Assessing the effectiveness of pest fish management

Peter C. Gehrke

NSW Fisheries Office of Conservation, Port Stephens Fisheries Centre, Private Bag 1, Nelson Bay, NSW 2315, Australia[1]

ABSTRACT

Natural resource management agencies often need to manage problems caused by pest fish, but are constrained by inadequate information and insufficient time to find the necessary information before acting. Pest fish management is therefore best approached in a context of adaptive management, in which management actions provide an experimental framework from which to learn about solutions to the problem. The evaluation phase of any adaptive management exercise does not simply determine whether the management actions worked and identify subsequent actions. Evaluation provides information to fill the initial knowledge gaps. The learning process prevents repetition of costly mistakes, and provides psychological reinforcement at the individual and organisational levels so that the lessons are remembered. Adaptive management allows an iterative approach to pest fish management and evaluation, with stronger focus on evaluation in the early stages where limited prior knowledge creates greater uncertainty in the outcomes. Strong investment in monitoring and evaluation during the early stages of a pest fish management programme can reduce the effort allocated to evaluation during later stages when there is a greater level of certainty about the outcomes. Simultaneous implementation of multiple management strategies is an experimental approach, and requires standardisation across strategies, replication of strategies and suitable control areas that receive no management treatment.

Keywords: pest fish, adaptive management, monitoring, assessment

1. INTRODUCTION—A FRAMEWORK FOR ADAPTIVE MANAGEMENT

There is a growing need for integrating research and management approaches to solving large-scale environmental problems. Scientific research may increase the level of understanding of some fundamental process at the heart of an environmental problem, but the results need to be transferred into practical management actions and policies to maximise the likelihood that the outcomes of the research will be implemented. Management decisions often need to be made despite the paucity of hard data, and it is common for there to be little capacity for evaluating the outcomes of those decisions. It therefore makes

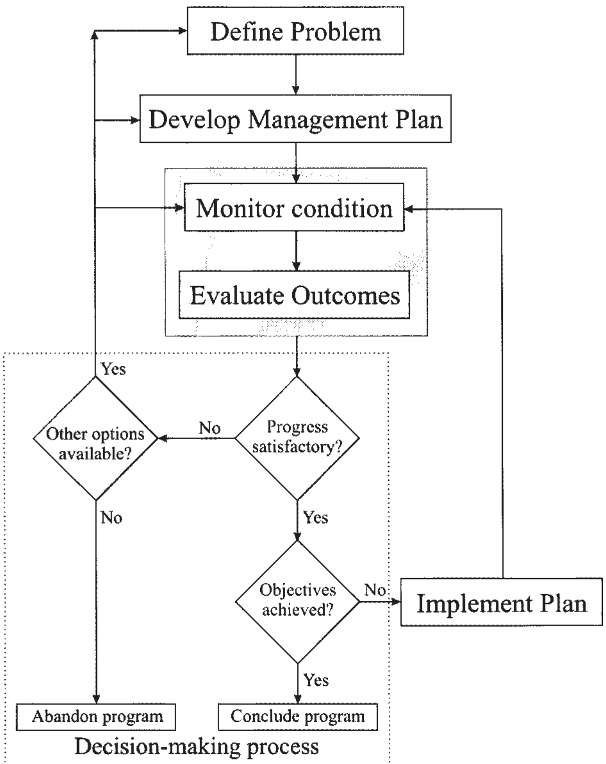
[1] Present address: CSIRO (Land and Water), 120 Meiers Rd, Indooroopilly, Qld 4068, Australia.

sense for scientists and managers to develop integrated solutions to environmental problems from the outset in a framework of adaptive management.

Adaptive management, or learning by doing (Holling 1978; Walters 1986), is much more than a synonym for learning by trial and error. Rather, Walters (1997) discusses the challenges involved in adaptive management as a carefully planned, structured process. These include designing well-planned management experiments that address the problem at hand, implementing options identified as efficient solutions, and carrying out cost-effective monitoring and evaluation so that agencies involved actually learn from the process. In this context, learning involves much more than simply knowing whether management actions worked or not—learning is to 'acquire knowledge of a subject as a result of study, experience or instruction' (The New Shorter Oxford English Dictionary).

