all tag recaptures were within 10 km of where they were released. Movement of fish was largely within the river systems as only 1.8% of fish were recaptured outside the river with a low of 0.6% for the Johnstone River and a high of 12.4% recaptured outside the Mulgrave River. There were very few fish tagged in the estuary and recaptured above an upstream barrier even though a number of the barriers have fish-ways to allow upstream movement of fish.

Of fish that left the Fitzroy River 87.8% were caught to the south. The movement for the wet-tropics rivers was mixed with most fish (70.0%) from the Johnstone River recaptured to the north, whereas all (100%) of those from the Mulgrave–Russell Rivers were caught to the south (Figure 5).

Determining interaction of stocked and wild fish

During 2000–11, a total of 70,639 stocked barramundi were tagged and 1,982 recaptured (2.8%) in the selected impoundments, weirs and river systems. Table 5 shows the number of stocked fish tagged and the numbers recaptured at locations within and outside the system.

Recapture rates of fish tagged in the impoundments and weirs ranged from 0.9% for Lake Dalrymple and Bedford Weir to 18.7% for Lake Callemondah. For the impoundments and weirs the percentage of fish recaptured in estuaries ranged from 0% for Lake Tinaroo to 11.9% for Lake Callemondah. Overall 0.8% of fish tagged in impoundments and weirs were recaptured in estuaries and had the opportunity to interact with wild fish.

Recapture rates for fish tagged in the rivers ranged from 1.4% for the Mulgrave/Russell Rivers to 2.4% for the Barron River. As these fish were released into systems that already had a wild population of fish, there were significantly greater opportunities for them to interact with wild fish.

Figure 6 shows the movement of recaptured stocked fish tagged in impoundments, weirs and rivers. There were very few movements of fish to locations above the impoundment in which they were stocked. This is likely to result from lower fishing effort above impoundments and the predominant movement of adult fish downstream. All impoundments movement of fish to below the impoundment were associated with flooding and water overtopping the dam spillway or weir wall allowing fish to move downstream.

Lake Awoonga did not overtop the spillway until late December 2010 so that all the recaptures below the dam have occurred since that time. Fish had to survive going over the approximately 20 m high spillway with concrete blocks at the bottom. While some fish died, most survived and have been distributed throughout the Boyne River below and beyond.

Lake Dalrymple overtopped the spillway each year during 2007–11. Fish leaving the lake had to survive going over the dam wall which is 37 m high with rocks at the base. Whilst fish deaths were recorded, there have been a significant number of tagged fish that survived going over the wall and being recaptured downstream and in the Burdekin estuary and beyond. Fish that made it to the estuary had to traverse a further two weirs.

For Lake Tinaroo there have been 300 recaptures, but none were caught below the Tinaroo Dam wall. There is a barrier net in the lake to prevent fish going over the 45-m high wall. Fish tagged in Lake Theresa were recaptured up to 800 km down river in the estuary and beyond with 34 (3.9%) fish being recaptured (Figure 6, map). To reach the estuary these fish had to negotiate a further 6 weirs along the

Table 4. Number of tagged barramundi and movement of recaptures in river estuaries on the east coast of Queensland

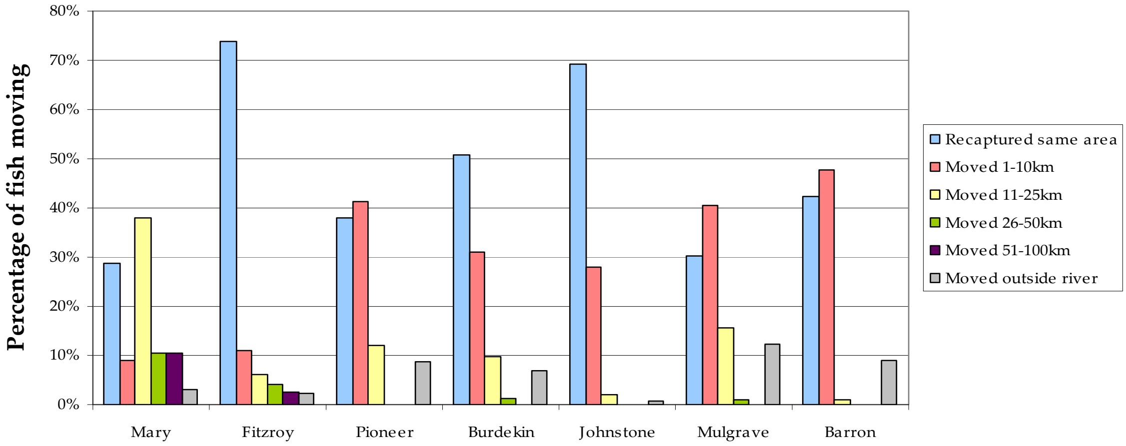
Tagged fish releases or recaptures	No. tagged barramundi released and recapture (and percentage) in each river estuary							
	Mary	Fitzroy	Pioneer	Burdekin	Johnstone	Mulgrave	Barron	Total
Total released	905	15802	619	671	6246	6694	2879	33816
Recaptured same area	19	1291	22	36	2159	27	38	3592
Moved 1–10 km	6	195	24	22	872	36	43	1198
Moved 11–25 km	25	108	7	7	63	14	1	225
Moved 26–50 km	7	73		1		1		82
Moved 51–100 km	7	43						50
Moved outside river	2	41	5	5	20	11	8	92
Total recaptured	66	1751	58	71	3114	89	90	5239
Percentage recaptured	7.3	11.1	9.4	10.6	49.9	1.3	3.1	15.5

Table 5. Numbers of barramundi tagged in impoundments, weirs and rivers and categories of recapture places

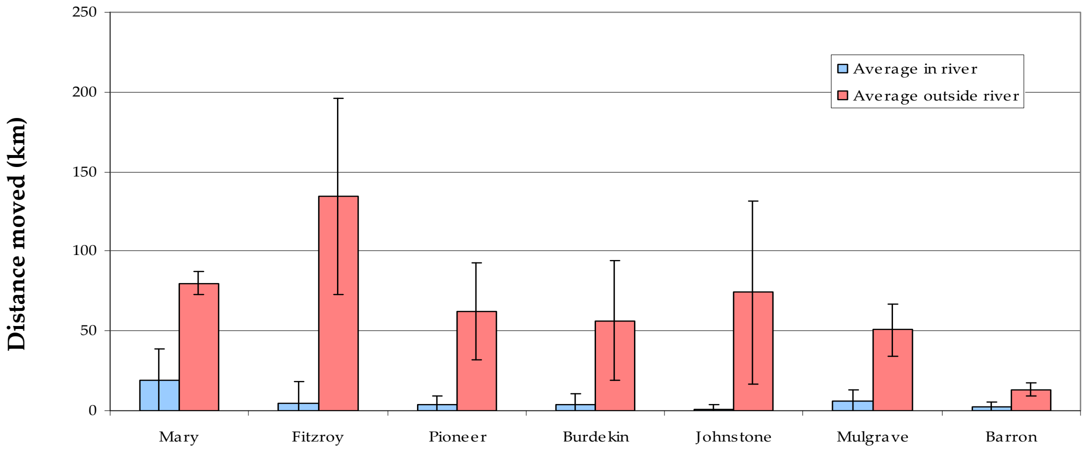
Tag release or recapture	Tag numbers released or recaptured in each impoundment, weir or river												
	Impoundments				Weirs						Rivers		
	Awoonga	Dalrymple	Tinaroo	Theresa	Callemondah	Moura	Bedford	Fitzroy barrage	Clare	Ross*	Mulgrave	Trinity	Barron
Released	9522	5268	15640	870	598	1366	4141	5144	3593	5967	6504	9441	2585
Recaptured within same impoundment, weir or river	106	3	300	7	41	94	0	14	2	379	78	173	55
Recaptured above impoundment or weir or outside river	0	4	0	0	0	0	0	1	13	1	10	13	8
Recaptured freshwater below impoundment	19	16	0	9	0	0	31	1	49	139			
Recaptured in estuary and beyond	14	27	0	34	71	8	6	121	17	118			
Total recaptures	139	50	300	50	112	102	37	137	81	637	88	186	63
Percentage recaptured	1.46	0.95	1.92	5.75	18.73	7.47	0.89	2.66	2.25	10.68	1.35	1.97	2.44
Percentage recaptured in estuary and beyond	0.15	0.51	0.00	3.91	11.87	0.59	0.14	2.35	0.47	1.98	0.15	0.14	0.31

* Ross includes three weirs on the Ross River within 5 km of each other.

Percentage of fish moving 0–100 km within estuaries and moving outside rivers



Average distance fish moved within rivers and outside river



Percentage of fish moving outside estuary to above estuary barrier, and north or south

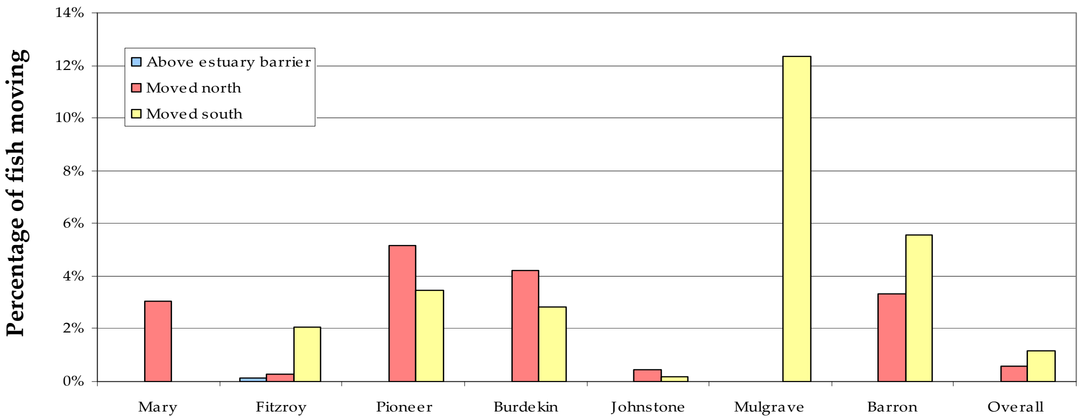
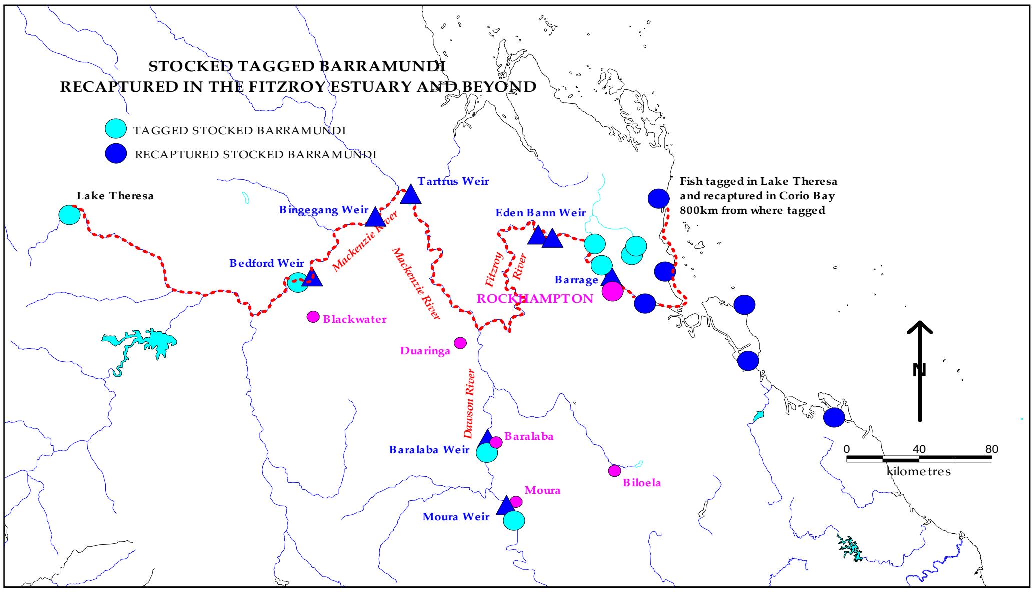
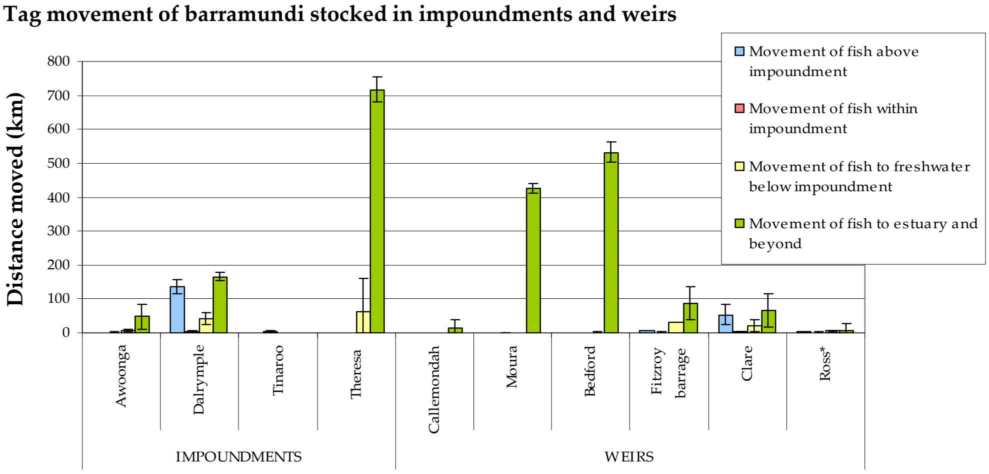


