Fisheries Occasional Publication No. 67, 2009

Review of Fisheries Research Report (177)

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Published by Department of Fisheries, Perth, Western Australia.
Fisheries Occasional Publications No. 67, June 2009.
ISSN: 1447 - 2058 ISBN: 1 921258 62 4

REVIEW OF FISHERIES RESEARCH REPORT (177) - APRIL 2009

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Review of Fisheries Research Report (177) - April 2009

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Terms of reference

To provide a review of the Research Report (177) on recreational boat-based fishing in the West Coast Bioregion during 2005/06 including:

- The appropriateness of the basic creel survey design used for deriving estimates of catch, effort and catch rates for this type of fishery.
- An assessment of whether the assumptions, scope and omissions were suitably identified.
- The robustness of the catch estimates, and any conclusions that were included in the report, and total and seasonal recreational catch estimates.

These initial terms of reference were expanded to include some discussion on issues raised by (a) the WA Fisheries agency; and (b) by stakeholders during discussions with fisheries managers and in the text of a submission prepared by Recfishwest. In the detailed review, I have listed the issues raised by the fisheries agency and have summarised the many issues raised by stakeholders that were outlined in attachments 1-3 and the Recfishwest submission into broad categories. I provide comments on these issues with regard to the survey design and results.

Review Summary

- The survey methods used in this study were appropriate for deriving estimates of catch, effort and catch rates for this type of fishery.

- Some conceptual and estimation problems were found during the review. The effect of these issues was twofold. Firstly, the levels of total recreational fishing effort and total catch have been under-estimated. It is not possible to determine the magnitude of the under-estimation. Secondly, the measures of precision associated with these total estimates have also been greatly under-estimated. Re-analysis of the survey data can rectify this problem.

- Suggestions have been made on ways to modify the survey design so that the estimation problems can be corrected for past surveys and the conceptual problems are minimised for any future surveys.

- Stakeholder concerns centred around their perception that the survey results were over-estimates of total recreational effort and catch. This was not true – the results are under-estimates of the real total. All of the methodological concerns articulated by stakeholders are addressed adequately by the survey design used in FRR 177.

- The suggestion by stakeholders that voluntary or mandatory logbook data will provide accurate and timely information on total recreational effort and catch is wrong. A probability-based survey such as that used in FRR 177 is the best option for delivering unbiased effort and catch statistics on a bioregional spatial scale.

Detailed Review of FRR 177

Sumner, N.R., Williamson, P.C., Blight, S.J. and D.J. Gaughan (2008). A 12-month survey of recreational boat-based fishing between Augusta and Kalbarri on the West Coast of Western Australia during 2005-06. Fisheries Research Report 177, 44 pp.

The stated objectives of the recreational fishing survey were:
1. To provide estimates of total catch and fishing effort of recreational boat-based ocean line fishing for the West Coast Bioregion.
2. To compare the results of the 2005-06 survey to a similar survey conducted in 1996/97.
After reading the report a further objective was identified:
3. To conduct a night-based boat ramp survey in Cockburn Sound to enable estimates of recreational night-based catch and fishing effort in that area.

An on-site survey method known as a bus route design was used to collect data to meet the objectives. The bus route method was developed for use in recreational fisheries that have many access points and cover a large geographical area (Robson and Jones 1989, Pollock et al 1994). The West Coast Bioregion has 61 public boat ramps that are used by anglers to access the ocean fishery and the West Coast Bioregion covers more than 900 km of coastline. Thus, the use of the bus route method in this fishery is an appropriate choice of survey method for deriving estimates of catch, effort and catch rates for this type of fishery.

I have identified some conceptual problems associated with the implementation of the bus route method and there are some additional problems associated with the calculation of effort and catch estimates and their associated measures of precision. Initially, I will deal with the conceptual problems and their implications for the interpretation of the survey results. Secondly, I will address the estimation problems and their implications for the interpretation of the survey results. Finally, I will address the issues raised by the fisheries agency and the stakeholders separately and provide some context with regard to the review.

Conceptual issues

The bus route method treats numerous access sites as a group and all of them can be sampled on the same day. The survey route is analogous to a bus route with stops at designated sites (i.e. in this case separate boat ramps) on a predetermined daily schedule which can be proportional to known usage. The survey route is treated conceptually as a closed loop. The starting place in the route should be chosen at random. This means that the daily schedule for each survey day is likely to be different. On each day, the survey staff must travel along the route according to a precise schedule and wait a predetermined time at every boat ramp. During the scheduled waiting times at each ramp the survey staff are required to interview fishing parties as they return from fishing and also conduct effort counts.