Learning begins in the process of identifying the problem when existing knowledge gaps are recognised. The learning process continues when designing and implementing solutions that reduce the problem, and improves the level of knowledge about the problem so that future occurrences can be dealt with more efficiently. Evaluation provides the psychological reinforcement of learning at the individual and organisational levels so that the lesson is retained. Reinforcement of learning is facilitated by formalising the evaluation process, which allows the results to be documented, reviewed and published. Publication subsequently enables other parties to learn from the management experiences of others, expanding the benefits of adaptive pest management beyond the immediate context of a local problem.

Figure 1. Strategic management approach for pest fish management (modified after Braysher 1993).



Best practice pest management is an iterative adaptive process that relies on monitoring and evaluation. This process allows informed decisions to continue, modify or abandon management action, and indicates whether the objectives of a programme have been met (Braysher 1993). The four components of strategic management which can be applied to managing pest fish have been outlined by Braysher (1993) as: (1) defining the problem; (2) developing a management plan; (3) implementing the plan; and (4) monitoring and evaluating performance (Fig. 1). These principles have been developed into a strategic framework for controlling carp in Australia (Bomford & Tilzey 1997; Koehn et al. 2000).

There is a role for scientific input to all phases of this process. The problem may have a deeper ecological basis than is immediately apparent. The objectives and performance indicators for the management plan may need to include detailed ecological information. Similarly, implementation may involve experimental procedures that require scientific supervision. But the main area for scientific input is arguably in the monitoring and evaluation phase.

Adaptive management experiments can implement either a single management strategy, or a number of alternative strategies which are all implemented simultaneously, monitored and evaluated, and then adapted according to which strategy is best (Walters & Holling 1990). Simultaneous implementation of multiple strategies is the more experimental approach, and requires standardisation across strategies, replication of strategies and, ideally, control areas that receive no management treatment.

The objective of this paper is to consider approaches to monitoring and evaluation, to maximise their value in pest fish management by describing the role of evaluation and the processes by which evaluation feeds into adaptive management.

2. PLANNING THE EVALUATION PHASE

The evaluation phase of pest fish management should be planned right at the start of the management process so that costs can be estimated and the necessary funding secured. In this way, the cost of evaluation can be managed in proportion to the cost of the problem.

2.1 What to evaluate

The fundamental issue for all evaluation exercises is determining what to evaluate. It is critical that evaluation assesses the effectiveness of the pest fish control programmeme in reducing the damage caused by the fish. To do so requires a clear understanding of the impacts caused by the pest, but the impacts are not always clear. In contrast to terrestrial vertebrate pests, such as possums in New Zealand (Montague 2000) or rabbits in Australia (Williams et al. 1995), where the impacts are often direct and observable, the impacts of pest fish are more likely to be indirect and not readily observable. Investigations may therefore be needed to establish whether any impact has actually occurred (Koehn et al. 2000).

The planning stage therefore needs to distinguish between known impacts and assumed impacts, which may point to knowledge gaps that can be addressed simultaneously and cost-effectively as part of the evaluation process. Whilst this step may appear elementary, it is not always straightforward. Consider a hypothetical example where a recreational lake fishery for trout declines whilst rudd populations expand. If the problem is presumed to be that rudd have caused the trout population to decline, then the performance criterion that should be evaluated is the number of trout caught by anglers. By focusing on the correct impacts, evaluation will determine whether the problem has been correctly identified. In this scenario, if rudd are affecting trout directly, then controls that are effective in reducing rudd numbers should allow trout numbers to increase. Alternatively, if rudd are responding positively to environmental changes that are detrimental to trout, such as eutrophication caused by inadequate catchment run-off controls, then controls that are effective in reducing rudd numbers are unlikely to improve trout catches. If the evaluation programme focused solely on the number of rudd removed, then no information would be obtained on either the effectiveness of reducing the rudd population, or changes in trout catches.

The primary aim of pest fish management should be to reduce the damage caused by the pests to acceptable levels (Bomford & Tilzey 1997; Koehn et al. 2000). Consequently, evaluation of pest fish management needs to focus on the extent of reduction in damage, rather than focusing simply, for example, on the number of pests removed from a system. If the number of fish removed is insufficient to reduce the impact, then an apparently successful pest removal programme may be a complete failure.