Figure 5. Barramundi movement within and among the rivers

Map of stocked tagged barramundi recaptured in the Fitroy estuary and beyond



Tag movement of barramundi stocked in impoundments and weirs



Tag movement of barramundi stocked in rivers

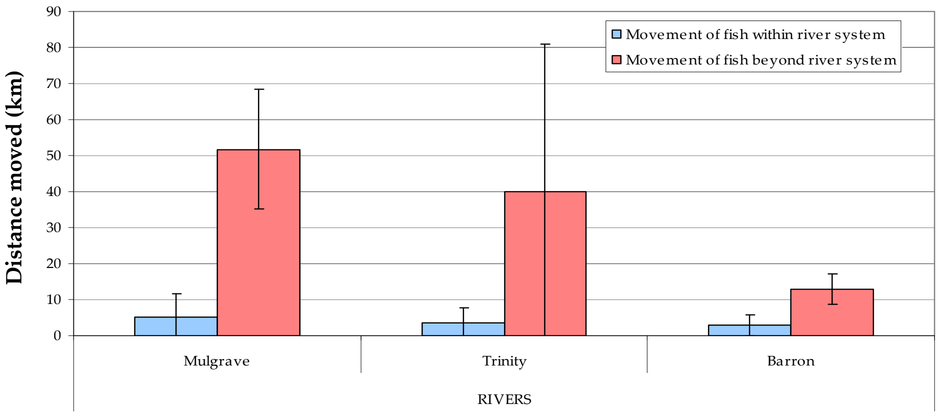


Figure 6. Movement of stocked barramundi in the Fitzroy River system and beyond

way. For fish tagged in Moura Weir, 8 (0.6%) were recaptured more than 400 km down river in the estuary and of those tagged in Bedford Weir, 6 (0.1%) were also recaptured in the estuary. Of fish tagged above the Fitzroy Barrage, 121 (2.4%) were recaptured in the estuary.

On the Ross River the three weirs below the Ross River dam were all stocked at various times; however, most fish were stocked in Black Weir, the upstream weir below the dam. Of the recaptures 139 (2.3%) were from a weir pool below where they were stocked; whereas 118 (2.0%) were fish that moved past all weirs and were recaptured in the estuary and beyond.

Barramundi were stocked in the Mulgrave River, Trinity Inlet and the Barron River in parts of the river already used by wild stocks, so there would have been mixing in those locations. Movements of stocked fish suggest that most remain in the system in which they were stocked with only 0.2% of fish moving outside the Mulgrave–Russell River, 0.1% moving out of Trinity Inlet, and 0.3% moving outside the Barron River.

Examining the relationship between barramundi movement and local climatic conditions

During 2000–11, there were 5,199 recaptures of barramundi in the selected river systems with 408 (7.8%) assessed in relation to river flows. Table 6 shows the numbers of barramundi recaptures that were at liberty for more than 30 days and moved over 10 km, and average distance moved for fish under low, medium and high flows in the Fitzroy, Burdekin and Johnstone Rivers. For each river, there were more fish moving over 10 km, and moving a greater average distance on high flows, than fish moving on low or medium flows.

In the Fitzroy River, there was a prolonged dry period during 2003–07, then a wet period during 2008–11, culminating in a large flood event in the 2010–11 wet season. In the Burdekin River, there was a dry period during 2002–06, a wet period during 2007–11, and large floods during 2009–11. In the wet tropics, the dry period was much shorter (2001–03) in both the Johnstone and Barron Rivers which limited the data from low flows.

Discussion

Whilst the results have been presented in separate sections, they are all interrelated. Barramundi movement and the opportunity for stocked fish to mix with wild fish are largely dependent on river flows, which in turn are largely dependent on local climatic conditions. Most barramundi (91.5%) were recaptured within 10 km of where tagged and overall only 1.8% were caught outside the river in which they were tagged.

The predominant movement of barramundi south from the Fitzroy River (87.8%) suggests that it is likely to be an important source of stocks for river systems towards the southern end of their range along the Queensland east coast. Movement of fish from the Fitzroy River was associated with above-average wet-season flows and flooding; however, the direction of movement does not appear to be correlated to the flood plume from the river. Satellite imagery consistently shows flood plumes from the Fitzroy moving north throughout Keppel Bay while most fish moved south.

In the wet tropics where river flows are more regular the movement south and north suggests that migration is more likely to be opportunistic as two adjacent systems, the Johnstone (70% north) and Mulgrave–Russell Rivers (100% south) show strong movements in opposite directions.

There was very little evidence of upstream migration of estuarine fish to freshwater where there was a barrier such as a barrage or weir, even where there is a fish-way on the barrier. Although some fish-ways work for many species, the evidence suggests their use by barramundi was low. The few upstream movements correlate with flooding when barriers can be bypassed. There were 2 recaptures of estuary tagged fish above the Fitzroy Barrage after the flooding in 2011. These were the first upstream recaptures since 1991 when 7 barramundi were recaptured above the Barrage after the major flood that year (Sawynok 1998).

Table 6. Number of recaptured barramundi related to river flow

Only barramundi recaptures moving >10 km in >30 days at liberty are included for selected river flow rates; low, flows less than median wet season flows; medium, flows between median and average wet season flows; high, flows above average wet season flows.

Variable	Number or average distance moved by tag recaptures				
	Total	Moved >10 km in >30 days	Maximum flow conditions		
			Low	Medium	High
Fitzroy River					
Number	1847	260	25	79	156
Average distance moved (km)			25.0	36.9	61.4
Burdekin River					
Number	190	59	6	21	32
Average distance moved (km)			33.2	38.7	46.6
Johnstone River					
Number	3066	83	4	1	78
Average distance moved (km)			15.0	16.0	30.7
Barron River					
Number	96	6	1	0	5
Average distance moved (km)			14.0	–	14.6

Barramundi have been extensively stocked in impoundments and rivers systems within their range along the Queensland east coast, particularly where barriers to movement have made them locally extinct in locations they previously inhabited. Local communities have used stocking as a means to recreate and maintain local fisheries. However barramundi that have been stocked in these locations have migrated downstream to the estuaries and beyond when flow opportunities have allowed.

The migration of fish from Lake Theresa down to the estuary some 700–800 km downstream and bypassing six other weirs along the way possibly occurred on a single flow event lasting only a few weeks. The survival of fish going over the 37-m high Burdekin Dam wall and going over two more weirs before reaching the estuary is testament to the migration urge and the tenacity of the fish.

Distance moved by stocked fish was directly related to the distance from where the fish were stocked to the estuary for the system. Fish stocked in estuary locations such as Trinity Inlet, Barron River, Mulgrave–Russell Rivers, and Johnstone River showed little movement irrespective of the flows. However, fish stocked in impoundments and weirs on the Fitzroy and Burdekin Rivers moved up to 700 km to reach the estuary. These fish were all adults that were likely to have migrated for spawning and in many instances made the journey on one or two flow events.

During the flooding in 2011, it was estimated that up to 30,000 stocked barramundi were recorded as going over the spillway on Awoonga Dam. Fish were also reported leaving Lake Monduran near Bundaberg and Lake Proserpine near Proserpine with dead fish being recorded below the dam walls. However, there were no reports of any of these fish being tagged.

Barramundi movement within estuaries and rivers in the dry-tropics rivers correlated with river flows, particularly above-average wet-season flows. For wet-tropics rivers there was less movement, although in the Johnstone River there was a correlation between above-average wet-season flows and movement. However, in the wet-tropics rivers above-average wet-season flows occurred more regularly with fewer periods of low flows compared with the dry-tropics rivers.

The relationship between local climate, barramundi stocks, movement and recruitment needs to be understood to assess the possible impacts of climate change (Sawynok and Platten 2011). Long-term data derived from tagging and the relationship between local climatic conditions and barramundi movement can help understand possible impacts.

However, tagging data and barramundi movement on their own provide only part of the picture. 'Research-anglers' involved in Suntag also provide catch and effort data and assist with recruitment surveys. These data combined with data collected by Fisheries Queensland and other researchers allow a comprehensive picture of barramundi stocks in river systems to be developed. In the Fitzroy River this led to the development of the "Crystal Bowl" to predict barramundi stocks for the next 2–3 years (Sawynok *et al.* 2009).

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New directions for monitoring recreational fisheries in Victoria, Australia

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Abstract

Victoria has deployed a range of methods for monitoring diverse recreationally and commercially harvested species of fish in freshwater, estuarine and marine waters. Information from monitoring and research is applied routinely for updating Victorian stock status reports and for contributing to similar national reports. The information also underpins legislative and licensing arrangements, including annual review of total allowable commercial catch for particular fisheries, designed for ensuring that catches from the state(Allen *et al.* 2009)'s harvested resources are sustainable and shared equitably. Within the Australian framework of ecosystem-based fisheries management, reporting requires specifying stock status against five classification categories relating to stock sustainability, which depends on understanding the interactions among biomass (or biomass proxy), recruitment and fishing intensity. For recreationally harvested stocks requiring only a biomass proxy, the 'research-angler diary' (RAD) method or 'fishery-independent survey' (FIS) method is preferred for monitoring catch species composition, and catch rate and length-frequency composition of each species. Whether to apply the RAD method or FIS method depends on the species and the water body, and initially it is likely that both methods need to be deployed together to provide ancillary biological samples and key information on fishing-gear 'selectivity' for fish length, 'encounterability' of the fish to the gear, and 'availability' within a water body. Where estimates of total catch are required, catch rate from the 'general-angler diary' (GAD) method is preferred, if the diarists are representative of the angling community, coupled with a survey method for estimating total fishing effort. The GAD method, on its own, provides a fishery-performance indicator, but because of targeting practices may provide biased stock-performance indicators. Extending the RAD and GAD methods to include routine tag release-recapture and sampling for length-at-age data provide scope for application of spatially-structured and age-structured stock-assessment models. Limiting the number of recreational-fisheries monitoring-methods allows for simpler cost-effective procedures for collection, management, analysis and reporting of data, whilst ensuring scientific rigor and angler engagement with fisheries monitoring, research, management and compliance.

Introduction

Victoria has numerous separate water bodies (lakes, rivers, estuaries, bays, inlets and coastal ocean waters) variously inhabited by a diverse range of freshwater, estuarine and marine species of fish. Many of these species are harvested by various fishing gears deployed by commercial and recreational fishers. Over time, commercial fisheries have been progressively restricted and phased out of many of these water bodies, particularly from the inland lakes and rivers, and the coastal estuaries and inlets. Commercial fishers have long provided mandatory logbook returns detailing catch of each species, and fishing effort and locality for each fishing method, from which catch per unit effort (CPUE) is computed to provide indices of relative abundance. Total catch, total fishing effort, and CPUE together from commercial fisheries have been used for monitoring many of the fish stocks across Victoria.

The gradual reduction of commercial fishing activity, coinciding with the expansion of recreational fishing across Victoria, however, has progressively diminished the monitoring data available for key species targeted by recreational fishers. Together with reduced investment in fisheries monitoring and research by governments, this has led to a situation where at any time the extent and priorities for monitoring, research and stock assessment depend on short-term demands and time lines associated with the fishery management issues of the day. In addition, there is increasing reliance on the local knowledge of recreational fishers and records from fishing clubs. The growing need for monitoring recreational species, coupled with reductions in field sampling resources and science capability to analyse and to interpret the data, necessitates streamlining monitoring programs. This is necessary to reduce costs, to develop simpler procedures for collecting and managing data, and to provide standard outputs from data summary and analysis for ready assimilation by all stakeholders.