Randomly selected survey days are regarded as the Primary Sampling Units. Daily totals of fishing effort and catch are calculated for the entire route, that is, the data from all access points on the route are combined to estimate the daily totals. Daily route totals are then averaged and these values are then expanded by the number of days in the survey stratum to obtain stratum totals. This means that the bus route method provides estimates of total effort and catch for only the defined length (time) of the bus route. Further, the estimates derived from a bus route represent an expanded total for the entire fishing area (body of water) that was accessed by fishing parties using all access points included within the survey route. These estimates of total effort and catch must be treated as a whole. They cannot be meaningfully subdivided according to individual access sites or spatially to individual areas within the broader fishing area.

The two bus route survey designs described in FRR 177, which I will refer to as the day study (West Coast Bioregion work) and the night study (Cockburn Sound work), each have some conceptual problems.
1. Defining the length (time of coverage) of the bus route
The day study has been assigned an 8 hour fishing day (09:00 to 17:00) which is constant throughout the year of survey coverage. This is an extremely restrictive constraint on the survey design given that the stated objective is to provide estimates of total catch and fishing effort of recreational boat-based ocean line fishing for the West Coast Bioregion. It is normally the case that on-site surveys aimed at providing estimates of total effort and catch are designed to at least provide coverage of all daylight hours in the fishery. It is also common that logistic and Occupational Health and Safety issues may preclude night-time sampling within the fishery. The restricted coverage of this survey means that the day study only delivers annual estimates of total effort and catch for an 8 hour period of the day between 09:00 and 17:00. There is a correction factor applied to the calculations so that fishing trips that start before 09:00 and finish within the designated survey time are included in the estimated totals. Even so, the day study underestimates the total effort and catch of boat-based fishers that use public boat ramps in the West Coast Bioregion because it does not include: (a) night-time sampling; (b) it excludes daytime fishing trips that begin and finish before 09:00 hours; and (c) it excludes all daytime trips that finish after 17:00 hours regardless of their trip duration.

The fixed length of the fishing day creates another problem for both estimation and interpretation of the survey results. The fixed 8 hour survey period does not account for seasonal changes in daylength. This means that if coverage of the entire daytime period was required, the magnitude of error due to underestimation would vary seasonally, obviously depending on differences in daylength among seasons. There will be a smaller level of underestimation during winter and the largest underestimation will occur during summer (the season when most anglers are active). The problems discussed above can be fixed by setting the bus route period to equal daylength (i.e. daylight hours). The daily bus route schedules can be easily adjusted to take this into account. An added advantage of adopting this strategy is that the survey design and the results (monthly, seasonal and annual totals of daytime fishing) will be easier to interpret and explain to the stakeholders.

The night study of Cockburn Sound has a similar coverage problem. This night study is described repeatedly in the report as a survey designed to provide estimates of night-time effort and catch in Cockburn Sound. Surprisingly, this survey has been assigned a 5 hour fishing period starting at 17:00 and finishing at 22:00 hours. The night survey was run from 15 August to September 30 2005 inclusive, did not include the closed season from October 1 to December 15 2005 inclusive, and then continued from December 16 2005 to the end of February 2006. I am amazed that this survey has been referred to as a night survey. During all months of the year this survey starts in broad daylight and covers only a very small fraction of the total night-time period. This problem is at its peak during summer when sunset occurs around 19:30 hours meaning that half of the survey period occurs in daylight.

2. Stratification
The day study has several levels of spatial stratification. The West Coast Bioregion contains four zones and each zone is further divided into districts. Each zone has a variable number of districts, ranging from one district only in the Kalbarri zone to five districts in the Metro zone. Each district represents a separate bus route survey. The number of access points (boat ramps) in each district varies between one and nine. This spatial stratification appears to be appropriate.

The temporal stratification was stated to be solely on the basis of two levels of day-type: (a) weekdays; and (b) weekends and public holidays. The logic for using two levels of day-type stratification is sound. However, there is a problem in the manner that this stratification was applied to the entire survey year. There is no mention of stratification according to months or seasons (or financial quarter years). I would expect these levels of stratification would have been included in the survey design given that: (1) the terms of reference include the robustness of "seasonal recreational catch estimates" within the scope of the review; and (b) the review asks for clarification over the interpretation of monthly estimates and monthly proportions of dhufish catch that were derived from the day study but reported in different documents (i.e. FMP 225 and 228).