Selected performance indicators need to reflect the objectives of the management strategy, and should be measurable with available resources. Koehn et al. (2000) present a hypothetical example where the objectives are to increase the amount of aquatic vegetation in a wetland by 20% per year by removing carp, and to prevent subsequent reinvasion by carp by installing barriers. Performance indicators in this instance need to measure the amount of aquatic vegetation each year and the number of carp inside the barriers.

Other useful performance indicators might include simple measures of habitat condition, aesthetics of areas used for public access and economic measures where the pest species is perceived to have an impact on local tourism, sale of fishing tackle or licenses.

Performance indicators need to use standardised measurement indices and procedures so that repeated measurements can be compared over time or among different locations. For example, the total number of carp caught by a community-based fish-out exercise is difficult to compare with other such exercises unless the number of anglers is known in each case, along with the length of time each angler fished and some measure of the competency of each angler. Angler-based methods can be prone to serious errors because of large differences in the skill of individual anglers, and do not always provide a reliable indicator of the size of the pest population. In contrast, the number of carp caught can be standardised in repeatable form as catch per unit effort from sampling equipment such as electrofishers, nets and traps, or from standardised poisoning stations.

Indicators known to fluctuate widely over time or among sites may require extra sampling to account for natural variation. For example, recruitment of early life-history stages of fish is notoriously variable because of variations in climate and river flow between seasons, between years and among river catchments. The cost of sampling adequately to reduce the uncertainty created by highly variable performance indicators can be reduced by measuring other, more stable indicators such as relative abundance of adults, the extent of the distribution of a given pest species or the area over which impacts have been detected.

2.2 How to evaluate effectiveness of pest fish management

Most evaluation programmes have resource constraints that may limit the number of sites where impacts can be assessed and the precision of those estimates. The power of analytical procedures to detect changes resulting from management intervention is strongly influenced by the number of estimates available. As a result, it can be more cost-effective to make a large number of low-precision estimates of, say, relative abundance of the pest by quantitative electrofishing samples, than to obtain greater-precision estimates of the actual population size from detailed mark-recapture programmes at only a small number of locations.

Bias in site selection can be a source of serious error in pest fish management programmes. For example, Gehrke & Harris (2000) selected sites throughout New South Wales on a stratified, randomised basis to avoid inadvertently selecting sites that were known to contain only good or poor fish populations. Similarly, riverine sites with good road access may be atypical of the real situation if river crossings consistently occur where the river is narrow or confined by geomorphological features that provide good bridge foundations. To avoid intentional or unintentional bias, it is often advisable to avoid sites with easy access or near towns where other urban impacts may occur. Randomised site selection procedures are available to avoid bias.

It is often useful to develop a hierarchical system of performance indicators so that the scale of evaluation can be matched to the perceived magnitude of the problem. A minimum evaluation design might estimate changes in pest abundance and impacts over a period of time, with reference to control sites where pest fish management is not applied (Underwood 1996). A more comprehensive design might extend to the development of complex ecological models that predict how various ecosystem components respond to changes in the pest population.

2.3 Challenges in detecting effectiveness

Any management activity in which the outcome involves an element of uncertainty should be considered as an experiment, so that the likelihood of successful or alternative outcomes can be assessed. Ecological changes in response to management are often subtle and subject to large variations between sites or over time. The degree of natural variation is often so large that it can obscure real responses to environmental management. To counter the effects of natural variation a large array of sampling and analytical methods has been developed. Examples include sampling designs developed for environmental impact assessment where one treatment site is compared with one or more reference sites before and after application of the treatment in an asymmetrical analysis of variance (Underwood 1996). Multivariate statistical approaches have also proved quite powerful in detecting responses to changed management at the fish community level (e.g. Gehrke & Harris 2001). Advances in computer modeling (Hilborn & Walters 1992) allow fish populations to be studied in more detail than conventional statistical approaches permit. Developments in ecological modeling provided by ECOSIM and ECOPATH approaches (Walters et al. 2000) also provide a capacity to analyse responses to pest fish management at the system level, and explore responses to alternative management scenarios.