The emerging strategy for monitoring Victoria's recreational fisheries is to encourage recreational fishers (anglers) to record details of their catches and fishing activities and to assess the stock of a species in a particular water body as the need arises. Although relevant data and information are available from the past, inevitably there is an ongoing need to augment this information with updated data and, depending on the scale of the fishery, provision of ongoing monitoring or periodic 'snapshots' of relative abundance and catch composition. Catch composition includes length-frequency distribution by species, which can be converted to a catch age-frequency distribution where an age-length key is available. Higher-level assessments require estimates of total catch from the fishery.

In summary, the Victorian monitoring strategy is to adopt the 'research-angler diary' (RAD) method or, where necessary, the 'fishery-independent survey' (FIS) method for monitoring catch rate, and species and fish-length composition of the catch. Choosing between the RAD method and the FIS method depends on the species and the water body, but it is likely that at some stage both methods need to be deployed together to provide ancillary biological samples and data for key information on population biology. Particularly important information for any species relates to selection for fish length by the fishing gear ('selectivity'), 'availability' of different components of a population (e.g. various length classes and age classes) within a water body and any connected water bodies, and 'encounterability' of the 'available' fish population to the gear. Where estimates of total catch are required, catch rate from the 'general-angler diary' (GAD) method is preferred (if available catch rates are considered representative of angling community), coupled with a survey method for estimating total fishing effort, which at its simplest requires estimating the total number of fishers engaged in the fishery.

The present study had five steps:

1. identify information required from fishery monitoring programs for management;
2. review the utility of available methods for monitoring recreational fisheries by listing the advantages and disadvantages against the types of data produced;
3. estimate by power analysis the number of 'fishing-days' required annually for monitoring by the GAD, RAD, and FIS methods using data from Victorian water bodies sampled in the past;
4. compare the costs of monitoring among the GAD, RAD and FIS methods; and
5. describe steps for implementation of a monitoring program using the GAD and RAD methods.

These steps broadly support Victoria's emerging sampling strategy that enables simpler cost-effective procedures for collection, management, analysis and reporting of data, whilst ensuring statistical rigor in sampling and close engagement of recreational fishers with the monitoring, research, management and compliance for the fisheries.

Information required from fishery monitoring programs for management

Framework for fisheries management information

Management decisions for fisheries, to a greater or lesser extent, take account of the condition of the stocks (Gulland 1983) or are based on assumptions about the stock dynamics (Hilborn and Walters 1992). Understanding of stock dynamics ranges from intuition to explicit representation in fishery stock assessment models. Fisheries are not static systems easily reshaped through management; yet, without adequate management, the fisheries can progress rapidly from early development through stages of sustainability to severe stock depletion. For sustainable use of fish resources, it has to be recognised that stock assessment involves understanding and making predictions about the response of fishery systems to alternative management actions involving choices in the face of uncertainty.

Various types of model are available for fishery stock assessment, which vary considerably in complexity. Their application inevitably requires data and expertise, the availability of which usually depends on the value of the fishery and willingness to invest in tailoring models to the peculiarities of particular fisheries. Their application also requires collecting appropriate fishery monitoring data, and studying the population biology and habitats of key species.

Management of fisheries is increasingly required to account for fishing impacts on habitats; by-catch species; threatened, endangered and protected species; and associated ecological communities. This has led to the concept of Ecosystem-based Fisheries Management (EBFM) (Pikitch *et al.* 2004) and, in Australia, development of an ecological risk assessment framework termed Ecological Risk Assessment for the Effects of Fishing (ERAEF). The framework is hierarchical in that information required increases through the hierarchy, and allows for assessment of data-poor fisheries; uncertainty in information is treated as high risk in accordance with the precautionary approach (Hobday *et al.* 2011).

Management of Victoria's fisheries variously applies many of the principles of EBFM and ERAEF and the associated hierarchical approach from qualitative, through semi-quantitative, to highly quantitative assessment. Qualitative scoping through setting fishery management objectives and identifying hazards to fish populations and habitats are presented in stock assessment reports and habitat reports such as those for Anderson Inlet (Kent and Coutin 2011) and Lake Tyers (Nicholson and Gunthorpe 2008). Semi-quantitative approaches are applied through examining trends in stock performance indicators derived from monitoring data (notably catch rate, catch length-frequency composition, and catch age-frequency composition) in most of Victoria's commercial and recreational fisheries. Examples of this approach include black bream (*Acanthopagrus butcheri*) in the Gippsland Lakes (Kemp *et al.* 2013), King George whiting (*Sillaginodes punctata*) in the eastern bays and inlets of Victoria (Kemp *et al.* 2012), and sand flathead (*Platycephalus bassensis*) in Port Phillip Bay (Koopman *et al.* 2009). Quantitative assessment, applying stock-assessment models integrating the population dynamics of key target (and by-product) species and the dynamics of fishing processes, is applied to several fisheries in Victoria. Marine fisheries include southern rock lobster (*Jasus edwardsii*) (Punt *et al.* 2013; Walker *et al.* 2013) and blacklip abalone (*Haliotis rubra*) (Gorfine *et al.* 2008), and is under development for snapper (*Pagrus auratus*) in Port Phillip Bay (Hamer and Whitten 2012). A similar approach is applied to the recreational fisheries in freshwater for Murray cod (*Maccullochella peeli peeli*) (Allen *et al.* 2009; Douglas *et al.* 2010; Rogers *et al.* 2010) and Macquarie perch (*Macquaria australasica*) (Hunt *et al.* 2011). Both semi-quantitative and quantitative approaches require information on mortality rates and reproductive (or recruitment) rates, and require time series of indices of relative abundance.

Species, water body, and stock identity

Assessment of one or more species in a water body depends on information or assumptions for each species about 'stock identity' in the water body and the connectivity of the population in that water body with the populations (or sub-populations) in other water bodies. Separate genetic populations within a Victorian water body are unlikely for most indigenous species, but differences in genetic strains between wild-bred stock and hatchery-bred stock released to enhance the available stock, such as for Murray cod (Rourke *et al.* 2009), potentially have different survival rates, reproductive rates and growth rates, which have implications for stock assessment. In addition, genetic studies confirm hybridisation between the sympatric species of Murray cod and trout cod (*Maccullochella macquariensis*) in the Murray–Darling River system (Douglas *et al.* 1995). The endemic species black bream and yellowfin bream (*Acanthopagrus australis*) are also known to hybridize (Rowland 1984), and of at least three distinct populations in Australia of the exotic European carp (*Cyprinus carpio*), one hybridizes with the goldfish (*Carassius auratus*) (Shearer and Mulley 1978). Furthermore, tag release-recapture studies (Sanders 1974) and genetic studies (MacDonald 1980; Meggs *et al.* 2003) indicate separate breeding stocks of snapper in Victorian waters roughly west and east of Wilson's Promontory. For most species, mixing among water bodies can occur through low rates of movement, such as indicated by tag release-recapture for black bream (Butcher and Ling 1962), or through periodic flood events distributing larvae and juveniles of species such as European carp (Koehn 2004). For a population distributed over more than one water body, differences in mortality, reproductive and grow rates are likely, and management of the population over its entire distribution needs to be considered.

Species 'biological productivity'

Species of high 'biological productivity' have rapid population turnover, whereas species of low biological productivity have slow population turnover. For a non-harvested population to remain in equilibrium, there has to be a balance between the natural mortality rate reducing numbers and the reproductive rate increasing numbers. Otherwise, over time, if the reproductive rate exceeded the natural mortality rate, the population would grow to infinity; conversely, if the natural mortality rate exceeded the reproductive rate, the population would become extinct. Low reproductive rate and low natural mortality rate together provide for low biological productivity, whereas high reproductive rate and high natural mortality rate together provide for high biological productivity. It follows, therefore, that either reproductive rate or natural mortality rate can serve as a proxy for biological productivity for the purpose of rapid assessment or ecological risk assessment (Walker 2005). Species with low 'biological productivity' include deep-sea dogfish, deep-sea teleosts, school shark *Galeorhinus galeus*, and marine mammals, and species of high biological productivity include squid, octopus, jellyfish and clupeids. Many of the species taken by recreational are of medium 'biological productivity' (longevity ~8–24 years); e.g. black bream, King George whiting, snapper and gummy shark (*Mustelus antarcticus*).

Using natural mortality rate as a proxy for biological productivity requires some caution, as the natural mortality rate might be density-dependent and age-dependent. Also, fishing is likely to remove the oldest animals from the population and reduce the maximum age detected in a sample of animals collected for ageing purposes. Notwithstanding these potential biases, rough estimates of natural mortality or maximum age can be used for broad categorisation of risk. The instantaneous mortality rate, Z, can be approximately related to maximum age, t_{max}, by the equation $\ln(0.01) = -Z\, t_{max}$ where 0.01 represents survival of 1% of the fish reaching maximum age (Hoenig 1983).

Other terms relating to biological productivity include the 'intrinsic rate of population growth' parameter applied variously in biomass dynamics models (Schaefer 1957; Schnute 1985), demographic models (Lotka 1922), and various adaptations of demographic models to include the term 'rebound potential' (Au and Smith 1997; Smith *et al.* 1998). In addition, 'intrinsic rate of population growth' is related to inter-generation period and reproductive output per generation (Heron 1972). Demographic analysis combines available parameter estimates for natural mortality rate and reproductive rate. Required information for this purpose of fish reproduction for a population includes the maturity ogive or for elasmobranch species maternity ogive (Walker 2007) (i.e. proportion of the female population contributing to annual recruitment expressed as a logistic function of length or age), and fecundity expressed as a function of maternal length or age. Unless these biological factors are related to age, the relationship between length and age is also required for the application of most models.

Information on biological productivity and general biology of a species are components for assessing susceptibility to the effects of fishing through Australia's framework of ERAEF. As a general rule species of low 'biological productivity' are at higher risk from the effects of fishing and take longer to recover from depletion than species of high 'biological productivity'. Fishery stock assessment, however, requires additional information for computing trends in biomass, stock numbers, and recruitment and for evaluating alternative harvest strategies.

Species stock performance indicators

The rationale for a fishery monitoring program is to provide time-series data that can indicate whether the trend in abundance of a harvested population (e.g. total biomass or total stock number), or a component of the population (e.g. mature biomass, available biomass, specific size-classes or specific age classes), is decreasing, stable or increasing. Potential indicators of relative abundance of the population include catch rate or of components of the population include *inter alia* length-frequency composition, age-frequency composition, or mean length, mean mass, or mean age of fish in the catch. A measure for any one of these indicators for one year alone is relatively uninformative because it cannot indicate a trend. Trends in time series for these indicators of only 3 or 4 years are uncertain because a time series of a longer period is required to distinguish a trend from natural inter-annual variability in the data. Nevertheless, catch length-frequency composition or, preferably age-frequency composition, for one or several years can indicate the presence or absence of various size classes or age classes in the catch (see Appendix 4). Relating catch rate applied as an index of relative stock abundance to a population or relating catch length-frequency distribution or catch age-frequency distribution to the population length-frequency distribution or population age-frequency distribution, however, requires invoking the concept of 'catchability' and its various components.

Species 'catchability', 'catch susceptibility', and their components

Irrespective of whether indices of relative abundance are provided from fishery-independent or fishery-dependent methods, catch rates and catch length-frequency distributions are affected by 'catchability' through one or more of its three components: 'availability', 'encounterability', and 'selectivity'. 'Catchability' is the proportion of the harvested population taken by one unit of fishing effort and has a value in the range 0–1 depending on length(s) or age(s) of fish. It is the product of three factors of which each also has a value in the range 0–1; i.e. 'catchability' = 'availability' x 'encounterability' x 'selectivity' (Walker 2005). For stock assessment catchability, q, is often considered to comprise the product of availability, q_a, and catching efficiency, q_c, such that $q = q_a q_c$ (Jennings *et al.* 2001). However, for the purposes of ERAEF and our understanding of catchability of alternative fishing gears for various species, the parameter q_c is expanded as the product of encounterability, q_e, and selectivity q_s, which allows q to be further expanded such that $q = q_a q_e q_s$.

'Availability' is the proportion of the population within the range of operations of a fishery, but is generally viewed as the proportion of the population's habitat area inside the range of the fishery (Quinn II and Deriso 1999). For ERAEF, a population with a habitat area extending well beyond the range of fishing has a low 'availability' value. Conversely, a population with a habitat area that falls entirely inside the range of the fishery has a high 'availability' value of 1, unless parts of the habitat area are inaccessible to the fishers.