In any case, if day-type was stratified across the entire year (as stated in the report) the random selection of survey days for each day-type stratum would be done with equal probability from the total number of days in each stratum in the full year. Such a random draw could easily provide a large cluster of survey days within a small period of time or even, by chance, distribute most of the sampling effort to a season that has the lowest effort and catch. These types of outcomes would surely be undesirable and lead to an inefficient survey design. I examined the database provided and found that the selection of survey days within each of the bus routes (districts) were quite evenly distributed throughout the year and they appeared to be spread relatively evenly across all months of the year. Clearly, there were further levels of temporal stratification used in the day study. This incorrect application of temporal stratification has implications in the analysis of the survey data, particularly the calculations involving estimates of precision (i.e. variances, standard errors and confidence limits). I will elaborate on these estimation problems in the next section of the review.

3. Dividing the expanded estimates of effort (units of fisher hours) and catch according to 5x5 nautical mile blocks (see Appendices E, H – O)
The presentation of the expanded estimates in this way is misleading. The bus route survey method was not designed to allow such a low level of partitioning of the estimates of effort and catch derived from its usage. As stated before, the estimates derived from a bus route represent an expanded total for the entire fishing area (body of water) that was accessed by fishing parties using all access points included within the survey route. These estimates of total effort and catch must be treated as a whole. They cannot be meaningfully subdivided according to individual access sites or spatially to individual areas within the broader fishing area. The sample of fishing

party data collected during the survey only provides an unbiased estimate of total effort and catch when daily estimates are averaged and then expanded to account for the unsampled survey days. To then partition these estimated totals using different spatial and temporal criteria is flawed. At best it could be said that a certain proportion of fishing effort and catch from the sample obtained was recorded from a particular block. At such a fine scale (5x5 nautical miles) the representativeness of the partitioned estimates would have to be highly questionable. Quite simply, another sample of similar size could show very different patterns at the fine scale because the survey design was never intended to provide unbiased estimates at this scale.

Estimation issues

1. Choice of estimation procedure for bus route design

There are two ways of estimating effort in a bus route design. The choice of effort estimation method then dictates how the catch estimates are to be derived.

FRR 177 uses the "Time Interval Count Method" for effort estimation. This method is based on time interval counts of cars and boat trailers at the access sites. It is recommended that this method be used for fisheries where there is little fishing effort, where few interviews can be expected and where the parked cars and trailers can be reasonably attributed to angling parties (Pollock et al. 1994).

The second method for estimation is known as the "Direct Expansion Method". This estimation method expands effort directly from interviews with fishing parties in a similar way to a traditional access point design. This method of estimation is recommended when the fishery has high activity and interviews are plentiful OR when parked cars and trailers may not belong exclusively to anglers (Pollock et al. 1994).

The report states that a total of 15,999 boat crews were interviewed and that only 10,382 had been ocean line fishing. The proportion of ocean line fishers is less than 65% of the total number of trips. Whilst, I do not want to be prescriptive about the choice of estimation procedure it is clear the assumption that the parked cars and trailers could have been reasonably attributed to ocean line fishing angling parties was not met. It is stated in the report p.10 that "The number of boats line fishing in the ocean was estimated by multiplying the total number of boats on the water by the proportion of boats line fishing in the ocean (e.g. not including those fishing in the estuaries)." This correction factor would have been unnecessary if the Direct Expansion Method had been used. Even so, the application of this correction factor should also require a correction be made to the variance estimates. The correction factor is not mentioned at all in Appendix C which gives the equations for the estimation of effort and catch and their associated estimates of precision (e.g. variances, standard errors, confidence limits).

2. Estimation using appropriate levels of stratification

The estimation of total effort, catch rates and total catch should be done at appropriate levels of stratification. As discussed before, the selection of survey days were made quite evenly across months and seasons (three monthly periods). The data analysis should include seasonal stratification at the very least. It would also be possible to stratify by month within season. These levels of stratification would be useful if seasonal or monthly estimates of effort and catch are needed for presentation to stakeholders. The inclusion of these monthly and seasonal scales may also provide some insights into patterns of effort and catch that may be important for better understanding of the behaviour of recreational fishers and the management of the resource.

3. Estimation of effort, catch rates and catch must be based on the Primary Sampling Unit (PSU)
The bus route design uses randomly selected survey days as the Primary Sampling Units. The PSU must be used as the base level of estimation for effort, catch rates and subsequently for catch. Thus, daily estimates are the appropriate level of replication for the estimation of total effort and catch rate from each district when the Time Interval Count Method is used.

The base level of estimation for fishing effort was done at the level of day – this is appropriate for the estimation of total effort.