It is commonly assumed that removal or reduction of pest populations will allow the system of interest to revert to a condition similar to that which existed before invasion by the pest (Fig. 2). However, the presence of multiple disturbances such as catchment disturbance, clearing vegetation, desnagging, altered river flows and changes in water temperatures, combined with environmental unpredictability, may lead to a successful pest fish reduction programme resulting in a switch to an unexpected environmental condition

Figure 2. Alternative outcomes from successful pest fish management (from Koehn et al. 2000). Following removal of pest fish, the fish community and habitat conditions may revert to a condition similar to their condition before invasion by the pest (left panel), or they may change to a different, unexpected condition (right panel).

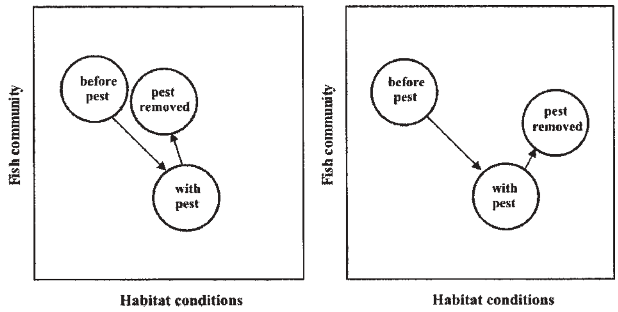
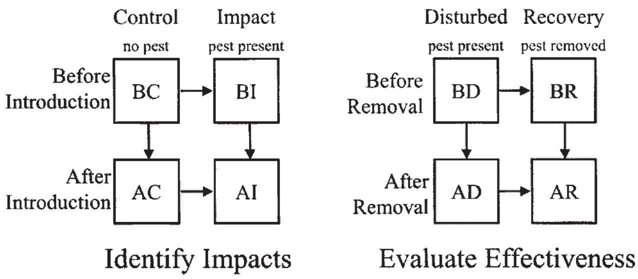


Figure 3. Conceptual representation of impact (left) and recovery (right) studies (modified after Koehn et al. 2000).



(Fig. 2). A return to near previous conditions is more likely in relatively simple systems where other disturbances are minimal. Consequently, the trajectory of recovery following implementation of the management strategy provides a hypothesis to be tested as part of the evaluation.

Standardised Before-After-Control-Impact (BACI) and related experimental designs (Underwood 1996) (Fig. 3) have several conceptual limitations when studying impacts caused by pest fish. Where widespread pest fish are concerned, for example, it is usually impossible to study the condition of habitats before the pest became established. In such instances, sites that have not been invaded by the pest may be fundamentally different from sites with the pest, making the comparison between control and impact sites meaningless. In contrast, BACI designs are likely to be useful at the early stages of pest fish invasion when comparable control sites may be available, and it may be possible to identify areas where the pest species does not yet occur but which are expected to be invaded during the study.

Simple modification of the BACI concept enables the same design to be applied to recovery studies (Fig. 3). Instead of attempting to detect the impact of pest species, recovery studies apply a pest management treatment, and the investigation focuses on detecting recovery following management intervention (Roberts & Ebner 1997). In this experimental management context, true controls are available which have pest fish and no management, whilst it is also possible to measure performance indicators before and after implementing the management treatment (e.g. King et al. 1997; Robertson et al. 1997). Recovery studies can be planned to suit most accepted experimental designs for impact assessment, and are particularly valuable in adaptive pest management programmes for demonstrating the effectiveness of management actions to reduce the impacts of pest fish (Roberts & Ebner 1997).

There is an important distinction between impact and recovery studies. The changes that occur after pest fish have been removed are not necessarily the reverse of the changes that followed the original establishment of the pest. Caution is required to ensure that data from impact and recovery studies are interpreted correctly.