'Encounterability' is the proportion of that part of the population available to the fishery encountered by the fishing gear for one unit of fishing effort. For any species, 'encounterability' depends on attributes of the fishing gear and on the biological attributes of that species. Species that actively swim in the water column are more likely than less active species to encounter passive gears such as gillnets or baited hooks, and therefore have a higher 'encounterability' to these gears than the less active species. For active gears such as demersal trawl, beach seine and electrofishing, low-activity species, such as Murray cod have a higher 'encounterability', and therefore higher probability of capture, than more powerful swimming species. 'Encounterability' explains a major part of the large differences in the magnitude of catch rates from among the various RAD and FIS methods; e.g., it is expected that a larger proportion of the population would encounter one haul of a demersal trawl or beach seine than a baited hook tended by a 'research-angler' for one hour. It is important to recognise that 'encounterability' can have a major effect on catch length-frequency distribution if fish of different length (or age) have different probabilities of encountering the gear. Under-representation of small estuary perch, black bream, and Murray cod in hook catches compared with demersal trawl, beach seine and electrofishing, respectively (Appendix 3), raises the question of whether this is because of the effects of 'encounterability' or because of the effects of 'length-selectivity'.

'Selectivity' is the proportion of the fish encountering the fishing gear captured by the gear. For any fishing gear, 'selectivity' gives rise to a range of complex dynamics that relate features of the fishing gear to length of fish captured. 'Selectivity' generally increases with length of fish logistically depending on mesh size in the cod-end and wings for demersal trawl (Millar 1994) and depending on mesh size in the bunt and wings for beach seine. The larger the mesh sizes the greater the escapement of small fish. For gillnets, 'length-selectivity' of fish is dome-shaped, such that small fish swim through gillnets, but become progressively more prone to capture as they grow. On reaching a length of maximum selectivity, the fish then become progressively less prone to capture with further growth as they deflect from the meshes of the gillnets. The mode of the dome-shaped selectivity distribution increases with mesh size (Kirkwood and Walker 1986). The effects of hook size on 'length-selectivity' of fish tends to be weak such that logistic and dome-shaped (Wolla *et al.* 2001) functions often fit experimental data equally well (Millar 1995). Numerous factors associated with electrofishing affect 'length-selectivity' of fish, which has been shown to be dome shaped for most species (Bayley and Austen 2002), but to decline with length for species such as blue catfish (*Ictalurus furcatus*) (Bodine and Shoup 2010) and brown trout (*Salmo trutta*) (Büttiker 1992).

For stock assessment applying monitoring data collected by the RAD and FIS methods, 'catchability' and 'selectivity' vary with length, whereas 'availability' and 'encounterability' are usually assumed constant for all lengths of fish (and implicitly all ages of fish) and their product (i.e. 'availability' x 'encounterability') can be given by q′ (i.e. $q' = q_a q_e$). This assumption needs modification if say the small fish were predominantly in one water body and the large fish in another. Hence, where fish are distributed homogenously by length, catchability q_l at length l can be calculated from the equation $q_l = q' s_l$, where 'selectivity' at length l (i.e. 'length-selectivity') is given by the variable s_l (Quinn II and Deriso 1999). The parameter q′ can be estimated by an integrated stock assessment model, but calculation of 'length-selectivity' requires equating the variable s_l to l and, for some types of fishing gear, a variable attribute of the gear such as mesh size of gillnets, mesh size in the cod-end of a demersal trawl net, or hook size of rod and line. This requires determining an appropriate mathematical function linking the relationships among the variables 'length-selectivity', length of fish, and variable gear attribute, and then undertaking a controlled selectivity experiment.

The concept of 'catchability' arose for stock assessment of target and by-product species where most of the fish captured is retained, but the concept has been broadened from 'catchability' to 'catch susceptibility' for rapid assessment and ecological risk assessment in data-poor fisheries. 'Catch susceptibility' adds the additional factor of 'post-capture mortality' to allow for mortality of that part of the catch released alive (Stobutzki *et al.* 2002), which can be all of the catch for by-catch species. Each of the factors 'catch susceptibility' and 'post-capture mortality' also has a value in the range 0–1 and the two factors are related to each other and to 'catchability' by the equation 'catch susceptibility' = 'catchability' x 'post-capture mortality', which can be expanded as 'catch susceptibility' = 'availability' x 'encounterability' x 'selectivity' x 'post-capture mortality' (Hobday *et al.* 2011; Walker 2005).

'Post-capture mortality' is the proportion of fish caught in the fishing gear dying because of capture. Target and by-product species that are mostly retained have a 'post-capture mortality' value approaching 1. This can be less if some are discarded because of their length or breeding condition or because of requirements to meet bag limits or catch quotas. 'Post-capture mortality' for discarded fish can vary markedly among species (Frick *et al.* 2010a; Frick *et al.* 2010b; Frick *et al.* 2012). In addition to handling by fishers, the fishing gear and biological attributes can contribute to various kinds of mortality referred to as 'unaccounted fishing mortality' or as 'collateral mortality' (Hall 1996). Post-capture mortality from normal handling by anglers is mostly low for 'jaw-hooked' fish, but high for 'deep-hooked' fish. Deep hooking in Victorian waters can be reduced by using large hook sizes with tight lines for black bream (Grixti *et al.* 2007), and 'deep-hooked' black bream have higher survival rates when the hooks are not removed rather than when they are removed (Grixti *et al.* 2008).

Anglers can tag and release large numbers of fish for determining (1) patterns of mixing between wild-bred and hatchery-bred fish in a population and (2) patterns of movement among separate regions (see Appendix 4). Large data-sets of tag release-recapture can be readily applied with the catch-rate data from the GAD method and periodic surveys to determine the distribution of fishing effort across the distribution of a population to provide estimates of movement rates among separate regions. A similar approach was used for school shark (*Galeorhinus galeus*) across southern Australia (Walker *et al.* 2008). Applying the RAD method for collecting catch rate data to provide a stock-performance indicator and for collecting length-at-age data allows the use of spatially-structured and age-structured stock assessment model. A similar model has been used to integrate the dynamics of the fish population and dynamics of the harvest processes for school shark (Punt *et al.* 2000).

Reporting stock status

Victoria routinely prepares fishery status reports. These reports describe selected fisheries, most of which have commercial and recreational fishing components, and the status of their stocks. Victoria also contributes to national stock status reporting with its standard terminology (Flood *et al.* 2012). Within the national framework, reporting for a species is at the level of 'biological stock' with its boundaries defined by stock delineation, but the stock can encompass separate management units and populations that may or may not coincide with jurisdictional boundaries. Five classification categories of stock status are used: 'sustainable stock', 'transitional recovering stock', 'transitional depleting stock', 'overfished stock', and 'undefined stock'. A 'sustainable stock' is where the biomass (or biomass proxy) is at a level sufficient to provide adequate recruitment and that fishing intensity is controlled to prevent recruitment overfishing. A 'transitional recovering stock' is where the biomass is recruitment overfished, but management measures are rebuilding biomass. A 'transitional depleting stock' is where the biomass is not yet recruitment overfished, but current fishing intensity is depleting the biomass. An 'overfished stock' is where the stock is recruitment overfished and the current biomass is inadequate for recovering the stock, or adequate management measures are in place, but have not improved the biomass. An 'undefined stock' is where the information is inadequate for determining stock status.

Preparation of a stock status report for a recreational fishery or for the recreational component of a mixed fishery for one or a group of water bodies requires review of available information and data. Where there is a need for updating a stock performance indicator or undertaking a full stock assessment, there will also be a need to identify the required data, monitoring methods, and fishing gear for sampling the population. Crucial to the selection of an appropriate method and sampling fishing gear for a particular stock is to ensure that planned data will be compatible with existing data. Other factors influencing the choice of method include the peculiarities of species in particular water bodies, level of sampling required, costs, priorities and time lines associated with fisheries management, and availability of suitable personnel and expertise. Consideration of the most appropriate method and fishing gear for a monitoring program requires examining the utility of a range of available methods for monitoring recreational fisheries, estimating the amount of sampling required to detect a change in stock abundance, and estimating potential costs as follows.

Utility of available methods for monitoring recreational fisheries

Various methods of monitoring stocks provide data for trend analysis directly and provide biological samples for provision of data and information on population biology. Biological samples can be used for estimating biological parameters required in stock assessment models (e.g. age and growth from otoliths, and fecundity and maturity from reproductive tissues) or can be used for validating model assumptions (e.g. stock structure from tissue genetic profiling, or trophic status from stomach contents analysis). Monitoring data used directly for stock assessment is summarised as catch species composition and, for any species, catch length-frequency composition, catch rate, catch rate change, and catch total from a fishery. Monitoring data applied in various models can provide estimates of instantaneous mortality, biomass and number of fish in the total population or in each cohort over time (including pre-recruit and recruit strength) over time. Fishing gear 'selectivity' parameters can be estimated from monitoring data, but a better approach is to adopt an experimental approach through controlled fishing trials. In addition, these methods can provide economic, social and fishery intelligence data and provide the benefit of improved fisher engagement in fishery monitoring, research and management processes.

Methods of data collection for monitoring fisheries can be categorised as fishery-dependent methods or fishery-independent methods. Fishery-dependent methods require participants in the fishery or scientific observers, to provide information on the catch, fishing effort, and fishing location. Fishery-independent methods require specialists to deploy fishing gear or other fish observing equipment to provide data and information about fish populations. Both types of method are constrained by scientific requirements (e.g. power analysis for determining sampling intensity to detect statistically a predefined change should it occur) and by level of financial investment in data collection.

Fishery-dependent survey-methods involving recreational anglers are categorised as off-site surveys or on-site surveys (Pollock *et al.* 1994). The data acquired by fishery-dependent methods are typically non-random, and driven by factors such as locations and times favoured by the fishery participants. These factors influence the species encountered and the size of the fish.

Off-site surveys are conducted away from the fishing location and include angler diary programs, logbooks and catch cards, mail surveys, telephone surveys, and door-to-door surveys. These surveys involve sampling anglers where the sample is a group of anglers considered representative of the angling community. These methods depend on self-reporting and therefore the recollection of anglers of fish encountered and their experience identifying fish species. One type of bias is 'prestige bias' whereby anglers exaggerate the number and size of fish encountered. The types of data, advantages and disadvantage of each of the off-site data collection methods are provided in Table 1.

On-site surveys are conducted at the fishing location, and include aerial, roving creel, and access point surveys. These surveys involve sampling a fishing event during or soon after the event at selected fishing locations. The advantage of on-site surveys over off-site surveys is that the data are recorded by specialist personnel, whereas off-site surveys, although cheaper than on-site surveys, the data are recorded by non-specialist personnel. The types of data, advantages and disadvantage of each of the on-site data collection methods are provided in Table 2.

Fishery-independent survey (FIS) avoids biases in fishery-dependent methods. The FIS method allows the monitoring fishing effort to be standardised by either time or number of shots, or both, and by fishing location. The relative costs, advantages and disadvantages of the FIS method vary depending on scale and fishing gears adopted for sampling fish populations. The types of data, advantages and disadvantages for each of four fishing gears adopted for the FIS method are provided in Table 3.

The suitability of the monitoring methods for collecting each type of data by monitoring programs is provided in Table 4, under the five method types: GAD, RAD, offsite, onsite and FIS. The GAD and RAD are included in Table 4 separately because they are among the preferred methods for monitoring in Victoria and because they are fishery-dependent and fishery-independent methods, respectively. GAD is a fishery-dependent method because the general-anglers choose the attributes of the fishing gear, and the localities and times to fish, whereas RAD is a fishery-independent method because the research-anglers operate according to an experimental design that prescribes the attributes of the fishing gear, and the localities and times to fish.

An important, but incidental, benefit of the GAD and RAD methods for Victoria is stakeholder engagement providing feedback on the effectiveness of the monitoring program. 'Word of mouth' communication among recreational fishers helps raise awareness and generally improve fishery monitoring, research, management and compliance. Meaningful involvement of stakeholders in resource management promotes ownership and stewardship leading to fruitful fishery outcomes. Comparisons among the GAD, RAD, and FIS methods for effectiveness were made from the 2010 trials of these methods for sampling the recreationally harvested fish populations of estuary perch in Anderson Inlet, black bream in Lake Tyers, and Murray cod in the Murray River (Appendix 3).

The choice of fishing gear for sampling a water body is best made with an understanding of the peculiarities of the population biology of the species of interest and the characteristics of the water body. Potential biasing effects of 'availability', 'encounterability', and 'selectivity' on catch rates and catch length-frequency distribution need consideration. The 2010 trials indicate that the FIS method

Table 1. Summary of utility of various fishery-dependent off-site data collection methods

Biological samples cannot be collected and tag and release cannot be undertaken for any of the four types of survey.