The calculation of catch rate is NOT done at the level of day. Instead, catch rates are calculated by pooling all interviews within a stratum. This treats individual interviews as the base replicates. This is a form of pseudoreplication – the failure of a statistical analysis to properly incorporate the true structure of randomness present in the data. The result of this problem will be to greatly underestimate the real variance. This means that precision of total catch estimates derived in this way will be implausibly small and spurious statistical significance may occur when comparisons are made between survey periods. The solution to this problem is to calculate catch rates on a daily basis for each district (and at an appropriate level of stratification – this issue is discussed elsewhere) and use the daily mean catch rate and its estimated variance (i.e. variance of a mean) in the calculation of total catch and its associated variance.

4. Correction factor used for estimation of ocean line fishing effort
The estimation of total effort as reported in Appendix C contains a correction factor that is intended to include fishing effort from trips that started prior to 09:00 hours and finished during the period of bus route coverage. The application of this correction factor is unorthodox. The bus route method was developed by Robson and Jones (1989) and the relative precision generated by the use of the traditional access point method and the bus route design have been compared by simulation (Jones and Robson 1991). Neither study included a correction factor to allow for a poorly chosen length of survey coverage. As such, I am of the opinion that the calculation of fishing effort and its variance should have been done as outlined in Robson and Jones (1989), Jones and Robson (1991) and Pollock et al. (1994). The correction factor then should be incorporated into the calculations as a separate step by using the mean daily number of additional hours of effort and its estimated variance (i.e. variance of a mean) in the calculation of total effort for a stratum. That is, the estimate of total effort for a stratum within a district would be multiplied by the mean daily effort correction to generate the new estimate of corrected total effort. The variance for this total corrected effort would be based on the equation for the variance of a product. These calculations would, of course, be done for each bus route (district).

5. Catch rate estimator
The catch rate estimator used was the ratio of means. This is the correct catch rate estimator when the objective is to estimate total catch and the interviews with fishing parties are based on completed trips. However, Appendix C provides Crone and

Malvestuto (1991) as the justification for the use of this catch rate estimator. This citation is inappropriate because it refers to catch rate estimators as they are used in roving survey designs. The bus stop survey method is an access point method. The appropriate citation is Pollock et al. (1997).

6. Weight estimation

There are similar problems in the estimation of total catch by weight as there were for total catch by number. Once again, the PSU has been ignored in the calculation of total catch resulting in pseudoreplication and an underestimation of the true variance. The calculation of catch by weight should be treated exactly the same as the catch by number because they are conceptually the same. The only difference in the calculation is that the units of the catch rate are different. The relevant catch rate should be expressed in units of kg fish per boat hour.

The solution for catch estimation by weight would be to calculate a mean daily weight for each stratum within a district and multiply this with the estimate of total effort for that stratum (ensuring that the units of the two variables are compatible). The variance of total catch by weight would be calculated as the variance of a product.

References

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Pollock, K.H., Jones, C.M. and Brown, T.L. (1994). Angler Survey Methods and Their Applications in Fisheries Management. **American Fisheries Society Special Publication 25, American Fisheries Society, Bethesda, 371pp.**

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Issues raised by fisheries agency
1. The issue of experimental design to estimate catch and effort at the bioregional level. How far can the data be "stretched" to accommodate requests for catch and effort estimates at finer spatial and temporal resolution?
A1. The survey design dictates the appropriate scale for reporting effort and catch estimates. The minimal spatial scale of reporting would be for each individual bus route (district) and the appropriate temporal scale would probably be seasonal (but could also be monthly given the very large amount of replication within each month).

2. Suggestions as to how creel surveys, or other techniques, could be improved or better applied, to increase the robustness of catch and effort estimates.
A2. The detailed review contains discussion on conceptual issues regarding survey design. In brief, I would suggest extending the survey coverage to include all daylight hours thereby eliminating the need for correction factors. The appropriate stratification of the survey (I suggest day-types within season) would provide more accurate seasonal estimates. The use of the primary sampling units (days) in calculations of effort, catch rate and total catch would avoid the problem of pseudoreplication and unrealistically small estimates of variance, standard errors and confidence limits.

3. Views on a process to review in more detail the methods of estimating recreational catch.
A3. Reviews of this type are always better done "in-house" by the agency hosting a workshop and inviting externally based scientists to comment on the work. Such a workshop would be more beneficial before a survey starts (i.e. to try and avoid problems before they arise). The Australian Society for Fish Biology has an active recreational fishing committee and it should be possible to facilitate more frequent interaction between researchers through this mechanism.