The scale of pest fish distributions can make it difficult to design meaningful evaluation programmes. Pest fish populations may inhabit large-scale lake or river ecosystems that have no logical replicates or controls. For example, there is only one Lake Taupo, and one Murray-Darling River system. In these situations it may be necessary to subdivide the large experimental unit into replicate sections. If different subunits can be safely assumed to be independent, then it may be possible to apply different management options simultaneously on groups of subunits and to compare results among spatial treatments and controls. Where pest fish are sufficiently mobile that it is unrealistic to assume independence among subunits, a sequential, iterative management process may be appropriate, with each management application evaluated before and after to assess effectiveness in reducing the impacts of the pest fish. This approach assumes that sequential treatments are independent and reversible (Walters 1997). For example, large-scale application of a chemical such as rotenone to a lake will have long-lasting effects on the fish community that would be irreversible in most circumstances. It would be nonsensical to apply another management treatment following rotenone application and to compare the effectiveness of the two methods, unless sufficient time elapsed in the interim for a stable fish community to become established.

In contrast to large systems, small, isolated habitats like ponds or billabongs where pest fish have become established provide logical experimental units that are often numerous, independent and easy to replicate.

2.4 When to evaluate

Data collection to evaluate performance indicators needs to commence before the management programme is implemented to ensure there is an adequate reference condition against which to assess the effectiveness of management. In situations where the variability of the system is adequately understood, it may be possible to determine the most appropriate duration and frequency of prior monitoring. In other instances, ongoing evaluation on an iterative basis may be needed to establish when the reference condition is adequately known to enable the effects of management to be detected. Power analysis (e.g. Peterman & Bradford 1987; Fairweather 1991) is an invaluable tool in these situations. Sometimes there may be a time imperative for the management plan to be implemented that leaves insufficient time to establish a reliable reference condition. Power analysis is again useful in this situation to estimate the magnitude of effect that is likely to be detectable under the constrained prior monitoring conditions. In these instances, power analysis may indicate that the most practical monitoring programme is unlikely to ever detect an effect of management, providing critical feedback on the value of proceeding with the management plan.

After the management plan is implemented, monitoring should be repeated as soon as possible, and periodically afterwards at appropriate intervals determined by the expected time-course of change in the selected performance indicators (Koehn et al. 2000). For example, performance indicators based on recruitment of pest species might most effectively be conducted annually before the spawning season commences to estimate the survival of recruits from the previous year. Alternatively, it may be preferable to sample after the spawning season if the objectives of management are to reduce spawning success. Performance indicators based on angling catches might be assessed annually through organised events such as those conducted by NSW Fisheries for the Angling Catch Database programme.

The duration of monitoring will vary with the nature of the management programme. An attempt to eradicate pest fish by applying management actions just once might require only one or two follow-up assessments to determine whether any pest fish remain (e.g. Lintermans 2000). If complete eradication has been successful, ongoing monitoring is not required unless there is a risk of re-introduction. In situations where ongoing management is required over an extended period of time, however, ongoing monitoring will also be required to follow the time-course of responses to management.

2.5 Budgeting for evaluation

Each pest fish population has unique characteristics that preclude a prescriptive approach to budgeting for monitoring and evaluation. It is clear, however, that the budget to evaluate the success of pest fish management programmes needs to be scaled appropriately to the scale of the entire management programme. The programme budget will be determined by the spatial scale of the problem, the cost of existing impacts, the risks associated with ineffective management, and the strategic importance of the programme with respect to competing programmes. If the pest problem is likely to persist over a long time, then the importance of long-term data on pest populations and their impacts should not be underestimated in establishing programme budgets.

Adopting an adaptive management approach to pest fish management provides capacity to guard against scientific self-interest to pursue open-ended research. Similarly, adaptive management with iterative evaluation guards against management self-interests to proceed confidently despite knowledge that there is a high level of uncertainty surrounding expected outcomes in naturally-variable systems (Walters 1997). Investment in evaluation in the early phases of management should allow identified knowledge gaps to be filled as part of the management programme, gradually reducing the requirement for evaluation in subsequent similar implementations.

3. CONCLUSIONS

Pest fish management programmes can be most effectively implemented by adopting an adaptive management approach. Adaptive management allows practical management options to be implemented in a timely, expedient manner. The integral monitoring and evaluation components provide feedback on the effectiveness of management, and guide decisions on whether the programme should be continued, modified or abandoned. By formalising the evaluation phase, knowledge gained from the management programme can be maximised, improving the effectiveness of future management and avoiding repetition of costly mistakes. Simultaneous implementation of multiple management strategies is an experimental approach, and requires standardisation across strategies, replication of strategies and suitable control areas that receive no management treatment.