Type of survey	Type(s) of data collected	Advantages	Disadvantages
Diaries, log books & catch cards	• Catch rate • Catch composition • Fish length & body mass • Fishing effort	• Useful for comparison purposes • Provides for stakeholder engagement • Comparatively inexpensive • Can be combined with methods such as telephone survey • Potential for anglers to supply data on line	• Self-reporting can lead to 'prestige bias', incorrect identification of species, misreporting of length and weight • Potential for high non-response rate • Difficult for a voluntary program to be built on a probability sampling frame (list frames are unavailable or too costly)
Mail survey	• Catch rate • Catch composition • Fish length & body mass • Fishing effort	• Relatively low cost • Simple • Undertaken in-house, whereas other off-site methods require trained operators	• Susceptible to a slow turnaround time, but email, social media, mobile phone applications, and online forms are now alternatives that can reduce turnaround times
Telephone surveys	• Catch rate • Catch composition • Fish length & body mass • Fishing effort • Sociological data • Demographic data	• Preferred off-site method when data are required urgently • Direct entry of data into database • Provides a high response rate, especially when used in conjunction with a letter in advance • Can be useful if the safety of the interviewer is under question • Useful when estimating the importance of non-access point and private access are to the fishery before undertaking more expensive on-site survey methods • Can provide good information on current attitudes and demographic and sociological data	• Selective recall biases can emerge (i.e. anglers generally remember details of more memorable experiences) • 'Recall bias' increases as time since a fishing trip increases • Avid anglers more likely not recall all fishing trips • Costs are higher if surveys are outside normal working hours
Door-to-door survey	• Catch rate • Catch composition • Fish length & body mass • Fishing effort • Sociological data • Demographic data	• Complex questions can be asked and explained through face-to-face contact • Probability sampling not susceptible to avidity bias (avid and non-avid anglers sampled with equal bias) • Non-response errors are less of a problem that with mail and telephone surveys • Literacy and language problems are less likely that mail and telephone surveys • Efficiency can be enhanced by targeting registered recreational anglers through RFL address database	• High cost and logistical complexity • Quota sampling approaches susceptible to a range of errors (estimators have unknown properties with potential bias) • Probability sampling under-coverage errors are likely with list frames (this can be negated using area frames with sufficient enumeration) • Can suffer from recall, prestige bias, and digital biases, species misidentification, and incorrect fish length and body mass • Scheduling can be an issue

Table 2. Summary of utility of various fishery-dependent on-site data collection methods

Type of survey	Type(s) of data collected	Advantages	Disadvantages
Aerial survey	• Sample counts of boats • Sample counts of fishers	• Cost-effective for estimating effort over large areas • Allows total enumeration of effort over large spatial scales • Provides fishery-independent estimates of effort • Provides spatial & temporal effort for on-site survey design • Can be used to assess illegal fishing activity • Total effort divided by CPUE from a different survey method gives estimate of total catch	• Need to combined with another type of survey method to provide estimates beyond effort alone • The expense of hiring aircraft can be prohibitive • Biological samples cannot be collected • Tag and release cannot be undertaken
Roving creel survey (anglers sought out for interview with anglers at the fishing sites)	• Catch rate • Catch composition • Fish length & body mass • Fishing effort • Sociological data • Demographic data	• Data collected by trained interviewers • Not limited by angler access & minimises 'recall bias' • Fish identified, measured & weighed by interviewer reduces 'prestige bias' • Additional data on conditions can be collected at fishing sites • Useful for a fishery with multiple access points • Produce more interviews per unit staff time • Precision of fishing effort estimates are improved if combined with aerial survey • Biological samples can be collected at the fishing site	• Data are often incomplete at time of angler interviews • Complex survey designs to account for interviewer mobility • Economic data can be biased as trip-cost is unknown by angler • Some anglers unwilling to participate in lengthy questionnaires • Higher probability of encountering active anglers ('avidity bias') • More costly than off-site methods, except door-to-door survey • Field staff require specialised training • Field equipment needs to be purchased and maintained • Use of vessels increases survey costs substantially • The number of interviews per unit staff time can be low when compared with phone surveys • At-sea operations have safety issues for interviewers • Less effective at estimating catch than catch rate • Tag and release cannot be undertaken
Access point survey	• Catch rate • Catch composition • Fish length & body mass • Fishing effort • Sociological data • Demographic data	• Data collected by trained interviewers • Interview anglers soon after fishing reduces 'recall bias' • 'Prestige bias' and 'recall bias' are reduced • 'Duration of fishing bias' is less than for roving creel survey • Probability-based sampling means statistical methods used to obtain catch and effort are straightforward • Illegal harvest can be assessed • Data best when access point is public and clearly defined	• Avid anglers will be disproportionately sampled more often • Data for the entire fishing day are collected, and thereby reducing assumptions for data analysis • Access point surveys are safer than roving creel surveys • Information on catches can be completed, but economic data will be incomplete as the angler still needs to return home • Presence of numerous access points that cannot all be monitored reduces statistical power of survey • Biological samples cannot be collected • Tag and release cannot be undertaken

Table 3. Summary of utility of four fishing gears for fishery-independent data collection method

Biological samples can be collected and tag and release can be undertaken from all four fishing gears, although it may not be feasible to tag and release all fish caught by demersal trawl and gillnet because of poor condition; OH&S, occupational health and safety.

Fishing gear	**Type(s) of data collected**	**Advantages**	**Disadvantages**
Electrofishing	• Catch rate • Catch composition • Fish length & body mass • Fishing effort	• Deep water can be accessed with boat unit • Shallow margins can be accessed with backpack unit • Sites need only be visited once • By-catch of birds and mammals is minimal • Fish can be returned to the water unharmed • Specific habitat types can be targeted	• Limited by electrical conductivity of the water body • OH&S & other water users limits use during heavy rain • Equipment is costly • Operation requires specialist training • Dome shaped selectivity for length of fish
Demersal trawl	• Catch rate • Catch composition • Fish length & body mass • Fishing effort	• Large area can be covered in a short period • Low selectivity for fish length with small mesh size • Catch wide range of species • Catches wide length of fish length	• Operations difficult in complex habitat (e.g. woody debris) • Operations damage sensitive habitat (e.g. seagrass beds) • Post-capture mortality can be high
Seine (haul)	• Catch rate • Catch composition • Fish length & body mass • Fishing effort	• Low selectivity for fish length with small mesh size • Catches wide range of species • Catches wide length range of fish • Post-capture mortality is low	• Operations difficult in complex habitat (e.g. woody debris) • Bank morphology creates safety issues (e.g. steep river banks)
Gillnet	• Catch rate • Catch composition • Fish length & body mass • Fishing effort	• Several mesh sizes together catch wide range of species • Several mesh sizes together catch wide length range of fish	• Post-capture mortality can be high • Highly selective for single or several mesh sizes together (need length-selectivity correction to relate catch to population)

Table 4. Suitability of method type for collection of various types of data

Biological data

Biological samples need to be collected according to a correct protocol for determining age and growth, fish health, population structure (genetic), maturity or maternity, and fecundity, and diet from stomach contents.

Method type	Suitable	Summary
GAD	Yes	GAD can collect biological samples during normal fishing operations. With correct training, fish specimens can be collected, stored and delivered for laboratory processing. Biological samples are not collected according to a sampling design and therefore not be representative of the fisher community or the species population.
RAD	Yes	RAD can collect biological samples during their normal fishing operations. With correct training, fish specimens can be collected, stored and delivered for laboratory processing. Depending on the survey design, RAD can provide biological samples according to a controlled sampling design.
Offsite	No	Offsite surveys are conducted away from the fishery and do not have access to biological samples.
Onsite	Yes	For access point surveys (excluding aerial survey), the interviewer can request biological samples, but they may be difficult to obtain from fishers, may not be representative of the fish population, will not have been stored correctly, and their collection locations may not be reported accurately.
FIS	Yes	FIS provides high quality biological samples representative of the population when conducted according to a sampling design and operators will be skilled in collection of biological samples.

Tag release-recapture data

Tag release-recapture data can provide general information on movement and mixing patterns in a population, and can be applied in tag models for estimating movement rates among separate regions of a population (Walker *et al*. 2008) and in stock-assessment models for fitting to tag-release-recapture exploitation-rates (Punt *et al*. 2000).

Method type	Suitable	Summary
GAD	Yes	GAD 'general-anglers' can tag and release all under-sized fish and any other fish they choose not to retain, and can report data on any tagged fish they recapture.
RAD	Yes	Similar to GAD.
Offsite	No	Offsite surveys are conducted away from the fishery and do not have access to live fish for tag and release.
Onsite	No	Any fish retained quickly die and therefore unsuitable for tag and release.
FIS	Yes	FIS 'operators' can tag and release all fish in live and good condition, and record data on any tagged fish they recapture.

Catch species composition

Species composition of the catch can be a measure of the number of different species represented in a defined area (Chao 2005) and can indicate a change in presence of indigenous and exotic species.

Method type	Suitable	Summary
GAD	Yes	GAD 'general-anglers' usually target specific species, and do not encounter many of the species present in the fish community.
RAD	Yes	RAD 'research-anglers' do not target specific species, and their catch is more representative of the fish community than the GAD catch.
Offsite	Yes	Similar to GAD.
Onsite	Yes	Similar to GAD.
FIS	Yes	Catch a broader range of species than all other methods.

Table 4. Suitability of method type for collection of various types of data (continued)

LML, legal minimum length.

Catch length-frequency composition

Catch length-frequency distribution, which can be converted to catch age-frequency distribution by an age-length key, provides information on length-class or cohort strength for both the recruited and pre-recruit components of the catch. Correction for any effects of 'length-selectivity' can provide length-frequency, and potentially age-frequency, distributions in the population, which contain information on recruitment and mortality patterns.

Under-sized fish

Method type	Suitable	Summary
GAD	Yes	GAD 'general-anglers' record length of captured fish <LML, and the catch length-frequency distribution is representative of the recreational-fisher community catch.
RAD	Yes	RAD 'research anglers' record length of captured fish <LML The catch length-frequency distribution is unrepresentative of the recreational-fisher community catch, but after adjustment for 'length-selectivity' (if required) is representative of the fish population.
Offsite	No	Offsite surveys are conducted away from the fishery and monitoring length of fish is not feasible.
Onsite	No	Illegally retained fish of length <LML can be measured, but these events are rare and the catch length-frequency distribution is unlikely to be representative of the recreational-fisher community.
FIS	Yes	FIS provides length of captured fish <LML. The catch length-frequency distribution is unrepresentative of the recreational-fisher community catch, but after adjustment for 'length-selectivity' (if required) is representative of the fish population.

Legal-sized fish

Method type	Suitable	Summary
GAD	Yes	GAD 'general-anglers' record length of captured fish ≥LML, and the catch length-frequency distribution is representative of the recreational-fisher community catch.
RAD	Yes	RAD 'research-anglers' record length of captured fish ≥LML. The catch length-frequency distribution is unrepresentative of the recreational-fisher community catch, but after adjustment for 'length-selectivity' (if required) is representative of the fish population.
Offsite	No	Offsite surveys are conducted away from the fishery and monitoring length of fish is not feasible.
Onsite	Yes	The retained catch of fish of length ≥LML are measured and the catch length-frequency distribution is representative of the recreational-fisher community.
FIS	Yes	FIS provides length of captured fish ≥LML. The catch length-frequency distribution is unrepresentative of the recreational-fisher community, but after adjustment for 'length-selectivity' (if required) is representative of the fish population.

Table 4. Suitability of method type for collection of various types of data (continued)

Catch rate

Catch rates are a fisher's catch divided by the fishing effort to take the catch. This is termed 'catch per unit effort' (CPUE) and is expressed as 'catch mass' or 'catch number' per 'angler-hour' for the GAD and RAD methods or per lift or haul for the FIS method for a define unit of fishing gear. Using catch rates includes data from the fishery participants (Puertas and Bodmer 2004). CPUE is a relative measure of abundance and can be related to absolute abundances through the parameter catchability (Skalski *et al.* 2005).

Under-sized fish

Method type	Suitable	Summary
GAD	Yes	GAD 'general-anglers' record fishing effort and the catch of fish <LML, and the computed catch rate is representative of the recreational-fisher community.
RAD	Yes	RAD 'research anglers' record fishing effort and the catch of fish <LML This is not representative of catch rate for the recreational-fisher community, but after adjustment for 'length-selectivity' (if required) is representative of relative abundance of the fish population.
Offsite	No	Offsite surveys are conducted away from the fishery and monitoring catch rate is not feasible.
Onsite	No	Illegally retained fish of length <LML can be counted, but these events are rare such that a calculated catch rate is markedly biased downwards and unrepresentative of the recreational-fisher community. In some fisheries, particularly if the catch rates are low for fish of length <LML, it may be feasible to record number of fish recalled by interviewees.
FIS	Yes	FIS provides catch rate of captured fish of length <LML This is not representative of catch rate for the recreational-fisher community, but after adjustment for 'length-selectivity' (if required) is representative of relative abundance of the fish population.