Issues raised by stakeholders
After examining attachments 1-3 and reading the Recfishwest submission it is apparent that the stakeholders do not believe the estimates of effort and catch derived from the recreational fishing survey. They believe the survey results over-estimate the recreational effort and catch. Arising from this lack of acceptance of the survey results are many other related issues which will be discussed below.
1. The stakeholders believe that the estimates of total effort and catch are too large.
A1. It is interesting to contrast this point of view with the fact that the estimates provided in FRR 177 are underestimates of the real values. All of the survey design issues discussed in the detailed review will generate underestimates of the real values. The estimation problems that have been identified in the detailed review will have large effects on the estimates of precision (variances, standard errors and confidence limits), however, it should be expected that a reanalysis of the survey data will only result in relatively small changes in the estimates of total effort and total catch (by number and by weight). The stakeholders have not expressed any concern over the estimates of precision.

2. Survey design and methodology are flawed
A2. There were numerous issues raised by stakeholders with respect to the survey design and methodology used. All of these issues stemmed from a lack of knowledge

of survey design and the way calculations of the total estimates are done. I will list some examples and provide a brief comment to provide context in terms of FRR 177:
(a) Good anglers are over represented in the interviews.
It is true that on-site surveys such as the bus route method sample fishing parties in proportion to their avidity. That is, fishing parties that fish more frequently have a higher probability of being included in the survey sample. However, this has no bearing on the accuracy of the estimates of total effort or catch.
(b) The creel survey was inadequate because it covered too broad a region.
The bus route method was an appropriate survey method to use for estimating total effort and catch in the West Coast Bioregion.
(c) Creel surveys done in two different areas had vastly different results indicating that the methods must be flawed.
It is often the case that the relative abundances of fish species vary greatly between different areas for a variety of reasons (e.g. habitat differences, latitudinal differences in water temperature etc). This finding is not surprising and does not constitute evidence of any problem with the survey methods.
(d) How were bad weather days handled in the analysis?
The random selection of survey days and the relatively large number of days sampled would ensure that bad weather days were not over-represented in the survey and therefore would not unduly affect the estimates of total effort and catch. These survey estimates would not be biased by changes in weather.
(e) What are the effects of recruitment spikes on recreational catch estimates?
The random selection of survey days and the relatively large number of days sampled would ensure that recruitment spikes would be detected and incorporated into the final estimates of total effort and catch. These survey estimates would not be biased by recruitment spikes.
(f) Consideration should be given to the changing environment and catchability in recreational catch estimates.
The random selection of survey days and the relatively large number of days sampled would ensure that the effects of the changing environment on fish availability and catchability would be incorporated into the final estimates of total effort and catch. These survey estimates would not be biased by the changing environment and variable catchability that is inherent in recreational fisheries.

3. Issues with the presentation and interpretation of survey results
A3. Many stakeholders had difficulty with the presentation and interpretation of survey results. The best example of this issue was the inability of stakeholders to reconcile apparent differences in monthly dhufish data presented in papers FMP 225 and 228. I fully accept the explanation provided by agency staff in Attachment 3. Figure 17 from FMP 225 was based on the proportion of dhufish by month in the raw catches of fishing parties in the Metropolitan zone. In contrast, Figure 5 from FMP 228 was based on the extrapolated catch of dhufish for the entire West Coast Bioregion. Clearly, the data used in FMP 225 are a subset of the data provided in FMP 228. The two figures should be expected to be very different given that the Bioregion is much larger than the Metropolitan zone.

4. Concerns with the lack of transparency of recreational survey data
A4. The stakeholders also continually referred to their perception that there was a lack of transparency surrounding the survey methods and analyses. Part of this confusion arises because the survey methods used and the calculation of total effort and total

catch are complex. It is exceedingly difficult to explain advanced statistical theory and the logic that underpins the complex calculations done with the survey data to a layperson. However, there are certainly some steps that can be taken to provide some clarity. For example, I would recommend that the agency include a detailed summary of the survey data in all future reports. This summary should include the:
(a) number of days sampled in each bus route (district) for the appropriate level of stratification (e.g. each day-type within each season OR each day-type within each month);
(b) number of interviews done in each bus route (district) for the appropriate level of stratification (e.g. each day-type within each season OR each day-type within each month);
(c) report the interview refusal rates (as per above). A low refusal rate provides evidence of stakeholder cooperation and quality control;
(d) raw number of fish counted by species during interviews at an appropriate level of aggregation;
(e) raw number of fish measured by species during interviews at an appropriate level of aggregation.
Finally, future reports should include evidence of quality assurance. For example, descriptions of any pre-testing of survey forms, level of training provided for survey personnel, fish identification procedures (use of a fish identification kit), survey protocols, data entry and checking procedures. This information would be useful for allaying the suspicions of many stakeholders.