4. ACKNOWLEDGEMENTS

I thank the New Zealand Department of Conservation for inviting me to this workshop, and for supporting my attendance. The ideas presented in this paper developed from discussions with Lindsay Chadderton and Tracie Dean, and are based on concepts developed for managing the impacts of carp and other vertebrate pests in Australia.

5. REFERENCES

Bomford, M.; Tilzey, R. 1997: Pest management principles for European carp. Pp. 9–20 in Roberts, J.; Tilzey, R. (eds) Controlling carp: exploring the options for Australia. Proceedings of a workshop 22–24 October 1996, Albury. CSIRO and Murray-Darling Basin Commission.

Braysher, M. 1993: Managing vertebrate pests: principles and strategies. Bureau of Resource Sciences, Australian Government Publishing Service, Canberra.

Fairweather, P.G. 1991: Statistical power and design requirements for environmental monitoring. *Australian Journal of Marine and Freshwater Research 42*: 555–567.

Gehrke, P.C.; Harris, J.H. 2000: Large-scale patterns in species richness and composition of temperate riverine fish communities. *Marine and Freshwater Research 51*: 165–182.

Gehrke, P.C.; Harris, J.H. 2001: Regional-scale effects of flow regulation on lowland riverine fish communities in New South Wales, Australia. *Regulated Rivers: Research and Management*.

Hilborn, R.; Walters, C. 1992: Quantitative fisheries stock assessment. Chapman and Hall, London.

Holling, C.S. (ed) 1978: Adaptive environmental assessment and management. John Wiley, New York.

King, A.J.; Robertson, A.I.; Healey, M.R. 1997: Experimental manipulations of the biomass of introduced carp (*Cyprinus carpio*) in billabongs. I. Impacts on water-column properties. *Marine and Freshwater Research 48*: 435–443.

Koehn, J.; Brumley, A.; Gehrke, P.C. 2000: Managing the impacts of carp. Bureau of Resource Sciences, Canberra. 247 p.

Lintermans, M. 2000: Recolonisation by the mountain galaxias *Galaxias olidus* of a montane stream after the eradication of rainbow trout *Oncorhynchus mykiss*. *Marine and Freshwater Research 51*: 799–804.

Montague, T.L. (ed) 2000: The brushtail possum. Biology, impact and management of an introduced marsupial. Manaaki Whenua Press, Lincoln, New Zealand.

Peterman, R.M.; Bradford, M.J. 1987: Statistical power of trends in fish abundance. *Canadian Journal of Fisheries and Aquatic Sciences 44*: 1879–1889.

Roberts, J.; Ebner, B. 1997: An overview of carp *Cyprinus carpio* in Australia. Final Report on NRMS Project R5058. An advisory document to the Murray-Darling Basin Commission. (unpublished).

Robertson, A.I.; Healey, M.R.; King, A.J. 1997: Experimental manipulations of the biomass of introduced carp (*Cyprinus carpio*) in billabongs. II. Impacts on benthic properties and processes. *Marine and Freshwater Research 48*: 445–454.

Underwood, A.J. 1996: Spatial and temporal problems with monitoring. Pp. 101–123 in Calow, P.; Petts, G.E. (eds) The rivers handbook. Vol. 2. Blackwell Scientific Publications, London.

Walters, C.J. 1986: Adaptive management of renewable resources. McGraw-Hill, New York.

Walters, C. 1997: Challenges in adaptive management of riparian and coastal ecosystems. *Conservation Ecology 1(2)*: 1. URL: http://www.consecol.org/vol1/iss2/art1 Viewed in April 2001.

Walters, C.J.; Holling, C.S. 1990: Large-scale management experiments and learning by doing. *Ecology 71*: 2060–2068.

Walters, C.J.; Pauly, D.; Christensen, V.; Kitchell, J.F. 2000: Representing density dependent consequences of life history strategies in aquatic ecosystems: EcoSim II. *Ecosystems 3*: 70–83.

Williams, C.K.; Parer, I.; Coman, B.J.; Burley, J.; Braysher, M.L. 1995: Managing vertebrate pests: rabbits. Bureau of Resource Sciences/CSIRO Division of Wildlife Ecology, Australian Government Printing Service, Canberra.