Legal-sized fish

Method type	Suitable	Summary
GAD	Yes	GAD 'general-anglers' record fishing effort and the catch of fish ≥LML, and the computed catch rate is representative of the recreational-fisher community.
RAD	Yes	RAD 'research anglers' record fishing effort and the catch of fish ≥LML The computed catch rate is not representative of the recreational-fishery community, but after adjustment for 'length-selectivity' (if required) is representative of relative abundance of the fish population.
Offsite	No	Offsite surveys are conducted away from the fishery and monitoring catch rate is not feasible.
Onsite	Yes	The retained catch of fish of length ≥LML by fishers is used to determine catch rate that is representative of the recreational-fisher community.
FIS	Yes	FIS provides catch rate of captured fish ≥LML. This is not representative of catch rate for the recreational-fisher community, but after adjustment for 'length-selectivity' (if required) is representative of relative abundance of the fish population.

Table 4. Suitability of method type for collection of various types of data (continued)

Catch rate change

Change in catch rate can indicate change in a species' abundance. Decreasing catch rate indicates poor recruitment, or increased fishing mortality, whereas unchanging or increasing catch rate indicates steady recruitment and sustainable harvest (Puertas and Bodmer 2004). Catch rates are affected by changes in angler behavioural and fishing technique, which need to be monitored and interpreted. Best practice is to standardise the effort (e.g. number and size of hooks), which controls for the reduction in catch resulting from subsequent fishing effort (Sutherland 2000).

Method type	Suitable	Summary
GAD	Yes	GAD 'general-anglers' provide data on catch rate change, which is representative of the recreational-fisher community, but is unrepresentative of a change for fish population. For some species, the fishers can maintain catch rates as fish in the declining stock re-aggregate (hyperstability), because of the lack of effort standardisation over time.
RAD	Yes	RAD 'research-anglers' provide data on change in catch rate, which is not representative of the recreational-fisher community, but after adjustment for 'length-selectivity' (if required) is representative of the fish population. Spatial and temporal standardisation of fishing effort prevents targeting of fish aggregations.
Offsite	No	Offsite surveys are conducted away from the fishery and monitoring catch rate change is not feasible.
Onsite	Yes	The retained catch of fish of length ≥LML by fishers is used to determine catch rate change and is representative of the recreational-fisher community.
FIS	No	FIS provides catch rate change of captured fish. This is unrepresentative of catch rate change for the recreational-fishery community, but after adjustment for 'length-selectivity' (if required) is representative change in relative abundance of the fish population.

Catch total for fishery

Total catch is the sum of all captured fish during a specified period. In commercial fisheries, the catch is reported by fishers and fishing can be regulated through a total allowable catch framework. Total catch in recreational fisheries is estimated by sampling the catch in the fishery and estimating the total fishing effort. Total catch is estimated by scaling up the sample catch by the ratio of available total effort estimate divided by the sample effort.

Method type	Suitable	Summary
GAD	Yes	Fisher community not sampled, but reported catch and effort could be applied to an estimate of total fishing effort provided by an onsite or offsite method designed to estimate total fishing effort.
RAD	No	Fisher community not sampled.
Offsite	Yes	Offsite surveys offer the most complete measure of fishery catch. These surveys require a complete and reliable sampling frame to determine fishers within the fishery. The strategy is to sample the fisher catch and effort for a representative section of fishers in the fishery. These samples are then scaled up to provide total catch. The reliance on fisher recall and a complete sampling frame for this method remains a limiting factor for total catch estimates. Under-size fish are not well represented in these total catch estimates.
Onsite	Yes	An estimate of total catch can be attained when all access points can be sampled according to a robust design. The method is limited in that fishers who return to the access point outside of the survey period (e.g. 09:00–20:00) will be missed. Under-sized fish are not well represented in these total catch estimates.
FIS	No	Fisher community not sampled.

Table 4. Suitability of method type for collection of various types of data (continued)

Instantaneous mortality rates

Mortality estimates are usually determined as part of fishery stock assessment, where instantaneous total mortality (Z) is the sum of natural mortality (M) and fishing mortality (F), which indicate the decline in abundance of each age group (cohort) in a fish population.

Method type	Suitable	Summary
GAD	Yes	GAD length-frequency distribution (<LML and ≥LML) indicate patterns of length-class (adjusted for effects of 'length-selectivity' or age-class (where age-length key is available) changes related to recruitment and mortality.
RAD	Yes	RAD length-frequency distribution (<LML and ≥LML) indicate patterns of length-class (adjusted for effects of 'length-selectivity' or age-class (where age-length key is available) changes related to recruitment and mortality. Instantaneous mortality can be determined from tag release-recapture data using RAD.
Offsite	No	No estimate is possible without fish length data.
Onsite	Yes	Only fish of length ≥LML can be assessed for mortality from onsite surveys, which complicates analyses when combined with data on fish of length <LML from other methods.
FIS	Yes	Collection of length-frequency by the FIS method (adjusted for the effects of 'length-selectivity') together with an age-length key is a preferred method of estimating cohort strength over time and hence mortality rates.

Gear 'length-selectivity'

Gear selectivity is needed if catch data for a given gear type is used to make inference about a fish population. Correction for the effects of 'length-selectivity' requires an equation that expresses 'selectivity' as a function of fish length and a varying attribute of the fishing gear, such as hook size or mesh size of gillnets.

Method type	Suitable	Summary
GAD	Yes	GAD data can be used to determine 'length-selectivity' of hooks if a range of hook sizes in a general region, each fish caught can be assigned to a particular hook size.
RAD	Yes	RAD data can be used to determine 'length-selectivity' of hooks if a range of hook sizes in a general region, each fish caught can be assigned to a particular hook size. An experimental approach where different hook sizes are stepped in size and controlled spatially and temporally to meet the underlying assumption that all of the fishing gear is fishing the one population provides for the best results.
Offsite	No	No estimate is possible without fish length data.
Onsite	Yes	An estimate is possible only for fish of length ≥LML. In addition, linking gear type to fish length in the data is problematic with potential to selectivity-parameter estimates.
FIS	Yes	FIS can manipulate gear and record captured fish to a gear type, thus making it feasible to estimate gear 'length-selectivity' parameters for various fishing gears. Length data collected by the FIS methods can then be adjusted for the effects of 'length-selectivity'.

Table 4. Suitability of method type for collection of various types of data (continued)

Biomass and stock size

In fisheries, biomass is a measure of the mass of one or more species in an area or across a population (Hilborn and Walters 1992). Total biomass is often broken into more useful fisheries categories such as spawning biomass (i.e. breeding component of total biomass) or available biomass (i.e. legally available component of total biomass). Biomass of wild fisheries are difficult to estimate and usually requires fishery-independent monitoring methods and complex estimation models or requires defining the population area, then sampling extensively across the area, and applying scaling the sample results to the total area.

Method type	Suitable	Summary
GAD	No	GAD is unsuitable because stock size estimates require a randomised structured-survey of the whole fish population.
RAD	Yes	The RAD method can provide an estimate of stock size if the 'research anglers' fish according to a randomised structured-design sampling the entire fish population. Difficulties achieving control over all RAD activities and the relatively low number of fish captured and the low percentage of all fish captured in any location by the gear suggests that the RAD method is probably at best able to provide an index of relative abundance that can be used as a proxy for biomass.
Offsite	No	Offsite surveys do not allow for randomised structured-survey of the whole fish population required for biomass estimates.
Onsite	No	Onsite surveys do not allow for randomised structured-survey of the whole fish population required for biomass estimates.
FIS	Yes	The FIS methods can provide estimates of stock size, if conducted as a randomised structured-survey. Similar to RAD, the limitation is covering the entire population.

Fisher socio-economic participation

Method type	Suitable	Summary
GAD	No	Fisher community not sampled.
RAD	No	Fisher community not sampled.
Offsite	Yes	Offsite surveys offer the most complete measure of fishery economic data. These surveys require a complete and reliable sampling frame to determine fishers within the fishery. The strategy is to sample fisher economic expenditure, social characteristics and levels of participation for a representative section of the fishery. These samples are then scaled up to provide total fisher estimates. The reliance on fisher recall and a complete sampling frame for this method remains a limiting factor for collecting socio-economic participation data.
Onsite	Yes	When all access points can be sampled according to a robust design an estimate of economic expenditure, social characteristics and levels of participation can be attained. The method is limited in that fishers who return to the access point outside of the survey period (e.g. 09:00–20:00 hours) will be missed.
FIS	No	Fisher community not sampled.

Table 4. Suitability of method type for collection of various types of data (continued)

Fishery intelligence

Method type	Suitable	Summary
GAD	Yes	GAD 'general-anglers' are typically highly-active fishers who have a passion and understanding of the fishery. As part of a GAD program, fishers can provide information on illegal fishing activities, fish kills, fish health, habitat disturbance and more. By already being connected to management, these fishers can provide real time feedback, collect evidence, and support better management responses.
RAD	Yes	Same as GAD fishers.
Offsite	Yes	Fishers surveyed by offsite methods vary in avidity and generally do not have regular communication with researchers and fishery managers. These fishers may provide intelligence information as part of their survey participation, but the reporting would not be much greater than how they would provide intelligence if they were not in the survey.
Onsite	Yes	Onsite surveys conducted regularly in a fishery can be a good source of fishery intelligence information.
FIS	Yes	FIS 'operators' can collect fishery intelligence they observe. FIS intelligence data is limited by frequency of sampling.

Fisher engagement

Method type	Suitable	Summary
GAD	Yes	The GAD is highly engaging for anglers and allows them to be part of the management process. In turn, fishery managers can learn about fisher behaviour and catches and have a team of fishers to call upon when interpreting fishery data and designing new data collection methods. 'General-angler' volunteers participating in a GAD program are likely to become educators and mentors for other fishers and can act as a conduit for information exchange.
RAD	Yes	Same as GAD fishers.
Offsite	Yes	Offsite surveys engage with fishers, but the relationship is typically a one-way channel with interviewers obtaining data after which time the relationship ends. Fishers can learn about management and provide data, but their actual engagement is usually low.
Onsite	Yes	Fishers are engaged only when they are interviewed. Providing information back to fishers and allowing time for answering their questions can improve the engagement, but generally, overall engagement is low. This engagement could be improved by collecting fisher contact details and adding them to a regular communication network.
FIS	No	Fisher community not engaged with this process.

provides information on a greater number of species and samples a much wider range of fish length and age for each species than do the GAD and RAD methods (Appendix 3).

The catch length-frequency distributions from the trials varied markedly with sampling method; e.g. the FIS (demersal trawl) method indicated the presence of smaller estuary perch pre-recruits than did the RAD method in Anderson Inlet, whereas the distributions from the FIS (beach seine) and RAD methods agreed well for black bream in Lake Tyers (Appendix 3). The trials indicate that the RAD (and GAD by implication) and FIS (gillnet) methods cannot be applied as indicators of the relative strengths of length classes or cohorts in the population without adjustment for the effects of species-specific 'length-selectivity' for each type of fishing gear separately. Although the FIS (gillnet) method is the most highly length-selective, the FIS (demersal trawl), FIS (beach seine), and FIS (electrofishing) methods are less length-selective than hooks associated with the GAD and RAD methods. For each key species separately, because the number of fish caught and the length-frequency distributions are biased by length-selective hooks for the GAD and RAD methods, the relationship between 'selectivity' and length of fish needs to be determined for each size of hook deployed. This requires determination of the mathematical equation that expresses 'selectivity' as a function of fish length and hook size from experimental fishing trials.

Estimating number of 'fishing-days' annually by power analysis required for monitoring

Power analyses were undertaken to determine the annual number of 'angler-days' required for the GAD or RAD methods and the annual number of 'sampling-days' required for the FIS method. Two types of available data were used for the power analyses: data from past GAD and RAD monitoring programs for each of five species variously monitored in six Victorian water bodies (Table 5) and data from the 2010 RAD and FIS fishing trials (Appendix 3). For past GAD and RAD monitoring, the five species were snapper, King George whiting, black bream, dusky flathead (*Platycephalus fuscus*), and estuary perch and the six water bodies were Port Phillip Bay, Western Port, Anderson Inlet, Gippsland Lakes, Lake Tyers, and Mallacoota Inlet. For the 2010 RAD and FIS fishing trials, data were used for estuary perch in Anderson Inlet and black bream in Lake Tyers, but available data for Murray cod in the Murray River were excluded from the analysis. The periods of available data for the GAD or RAD methods range from 4 years for dusky flathead in Mallacoota Inlet to 13 years for three species in three water bodies, where the methods were first applied in 1997 (Table 5). Two separate power analyses were performed for snapper by selecting November–December data only to represent mature fish and January–April data to represent juvenile ('pinkie') fish. Similarly, January–April data only were selected for King George whiting because most fishing occurs during this period. For all other species, available data were pooled for each calendar year. No account was taken of hook size or the need to stratify sampling in large water bodies.