5. Delivery of research results is too slow and when released the information is outdated and no longer relevant.
A5. This is a criticism levelled at all fisheries agencies throughout the world. The only real solution to this complaint is to provide significant additional resources to the fisheries agency so that the complex analyses can be done quickly. This level of resourcing is only ever supplied for recreational fisheries that are managed by strict catch quota to ensure that catches do not exceed the sustainable limits set for the fishery. The solution offered by Recfishwest (i.e. angler logbooks) would suffer from these same problems and additionally would provide inaccurate records of the total recreational catch (see next point).

6. Recfishwest believes that volunteer or compulsory angler logbooks are a cost-effective option for providing accurate information about the fishery in a timely fashion. Should such a logbook system be adopted it follows that this data collection would replace the need for probability-based recreational fishing surveys.
A6. Reliance on angler generated data via a logbook system (voluntary or mandatory) would be a backward step for the proper management of the recreational fishery. There would be considerable bias (inaccuracy) in the angler generated data. It would be impossible to make all anglers send their information to a logbook coordinator. The data received would be biased towards the catches of good anglers when they catch fish. It is well established that logbook data suffer from prestige bias (i.e. anglers are reluctant to report zero or low catches) and the logbook returns will be predominantly from the most passionate and avid anglers within the general angling population. The result of these biases will be to overestimate the size of recreational catches. For further discussion please see the attached summary of my presentation at the 2008 workshop on recreational fishing that was hosted by the Australian Society for Fish Biology.

Recommendations

- Future surveys should extend the survey coverage to include the entire period of daylight hours.

- Data from FRR 177 should be reanalysed to correct for issues identified in the review. This is particularly important in the estimation of precision and in the calculation of catch rates.

- Future reports should include a detailed summary of the survey data. This summary should include the:

(a) number of days sampled in each bus route (district) for the appropriate level of stratification (e.g. each day-type within each season OR each day-type within each month);
(b) number of interviews done in each bus route (district) for the appropriate level of stratification (e.g. each day-type within each season OR each day-type within each month);
(c) report the interview refusal rates (stratification as per above). A low refusal rate provides evidence of stakeholder cooperation and quality control;
(d) raw number of fish counted by species during interviews at an appropriate level of aggregation;
(e) raw number of fish measured by species during interviews at an appropriate level of aggregation.

- It would be prudent to include evidence of project quality assurance in any future reports. This type of information will increase the transparency surrounding the survey methods and analyses, which in turn will minimise the concerns of stakeholders.

Research Challenges Arising from Differing Stakeholder Objectives and Perceptions

Aldo S. Steffe (NSW Department of Primary Industries)

Introduction

Conflict over resource sharing, the allocation of fisheries resources and concerns about the sustainability of fish stocks have been present since at least the late 1800's in NSW. The Fisheries Inquiry Commission of 1880 was established to "make a diligent and full investigation into the actual state and prospect of the Fisheries of the Colony, the best means of developing and preserving them, the expediency of encouraging Pisciculture, or of supplementing the natural supply by the introduction and acclimatization of useful foreign species, and upon all matters bearing upon this subject". Prominent commercial and amateur fishers from that period provided testimony to the inquiry on a range of topics that included: the type of fishing they did; the areas they fished; their observations of seasonal fish abundance and spawning; their opinions on the status of the fish stocks and the causes of the declines in local fish stocks; and finally, their suggestions for addressing these concerns and improving the supply of fishes.

It is interesting that the management options proposed in 1880 are much the same as those being debated now. The commercial and amateur fishers from 1880 commented on unsustainable commercial fishing practices, the destruction of large numbers of juvenile fishes, the need to reduce populations of the enemies of prized foodfish (e.g. sharks and cormorants) and spatial management. In particular, many fishers suggested that seasonal closures and/or a system of rolling closures in which different fishing grounds were spelled routinely by rotation would aid the recovery of the local fish stocks. Today, we use bycatch reduction devices and minimum legal lengths to minimise the fishing-related mortality of juvenile fishes. We still strive to eliminate unsustainable fishing practices. We are increasingly allocating access to fisheries resources along sectoral divisions (e.g. estuarine Recreational Fishing Havens in New South Wales and the commercial closure in the Perth metropolitan area in Western Australia). Also, we continue to struggle with temporal and spatial closures (e.g. zoning issues related to Marine Protected Areas within Marine Parks).

The simple conclusion derived from this historical comparison is that all stakeholder groups (past and present) want sustainable fisheries but they differ on preferred management options to achieve the goal of sustainable fishing into the future. Regardless of the management options that are implemented it is important to test the effectiveness of the management initiative. The fisheries scientist is usually given this task knowing that the various stakeholder groups have different views and that they all want to have scientifically defensible information to support their position. This is true across sectors (commercial and recreational) and within sectors (i.e. there are many different groups within each sector).

This brings us to two key questions:
1. What implications does this need for scientifically defensible data have for the scientist?
2. What are the emerging research challenges?

I discuss five main points which, in my opinion, encapsulate the implications for researchers and identify the emerging research challenges that lie ahead.

Implications for researchers and emerging research challenges

1. Representative data

The implementation of sound scientific methodology is the most important consideration for any researcher with respect to designing a cost-effective recreational fishing survey that collects data that are representative of the entire fishing population in the area of interest. That is, it is vital that recreational fishing data be collected using probability-based survey designs. Biased or unrepresentative data collection can occur in many guises. For example, consider a project that aims to document recreational catch and effort in an area or even to simply monitor trends in recreational catch rates of avid anglers in an area. The data are then collected in an *ad hoc* manner by simply accepting information via a web-based forum from anyone who is willing to provide it. This sampling approach may generate a large sample and appear to be cost-effective, however, this information is seriously biased towards those avid anglers that have internet access and have caught fish. These biased data cannot be used to make inferences about the general angling population or of the status of the fishery in the area of concern. These data cannot even provide general insights about the catch rates of avid anglers because: (a) these anglers are much less likely to report zero or low catches; and (b) the fishing characteristics of avid anglers that do not have internet access are likely to differ from those anglers that have provided the sample. The message is twofold: (a) it is imperative to use probability-based sampling methods because they provide protection against biased data collection; and (b) it is wise to maximise sample size but this is only relevant when the data collected are representative. When data are biased they are inaccurate and the effect of increasing the sample size is to make the data precisely inaccurate.

2. Reversal of the burden of proof

Precautionary management of any wild resource requires a buffer for uncertainties to safeguard the future health (sustainability) of the fish stock or ecosystem. Reversing the burden of proof has been suggested as a method for providing this buffer (Peterman 1990, Mapstone 1995, Underwood 1997). This means that it cannot be assumed that a fishing activity is benign simply because there is little or no information available to formally test the assumption of no impact. Instead, the onus has now been shifted to the proponents of development and/or resource user groups (i.e. recreational fishers in this specific example) to show that they do not have an unsustainable impact on fisheries resources. This reversal of the burden of proof is designed to minimise the frequency of Type II errors (i.e. failure to detect significant impacts when they in fact do occur) so that statistical errors should favour the long-term sustainability of the fishery. The consequence for researchers is that they will need high levels of replication to ensure that any fishery-related impacts on the resource can be detected. This will, of course, increase the cost of surveys. However, should highly replicated and statistically powerful survey designs be absent, it will be necessary for fisheries managers to make decisions in a precautionary framework to ensure that fisheries are sustainable. A precautionary framework has to assume that recreational fishing has unsustainable impacts on the resource. Clearly, this is an undesirable consequence for recreational fishers and it would be prudent to invest additional funds towards data collection so that fisheries managers can make decisions based on scientifically defensible advice rather than predetermined and politically mandated solutions.

3. Developing cost-effective ways of collecting representative data

There is clearly a need for researchers to investigate novel and cost-effective ways of collecting representative data. The solutions to this problem are likely to differ depending on the spatial scale of the proposed survey. The greatest challenge lies in the cost-effective estimation of recreational effort and catch over a large spatial scale (e.g. statewide or national). A recent review of recreational fisheries survey methods by a committee of international experts offers some possible solutions (Committee on the Review of Recreational Fisheries Survey Methods 2006). This panel of experts reviewed existing survey methods with a view to improving the methodology used in the Marine Recreational Fisheries Statistical Survey (MRFSS), a survey intended to provide national estimates of the recreational effort and catch of saltwater fishers in the United States of America. A major recommendation arising from this review was that a comprehensive, universal sampling frame with national coverage should be established. This universal frame was to be achieved "through a national registration of all saltwater anglers or through new or existing state saltwater license programs that would allow no exemptions and that provide appropriate contact information from anglers fishing in all marine waters, both state and federal." (p. 5 Committee on the Review of Recreational Fisheries Survey Methods 2006). Importantly, this system allows certain groups (e.g. pensioners, children) to continue to fish for free as long as they are registered in the universal sampling frame. The review committee also pointed out that "an updated, complete registration list would greatly improve sampling efficiency in terms of time and cost. Although these savings might not cover the entire cost of maintaining such a database, the benefit from the increased quantity and quality of the data would be worth the extra cost, especially if there is an associated increase in public confidence in the final estimates." (p. 6 Committee on the Review of Recreational Fisheries Survey Methods 2006).