Power analysis is based on statistical theory invoking the concept of a null hypothesis, which depending on a statistical test requires consideration of either the null hypothesis or the alternative hypothesis. The null hypothesis is either true or false, and the null hypothesis is either rejected or not rejected, where there are four possibilities: the null hypothesis is true and accepted correctly, the null hypothesis is true and rejected incorrectly (Type I error), the null hypothesis is false and accepted incorrectly (Type II error), and the null hypothesis is false and rejected correctly. In practice, the permitted Type I error rate α is usually below a probability of 0.05 and the Type II error rate β needs to be low. The power of a statistical test is defined as the probability that the test will correctly reject the null hypothesis when the null hypothesis is false. This is the probability $1-\beta$ of not committing a Type II error; i.e. avoid incorrectly accepting a false null hypothesis (false negative). As power increases, the chance of a Type II error occurring decreases. Statistical power should be ≥ 0.80 to detect a reasonable departure from the null hypothesis.

For the present study, the mean and distribution of daily catch rates expressed as number of fish per hour were computed for N 'fishing-days' (i.e. N 'angler-days for the GAD and RAD methods and N 'sampling-days' for the FIS method) from the available data for each species in each water body.

Table 5. Number of years and 'angler-days' for the GAD and RAD methods by species in each water body

GAD, 'general-angler' diary; RAD, 'research-angler' diary.

Species		Water body	Year commenced		Number of years of data		Number of 'angler-days'	
Common name	Scientific name		GAD	RAD	GAD	RAD	GAD	RAD
Snapper	*Pagrus auratus*	Port Phillip Bay	1998	1997	13	13	1994	1419
		Western Port	1998	1998	13	13	333	61
King George whiting	*Sillaginodes punctata*	Port Phillip Bay	1998	1997	12	12	726	769
		Western Bay	1998	1998	13	13	1492	211
Black bream	*Acanthopagrus butcheri*	Gippsland Lakes	1998	1997	13	13	737	598
		Lake Tyers	2001	2002	10	10	240	464
		Mallacoota Inlet	1998	1997	12	12	389	250
Dusky flathead	*Platycephalus fuscus*	Gippsland Lakes	2004	2000	6	6	64	21
		Lake Tyers	2002	2000	6	6	89	120
		Mallacoota Inlet	2007	2004	4	4	79	67
Estuary perch	*Macquaria colonorum*	Anderson Inlet	2005	2006	6	6	65	130

Applying power analysis with α=0.05 and fishing power 1−β=0.80, the mean and variance of the distribution of daily catch rates for each of these data sets were then used to determine the minimum sample size (i.e. minimum 'number of fishing-days') required to detect a change in mean catch rate in a future year from the past overall mean annual catch rate for each of a 100% change, 80% change and 50% change (Table 6). The power analyses were performed using the procedure GLMPOWER with a contrast statement in the statistical and data management package SAS (version 9.3) (SAS Institute, Cary, North Carolina, USA).

Cost comparisons for monitoring recreational fisheries among RAD, GAD & FIS methods

A comparison of cost-effectiveness among the GAD, RAD and FIS methods was made from the 2010 trials sampling the fish populations of the recreational fisheries for estuary perch in Anderson Inlet, black bream in Lake Tyers, and Murray cod in the Murray River (Appendix 3). Cost items were categorised as 'start-up costs', 'annual costs', and 'operational costs' for each of four sampling methods identified for the purpose of the cost comparison as GAD, RAD, FIS (one gear), and FIS (two gears). 'Angler diarists' targeting Murray cod in the Murray River were treated as 'research anglers' as part of the RAD method for the purpose of data analysis (Appendix 3), but for the purpose of cost comparison, they were treated as 'general-anglers' as part of the GAD method (Table 7). Because of the large distances involved in fishing the Murray River, choice of RAD angling days had to be flexible and left to the discretion of the 'research-angler' as occurred for 'general anglers' in all three water bodies. 'Angler diarists' targeting estuary perch in Anderson Inlet and those targeting black bream in Lake Tyers were treated as 'research-anglers' for both data analysis (Appendix 3) and cost comparison (Table 7).

The sum of the 'start-up costs' and 'annual costs' were similar among the four methods: GAD ($67,500), RAD ($67,500), FIS (one gear) ($67,500), and FIS (two gears) ($71,000). For all practical purposes, these differences are small enough to ignore. Most of the differences among the methods are attributable to operational costs. The highest costs were for FIS (two gears) targeting estuary perch in Anderson Inlet ($86,160) followed by FIS (one gear) targeting black bream in Lake Tyers ($43,080) and targeting Murray cod in the Murray River ($28, 720). Considerably cheaper was RAD in each of Anderson Inlet ($6300) and Lake Tyers ($6300) and GAD in the Murray River ($315) (Table 7). This cost analysis demonstrates cost savings with GAD and RAD methods over the FIS method. However, there are other trade-offs considered above when selecting an appropriate method for monitoring fish populations.

The value of evaluating the utility and comparing cost-effectiveness among methods for sampling tropical and temperate fish assemblages on reefs was clearly demonstrated in Western Australia. That comparison indicated that in general the 'baited remote underwater stereo-video station method' is more cost-effective, can be deployed in greater depths of water, and produces less variable estimates in metrics of biomass and species richness than the 'diver-operated stereo-video transect method' (Langlois *et al.* 2010).

Implementation of GAD, RAD and FIS monitoring programs for recreational fisheries

Victorian recreational fishery monitoring strategy

The standard procedures being implemented for monitoring recreational fisheries in Victoria are cost-effective, statistically rigorous, and engage recreational fishers. The procedures are designed to simplify not only the field operations, but the management, analysis and reporting of data. The data provided need to be comparable and compatible over time to allow for time-series analyses of both continuous (non-broken) and non-continuous (broken) data-series.

The RAD method is preferred for monitoring catch rate and catch length-frequency composition, with the FIS method as an alternative or addition depending on the species, water body, and initial needs for provision of ancillary data. Important ancillary data relate to 'selectivity' for fish length by the fishing gear, 'encounterability' of the fish to the gear, and 'availability' of the fish population in the

Table 6. Power analysis results for minimum number of 'angler-days' required to detect 100%, 80% and 50% change in mean catch rate from available data

GAD, 'general-angler' diary; RAD, 'research-angler' diary; FIS, fishery-independent survey; sample size determined with statistical power of 1–β=0.80 and α = 0.05; number of fishing days (sample size) was determined from monitoring data in Table 5 and for 2010 trials in Appendix 4.

			Number of 'angler days' required in any future year to detect a change of 100%, 80% and 50% in mean catch rate determined from available data																	
Species	Data type	Method	Port Phillip Bay			Western Port			Anderson Inlet			Gippsland Lakes			Lake Tyers			Mallacoota Inlet		
			100%	80%	50%	100%	80%	50%	100%	80%	50%	100%	80%	50%	100%	80%	50%	100%	80%	50%
Snapper	Monitoring	GAD	153	237	615	66	111	264												
	(Nov–Dec	RAD	93	144	369	39	66	159												
	Monitoring	GAD	105	168	402	72	108	252												
	(Jan–Apr)	RAD	60	90	210	24	33	75												
King George whiting	Monitoring	GAD	144	207	534	99	153	363												
	(Jan–Apr)	RAD	90	120	300	39	60	141												
Dusky flathead	Monitoring	GAD										36	48	111	36	48	120	54	84	210
	(Jan–Dec)	RAD										36	51	123	33	48	111	24	36	84
Black bream	Monitoring	GAD										111	168	435	78	111	276	66	90	222
	(Jan–Dec)	RAD										78	105	261	51	81	189	45	60	150
	2010 trials	RAD													9	12	24			
	(Feb–Apr)	FIS (beach seine)													6	8	19			
Estuary perch	Monitoring	GAD							42	63	162									
	(Jan–Dec)	RAD							36	54	126									
	2010 trials	RAD							27	39	99									
	(Feb–Apr)	FIS (gillnet)							8	12	27									
		FIS (demersal trawl)							10	15	37									

Table 7. Summary of indicative costs for conduct of RAD and FIS programs

GAD, 'general-angler' diary; RAD, 'research-angler' diary; FIS, fishery-independent survey.

Cost item	Costs for each sampling method				Description
	GAD	RAD	FIS (1 gear)	FIS (2 gears)	
Start-up costs					
Planning and design	$ 15,000	$ 15,000	$ 15,000	$ 15,000	Staff time for statistical power analysis and consultation with experts and anglers
Training anglers or staff	$ 2,000	$ 2,000	$ 3,500	$ 7,000	1-day training session for GAD[A] and RAD[A] and 1 day field trials for each FIS gear[A] and associated travel, accommodation and meals
Modification of databases	$ 1,000	$ 1,000	$ 1,000	$ 1,000	Modification to SQL database
Purchase of field operating equipment	$ 1,000	$ 1,000	$ 1,000	$ 1,000	Forms, pencils
Purchase of fishing gear	$ - [B]	$ - [B]	$ 2,500	$ 5,000	Purchase demeral trawl and gillnets for Anderson Inlet, purchase of beach seine for Lake Tyers, electrofishing unit for Murray River is part of ves
Recruitment of ten angler diarists	$ 2,500	$ 2,500	$ -	$ -	Staff time and advertising
Sub-total	$ 21,500	$ 21,500	$ 23,000	$ 29,000	
Annual costs					
Administration	$ 5,000	$ 5,000	$ 5,000	$ 5,000	1 person-day per 2 weeks for reporting, extension and seeling approvals such as Fish Animal Ethics Authority & OH&S
Project and data mangement	$ 12,000	$ 12,000	$ 12,000	$ 12,000	1 person-day per 1 week for science leadership, training and meetings
Quarterly e-mail newsletter	$ 4,000	$ 4,000	$ -	$ -	For keeping GAD and RAD anglers well informed
Website and extension	$ 10,000	$ 10,000	$ 10,000	$ 10,000	For engagement with all stakeholders
Data analysis and reporting	$ 15,000	$ 15,000	$ 15,000	$ 15,000	For synthesis of data and preparation of reports
Sub-total	$ 46,000	$ 46,000	$ 42,000	$ 42,000	
Operational costs per fishing day					
Staff	$ -	$ 100	$ 3,000	$ 6,000	1 'research-angler' per day for RAD[A] and 1 day field operations for each FIS gear[A] and associated travel, accommodation and meals
Data entry and verification	$ 5	$ 5	$ 90	$ 180	15 minutes per GAD and RAD angler-day and 3 hours per FIS sampling-day
Fishing vessel day	$ -	$ -	$ 500	$ 1,000	1 day for hire, insurance and fuel
Sub-total	$ 5	$ 105	$ 3,590	$ 7,180	
Sum of start-up and annual costs					
Sub-total	$ 67,500	$ 67,500	$ 65,000	$ 71,000	
Total operational costs for each target species in its water body					
Estuary perch in Anderson Inlet		$ 6,300		$ 86,160	RAD: 5 'research-anglers' x 12 'angling-days' x $105 per day = $6,300; FIS: 12 'sampling-days' x $7180 per day = $86,160
Black bream in Lake Tyers		$ 6,300	$ 43,080		RAD: 5 'research-anglers' x 12 'angling-days' x $105 per day = $6,300; FIS: 12 'sampling-days' x $3590 per day = $86,160
Murray cod in Murray River	$ 315		$ 32,720 [C]		GAD: 7 'research-anglers' x 9 'angling-days' x $5 per day = $315; FIS: 8 'sampling-days' x $4090 per day = $32,720

[A]1 staff for each of 10 angler diarists and 3 staff for each FIS gear.

[B]'General-anglers' and 'research-anglers' provided the fishing gear at their expense.

[C]Extra $500 per day added for electrofishing cost.

water body. The FIS method is preferred for collection of ancillary data from the catch or from biological samples. The GAD method is preferred for monitoring the performance of anglers and, if participating 'general-anglers' are considered representative of the angling community, for estimating total catch, determined from GAD catch rates combined with total fishing effort estimates by an onsite or offsite survey method. Other methods are used only where these methods are considered inadequate for a particular species or water body.

Implementation of a new or renewed monitoring program for particular species in a water body inevitably requires review of available information and of how this information and any new information collected will be used for determining stock status or addressing some other fishery management needs. Important considerations include compatibility of the data to be collected with existing data and how the data can be applied for short-term and long-term requirements. In addition to assessing the information needs for fishery management, the peculiarities of the species and the water body to be monitored and the various attributes of the fishing gear to be used for sampling need careful consideration. Other factors requiring consideration include potential environmental gradients that might be encountered, rare and threatened species, the level of sampling required as determined by power analysis, availability and location of 'general-anglers' and 'research-anglers', management of the monitoring program, methods for communication and extension of GAD and RAD programs, and costs.

Species and water body features and suitability of fishing method for sampling

Environmental conditions varying spatially and temporally within a water body can cause catch rates and catch length-frequency distributions of a species to change directly because of redistribution of the fish or appear to change because of changes in the effectiveness of the fishing gear. For example, heavy rains in the catchments of rivers flowing into Anderson Inlet, Lake Tyers and other estuaries, and the Gippsland Lakes, are likely to affect the distributions of species such as estuary perch and black bream following changes in salinity. In addition, most electrofishing equipment is ineffective in saline waters, and video methods are inappropriate for turbid conditions. Sheltered waters can typically be accessed by anglers for much of the year, but catchability of the fish might vary seasonally. Certain fishing gears for the FIS method might not suit particular species in a water body; e.g., electrofishing is ideal for Murray cod in the shallow-water sections of the Murray River, but is inefficient in slower-flowing, deep-water sections. Furthermore, gaining adequate sampling coverage in a large water body such as the Murray River poses special problems, and requires a stratified sampling design.

Rare or threatened species such as platypus (*Ornithorhynchus anatinus*) create special problems for sampling. If the aim is to avoid capture of such species, then the GAD and RAD methods are an advantage because they rarely encounter such species, although hooking and release can cause injury. On the other hand, if the aim is to catch a rare or threatened species for the purpose of assessing its abundance, then the FIS method increases the likelihood of catching such a species. Sampling to determine the risk of such encounters is problematic, because a large sampling effort is required to determine accurately the probability of rare events.

Managing a recreational fishery monitoring program

Recruiting and managing personnel, field operations, and data management associated with a GAD, RAD and FIS program require managerial, technical and administrative capability. Follow-up analysis of the data and its interpretation, and reporting and public presentation require science capability.

Initiation of a monitoring program requires an adequate period for general planning and for recruiting and training anglers for the roles 'general-angler' or 'research-angler'. Recruiting such personnel at a convenient location is difficult in some water bodies at short notice. 'General-anglers' for the GAD method are easier to recruit and train than 'research-anglers' for the RAD method. There are advantages starting anglers as 'general-anglers' and then progressing them to become 'research-anglers'; this provides time to build the program and to improve reporting skills.

Cost of monitoring varies among the GAD, RAD and FIS methods. The GAD method, as the cheapest of all monitoring methods to implement, provides the greatest opportunity for ongoing monitoring. A GAD program requires little direction; 'general-anglers' simply record details of their normal fishing operations. The relatively low costs of GAD and RAD monitoring programs improve the likelihood of on-going monitoring and improve coverage across the numerous water bodies across Victoria.

Communication and extension are essential for maintaining the commitment of 'general-anglers' and 'research-anglers' in GAD and RAD programs. Keeping volunteer 'general-anglers' and 'research-anglers' well informed and providing recognition for their efforts is essential (see Appendix 6).

Checklist of steps for implementation of GAD and RAD programs

1. Define the species and water body to be monitored. The GAD method is likely to provide less representative samples of species populations in a water body than the RAD or FIS method; 'general-anglers tend to target specific species, whereas the RAD and FIS methods have fixed-site or stratified-random sampling-designs.
2. For the RAD method, define the attributes of the fishing gear for sampling the water body; i.e. specify hook or lure sizes and ensure all 'research-anglers' fish the same way. Seeking to provide wide coverage of a water body with carefully defined fishing locations (e.g. with marks from the global positioning system and sampling periods (e.g. set dates for fishing days) provide for good data quality, but rigid rules for fishing areas and fishing days can reduce interest by anglers in participation in the program.
3. Create a diary for the program to obtain standard data for inclusion in a standard database: notably species, length, and, if practical, sex, tag release and recapture number(s), and biological sample number(s) of each fish, location (site or grid) and depth of fishing, specifications of hooks and other attributes of the fishing gear, and period of fishing (start and finish times). Additional information may be required and the diary might need tailoring to suit the species and water body. Facilitate ease-of-use by 'general-anglers' and 'research-anglers' by use of waterproof paper, simple columns and headings, and sufficient writing space.
4. Determine the number of 'general-anglers' or 'research-anglers' or both to be recruited for the water body; this is best undertaken by power analysis using existing data.
5. Develop a recruitment plan using posters for websites, local newspapers, magazines, forums, fishing clubs, and boat ramps for 'general-anglers' or 'research-anglers' or both.
6. Develop a selection plan for 'general-anglers', who pay attention to detail, motivated to participate, and operate similarly to most 'general anglers', or for 'research-anglers', who must be prepared to fish less effectively and have experience for the defined water body, or both.
7. Develop a training plan by one-to-one or one-to-group training and avoid distributing diaries and relying on instruction sheets for provision of complete and accurate recording of data, collection of biological samples, and tag and release. Consider periodically accompanying the 'general-angler' or 'research angler' or both to provide tips on how other anglers complete their diaries and aim to minimise compromising the quality of their fishing experience.
8. Maintain contact systems through newsletters and social media and feedback mechanism such as phone calls and meetings. To ensure good data quality, discuss errors detected in the data with 'general-anglers' and 'research anglers'.
9. Develop a program awareness campaign. Data quality and angler satisfaction requires community awareness and credibility gained through publicising the program's achievements such as results to date and provide awards to participants for excellence.
10. Strive to maintain stakeholder support and recognition of the program, which may help secure funding for the program.

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Recognition for value and utility of RAD programs

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Recognition

The 'Reel Scientist' program won two prestigious awards during 2011. These awards recognised the importance of 'Reel Scientists' to sustainable fisheries management and also for the leadership example they provide to both the Victorian recreational fishing community and the broader Victorian community.

Victorian Coastal Council Awards for Excellence
Joint winner of the '2011 Community Action and Partnership Award'

Environment and Climate Change Minister Ryan Smith and Victorian Coastal Council chair Libby Mears recognised the works of Reel Scientists' at the Victorian Coastal Awards. Simon Conron ('Reel Scientist' Program manager) and Allan Rodgers (Reel Scientist) collected the award on behalf of all anglers.

United Nations Association of Australia

Winner of the 'Excellence in Marine and Coastal Management Award'

Reel Scientists' Ken Radley and Tony Ramunno together with 'Reel Scientist' program manager Simon Conron accepting the United Nations award for excellence in Marine and Coastal Management from Climate Action, Environment and Heritage Shadow Minister Greg Hunt.

Media

In the 2011 articles about the 'Reel Scientist' program have featured in:

- Fishing monthly
- The Age newspaper
- Echo (Bellarine edition)
- Portland Observer
- SW TAFE Communicator
- Latrobe Valley Express

"Reel Scientists" work voluntarily to ensure Victoria's fish populations don't dwindle

Dangling a line to save their sport

Every time they dangle a line in the State's rivers and freshwater lakes, members of a small army of amateur anglers across the length and breadth of Victoria are capturing vital information that is used to help preserve their sport.

They call themselves "Reel Scientists", and they work voluntarily with the Department of Primary Industries to collect information to ensure that Victoria's fish populations are harvested sustainably.

The 296 recreational fishermen in the program keep diaries on their catches, and provide their data to fisheries scientists from the Marine and Freshwater Resources Institute who enter it into a database to help assess fishery trends and fish stocks.

And the program has so impressed judges for the United Nations Association of Australia Environment Day Awards that they have selected it as one of the finalists in tonight's presentation at the Grand Hyatt in Melbourne. As part of the Reel Scientists project, each volunteer angler is supplied with the two pieces of vital scientific equipment they need to successfully undertake the survey — a special diary and a fish ruler.

Armed with this equipment, their fishing gear and their fishing knowledge, they turn their normal fishing trips into valuable research expeditions.

The dedicated anglers keep details of each of their trips, including how long they spent fishing, the number and size of the fish they caught, and whether they were kept or released.

The program is unique. It is Australia's first and longest running volunteer research angler program, and has been the model for other angler diary programs established in other states around Australia.

The information collected in Victoria enables fisheries managers at the Marine and Freshwater Resources Institute in Queenscliff to assess the status of fisheries and fish stocks so that they can be kept at the most appropriate level.

"The information is fundamental to Fisheries Victoria's stock assessment process," says Simon Conron, one of the Institute's fisheries scientists involved in overseeing the program.

Recreational fishermen in the project have recorded 18,000 trips involving 107,000 fishing hours, and have provided approximately 190,000 capture records that include 108,000 fish measurements from 160 species in 350 different bodies of water.

The program continues to expand and be deployed in recreational fishing hotspots across the state, and collectively, the Reel Scientists have already contributed 1620 years of fishing experience.

"The information on fish released is particularly valuable," Dr Conron says. "In some fisheries — involving snapper and bream for instance — it has been vital in indicating strong or weak year classes well before they reach legal size and enter the fishery."

The research has helped with the scientific assessment of the trout fishery in the Goulburn River, black bream fisheries across Victoria, King George whiting stocks in Port Phillip and Western Port Bays, and 'pinky' snapper fisheries in the Portland area.

Project data has also enabled investigation of hook types and handling practices that can maximise the survival chances of under size snapper caught and released by anglers, and the monitoring of Australian Bass fish stocks in East-Gippsland.

"Anglers generally have an insatiable thirst for information, tips and insights into anything to do with fish," the organisation says.

"Reel Scientists chatting with other recreational anglers at boat ramps, in the bait shop or on the shore open up channels of communication that media campaigns can't reach."

Since 1997, the program has been co-funded by the Victorian Government through revenue collected from recreational fishing licence fees and the peak recreational fishing body in Victoria, VRFish.

Reeling in to take the big ...

Fishing set to improve ...

King George whiting: just one of the fish species that a small army of reel scientists are working to protect.

LEGAL sized black bream should become a common sight in the Glenelg River by the end of 2011

A DELICIOUS fish to eat, mulloway stocks in the Glenelg River are set to improve.

Community link brings benefits for students

Volunteering as a diary angler has helped Ken Radley (Manager of the Centre for Health and Community Services) forge close links with the Department of Primary Industries (DPI) over the past 15 years. Thanks to this, the DPI's Marine Discovery Centre in Queenscliff has given enormous support to our VCAL students through the provision of hands-on activities allowing students access to their research facilities and enabling students to discover potential employment pathways through this initiative.

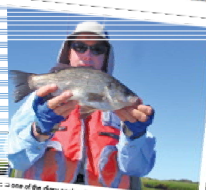
Last month, Ken's voluntary work paid off when he was part of a team of DPI volunteers to receive two major awards: the United Nations Association of Australia's Excellence in Marine and Coastal Management Award and the Victorian Coastal Council Awards for Excellence 2011 Community Action and Partnership. This was an excellent achievement in a 'sea of big fish' such as BHP Billiton, Rio Tinto and National Australia Bank.

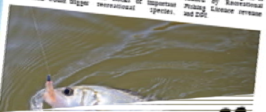
Ken's involvement with the DPI is testament to the value of forming relationships with government departments and industry groups as a means of improving our students' learning experiences.

(Check out http://new.dpi.vic.gov.au/fisheries/science-and-research/angler-diary-program if you want to know what a diary angler is!)

FEATURE

Diary Shows Angler is Perfect for Perch





Hard work often pays off

Fishing with Slates

Nice catch: Daniel Kent caught this fine bream on soft plastics in the Erskine River.

Information on the 'Reel Scientist' program can be found on the DPI website, via web videos or through the quarterly 'Reel Scientist' program newsletter.

DPI Website

Information about the 'Reel Scientist' program can be found at the DPI website:

http://www.dpi.vic.gov.au/fisheries/science-and-research/angler-diary-program

The website also contains links to the web video and 'Reel Scientist' program newsletters.

'Reel Scientist' Program Web Video

Visit the DPI website to view a three part documentary series about the 'Reel Scientist' Program.

Part One – Introduction to the program

Part Two – Angler involvement in the program

Part Three – How Fisheries Victoria use the information

'Reel Scientist' Program Newsletters

The quarterly 'Reel Scientist' program newsletters contain all the latest news, including profiles of our 'Reel Scientists' and current scientific information about research and management.

Newsletters are sent to all 'Reel Scientists' and can be found on the DPI website.

DPI Website

DPI 'Reel Scientist' Program videos