Some states in Australia have implemented a recreational fishing fee (New South Wales) or a licence system for some recreational fisheries (Victoria, Tasmania, Western Australia). These recreational licencing systems do not provide a complete list of all recreational fishers participating in those fisheries because of various exemption categories. Within Australia, the establishment of comprehensive statewide and/or national registers of recreational fishers would supplement existing licencing systems and can be expected to deliver similar benefits to those described for the fisheries of the United States of America, whilst also providing a valuable tool for fisheries agencies to facilitate communication and consultation with their recreational stakeholders.

At regional and local spatial scales, the use of new technologies for monitoring fishing effort show great promise for providing cost-effective solutions to survey problems. For example, the deployment of automated traffic counters at boat ramps has been used successfully to improve the accuracy and precision of effort and catch estimates within an estuary (Steffe et al. 2008). This type of effort monitoring can also be expected to work well on a regional scale. Similarly, the use of web cameras and artificial neural network software have great potential value for reducing costs associated with regional monitoring of boat movements at many choke points in a fishery, such as at entrance areas that connect estuaries to the ocean.

At all spatial scales, power analyses of past survey data are useful for designing more cost-efficient future surveys (Peterman 1990, Hoenig and Heisey 2001).

4. Involvement of volunteers and anglers in research programs

There is a growing trend for fisheries agencies to involve volunteers and anglers in research programs (e.g. filling out logbooks describing their fishing trips or interviewing other fishers during recreational fishing surveys). This is done for a variety of reasons that include: improving public relations; increasing education and awareness of important issues among recreational stakeholders; the enthusiasm and labour provided by volunteers allows the collection of additional data; and stakeholder support and cooperation is needed to run successful surveys. Therefore, the use of volunteers is often seen as a cost-effective way of collecting data and empowering recreational stakeholders. However, there are two major issues that are rarely acknowledged but need to be considered when involving volunteers and anglers in research programs. Firstly, the management of a volunteer work force requires a large investment of resources (time and money) and the researcher must have superior organisational and inter-personal skills to reduce turnover in the ranks of the volunteers. Secondly, the utility of volunteer generated data can be easily compromised. This can occur when volunteers cannot understand or refuse to follow instructions and revert to *ad hoc* unrepresentative data collection. This type of problem is difficult to detect during the data collection phase of a survey and may introduce serious bias into the results of a survey. For these reasons, I recommend that volunteers involved in research programs need to be supervised by a scientist trained in probability-based data collection.

5. ESD-based indicators of fishing quality derived from surveys

Important management decisions relating to the allocation of shared fisheries resources and the assessment of sustainability for recreational fisheries are made difficult by: (a) the expense of collecting information for large recreational fisheries that have diffuse access; (b) the paucity of quantitative information available for most recreational fisheries which also weakens stock assessments; and (c) the lack of work aimed at determining reliable and robust ESD-based indicators of recreational fishing quality for different fisheries.

There is a national need to develop reliable ESD-based indicators of recreational fishing quality for each major type of regional recreational fishery (eg. charter boat, gamefish, marine trailer boat, ocean rock and beach, estuarine, and various freshwater fisheries). These indicators should provide a cost-effective way of monitoring the relative quality (status) and sustainability of important regional fisheries. The development of ESD-based indicators of recreational fishing quality should be derived from existing survey information that has been collected by various fisheries agencies. These historical data could be used to provide fishing quality benchmarks for different fisheries. The development of these ESD-based indicators provides a cost-effective way of assessing the status of recreational fisheries through time. They also have the potential to provide an improved and easily understood method for communicating complex information to stakeholders.

Conclusions

I have written this critique from the point of view of an active researcher. I have identified five main points that summarise the emerging research challenges and the implications for researchers working on recreational fishery issues. The challenges for researchers are: (a) to use survey methods that are probability-based to ensure data are representative (unbiased); (b) to consider a precautionary framework (reversal of the burden of proof) when designing surveys so that the level of replication within surveys is maximised; (c) to develop cost-effective ways of collecting representative data. Angler registers offer a possible solution for addressing recreational fishery issues over large spatial scales; (d) to involve volunteers and anglers in research programs but only when supervised by a scientist trained in probability-based data collection; and (e) to develop ESD-based indicators of fishing quality for a variety of different fisheries. These ESD-based indicators can provide important benchmarks for assessing changes in recreational fisheries through time. The indicators should be derived from existing survey data held by different fisheries agencies.

References

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